Ministry of Defence
Defence Standard 02-706 (NES 706)

Issue 1 Publication Date 01 April 2000

Welding And Fabrication Of Ship's Structure

Incorporating NES 706 Category 2

Issue 2 Publication Date March 1983

AMENDMENT RECORD

Amd No	Date	Text Affected	Signature and Date

REVISION NOTE

This standard is raised to Issue 1 to update its content.

HISTORICAL RECORD

This standard supersedes the following:

Naval Engineering Standard (NES) 706 Issue 2 dated March 1983.

Ministry of Defence

Naval Engineering Standard

NES 706 Issue 2 (Reformatted) March 1983

WELDING AND FABRICATION OF SHIP STRUCTURE

This NES Supersedes
NES 706 ISSUE 1 SECTION 19 OF THIS NES (ISSUE 2) HAS NOW BEEN SUPERSEDED BY NES 768

Record of Amendments

AMDT	INSERTED BY	DATE
1	Incorporated	
2	Incorporated	
3	Incorporated	
4	Incorporated	
5	Incorporated	
6	Incorporated	
7		
8		
9		
10		

NAVAL ENGINEERING STANDARD 706

ISSUE 2 (REFORMATTED)

WELDING AND FABRICATION OF SHIP STRUCTURE

The issue and use of this Standard

is authorized for use in MOD contracts

by MOD(PE) Sea Systems and

the Naval Support Command

Published by:

Director of Naval Architecture
Procurement Executive, Ministry of Defence
Sea Systems, Foxhill, Bath BA1 5AB

SCOPE

1. The requirements for the fabrication, welding and inspection of structures and associated components produced in MOD(PE) structural materials (as defined in Section 1.)

2. The welding and fabrication requirements for Q1N, HY80 or QT35 quality steels are described in NES 770.

iv

FOREWORD

Sponsorship

1. This Naval Engineering Standard (NES) is sponsored by the Procurement Executive, Ministry of Defence, Director General Ships (DG Ships), Section D123c.

2. It is to be applied as required to any Procurement Executive, Ministry of Defence contract for the welding and fabrication of ship structure and is applicable to surface ships and submarines.

3. If it is found to be technically unsuitable for any particular requirement the sponsor is to be informed of the circumstances with a copy to the DG Ships D191a.

4. Any user of this NES either within MOD or in outside industry may propose an amendment to an NES. Proposals for amendments which are:

   a. not directly applicable to a particular contract are to be made to the sponsor of the NES;

   b. directly applicable to a particular contract are to be dealt with using existing departmental procedures or as specified in the contract.

5. No alteration is to be made to this publication except by the issue of a formal amendment.

6. Unless otherwise stated, reference in this NES to approval, approved, authorized and similar terms means by the Procurement Executive, Ministry of Defence.

Conditions of Release

General

MOD Tender or Contract Process

10. This NES is the property of the Crown and unless otherwise authorized in writing by the MOD must be returned on completion of the contract, or submission of the tender, in connection with which it is issued.

11. When this NES is used in connection with a MOD tender or contract, the user is to ensure that he is in possession of the appropriate version of each document, including related documents, relevant to each particular tender or contract. Enquiries in this connection may be made of the local MOD(PE) Quality Assurance Representative or the Authority named in the tender or contract.

12. When NES are incorporated into MOD contracts, users are responsible for their correct application and for complying with contracts and any other statutory requirements. Compliance with an NES does not of itself confer immunity from legal obligations.

Related Documents

13. In the tender and procurement processes the related documents listed in each section and Annex A can be obtained as follows:

a.	British Standards	British Standards Institution, 389 Chiswick High Road, London W4 4AL
b.	Defence Standards	Directorate of Standardization and Safety Policy, Stan 1, Kentigern House, 65 Brown Street, Glasgow G2 8EX
c.	Naval Engineering Standards	CSE3a, CSE Llangennech, Llanelli, Dyfed SA14 8YP
d.	Other documents	Tender or Contract Sponsor to advise.

Note: Tender or Contract Sponsor can advise in cases of difficulty.

14. All applications to Ministry Establishments for related documents are to quote the relevant MOD Invitation to Tender or Contract Number and date, together with the sponsoring Directorate and the Tender or Contract Sponsor.

15. Prime Contractors are responsible for supplying their subcontractors with relevant documentation, including specifications, standards and drawings.

Health and Safety

Warning

16. This NES may call for the use of processes, substances and/or procedures that may be injurious to health if adequate precautions are not taken. It refers only to technical suitability and in no way absolves either the supplier or the user from statutory obligations relating to health and safety at any stage of manufacture or use. Where attention is drawn to hazards, those quoted may not necessarily be exhaustive.

CONTENTS

1. MATERIALS

a. This section contains information regarding the materials for which the requirements of this NES apply. The materials are divided into the following groups and the information is displayed in TABLE 1.1.

GROUP	MATERIAL TYPE
1	Current structural steels
2	Obsolete structural steels
3	Steel forgings
4	Steel castings
5	Current protective plating
6	Obsolete protective plating
7	Current structural aluminium alloy Obsolete structural aluminium alloy

b. The full material specification requirements and particulars of test procedures are contained in the material specifications quoted. It is to be noted that specification test requirements differ with variation in material thickness, not all of these have been included in the table, only sufficient to provide background information for weldability has been shown.

c. Group 2 and 6 contain the now obsolete structural steels and protective plating respectively, which may be encountered in older vessels. Because of war time production difficulties these steels may be outside specification requirements, therefore the information shown must be used for guidance only.

d. The Carbon Equivalent (CE) has been calculated from the maximum chemical composition permitted by the applicable material specification by use of the following formula:

$$CE = C + \frac{Mn}{6} + \frac{Ni}{40} + \frac{Cr}{5} + \frac{Mo}{4} + \frac{Si}{24}$$

GROUP	MATERIAL	SPECIFICATION	FORM OF SUPPLY & CONDITION	COMPOSITION % max											CHEMICAL RESTRICTIONS	YIELD OR P.S.	TENSILE STRENGTH	ELONGTN	CHARPY	C.E.
				C	Mn	Si	P	S	Ni	Cr	Mo	Cu	Nb	V						
1	CURRENT STRUCTURAL STEELS															N/mm^2		%	Min	
	MILD STEEL	DG SHIPS 1207	P.AR	0.3			0.06	0.06								245	430–510	22		0.38
	NOTCH TOUGH	NES 791 Pt 2	S.AR	0.16	1.50	–0.5	0.04	0.04					0.03–0.1	0.03–0.1		255	"	"		"
	'B' QUALITY	DG SHIPS 1257	P.N	0.19	1.2–1.7	0.1–0.35	0.04	0.04							Mn+Cr+Mo/C + 6 5 ≯ 0.45%	280–310	450–590	20	40J @ –30° C	≯ 0.45
	" "	DG SHIPS 322	S.AR or N	"	"	"	"	"							– ditto –	295–310	460–590	"	25J @ –30° C	"
	UXW		P.NT	0.19	1.6	0.3	0.05	0.05	0.5	0.3	0.3				Mn+Ni+Cr+Mo ≯ 2.6%	0.3%PS 387	575–665	15	25J @ –20° C	0.59
	"	DNC/S.26	T.SA	0.20	"	"	"	"	"	"	"				– ditto – ≯ 2.5%	"	510–665	"	20J @ 0° C	"
	Q.T. 28	DG SHIPS 346	P.QT	0.17	1.3	0.35	0.035	0.04	0.5	0.3	0.3	0.3			– ditto – ≯ 2.2%	0.2% PS 430	540–695	20	61J @ –20° C	0.52
2	OBSOLUTE STRUCTURAL STEELS																			
	'A' QUALITY		P.AS or N	0.17	0.8–1.5	0.1–0.35	0.05	0.05							Mn Cr Mo C + 6 + 5 + 4 0.4%	250	430–495	22	41J @ –30° C	0.40
	'S' QUALITY		P.A	0.21	0.8	0.35	0.06	0.06							Mn+Ni+Cr+Mo ≯ 1.5%	285	460–525	20		0.49
	" "		S.A	"	"	"	"	"							– ditto –	"	"	"		"
	SU. QUALITY		P.NA	"	"	"	"	"							– ditto –	"	490–560	"		"
	" "		S.NA	"	"	"	"	"							– ditto –	"	"	"		"
	'D' QUALITY		P & S	0.3													570–680	17		0.38
	'D1' QUALITY		P & S.N	0.3	1.2	0.35	0.06	0.06							Mn+Ni+Cr+Mo ≯ 2.0%		"	"		0.5
	'DW' QUALITY		P.N	0.23	"	"	"	"							– ditto – ≯ 1.8%		510–630	17		0.44
	" "		S	"	"	"	"	"							– ditto –		"	"		"
3	CURRENT STEEL FORGINGS	ADSPEC 1100	F												✓ BS 970 STEELS TO BE USED ✓			(LONGL)	(IZOD)	
	CLASS ((a)	< 150mm RS	N or NT	0.15–0.3	0.4–1.0	0.05–0.35	0.06	0.06							Mn ≮ 2.5 ¢ C. 070M26		430–525	29	27J @ 0° C	0.56
	(b)	> 150mm "	"	"	"	"	"	"									"	"	"	"
	CLASS II (a)	< 150mm "		0.25–0.4	"	"	0.05	0.05							✓ 080M40		525–590	23		0.66
	(b)	> 150mm "		"	"	"	"	"									"	"		"
	CLASS III (a)	< 150mm "	MAY BE REQUIRED IN QT CONDITION	0.35–0.45	"	"	"	"							✓ 080M46		590–665	19		0.71
	(b)	> 150mm "		"	"	"	"	"									"	"		"
	CLASS IV (a)	< 150mm "		0.45–0.6	"	"	"	"							✓ 070M55		650 min			0.86
	(b)	> 150mm "		"	"	"	"	"									"			"

Key to Symbols:

C: –Castings
F: – Forgings
P :– Plate
S :–Section
T :–'T' Bar

O: –Annealed (Al. Alloys)
A :–Annealed
AM :–As manufactured
M :– " " (Al. Alloys)
AR :–As Rolled

N: –Normalized
NA: –Not Annealed
NT :–Normalized & Tempered
QT :–Quenched & Tempered
SA :–Subcritically Annealed

TABLE 1.1 LIST OF MATERIALS

GROUP	MATERIAL	SPECIFICATION	FORM OF SUPPLY & CONDITION	COMPOSITION % max									CHEMICAL RESTRICTIONS	YIELD OR P.S	TENSILE STRENGTH	ELONGTN	CHARPY	C.E.
				C	Mn	Si	P	S	Ni	Cr	Mo	Cu						
4	CURRENT CARBON STEEL CASTINGS—GENERAL PURPOSE	DG SHIPS 8081	C	0.25	0.90	0.50	0.05	0.05	0.40	0.25	0.15	0.40	Ni+Cr+Mo+Cu ≯ 0.8%	N/mm^2 0.5% P.S 250	460	% 20	min	0.51
5	CURRENT PROTECTIVE PLATING													0.2% PS	PS/uts			
	NAVY Q1	NES 736	P. QT	0.18	0.1−0.4	0.15−0.35	0.015	0.015	2.25−3.25	1.0−1.5	0.2−0.6			550−650	≯ 0.88	20	101.7J@−84°C	0.85
	'B' QUALITY—SEE GROUP 1																	
	320 S.17	BS 1449 Pt 2	P.	0.08	0.5−2.0	0.2−1.0	0.04	0.03	11.0−14.0	16.5−18.5	2.25−3.0			0.2% PS 210	490	40		
				Al	Cu	Mg	Si	Fe	Mn	Zn	Cr							
	AL. ALLOY N8	BS 1470	P.	Rem.	0.1	4.0−4.9	0.4	0.4	0.5−1.0	0.2	0.25			0.2% PS 130	280	12		
6	OBSOLETE PROTECTIVE PLATING																	
	NON-CEMENTED ARMOUR	SEE DESCRIPTION IN SECTION 15. CLAUES 12.2a. to 12.2c.																
	CEMENTED ARMOUR																	
	NMMQ																	
	DKM																	
	SPECIAL QUALITY																	
	UXWHT	AS FOR UXW (GROUP 1) BUT WITH SPECIAL HEAT TREATMENT.																
	D1 HT	" 2 D1 (GROUP 2) " " " "																
	Q.T. 35		P. QT	0.15	1.2	0.3	0.03	0.04	1.2	1.0	0.5		V :−0.12% max	0.2% PS 555−680	> 1.1 ¢ PS	20	81J @ −40°C	0.7
7	CURRENT STRUCTURAL AL. ALLOYS			Al	Cu	Mg	Si	Fe	Mn	Zn	CR							
	N.8	BS 1470 BS 1474	P.O S.O	Rem.	0.1	4.0−4.9	0.4	0.4	0.5−1.0	0.2	0.25			0.2% PS 125	275	12		
	OBSOLETE STRUCTURAL AL.ALLOY																	
	N 5/6	BS 1470	P.M	Rem.	0.1	3.5−5.5	0.6	0.7	1.0	–	0.5			0.1% PS 125	265	12		
	N 6	BS 1474	S.M	Rem.	0.1	4.5−5.5	0.6	0.5	1.0	0.2	0.25			–	265	18		

NOTE: For welding purposes the following steels are to be treated the same as the MOD(N) steels indicated: BS 4360 43A or BS 1449—Mild steel (DG Ships 1207); BS 4360 43D. Notch Tough Mild Steel (NES 791 Pt 2); BS 4360 50D or BS 4360 50E—'B' Quality (DG Ships 1257): BS 4360 50D HYZED or BS 4360 50E HYZED—'BX' Quality (DG Ships 322); BS 1504 161 1420—Carbon Steel (DG Ships 8081); BS 1504−245—Carbon Molybdenum (DG Ships 6081). This is not to be taken as approval to use the stated materials as direct equivalents; Design Authority approval is required for such a change.

TABLE 1.1 (Contd) LIST OF MATERIALS

2. WELDING PROCESS AND EQUIPMENT

a. This section contains the instructions regarding the qualifications of welding processes and equipments and defines the requirements for installations of welding circuits.

2.1 Qualification Requirements

a. Welding processes and equipments are to be qualified for use by forming an integral part of pre-production procedure tests. Welding processes and equipments are not to be used beyond the limits established by pre-production procedure tests without further qualifications.

b. Welding process and equipment qualification tests are not in general required for individual equipments that have been used in production and proved capable of producing acceptable welds. If the Inspecting Authority suspect the performance of any equipment they are to request that it be demonstrated that it is capable of producing acceptable welds when used by a competent welder using an approved weld procedure. Equipment failing to meet the Inspecting Authority’s approval are not to be used. Welding plant and ancillary equipment are to be regularly inspected and maintained in good working order.

2.2 Installation of Welding Circuits

a. Manual Metal Arc (MMA) welding on ships afloat, when being supplied from a dc power source on shore, can cause extensive corrosion to the underwater hull, shafting and propellers. Automatic and semi-automatic processes supplied from a dc transformer metal rectifier set can also contribute to the corrosive effect where the transformer rectifier is placed on shore. Direct current flowing in a random manner through the ship’s hull and water causes electrolytic action to be set up with corrosive effects. These corrosive effects are absent when the dc power source is placed on board or when welding with an ac power source. With the dc power source on board the weld current return path is confined to the ships structure and cannot pass through water. To reduce corrosion and for other reasons the maximum use of ac is to be encouraged.

2.3 Capacity of Cables

a. Welding can only take place when a circuit is completed between the output terminals of the power source via the current adjusting device, the welder’s lead, electrode holder, electrode, welding arc, work piece and welding return lead back to the power source. If the current carrying capacity of any of these circuit components is inadequate correct welding conditions will not exist, since either insufficient current will be available or the losses due to heating will reduce the voltage at the arc and so produce unsatisfactory welding. The total current carrying capacity of all the cables connecting one pole of the power source to the several welders electrode holders on board ship is to be matched by an equal current carrying capacity in the one or more cables forming the welding return from the ship’s hull back to the other pole of the power source. The current rating of cables when used as welding leads are shown in TABLE 2.1.

2.4 Return Leads

a. In every instance, whether using ac or dc for welding it is to be ensured that the return leads from the structure are adequate to carry the total welding current used by all the welders. If the return lead is inadequate, a path may exist through water and hull so that while satisfactory welding may be possible excessive corrosion may result when using a dc power source.

Max Hand Welding Current	Nominal Cross Section Area	No and Dia of Wires	Nominal Overall Dia	NSN 6145−99 NS Class/ Group 0561
Amps	mm^2	mm	mm	
10	16	513/0.20	11.5	521−8535
150	25	783/0.20	13.0	521−8536
250	35	1107/0.20	14.5	521−8537
400	50	1566/0.20	17.0	521−8538
650	70	360/0.50	19.7	521−8482
	70	2214/0.20	19.5	
700	95	1332/0.30	22.7	521−8483
	95	2997/0.20	22.0	
	120	608/0.50	24.0	
1000	185	925/0.50	29.6	521−8485
1200	300	1525/0.50	31.2	523−2806
1800	630	2257/0.60	50.2	521−8339

TABLE 2.1 CURRENT RATING OF WELDING LEADS (COPPER)

b. Even with adequate return leads alternative conducting paths often exist and are sometimes difficult to avoid. The current through the water can in general be minimized by reducing the resistance of the welding return cables. This can be done by:

(1) keeping the length of cable to a minimum;

(2) using heavier cable or more than one cable;

(3) improving the connections.

c. Several smaller cables connected at intervals around the ship present less resistance to the current than a heavier cable connected at one point. An ideal arrangement would be for each welder to bring his own return cable on board and connect it to the ship in close proximity to his work. The resistance of the joint and the metalwork of the ship in the vicinity of the joint can be considerably higher than that of the welding return cable. If much welding is to be carried out, special lugs similar to that shown in FIGURE 2.1 are to be welded to the ship's hull. Care is to be taken to see that all the connections are clean and tight and in good electrical contact with those parts of the ship where welding is to be carried out.

d. The current Rating of Welding Leads (Aluminium) are shown in BS 638.

e. Cables looped between ships are to be bolted to a common connection on ship 'A' as shown in FIGURE 2.2.

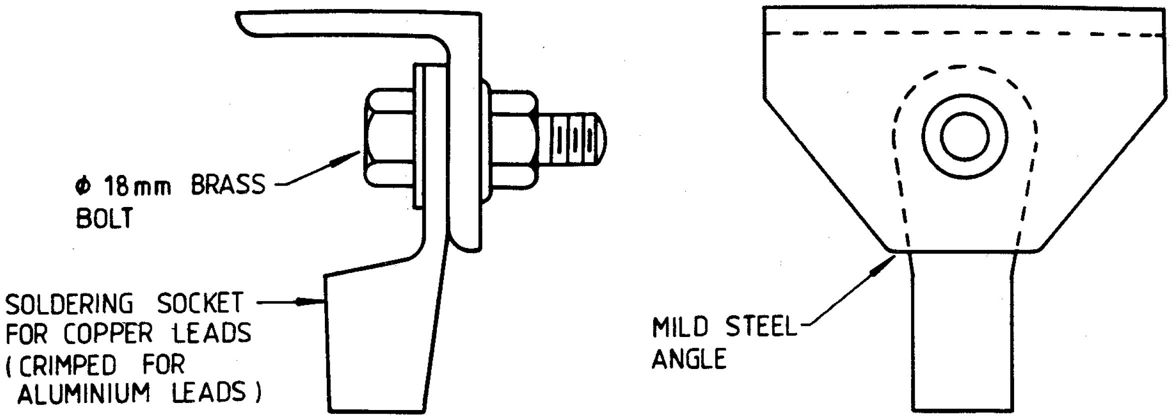


FIGURE 2.1 LUGS FOR ATTACHMENT OF RETURN CABLES

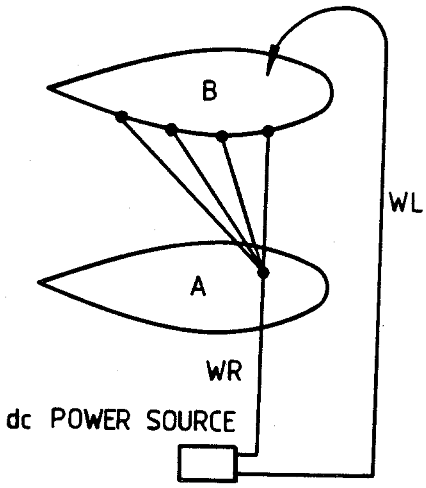


FIGURE 2.2 CABLES LOOPED BETWEEN SHIPS

2.5 DC Power Sources

a. On no account is either pole of a dc power source on shore to be ‘earthed’ when in use supplying welding load on board ships afloat. This automatically prohibits the use of such a power source for welding on shore while the set is simultaneously supplying welders afloat.

b. A multi-operator dc power source is to supply one ship only and a welding return of adequate size provided direct from the ship to the power source. FIGURE 2.3 shows the normal arrangement of cables for a single or multi-operator dc power source supplying a single ship.

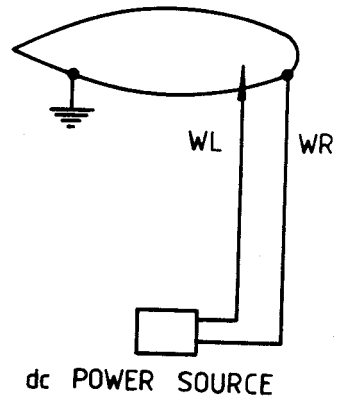


FIGURE 2.3 DC POWER SOURCE SUPPLYING A SINGLE VESSEL

c. The normal arrangement for single or multi-operator dc power sources each supplying separate vessels berthed alongside one another is shown in FIGURE 2.4.

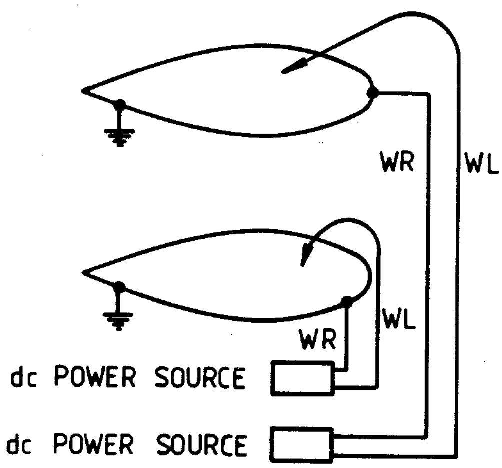


FIGURE 2.4 DC POWER SOURCES SUPPLYING VESSELS BERTHED TOGETHER

d. If a multi-operator dc power source be used to supply more than one ship afloat each with a welding return current, water borne, between the ships is unavoidable and will be a corrosion hazard. If it is essential to use a multi-operator dc power source to supply more than one ship afloat, the arrangement of cables is to be as shown on either of the arrangements indicated in FIGURE 2.5. In both cases some part of the return from ship 'B' will flow through water.

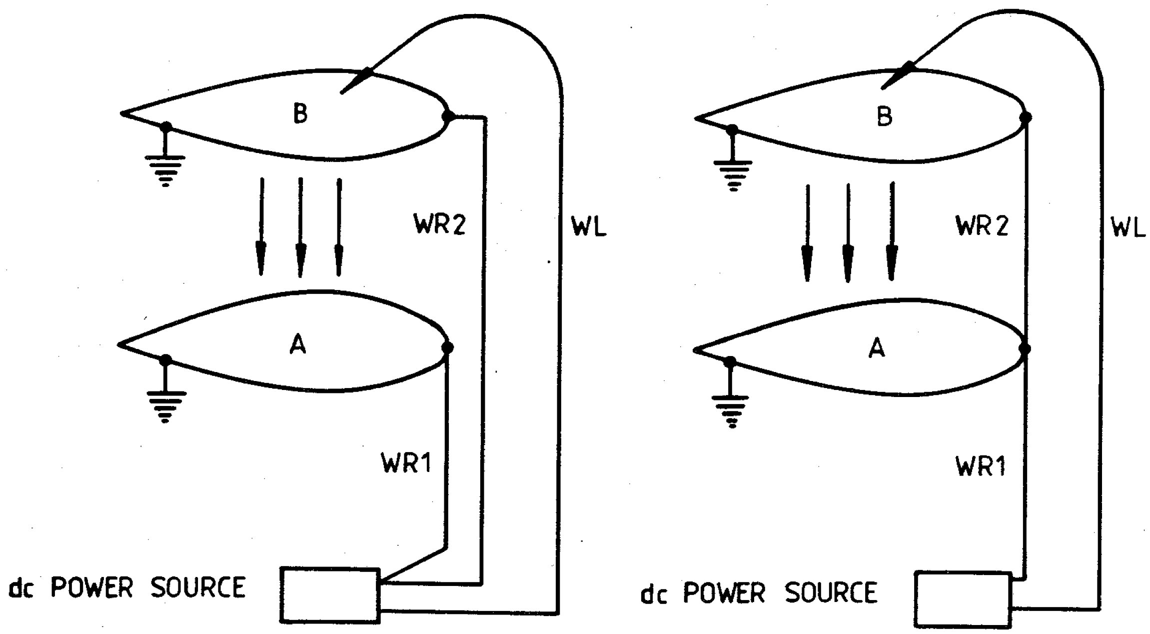


FIGURE 2.5 MULTI-OPERATOR DC POWER SOURCE SUPPLYING TWO SHIPS BERTHED ALONGSIDE ONE ANOTHER

3. WELDER QUALIFICATION

a. This section contains the requirement for welder qualification of all welding within the scope of this NES. Welders employed in welding QT35, HY80, Q1N or steels where CE exceeds 0.7 or these materials in combinations with the materials contained within this NES are to be qualified in accordance with NES 770.

b. Each welder is to be qualified to meet the appropriate acceptance standard using the welding process/processes he will operate in production work. No welder is to be employed to an acceptance standard beyond his capabilities.

c. It is the fabricator's responsibility to qualify each welder by ensuring that he is capable of working strictly to welding procedures and of welding under production conditions to the relevant acceptance standard. It is also the fabricator's responsibility to ensure that all welders maintain the required acceptance standard in production welding by checking an individual welder's work as a result of the normal production's non-destructive testing. Particular care is to be taken in the early stages of a project to establish that the specified standard is being achieved.

d. Where a welder is unable to consistently meet the acceptance standard or fails to work in accordance with the welding procedure the Inspecting Authority is to have the right to require the welder to be removed from production work. Re-establishment of welder qualification for production work will be subject to acceptance by the Inspecting Authority.

4. WELDING PROCEDURES

a. This section defines the requirements for procedural control of welding operations which are carried out within the scope of this NES and as required by 'Fabricator's Approval' in NES 769.

b. Welding procedure is a specified course of action to be followed in welding. It must take into account the facilities and equipment available. It is to be arranged to suit the details of the joints as shown on the drawings and the positions in which the welding is done. It is to such as to ensure that weld metals can be satisfactorily deposited throughout the length and thickness of all joints, that the quality of welds meet the required standard and that all required mechanical or physical properties of the weld/base material are maintained. It is to contain sufficient information to ensure repetition of the same quality of welding to the appropriate acceptance standard. A high degree of testing is carried out by MOD(PE) on all welding consumables and weld processes prior to approval for use. Mandatory requirements arising from these tests are included in this NES as pre-heat, interpass temperature and heat input etc. Additional requirements may be noted against particulars of weld metal approvals in NES 769.

4.1 Written Weld Procedures

a. Written weld procedures are to be provided for all production work within the scope of this NES. Weld procedures shall be approved by the Inspecting Authority except where specific instructions within this NES or Contract Documents, require weld procedures to be forwarded to Ship Department for approval. It is not intended that written welding procedures are produced for issue to each welder, but that Work Instructions contain the basic welding information which is related to the typical joint configurations involved in the particular structure. It is, nevertheless, important that welders are informed of the relevant requirements.

4.2 Preparation and Qualification of Welding Procedures

a. Written weld procedures are to be prepared embodying the relevant information from this NES and from pre-production tests which represent the envisaged production applications in as many respects as possible.

b. The approval of pre-production procedures will normally be based on the attainment of weld soundness to the appropriate acceptance standard, but where the Inspecting Authority suspects that the physical weld/base material properties will not, or for procedures in use, are not, being attained by a particular weld procedure then the fabricator may be required to prove the procedure by mechanical tests from a test weldment. The weld metal properties required for structural steels are shown in NES 769.

c. Weld procedures for use on the structural steels defined herein are to be limited to the use of approved welding consumables, see NES 769. Use of these consumables are to be restricted to the following processes and may only be used within the specified conditions imposed by that NES;

(1) manual metal arc (MMA):

(2) submerged arc;

(3) metal arc inert gas (MIG).

The use of other welding processes or consumables are to be subject to individual approval between the fabricator and MOD(PE). Proposals are to be made to DG Ships who will normally require the fabricator to carry out full pre-production procedure tests and demonstrate its suitability for the envisaged application.

d. Fabricators experienced in MOD(PE) work may offer this experience as proof that they have established satisfactory welding procedures and then the testing required by Clause 4.2a. need not be done. The acceptance of such evidence is to rest with the Inspecting Authority. No welding is, however, to be undertaken without a written procedure based on the actual consumables selected for use.

4.3 Non-destructive Examination and Acceptance Standards

a. The non-destructive examination and acceptance standards applied to pre-production procedure testing are to be in accordance with the normal fabrication requirements for the particular procedure involved, see Section 17.

4.4 Procedure Information for Fusion Welds

a. The following information where relevant is to be contained in weld procedures for all welds other than stud welding:

base material/materials, types and conditions;

welding consumables, size and name;

method of joint preparation and cleaning;

joint design;

bead deposition sequence;

welding process and type and equipment;

polarity, welding current range, arc voltage range;

pre-heat and interpass temperature;

run off length and speed of travel;

shielding gas, composition, flow rate;

welding position;

welding sequence;

post weld heat treatment;

NDT and acceptance standard;

electrode wire stick out;

nozzle to work piece distance;

special instructions (ie composition requirements for cladding);

back gouging methods and requirements;

depth of weld deposit, ie cladding.

4.5 Procedure Information for Stud Welds

a. The following minimum information where relevant is to be contained in weld procedures for all stud welding:

intended applications;

process and type of equipment used;

stud, material and size, ferrules;

base material;

gas shield and flow;

timer range setting;

maximum cable length;

amperage range;

test requirements.

5. DESIGN OF WELDED JOINTS, STRUCTURAL STEEL

a. This section contains the requirements for design of welded joints when used for structural purposes. The welding processes for which the requirements of this section apply are:

(1) manual metal arc (MMA);

(2) submerged arc;

(3) metal inert shielding gas (MIG).

The use of other welding processes is to be subject to the requirements of Clause 4.2c.

b. The design of joints is a vital part of welding procedure and correct designs will help control distortion, reduce shrinkage, facilitate good workmanship and produce sound welds economically. The details must be arranged to permit the use of a satisfactory welding procedure and the combination of joint design and welding procedure must be such that the resulting joint will comply with the requirements of the design of the structure. Local conditions and the availability of equipment have to be considered and for these reasons the various examples of joint design included in this section are intended only for general guidance. The general requirements of this section, however, are to be observed and the design is subject to MOD(PE) approval.

5.1 Qualification of Joint Design, Edge Preparation

a. Edge preparations are to be qualified for use by being part of the pre-production procedure tests defined in Section 4. Particular care is to be taken in selecting edge preparations for use with submerged arc or metal arc inert gas welding. The selection of edge preparations which necessitates using consumables outside the conditions defined in NES 769 are to be subject to individual approval between the fabricator and MOD DG Ships.

5.2 Stresses in Welds

a. Consideration is to be given at the design stage to the stress capabilities of the different types of welds:

(1) **Butt joints** Full penetration butt welds have a pronounced superiority over fillet welded lap joints under all loading conditions. Lap welded joints will only be permitted in accordance with Clause 5.13a.

(2) **Tee joints** The selection of joint designs for tee connections is more complicated. The following will influence the choice of weld type suitable for a particular application:

(a) Double fillet welded tee connections are adequate for static loading conditions but for material of 19mm and above, the fillet weld size becomes unduly large, inducing high residual stresses and increasing distortion. Thus for material 19mm it is recommended that fillet welds are replaced by partial penetration welds as shown in FIGURE 5.25. Where abutting tee members exceed 38mm, depending on the structural configuration, full penetration tee butt welds will be required to reduce distortion and the degree of residual stress.

b. Where dynamic loadings, cyclic or explosive, are involved then improvements in the structural performance can be obtained by the following:

(1) smooth well radiused profile achieved by weld depositions;

(2) mechanical grinding of weld toes to provide optimum profile, ie minimum radius of 6mm.

c. The choice of tee joint design is further influenced by the structural importance of the joint which will dictate the extent of non-destructive testing as defined in DG Ships/G/10000. Where 100% non-destructive testing other than visual examination is needed full penetration tee butt welds will be required because of the difficulty of examining fillet or partial penetration welds due to the inherent root discontinuities.

d. The effective cross-sectional area of welds is to be calculated by multiplying the length of the weld by the effective throat thickness. Throat thicknesses are specified in Clause 5.7a. for butt welds and in Clause 5.12b. for fillet welds.

5.3 Abrupt Changes of Section

a. Abrupt changes of section are to be avoided to minimize stress concentrations. Where parts of different thicknesses are to be butt welded, excluding tee joints, the thicker part is to be tapered, at a slope of about 1 in 4, down to the thickness of the thinner part. Where the difference in thickness is 3mm or less, tapering is not necessary but the weld is to be built up to the thickness of the thicker part. For details see FIGURE 5.1. Where local increase in plating thickness is required the use of a thicker insert plate is to be used as opposed to a fillet welded doubler so that the abrupt change in section is avoided. The welding of inserts into a structure which is otherwise complete often presents difficulties due to the high degree of restraint, thus the rules of Section 10. for welding inserts must be observed. Inserts are not to be fitted in sheer strakes or deck stringers without MOD(PE) approval.

FIGURE 5.1

b. There is no general requirement for edge strips to be fitted between decks, bulkheads, frames, stiffeners etc and passing plating. Such strips between abutting Tee members need only be fitted where some special advantage may be gained, ie where light plating is subjected to slamming or panting.

5.4 Location of Welds

a. To facilitate sound welds being made joints are to be located such that the entire weld preparation is visible to the welder; that there is adequate access for the welder and his shield; and he is able to maintain the electrode at the correct angle and position. Where back gouging is required sufficient access must be provided for this operation. The location of weld joints is to aim at avoiding the following situations which may increase the risk of 'in fabrication' or 'in service' cracking resulting from the creation of stress concentrations or high residual stresses:

(1) bunching of weld deposits, ie parallel lines of welding close together. See Section 10. concerning rules for positioning inserts;

(2) placing welds in positions of high stress concentrations;

(3) placing attachment or minor welds on main structural welds.

5.5 Welding Position

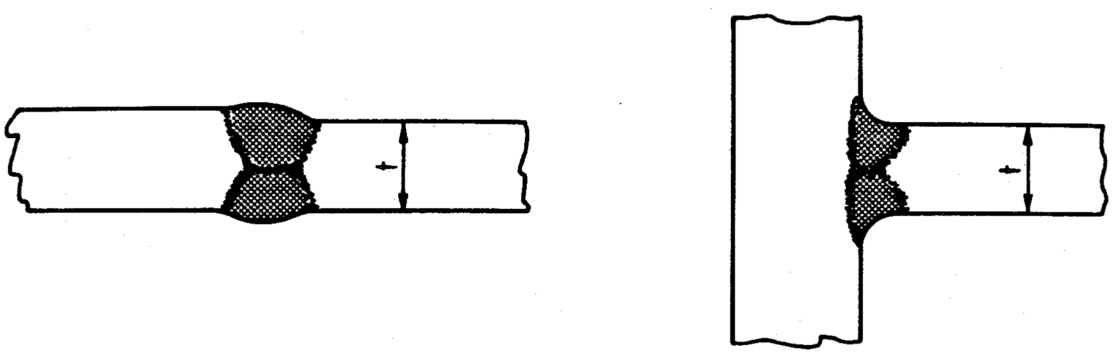
a. Welded joints are to be arranged to allow the maximum amount of welding in the flat position. Where rotation of the weldment is not practicable asymmetrical preparations can be used to reduce the amount of overhead welding. Welding in the vertical and overhead positions requires manipulation of the electrode and the included angle in a butt joint must be large enough to permit satisfactory manipulation. A 70° included angle is recommended for welding in these positions. Consideration is to be given to which side of the joint back gouging will be done. Under certain circumstances it is beneficial for the overhead welding to be done first followed by back gouging in the flat position. When this practice is adopted sufficient weld metal must be deposited to withstand the stresses induced by back gouging.

5.6 Welding Processes

a. The size of the root face in a butt joint depends on the anticipated depth of penetration and this is controlled mainly by the arc voltage and current density. The root face is to be small enough to obtain adequate penetration but large enough to prevent 'blow through'. For MMA welding a 3mm root face is the maximum generally desirable but for large structures in thick materials this may be increased to a maximum of 6mm to assist in joint alignment. The ability to change and control the arc voltage and high current densities are features of the automatic welding processes which can give deeper penetration and permit the use of larger root faces, assuming that the heat input restrictions for particular consumables are not exceeded (see NES 769). The use of hydrogen controlled electrodes requires a somewhat different technique from that normally used for other types of ferritic electrodes: a short arc length and controlled angle of electrode are essential. Close fitting joints and the maximum included angle indicated in the various figures of this section are desirable when using these electrodes.

5.7 Butt Welds

a. The throat thickness of a butt weld is to be taken as the thickness of the thinner member of the joint, see FIGURE 5.2. The maximum permissible out of alignment of root faces or edges is stated in Clauses 7.20a. to 7.20c.



a b

't' = effective throat thickness

FIGURE 5.2

b. Butt joint edge preparations must be such as to facilitate the production of sound welds with the particular consumable involved, the required degree of penetration with a minimum of weld metal and wherever possible to permit welding from both sides. The dimensions of the preparation depend on the welding process, position and technique used. The root of the first side welded is to be back gouged to sound bright metal prior to welding the second side. If for any reason it is proposed to make a full penetration butt or tee butt weld from one side only, prior MOD(PE) approval is to be obtained. Full details of the technique and proposed procedure are to be submitted.

c. Butt welds are to be deposited so that the thickness of the reinforcement at the centre of the weld is approximately 10% of the design thickness of the weld or 3mm whichever is the smallest. Excessive reinforcement does not increase the strength and may impair the fatigue properties of the joint. Where a flush weld surface is required for non-destructive examination or for the requirements of design the butt weld is to be welded normally and then dressed flush.

d. All back gouging, flushing and dressing operations are to be done in accordance with Clauses 9.12a. to 9.13d.

5.8 Backing Bars and Strips

a. For the purpose of this Standard the following definitions are to apply:

Backing bar — A backing bar is a piece of metal or other material used to assist in making a weld but not intended to become part of the weld.

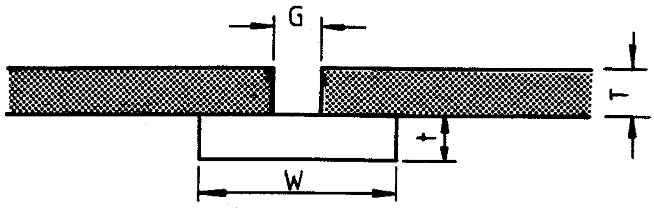
Backing strip — A backing strip is a piece of metal placed at the root and penetrated by weld metal. It may remain as part of the joint or be removed by machining or other means.

b. In certain circumstances the use of backing bars or strips produce high stress concentrations in the joint; they must therefore be limited to applications where it is not possible to arrange the joint so that it can be welded from both sides.

The use of backing bars or strips will be subject to MOD(PE) approval. Where a copper bar is used the surface of the penetration bead is to be lightly ground to remove copper 'pick up'.

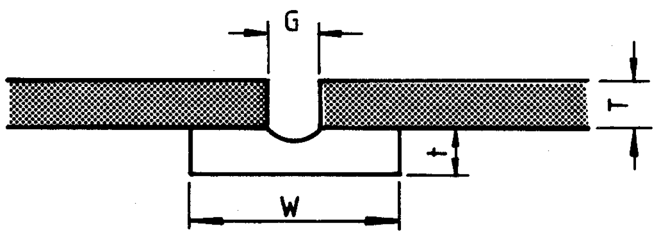
5.9 Joint Dimensions

a. Recommended dimensions for joints with backing are shown in FIGURE 5.3 to FIGURE 5.6; the backing is to be in close contact with the plate edges along the whole length. The width of the gap must be sufficient to allow access of the electrode and the shape of the groove in a copper bar which will produce the required bead shape is to be established on trial plates.



	MANUAL WELDING	MACHINE WELDING
T =	5mm max	5mm to 12mm
G =	T	3mm
t =	T	5mm min when T is less than 10mm 6mm min when T is more than 10mm
W =	4T min	

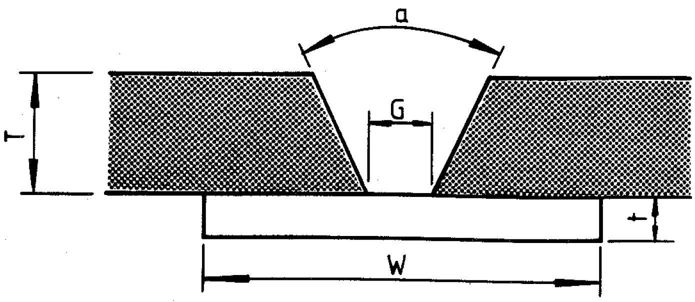
FIGURE 5.3 SQUARE BUTT JOINT WITH STEEL BACKING STRIP



MANUAL WELDING ONLY

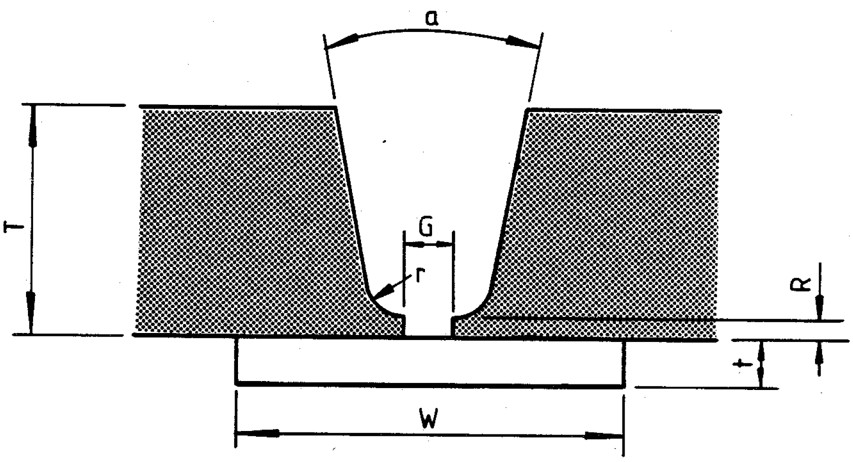
T = 5mm max
G = T
t = T
W = 4T min

FIGURE 5.4 SQUARE BUTT JOINT WITH COPPER BACKING BAR



	MANUAL WELDING	MACHINE WELDING
T =	6mm to 19mm	8mm to 25mm
G -	6mm min	5mm min
a =	45° min	30° min
t =	(5mm min when T is less than 10mm (6mm min when T is more than 10mm	
W =	4T or 51mm whichever is less	

FIGURE 5.5 V BUTT JOINT WITH STEEL BACKING STRIP



	MANUAL WELDING	MACHINE WELDING
T =	19mm to 32mm	19mm to 38mm
G =	6mm min	1mm max
R =	1.5mm to 3mm	1.5mm to 3mm
a =	20°	20°
r =	5mm	8mm
t =	6mm min	6mm
W =	51mm	51mm

FIGURE 5.6 U BUTT JOINT WITH STEEL BACKING STRIP

5.10 Types of Butt Joints

a. They are generally described according to the way the plate edges are prepared. The types in most common use are:

(1) Square butt joint;

(2) Single V butt joint;

(3) Double V butt joint;

(4) Single U butt joint;

(5) Double U butt joint;

(6) Single bevelled butt joint;

(7) Single J butt joint;

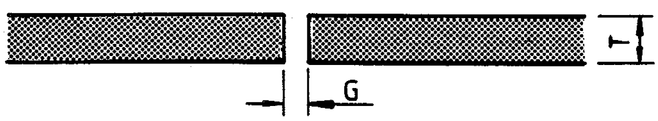
(8) Double bevelled butt joint;

(9) Double J butt joint;

(10) Tee butt joint.

Note: Joints (9) to (10) require the preparation of one plate only and therefore are more difficult to weld than joints where both plates are prepared.

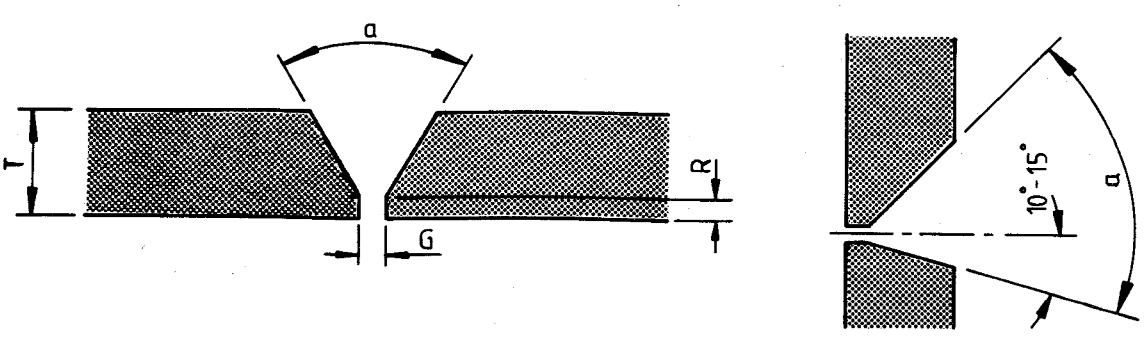
b. **Square butt joint** Economical in preparation and welding and is to be used where practicable. Recommended dimensions are shown in FIGURE 5.7.



	MANUAL WELDING	MACHINE WELDING
T =	5mm max	19mm max (depending on approved (limit of consumables (see NES 769
G =	$^T/2$	1mm max

FIGURE 5.7 SQUARE BUTT JOINT

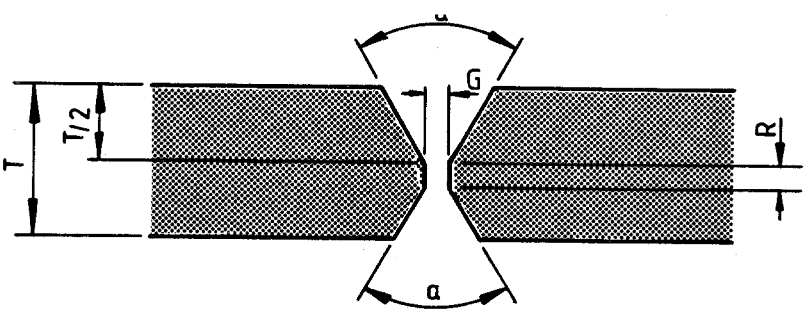
c. **Single V butt joint** Welding is mainly from one side and it is difficult to prevent angular distortion. It is generally uneconomical for plates over 16mm thick for manual welding and over 25mm for automatic welding. Recommended dimensions are shown in FIGURE 5.8. For welding in the horizontal−vertical position it is advantageous for the included angle to be made up of two unequal bevels, 10° to 15° off the lower plate and the remainder off the top plate.



	MANUAL WELDING	MACHINE WELDING
T =	6mm to 16mm	8mm to 25mm
G =	0 to 3mm	1mm max
R =	1.5mm to 3mm	3mm to 10mm
a =	60° to 70°	45° min

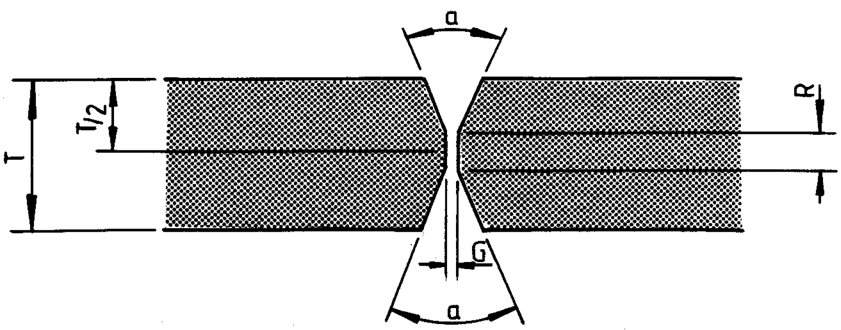
FIGURE 5.8 SINGLE V BUTT JOINT

d. **Double V butt joint** Welding can be balanced with a minimum of angular distortion but care has to be taken to ensure satisfactory fusion at the centre of the weld. It requires less weld metal than single V preparation and is generally economical in plate thicknesses between 16mm and 38mm. Recommended dimensions are shown in FIGURE 5.9 to FIGURE 5.12. In FIGURE 5.11 it will be noted that the 90° included angle reduces the amount of back gouging and that after this operation the angle is to be between 60° and 70°. It may be advantageous to complete the overhead welding first, to ensure good edge preparation for the more difficult welding position and less fatigue during back gouging. In such cases the inclusive angle of the small vee is to be reduced to between 60° and 70°.



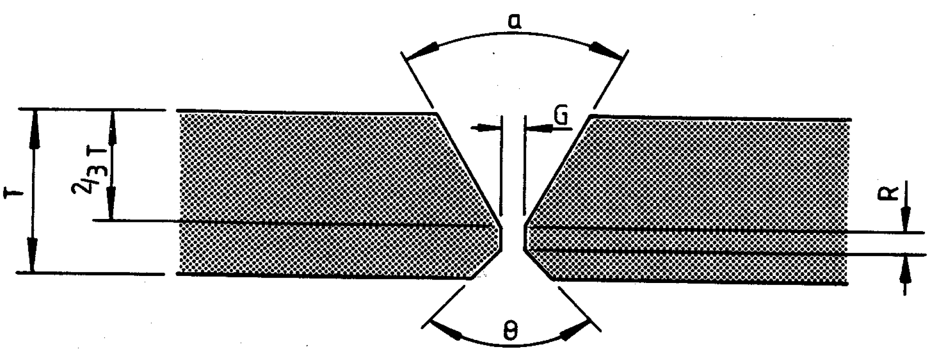
T = 16mm to 38mm
G = 0 to 3mm
R = 1.5mm to 3mm
a = 60° to 70°

FIGURE 5.9 MANUAL WELDING, BOTH SIDES IN FLAT POSITION



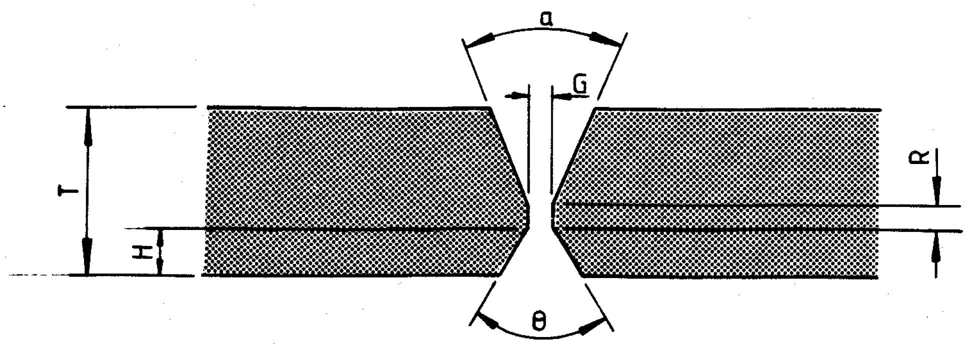
T = 19mm to 38mm
G = 1mm max
R = depending on approved limit of consumables see NES 769
a = 45° min

FIGURE 5.10 AUTOMATIC WELDING, BOTH SIDES IN FLAT POSITION



T = 16mm to 32mm
G = 0 to 3mm
R = 1.5mm to 3mm
a = 60° to 70°
θ = 90°, reduced to 60° to 70° after back gouging

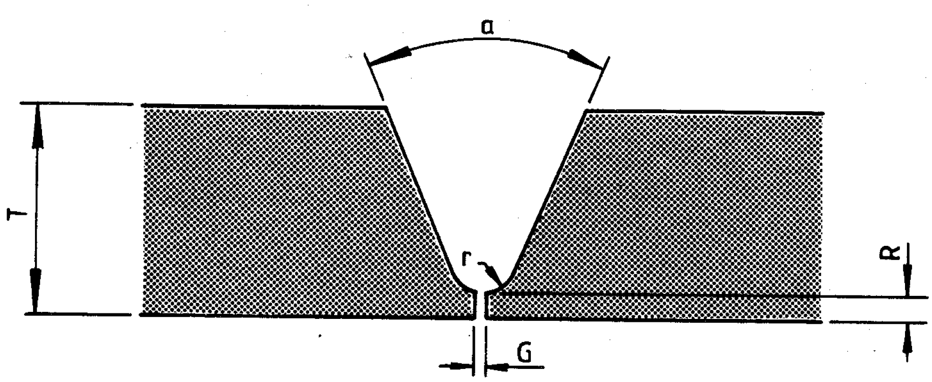
FIGURE 5.11 MANUAL WELDING, ONE SIDE IN OVERHEAD POSITION



T = 19mm to 38mm
G = 0 to 3mm
R = 1.5mm to 3mm
H = 6mm min
a = 45° min
θ = 60° to 70°

FIGURE 5.12 AUTOMATIC WELDING WITH MANUAL BACKING IN THE OVERHEAD POSITION

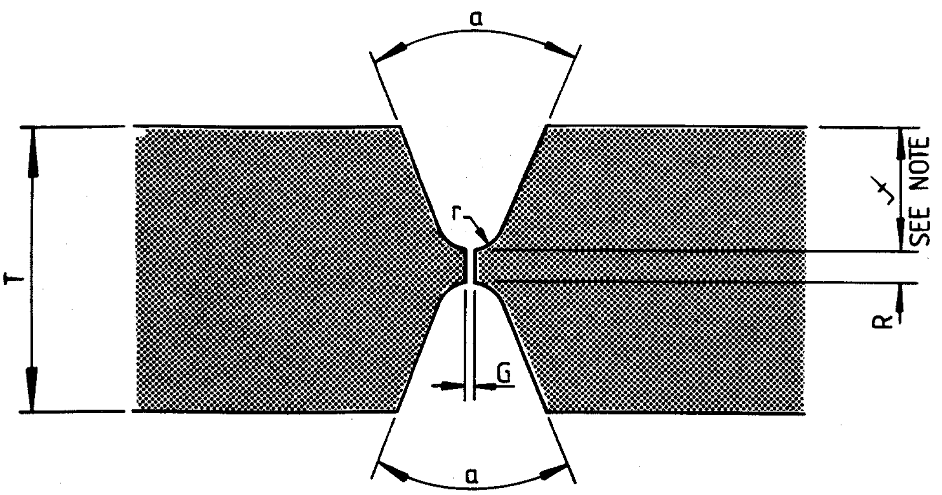
e. **Single U butt joint** Welding is mainly from one side; the preparation is more costly than the single V but there is a saving in weld metal, it is easier for welding and there is less distortion. It is generally uneconomical for plates under 19mm thick. Recommended dimensions are shown in FIGURE 5.13.



	MANUAL WELDING	MACHINE WELDING
T =	19mm to 32mm	19mm to 32mm
G =	0 to 3mm	1mm max
R =	1.5mm to 5mm	6mm max (depending on approved (limit of consumables (see NES 769
r =	3mm	3mm
a =	45°	45°

FIGURE 5.13 SINGLE U BUTT JOINT

f. **Double U butt joint.** This preparation is expensive and is not generally recommended for plates less than 38mm thick. The welding can be balanced with a minimum of angular distortion. Recommended dimensions are shown in FIGURE 5.14.

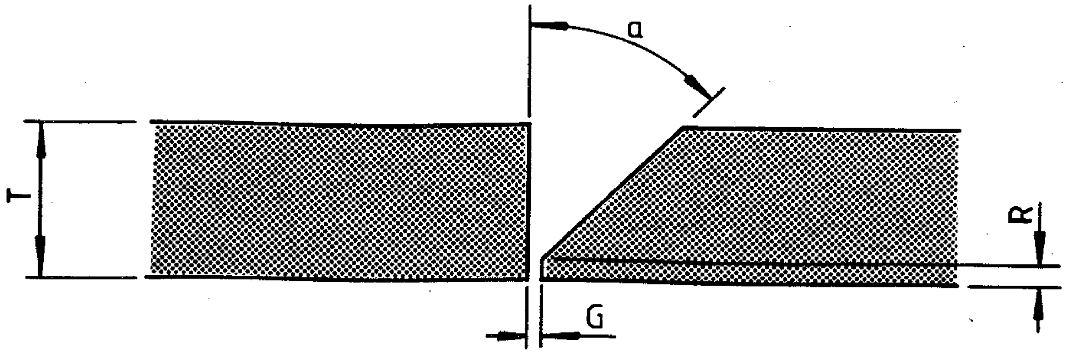


	MANUAL WELDING	MACHINE WELDING
T =	38mm and above	38mm and above
G =	0 to 3mm	1mm max
R =	1.5mm to 5mm	6mm min (depending on approved (limit of consumables (see NES 769
r =	3mm	3mm
a =	45°	45°

Note: Thick material may require two values of **a** in any preparation ie **a** = 45° where it is up to 25mm in depth, thereafter a is reduced to 20°.

FIGURE 5.14 DOUBLE U BUTT JOINT

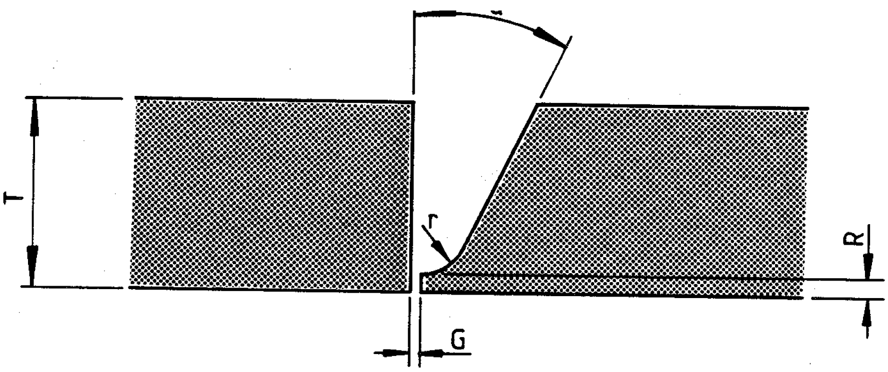
g. **Preparation of one plate only** Where it is difficult to prepare both sides of a joint the preparation shown in FIGURE 5.15 to FIGURE 5.18 may be used.



	MANUAL WELDING	MACHINE WELDING
T =	6mm to 16mm	8mm to 19mm
G =	0 to 3mm	1mm max
R =	1.5mm to 3mm	3mm to 10mm (depending on approved (limit of consumables (see NES 769
a =	45° min	45° min

Note: **a** may require increasing for positional depositions or where electrodes produce bulbous cross-sections.

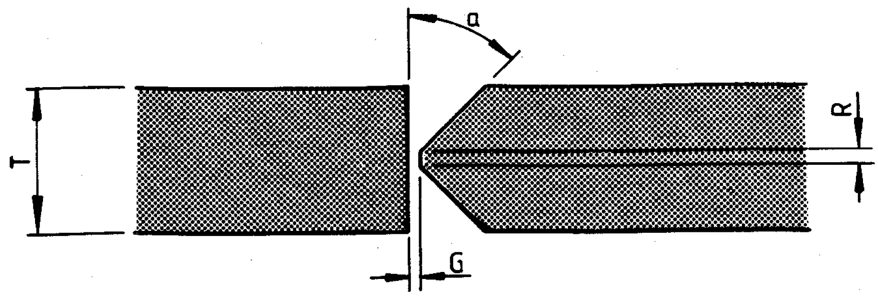
FIGURE 5.15 SINGLE BEVELLED BUTT JOINT



	MANUAL WELDING	MACHINE WELDING
T =	19mm to 25mm	19mm to 28mm
G =	0 to 3mm	1mm max
R =	1.5mm to 3mm	3mm to 10mm
r =	6mm	6mm
a =	25°min	25°

Note: **a** may require increasing for positional depositions or where electrodes produce bulbous cross-sections.

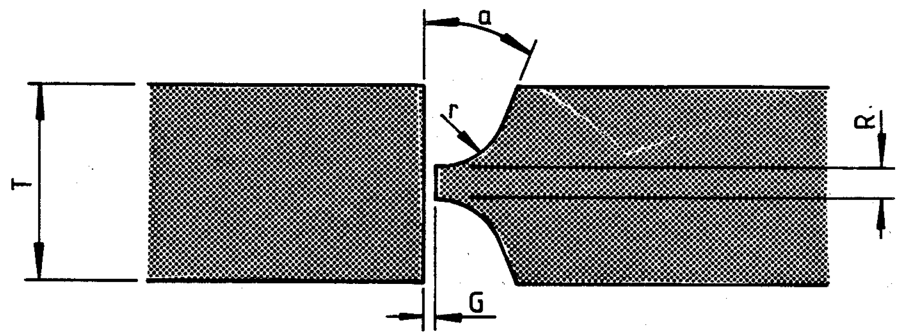
FIGURE 5.16 SINGLE J BUTT JOINT



MANUAL WELDING		MACHINE WELDING
T =	19mm to 38mm	19mm to 38mm
G =	0 to 3mm	1mm max
R =	1.5mm to 3mm	6mm (depending on approved (limit of consumables (see NES 769
a =	45° min	45° min

Note: **a** may require increasing for positional depositions or where electrodes produce bulbous cross-sections.

FIGURE 5.17 DOUBLE BEVELLED BUTT JOINT



MANUAL WELDING		MACHINE WELDING
T =	25mm and above	25mm and above
G =	0 to 3mm	1mm max
R =	3mm to 6mm	3mm to 10mm
r =	8mm	8mm
a =	20° min	20° min

FIGURE 5.18 DOUBLE J BUTT JOINT

5.11 Tee Butt Joints

a. Regarding the application of these joints, see Clauses 5.2(1) to 5.2d. The shape and smoothness of the surface of the weld may be important factors and the correct contour may be obtained by the manner of weld deposition of the final weld passes and/or machine profiling. As a general rule the final contour of tee butt welds is to have a minimum radius of 6mm; see FIGURE 5.19. Recommended dimensions for tee butt joints are shown in FIGURE 5.21 to FIGURE 5.23.

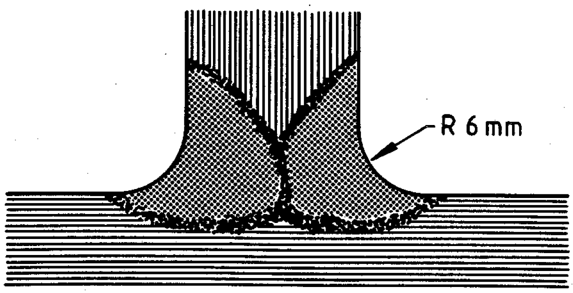


FIGURE 5.19

b. Care is to be taken in selecting or designing tee butt edge preparations or large fillet weld joints on material which is susceptible to lamellar tearing. This particularly applies to thick plate where high restraint is present, ie flange rings to thick wall tubes or hatch coamings passing through submarine pressure hull plating. The basic cause of such failures is the low ‘through the thickness’ properties of plates due to non-metallic inclusions in the steel. Welding tee butt joints can result in contractional stresses above the capabilities of the plate ‘through the thickness’, thus inducing lamellar tearing. The risk of this type of cracking may be minimized on flange ring joints or corner joints by use of edge preparations in which the fusion line is arranged to run across the plane of weakness, see FIGURE 5.20a and FIGURE 5.20b. Further information on this subject, including various buttering techniques and procedures aimed at reducing the risk of lamellar tearing can be found in Annex F.

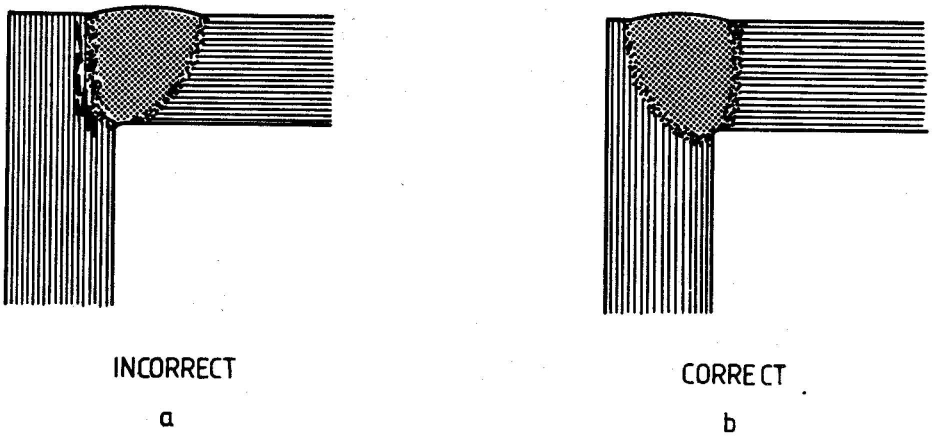
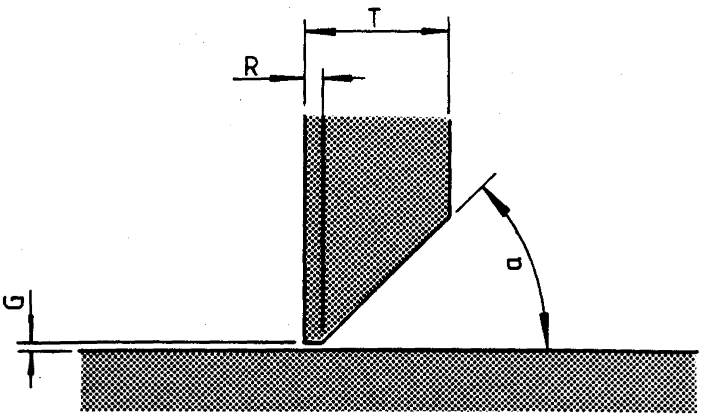
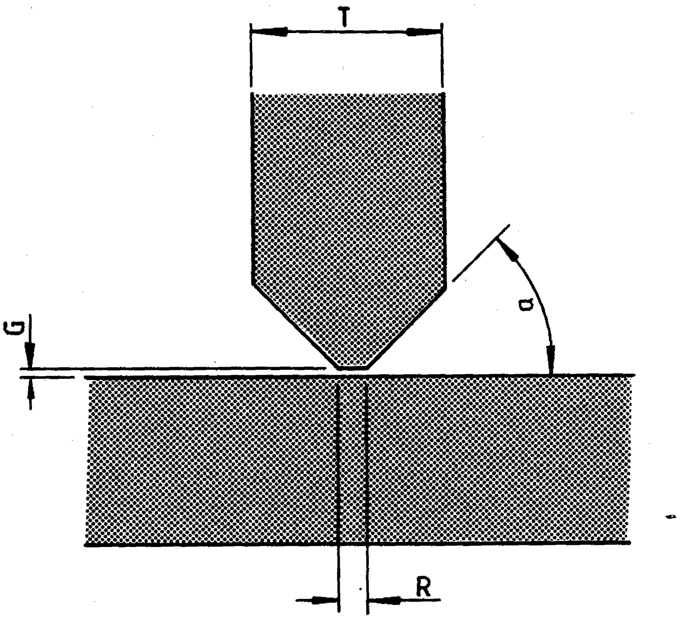


FIGURE 5.20



	MANUAL WELDING	MACHINE WELDING
T =	5mm to 19mm	6mm to 22mm
G =	0 to 1.5mm	1mm max
R =	1.5mm to 3mm	3mm to 10mm
a =	45^{o} min	45^{o} min

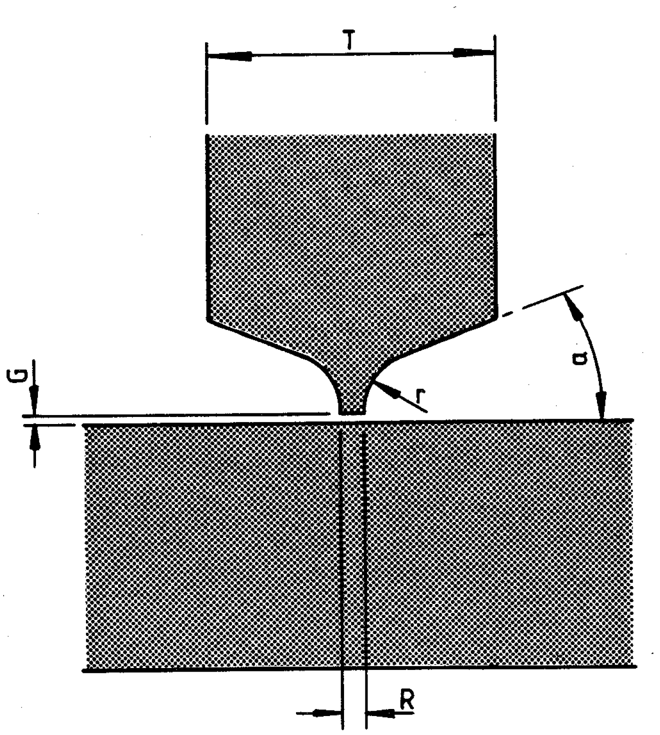
FIGURE 5.21 SINGLE BEVEL TEE BUTT JOINT



	MANUAL WELDING	MACHINE WELDING
T =	19mm to 38mm	22mm to 38mm
G =	0 to 1.5mm	1mm max
R =	0 to 5mm	0 to 5mm
a =	45^{o} min	45^{o} min

Note: **a** may require increasing for positional depositions or where electrodes produce bulbous cross-sections.

FIGURE 5.22 DOUBLE BEVEL TEE BUTT JOINT



	MANUAL WELDING	MACHINE WELDING
T =	32mm and above	32mm and above
G =	0 to 1.5mm	1mm max
R =	0 to 5mm	0 to 5mm
a =	20° min	20° min

Note: **a** may require increasing for weld visibility of root runs and for positional deposition or where electrodes produce bulbous cross-sections.

FIGURE 5.23 DOUBLE J TEE BUTT JOINT

5.12 Fillet Welds

a. Double fillet welds are made between plate surfaces which are normally at right angles, but the angle between the plates may vary from 60° to 120°. Generally no plate preparation is required provided the mating edges are reasonably true and smooth. The depth of penetration at the root and the contour of the weld depended on the electrode or welding process and the welding procedure. Penetration at the root is negligible in manual metal arc welding. Deep penetration can be obtained with automatic welding processes. Where structural members passing through WT or OT boundaries are fillet welded, the unfused area at the root can provide a leak path. To prevent leakage into adjacent compartments the fillet welds are to be made into full penetration welds to form ‘stopwaters’ over a length of about 75mm. ‘Stopwaters’ are to be close to the WT or OT boundary and be located on the external side.

b. The size of a fillet weld is specified by its minimum leg length. The relationship between the thickness of material, leg length and throat thickness of full strength tee fillets with the plate surfaces at right angles is shown in FIGURE 5.24. Where the use of deep penetration fillets has been approved the leg length can be reduced to take into account the increase in throat thickness. The depth of penetration is to be ascertained from a series of test plates. For further information regarding the strength of tee fillet welds see Clauses 5.2(2) and 5.2d.

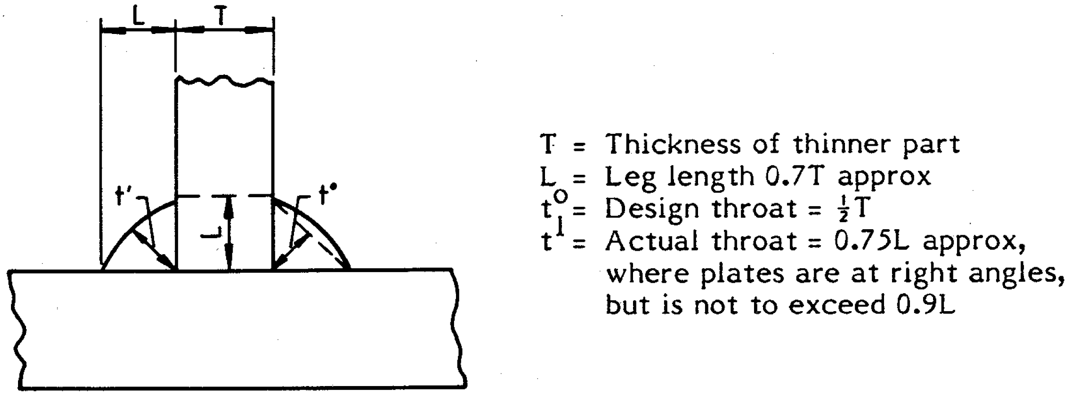


FIGURE 5.24 DIMENSIONS OF FULL STRENGTH FILLETS

c. **Prepared fillet welds** A compromise between twin fillet welds and a full penetration butt weld may be required when making a tee connection, see Clauses 5.2(2) and 5.2d. This type of weld is referred to as a prepared fillet weld. Where this type of weld has been approved the dimensions of the joint and weld are to be as shown in FIGURE 5.25.

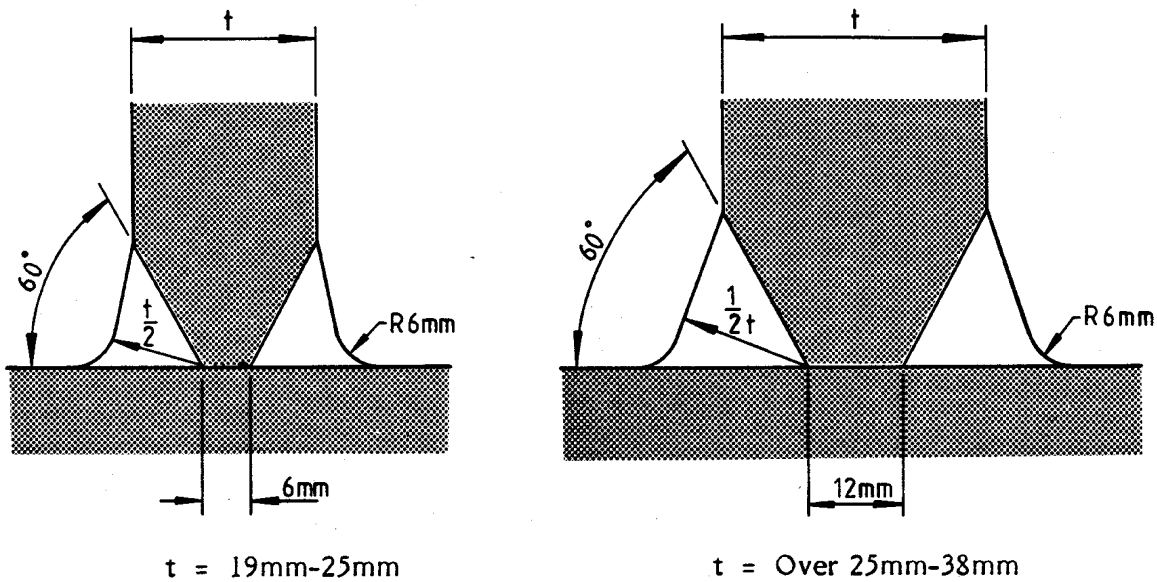


FIGURE 5.25 PREPARED FILLET WELDS

d. **Sub-size fillet welds** When welding attachments, or other welds which do not contribute to the structural strength of a vessel or component it is not always necessary to match the joint strength to that of the parent material. In such cases providing it does not infringe any instructions regarding the minimum size of a single run of weld, the size of the fillet weld may be reduced consistent with the degree of strength required. It is however necessary for such welds to be continuous.

e. Intermittent welding of ship structure is prohibited with the possible exception for framing under thin decks or flats in dry spaces and is not to be used without specific MOD(PE) approval. Where the use of intermittent welding has been approved, it is to consist of 100mm deposits and 100mm gaps so arranged that the runs of welding on opposite sides of the joint are opposite each other. At the ends of framing or in way of bracks or stiffeners the welding is to be continuous for the extent of the intersection plus 150mm; see FIGURE 5.26.

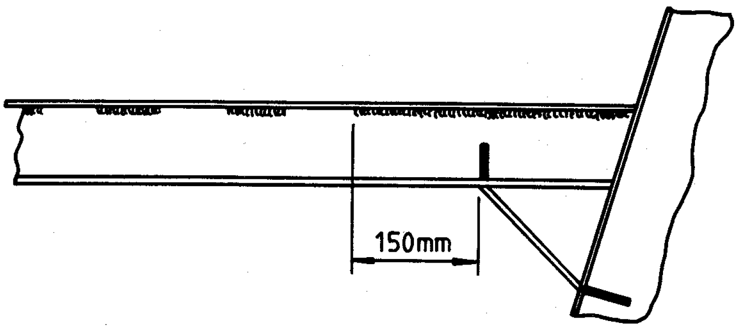


FIGURE 5.26 INTERMITTENT WELDING

5.13 Lap Joints

a. Lap joints are to be confined to work of minor structural importance. When lap joints have been approved, the length of overlap is to be four times the thickness of the thinner part and the leg length of the fillet welds just less than the thickness of the thinner part to obtain the maximum size of weld without fusing the top edge of the plate away. If the edge of plate is fused away a false idea of the leg length is obtained. Details of lap joints are shown in FIGURE 5.27.

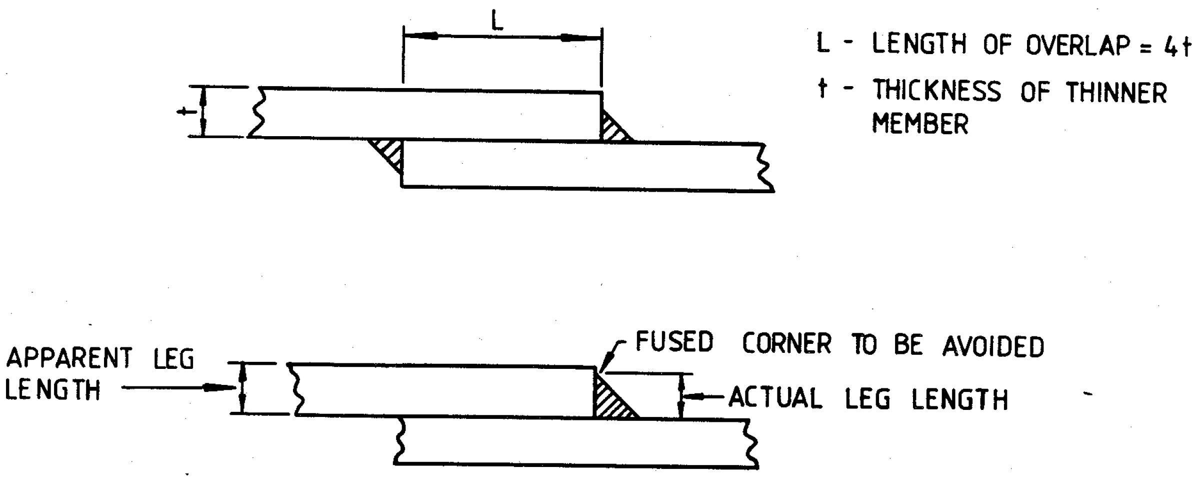


FIGURE 5.27 FILLET WELDED LAP JOINTS

5.14 Crossing of Butt Welds by Fillet or Tee Butt Welds

a. Where butt welds are completed prior to the erection of framing or stiffening then the attachment of tee butt or fillet welds may be deposited directly across butt welds. To facilitate good fit up the butt weld reinforcement is to be removed locally in way of the abutting member. The dressed weld is to be smoothly blended into the remaining reinforcement.

b. Where plating is erected to framing or stiffeners and butt welding is to be done subsequently, sufficient access must be provided to complete the weld. This may be accomplished by introduction of scallops cut into the frames or stiffeners. Scallops are to have a minimum radius of 25mm. Fillet or tee butt welds are to be continued around the scallop ends to reduce stress concentrations; see FIGURE 5.28.

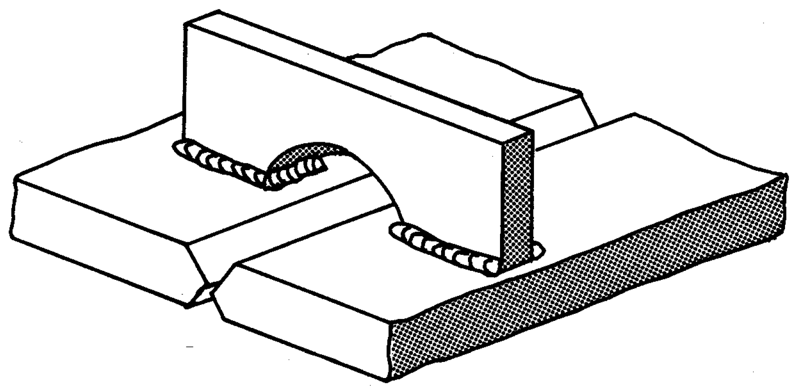


FIGURE 5.28 SCALLOP CROSSING BUTT WELD

c. As an alternative to using scallops the ‘no scallop’ technique may be employed. Where this practice is adopted the details are to be in accordance with Clause 9.10a.

5.15 Plug and Slot Welds

a. Plug and slot welds are not to be used except where absolutely necessary. The approved method of making a slot weld is to cut an oval slot large enough so that a fillet weld can be made around the inside periphery. The width of the slot is to be at least 1½ times the plating thickness and the length is to be a minimum of 3 times the slot width. Slot edges may be bevelled to provide better access for the welder. Slots are not generally to be filled with weld metal, except for rudders or other underwater locations where it is not possible to use tongues, see Clause 5.16a. Where slots are filled with weld metal the surface is to be ground smooth with the adjacent plate and examined by crack detection.

5.16 Tongue Welds

a. In cases of welding closing plates to rudders or hydroplanes where attachment to the internal stiffeners or diaphragm is required the method indicated in Clause 5.15a. may be used. Alternatively the diaphragm may be made to have projecting tongues; aligning slots are then to be cut in the closing plate. Such slots are to be cut to the same size as the tongue with the slot edges bevelled at 45° to form an edge preparation for subsequent welding. It is recommended that slots are at least 75mm long and are spaced at distances equal to the slot length. Before welding, the plating in the vicinity of the slot is to be forced to contact with the internal member, see FIGURE 5.29.

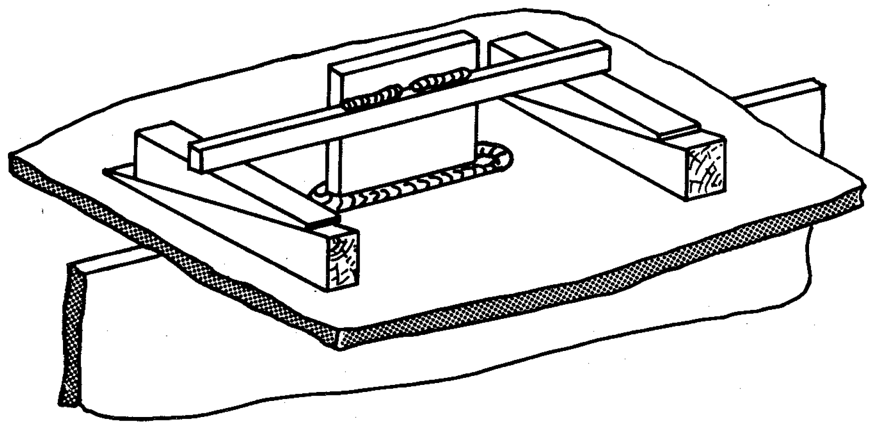


FIGURE 5.29

6. DRAWINGS: WELDING INSTRUCTIONS

a. This section contains the requirements regarding welding information which is to be shown on structural or hull component drawings.

b. All the information required for welding is to be included on the relevant drawings or in separate welding procedure sheets, in accordance with Section 4. Where separate welding procedure sheets are used the relevant drawings are to contain a reference to the procedure sheets. Drawings are to include a note that welding is to be in accordance with NES 706 'Welding and fabrication of ship structure'; this notation is not, however, to relinquish the requirement for the above welding information to be shown.

6.1 Preparation of Drawings

a. When drawings are being prepared consideration is to be given to the fabrication and welding operations as a whole, in particular, access for welding, the maximum use of down hand welding and the effects of pre-heat especially in confined spaces. Where a particular sequence of erection and welding is essential, eg in order to achieve reasonable working conditions for the welder, or where fabrication or heat treatment operations prior to or subsequent on welding dictates the sequence of operations, this is to be clearly stated on the drawing or procedure sheets. The use of symbols on drawings is not a requirement as it is preferred that all welds be suitably detailed. Where symbols are used to indicate weld details they are generally to conform to BS 499. Where other symbols are used a complete explanation of their meaning is to be given.

6.2 Information to be Shown

a. The following information is to be shown:

(1) specification of materials to be welded;

(2) location, size and details of all welds, ie type of joint, angle between fusion faces, fit up etc;

(3) welding process and type of consumables to be used for each material;

(4) welding procedure to be used or information as shown in Section 5 stated in full;

(5) details of any heat treatments;

(6) special sequences of welding, fabrication, erection, etc;

(7) special instructions for in process inspections and tests;

(8) final material thickness dimensions where hot working is specified, see Clause 7.12b.

6.3 Special NDT Requirements

a. Any special NDT requirements over and above those required by the Contract documents are to be clearly indicated on the drawings.

7. FABRICATION REQUIREMENTS

a. This section defines the requirements for fabrication: material preparation, forming, erection, and assembly of ship's hulls or associated components made from structural steels (see Section 1. Group 1 for details of materials). In general the requirements defined in Clauses 7.1a. to 7.4b. inclusive are to be applied to the obsolete steels, castings and forgings when these are joined in a structural manner (see Section 1. Groups 2, 3 and 4 respectively).

7.1 Preparing Plate Edges

a. Plate edges and weld preparations may be produced by any of the following methods:

(1) machining (planing, milling etc);

(2) gas cutting;

(3) arc air gouging;

(4) chipping;

(5) grinding or burring.

b. Where gas cutting is used it is to be carried out to the fullest extent with machine controlled equipment; hand cutting is to be restricted to applications where it is impractical to use automatic equipment. Where it is necessary to use hand equipment a form of guide is to be used. No unguided gas cutting is to be used without the prior approval of the Inspecting Authority.

c. Edges which are subsequently incorporated into a welded joint are to be inspected for any irregularities which may interface with the attainment of the requisite weld acceptance standard. Such irregularities are to be rectified by grinding or other approved means.

d. All edges which in the final structure have not been incorporated into a welded joint are to be inspected for irregularities and are to be dressed smooth by grinding.

7.2 Surface Marking

a. Care is to be taken to avoid chisel or similar marks being made on steels used for structural members. Where centre punching is essential it is to be kept to an absolute minimum and carried out using round nose punches. Draft marks and waterline datums are to be marked with widely spaced centre punch markings.

7.3 Cleanliness

a. Special care is to be taken in the preparation of plate edges prior to welding. Fusion and adjacent faces are to be regular, clean and free from rust, oil, paint, water or other contamination. These precautions are necessary with all welding processes but of critical importance with MIG or submerged arc welding. Where structural members have been erected but not immediately welded, or only part welded, the edge preparation is to be cleaned and wire brushed to bright material before again welding.

7.4 Welding on Coated Structure

a. Welding on galvanized, zinc and metal sprayed structure is prohibited. Before metal spraying with zinc or other metals, the exposed welding edges are to be masked with white wash or claywash for at least 75mm or greater so as to leave at least 25mm from the estimated position of the outside of the final weld bead. Where masking is not feasible, the coating is to be removed by mechanical grinding back to bright steel before welding.

b. Welding on approved prefabrication may be permitted with the following exceptions:

(1) where automatic twin fillet welding will be used;

(2) where the thickness of the paint primer exceeds the thickness recommended by the manufacturer;

(3) for butt and T butt welds made using the MIG process the fusion faces are to be free from shop primer where this is not removed during the edge preparation operations then the primer is to be locally removed by approved means.

7.5 Shaping and Forming of Plate and Sections

a. The requirements defined in Clauses 7.6a. to 7.13c. inclusive refer to the structural steels shown in Section 1. Group 1. Under normal circumstances the obsolete structural steels shown in Section 1. Group 2 will only be encountered during refits of older vessels and therefore are not to require shaping or forming operations to be done. The latter steels are not to be shaped or formed without prior approval from MOD(PE), except for 'A' quality material which is to be worked in accordance with requirements for 'B' quality material.

7.6 Cold Work

a. The normal method of forming or shaping is to be by cold rolling. Pressing may be allowed but is to be carried out by a procedure approved by the Inspecting Authority. Cold working is to be done below a temperature of 260° C. Cold working will only be permitted where adequate equipment is available which is capable of obtaining deformation without fracture of the surfaces or local indentations. TABLE 7.1 shows the permitted cold work strain limitations.

MATERIAL	PERMITTED STRAIN LIMITS FOR COLD WORK	
	WITHOUT FURTHER TREATMENT	WITH SUBSEQUENT HEAT TREATMENT
Mild Steel	25% (R=2t)	Not permitted
B quality	6% (R=8t)	Normalized 6% (R=8t) −25% (R=2t)
QT28	3.3% (R=15t)	Not permitted
UXW Frames	Not permitted	10% stress relieved (see Clause 7.6a.)

TABLE 7.1 PERMITTED COLD WORK STRAIN LIMITATIONS

NOTE: R = Radius of bend for plates only; measured from mid-plate thickness

(1) **Mild steel** Where requirements exist for mild steel to be deformed in excess of the above strain limit this is to be achieved by hot work see Clause 7.7.a.

(2) **B quality steel** Where the steel is cold worked in excess of 6% strain then up to 25% strain may be done by cold work if followed by normalizing by heating to a temperature between 880° C and 910° C followed by cooling in still air, see Clause 7.9a. These steels may also be hot worked if larger deformations are required; see Clause 7.7.a.(1)

(3) **QT28 quality steel** Where requirements exist for QT28 steel to be deformed in excess of the above strain limit this is to be achieved by hot working followed by re-quenching and tempering; see Clause 7.7a.(2)

(4) **UXW frames** The cold working of UXW material will only be permitted within the above limits when followed by stress relieving and only in the following circumstances; UXW frame bar sections for use as submarine pressure hull frames which are produced as 267mm ¢ 102mm ¢ 102mm ¢ 59.7Kgm/m rolled I bar sections and then converted to the correct T bar section by removal of one flange. Where the flange has been removed by a terminal process the hardened HAZ is to be removed by cold mechanical means or grinding prior to cold working operations being done. Chipped edges are to be inspected and unacceptable irregularities are to be removed by grinding. T bar frames may be cold worked to the above limits, ie minimum radius measured to the outer fibre of 1300mm. Cold working is to be followed by stress relief heat treatment between 600° C and 625° C followed by cooling in still air. UXW STEEL IS NOT TO BE HOT WORKED.

7.7 Hot Work

a. Prior to hot working operations, the surfaces of the materials are to be free from oil, grease, zinc, lead, tin, copper, substances which contain these materials or elements of other low melting point constituents. After forming, the material is to be heat treated and/or cooled to produce properties conforming to those specified in the applicable material specification. Test specimens are to be produced and tested as defined in Clauses 7.13a. to 7.13c.

(1) **Mild steel and B quality steel** Hot working operations are to be performed between 800° C and 1250° C. After hot working, mild steel is to be allowed to cool in still air; B quality steel is to be normalized by heating to a temperature of between 880° C and 910° C followed by cooling in still air.

(2) **QT208 quality steel** Hot working operations are to be performed between 800° C and 1000° C. After hot working the material is to be quenched and tempered to produce properties conforming to the applicable material specification, see Clause 7.10a. for quenching and tempering.

7.8 Shaping and Forming of Weldments (Containing Welds)

a. **Mild steel** Welded fabrications may be curved, bent, or joggled hot or cold provided the permitted strain limits in TABLE 7.1 are not exceeded. Stress relieving of cold worked welded fabrications is permitted at a temperature range between 600° C and 650° C but is not considered necessary for structural applications. For dimensional stability during machining operations stress relief may be beneficial and is permitted for this purpose.

b. **B quality steel:**

(1) Welded fabrications may be cold worked provided the amount of work does not exceed 6% strain, eg provided plate containing a butt weld is not bent to a radius which is less than 8 times its thickness. Further cold work is not permitted. Stress relieving of these welded fabrications is not normally necessary but if done for dimensional stability the stress relieving temperature is to be in the range 600° C to 650° C. Hot working and/or normalizing of welded B quality fabrications is not normally permitted. Should circumstances arise in which hot working and/or normalizing is considered essential, then MOD, DG Ships is to be consulted.

(2) Where stress relieving or hot working and normalizing is permitted for B quality steels then only those welding consumables noted as approved for those heat treatments are to be used; see NES 769. Where hot working of B quality material is done mechanical testing is to be carried out in accordance with Clauses 7.13a. to 7.13c.

c. **UXW** Shaping and forming or stress relief of UXW fabrications containing weld metal is NOT permitted.

d. **QT28 quality steel:**

(1) QT28 welded fabrications may be cold worked provided the amount of cold work does not exceed a strain of 3.3% and provided that the fabricator demonstrates by mechanical testing that the weld metal properties, for the particular consumable used, continues to meet the approved weld metal properties; see NES 769. Further cold work is not permitted. Stress relieving of structural welded fabrications is not normally considered necessary but if done the stress relieving temperature is to be 20° C lower than the tempering temperature for the particular piece of material involved. In the exceptional case where this information is not available stress relief is to be carried out at a temperature not exceeding 575° C.

(2) Where stress relieving of QT28 fabrications is permitted then only those welding consumables noted as approved for stress relief in NES 769 are to be used.

(3) Hot working of QT28 fabrications containing weld metal will NOT be permitted. Where it is necessary for such fabrications to be hot worked then the weld metal heat treated is to be removed and replaced by new welding on completion of hot working operations.

7.9 Stress Relieving or Normalizing

a. Where MOD(PE) approval to stress relieve or to normalize is given the heat treatment is to be carried out as follows:

(1) The item is to be heated in a furnace. Support for the item is to be provided to minimize any change in shape. There is to be no direct impingement of flame on the material being heated.

(2) Stress relief or normalizing is to be done within the temperature range stated for the particular material; see Clauses 7.6a.(1), 7.6a.(4), 7.8a., 7.8b. and 7.8d. It is important that the upper limit is not exceeded particularly for UXW and QT28 steels which are tempered near the upper stress relief limit. It is, however, necessary to approach the upper limit to derive maximum benefit from the stress relief operation. The temperature is to be held for one hour per 25mm of thickness based upon the thickest member in the weldment.

(3) To avoid setting up harmful stresses due to temperature gradients within the component, the rate at which the temperature of the weldment is raised above 250° C is not to exceed 200° C per hour or 200° C/T per hour whichever is the lower. (T = maximum material thickness in units of 25mm.)

(4) Where thermocouples attached directly to the component are used to control the temperature, the rate of heating is to be controlled to maintain a maximum temperature difference of not more than 50° C between any two thermocouples when the average temperature is greater than 250° C.

(5) Cooling is to be achieved in a steady controlled manner by removal from the furnace and holding in still air.

7.10 **Quenching and Tempering**

a. The precise quenching and tempering treatments required for a particular piece of QT28 will depend upon the alloy content and is to be obtained from the test certificate supplied with the item or by reference to the steel mills, quoting the plate number. In exceptional circumstances where it is not possible to identify the original heat treatment the following information is given for guidance:

(1) The material is to be placed in a cold furnace and heated slowly to a temperature of between 880° C and 920° C and held at this temperature for approximately 1 hour. Rapid quench from this temperature is essential and the time between removal from the furnace to placing in the quench bath is not to exceed 30 seconds. Copious supplies of cold water are required and the item is to be agitated in the bath to avoid a blanket of steam covering it and thus reducing the cooling rate.

(2) The tempering temperature is to lie between 580° C and 650° C depending on the alloy content. The time of soak is to be approximately one hour at the tempering temperature and the material is to be cooled in still air after tempering.

(3) Double tempering is allowed if necessary to achieve the specified properties.

7.11 **Heat Treatment Furnaces**

a. Accurate control of furnace temperature, within the immediate vicinity of the item being heated, to within ± 10° C is necessary during all operations. Temperature measuring equipment is to be provided to indicate the temperature of the item. The temperature of the item is to be taken to be the average of the observed temperatures at different locations. Where it can be demonstrated that the temperature of the item can be maintained within the required range by controlling the furnace temperature then the average of the pyrometer readings will be accepted.

b. Autographic records are to be made of all heat treatment operations.

c. When used, thermocouples are to be located to measure temperature at the anticipated hottest and coldest points of the weldment. The number of thermocouples provided are to ensure complete coverage of the item and adequate temperature history. In the case of stress relieving, if more than one item is to be stress relieved at the same time thermocouples are to be provided for each item. However, not more than 6 thermocouples are required for a furnace charge.

d. Thermocouple wires are to be electrically insulated except at their hot junctions. In order to avoid erroneous readings they are to be arranged so that flames do not impinge on cold or hot junctions or the wires themselves. They are to be attached to the item by a method which ensures that the wires have firm metallic contact with the item; this may be accomplished by inserting thermocouple wires in a small pool of molten weld metal or by mechanical means.

7.12 NDT Requirements for Shaped Materials or Weldments

a. The operation of shaping and forming of some materials, namely B quality steel and to a lesser extent QT28 steel, may induce the risk of forming unacceptable laminations by initiation from plate inclusions or propagation from existing laminations which would otherwise be considered acceptable. To minimize the rejection risk of processed material the following examinations are to be done on materials which are to be used for important structure or components, ie submarine pressure hull plating, inserts, penetrations, torpedo tube sleeves etc.

(1) **B quality material** is to be ultrasonically examined before and after cold or hot working which exceeds 4% strain. Where material has been examined at the steel works and certification of compliance with DG Ships 1257 is available the pre-working examination need not be done. Ultrasonic examination is to be done in accordance with DG Ships 1257 where such certificate is not available and in any event after working as above.

(2) **QT28 material** is to be ultrasonically examined before and after cold or hot work. Where material has been examined at the steel works and certification of compliance with DG Ships 86 is available the pre-working examination need not be done. Where certification is not available ultrasonic examination is to be done in accordance with DG Ships 86.

b. In addition to the above examination thickness measurement is to be done on hot worked plate material defined in Clause 7.12a. in accordance with NES 729 and DG Ships 137 except that grid lines are to be spaced sufficiently close to ensure that the specified dimensions have been attained on the entire worked area. The final required dimensions are to be shown on the drawings, see Clause 6.2.a.(7) and (8).

7.13 Mechanical Test Requirements

a. Mechanical testing for compliance to the relevant material specification is to be carried out on the following materials when involved in the operations shown in TABLE 7.2.

MATERIAL	OPERATIONS
B quality	Normalizing Hot working
QT28	Stress relieving Hot working Re-quenching and tempering
QT28 weldments	Cold working welded joints

TABLE 7.2

b. Special requirements in addition to the above will be shown on individual drawings.

c. Final acceptance is to be based on the attainment of the specified mechanical properties for the applicable material. Where weldments are subjected to the above operations then separate tests are to be done on the weldments to ensure compliance with the mechanical properties appropriate to the weld metal; see NES 769. Test specimens for determining mechanical properties are to be removed from material which is an integral part of the component. Separate test blocks may be used provided they are from the same heat of materials of approximately the same maximum cross section, and are subjected to the same operations and on treatments as the component.

7.14 Erection and Assembly Requirements

a. The erection and welding of hull structure are generally to progress symmetrically so that distortion is minimized. Allowances are to be made for shrinkage due to welding. Sub-assemblies may be provided with excess material (ie Green) at the outer boundaries, as required, to compensate for weld shrinkage. Upon completion of welding sub-assemblies, excess material at the outer boundaries is to be trimmed to meet designed dimensions prior to incorporation into the general hull structure. Annex D. is to be read to provide general background information on distortion shrinkage and this is to be used in conjunction with fabricators' experience to minimize the degree of distortion induced by welding, and to meet the requirements of Clause 7.15.a. Where necessary welding sequences are to be shown on welding procedures but in all cases are to be clearly indicated to the welders.

b. Where preventive measures are insufficient to control distortion and fairness, straightening may be employed at the discretion of the Inspecting Authority. Where flame or thermal straightening is used (see Annex D.), the temperature is not to exceed 650° C and water cooling is not to be permitted on notch tough steels, B, UXW or QT28. B quality steels may be flame heated to 650° C and air cooled. No thermal straightening of UXW and QT28 is to be done without prior MOD approval. The use of force in conjunction with heating may be carried out as necessary to assist in straightening operations. Careful visual examination of areas subjected to straightening operations are to be carried out to ensure freedom from cracking.

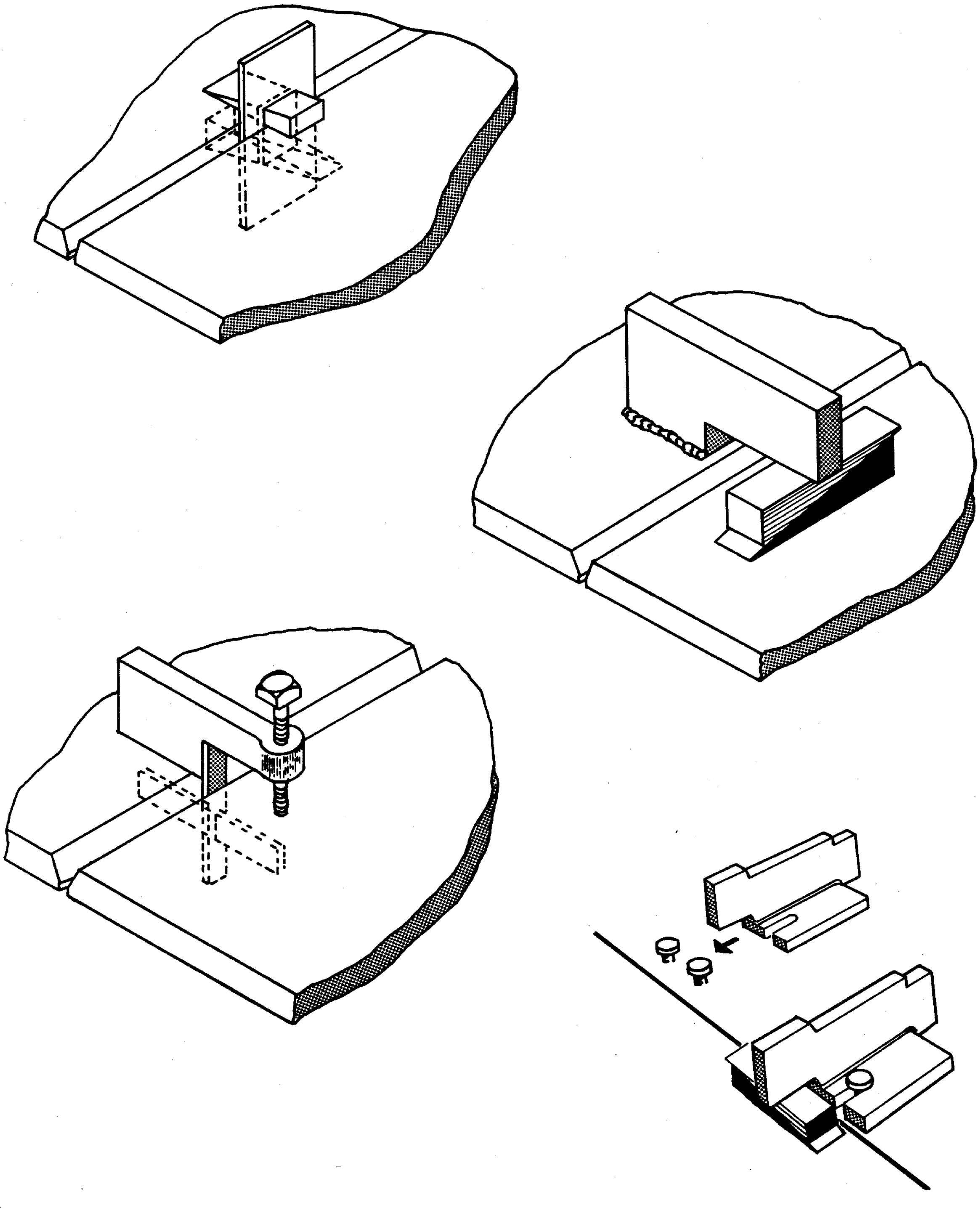
7.15 Dimensional Accuracy

a. Final dimensional accuracy including submarine pressure hull circularity, compartment lengths, levelness of seatings etc are to be in accordance with the Contract Documents.

b. The means of assembly are to be adequate to maintain the parts to be welded in the correct relative position yet allow lateral movement induced by welding to minimize built-in residual stresses and reduce the risk of root run cracking. All assemblies after fitting and prior to welding are to be inspected to ensure that the joint preparation and fit up is in accordance with the approved procedure.

7.16 Strongbacks

a. The alignment of joint members may be by welded erection clips, clamps or fitting attachments such as those shown in FIGURE 7.1. Strongbacks or bracing may be used as necessary to maintain alignment during welding/tacking. Examples of strongbacks are shown in FIGURE 7.2.



Cont'd

FIGURE 7.1 CLAMPS OR FITTING ATTACHMENTS

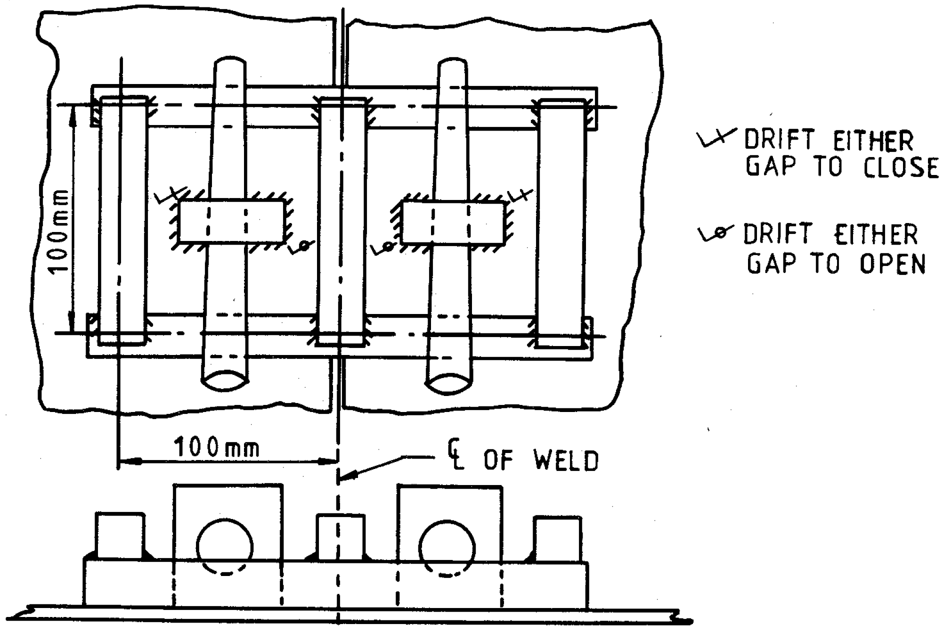


FIGURE 7.1 (Contd) CLAMPS OR FITTING ATTACHMENTS

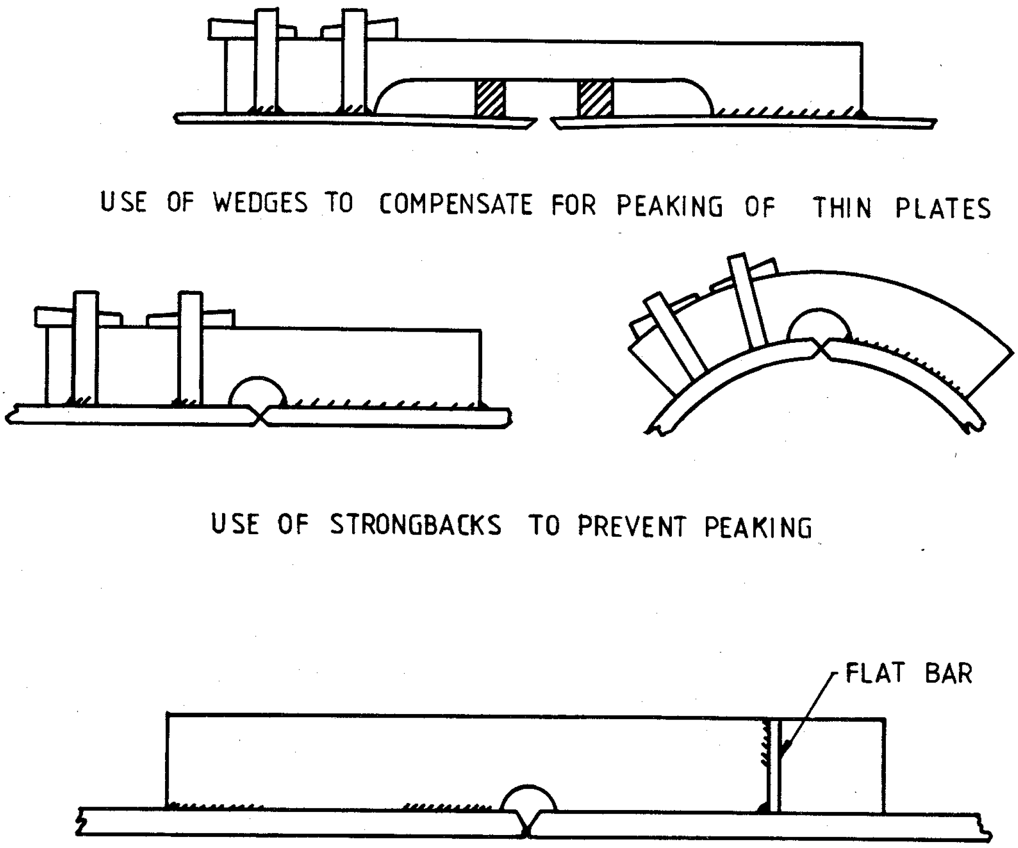


FIGURE 7.2 EXAMPLES OF STRONGBACKS

7.17 Stud Welded Strongback System

a. Strongback systems using studs, as shown in FIGURE 7.3, may be used. The studs are to be welded and removed in accordance with Section 13.

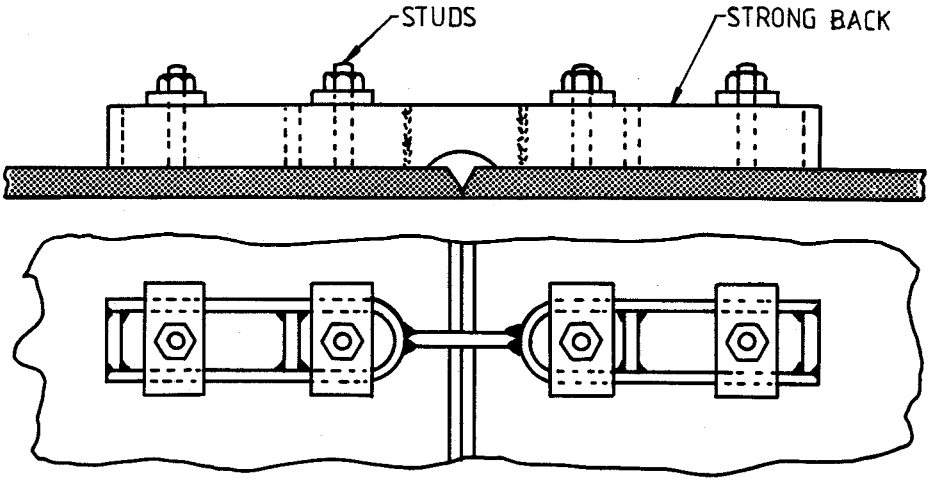


FIGURE 7.3 STUD WELDED STRONGBACK

7.18 Fillet Welded Spools

a. On steels where only capacitor discharge stud welding is permitted for temporary studs the fillet welded spools may be used. These allow for the use of a larger diameter stud than would normally be possible with capacitor discharge equipment. A circular spool with a central tapped hole is fillet welded to the base material. A stud is screwed into the tapped hole thus providing a similar member to that achieved by stud welding. Removal and re-use of both spools and studs can be arranged by locating a drill spindle in the central hole and removing the fillet weld with an offset cutter, see FIGURE 7.4a. and b.

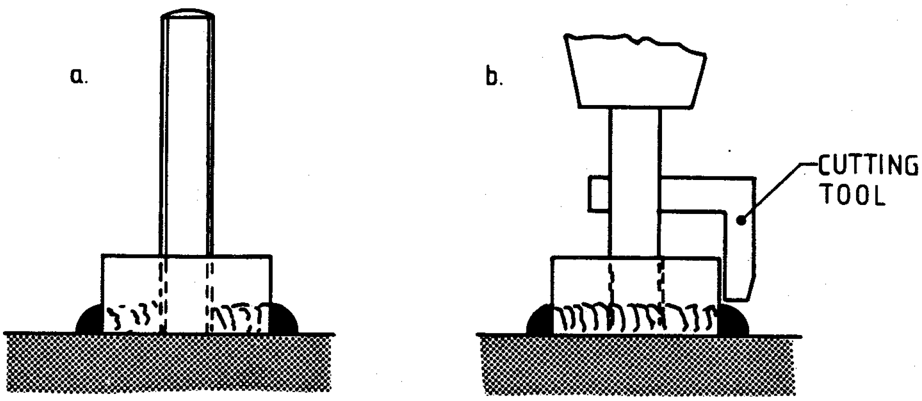


FIGURE 7.4 FILLET WELDED SPOOLS

b. Alternatively, studs to Clause 7.17a. or studs and spools to Clause 7.18a. can be secured in pairs and by use of large plate washers form a bridge for securing conventional strong backs, see FIGURE 7.5 and photograph FIGURE 10.3 in Section 10.

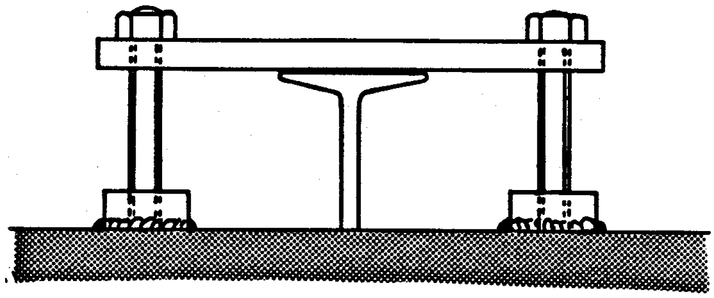


FIGURE 7.5 BRIDGE FOR SECURING STRONGBACKS

7.19 Temporary Attachments

a. Temporary attachments such as lugs, bolts etc for assembly purposes are to be welded with the full precautions stated herein. Precautions are to be taken to ensure that such attachments, including temporary studs, are not used indiscriminately. Care is to be taken to avoid undesirable locations such as toes of brackets, corners of openings or other points of stress concentrations. In order to ensure clean and uniform fillet welds the attachments are to have smooth flat faying surfaces and clean square edges. Removal of temporary attachments is to be carried out with care to ensure that the plating is not damaged. They are to be flame or mechanically cut off close to, but not at, the plate surface. Excess welding and the remains of temporary attachments are to be removed by grinding. After removal of temporary attachments the ground area is to be visually examined. In addition for submarine pressure hull structure or other structure subjected to diving pressure, magnetic particle inspection is to be done in accordance with NES 729 and meet the acceptance standard of DG Ships/G/10000.

b. The number of tack welds is to be kept to a minimum and they are to be spaced only as closely as necessary to hold the parts safely and in proper alignment. The conditions of welding, particularly in respect of weld pass size and pre-heat specified for the main weld are to apply for all tack welding. Where tack welds are to be incorporated into the main weld they are to be shaped suitable for incorporation with the finished weld and be free from cracks or other deposition faults. Tack welds which are cracked are to be removed; on no account are they to be covered by weld metal.

7.20 Misalignment

a. The acceptable amount of misalignment of butt joints is to be at the discretion of the Inspecting Authority but on no account is this to exceed 20% of the thickness of the thinner material being joined in thickness up to 12 mm or more than 3mm for thicker material, see FIGURE 7.6. In fillet welded lap or tee joints where the parts are designed to be in contact, at no point is the gap to exceed 1.5mm. Where the toes of rolled sections are to be incorporated in a welded joint they are to be cut square, unless the Inspecting Authority is satisfied that the toe is nearly square, such that an acceptable welded joint will be produced.

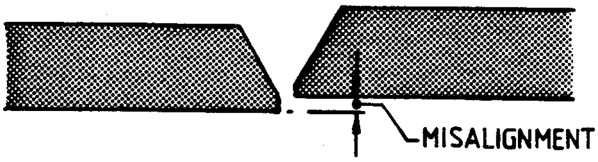


FIGURE 7.6 MISALIGNMENT

b. Root gaps in butt welds are to be within the designed dimensions shown in Section 5. except for inserts which are to be fitted in accordance with Section 10. Where root gaps are less than those specified deeper back gouging may be required and where root gaps are excessive a higher risk of root run cracking will be encountered. The build up by welding on the joint surfaces to correct excessive gap is permitted subject to the approval of the Inspecting Authority and is to be carried out prior to the final fitting. Where practicable the electrode and welding process specified for the main weld is to be used for this purpose but in any case only welding consumables approved for the materials involved are to be used. See Clause 9.15a. for specific details of buttering or build up.

c. When errors in fit up are greater than can be remedied by weld build up, the approval of the Inspecting Authority is to be obtained before rectification by other means is allowed. Methods employed to correct such errors are to fully meet the design requirements and take due regard of the welding requirements herein.

8. CARE AND STORAGE OF WELDING CONSUMABLES

a. This section defines the requirements for care and storage of all welding consumables for use on structural steelwork. The requirements for care and storage of welding consumables for use on other materials such as aluminium alloys are to be in accordance with the respective sections dealing with those materials.

8.1 Studs

a. Welding studs are to be stored in dry conditions to prevent deterioration of the fusion faces. Studs which have rusted fusion faces or have lost the de-oxidation pellet from the fusion tip are unfit for use and are to be scrapped.

8.2 Fusion Welding Consumables

a. These consumables are to be supplied in packages or containers in accordance with NES 769; in particular hydrogen controlled consumables are to be supplied in non-vacuum, sealed tin containers. MMA, continuous covered, cored electrodes and submerged arc fluxes, being hygroscopic by nature, are to be kept in a store which is to be uniformly heated as necessary to ensure warm dry conditions. Other welding consumables not hygroscopic in nature, bare wire, are to be stored in dry conditions to prevent surface rusting. All consumables are to be left in their original manufacturers' packages until required for distribution or baking.

b. With satisfactory storage conditions as above welding consumables will retain their properties for considerable time, but every effort is to be made to ensure that consumables are used in the order in which they are delivered from the manufacturer. Hydrogen controlled consumables are not to be retained for use after storing for a period exceeding 4 years.

c. Care is to be taken in storage and handling of all electrode wires to prevent contamination by grease and oil. Steel electrode wires will generally be copper coated as a protection against corrosion. Prevention of contamination and oxidation is particularly important when argon oxygen mixtures are the shielding gases. Where the surface has deteriorated and corrosion of the electrode wire has started such wires are not to be used for production welding. Other surface contamination, eg grease, oil etc, is to be effectively removed before welding.

d. Care is to be taken in storage and handling of all covered electrodes to prevent damage to the coating. The coverings are reasonably robust but can be damaged by rough handling. Electrodes damaged in this way are unfit for use and are to be scrapped.

8.3 Pre-issue and Issue Requirements for Other than Hydrogen Controlled Welding Consumables

a. Covered electrodes, cored or continuously coated electrodes or submerged arc flux which has become slightly damp may be dried in controlled heating ovens for at least one hour at a temperature not exceeding 150° C. Where consumables have been maintained in stores as defined in Clause 8.2a. they may be issued to welders without further treatment. Only sufficient consumables to meet the daily/shift needs are to be held by welders; such issued consumables are to be protected from inclement weather or adverse conditions. Consumables not used during the day/shift of issue are to be stored in dry warm conditions and not left at job sites during night or off-shift periods.

8.4 Pre-issue and Issue Requirements for Hydrogen Controlled Welding Consumables

a. The moisture content of electrode coatings or fluxes is of considerable importance when using hydrogen controlled electrodes or basic fluxes. For basic submerged arc fluxes see electrode manufacturers' literature. Such consumables which have been exposed to adverse conditions and have become slightly damp are to be heated to a temperature not exceeding 400° C for between 2 and 3 hours. Where such consumables have been maintained in stores as defined in Clause 8.2a. they are to be baked before use in accordance with TABLE 8.1 and subsequently transferred to holding ovens without being allowed to cool below 65° C. Alternatively where more convenient the baking oven may also be used as a holding oven. Transfer is to be accomplished in sheltered areas protected from inclement weather. The holding ovens are to be sited near the work and the holding temperature is to be 150° C. The baking and holding ovens are to be under the control of one man who is to be responsible for ensuring that the consumables have been correctly baked.

CONSUMABLE	TEMPERATURE	TIME
MMA electrodes hydrogen controlled	150° C	2 to 3 hours
Continuous covered or cored hydrogen controlled	150° C	2 to 3 hours
Submerged arc fluxes	As shown in NES 769 or, where not shown to be in accordance with electrode manufacturers' recommendations.	

TABLE 8.1

b. Covered welding electrodes are to be issued to the welder in electrically heated quivers or closed quiver containing silica gel. The silica gel is to be of the type which changes colour when inactive and its condition is to be checked daily. Basic submerged arc flux issued to welders after baking is to be kept under warm dry conditions at job sites.

c. The issue of consumables to welders is not to exceed his requirements for the ensuing shift. Covered electrodes of flux unused at the ends of these periods are to be returned to the holding ovens and held at the required holding temperature for at least 8 hours, or re-baked in accordance with Clause 8.4a. Covered electrodes are not to be re-baked more than once.

d. The baking and holding ovens are to be designed specifically for the purpose and fitted with thermostatic control. The consumables are to be removed from their containers before insertion into the ovens, electrodes are to be stacked and submerged arc flux placed in shallow trays to allow a free circulation of air around the consumables.

8.5 Use of Reclaimed Submerged Arc Flux

a. Submerged arc flux which is reclaimed and filtered to remove fused flux, dust and other inclusions, may be mixed with a minimum of 25% of the original quantity, eg ¼ addition, of new flux and continued to be used so long as the weldability characteristics remain acceptable, except that basic fluxes are to be re-baked in accordance with Clause 8.4a. before re-use is permitted.

9. WELDING REQUIREMENTS

a. This section contains the welding requirements for the structural materials shown in Section 1., Groups 1, 2, 3 and 4. General guidance concerning the development and weldability of structural materials can be found in Annex C.—Weldability of Ferritic Steels.

9.1 Selection of Welding Consumables

a. Only MOD(PE) approved welding consumables as stated in NES 769, are to be used for the structural steels shown in Section 1., Group 1. Manual metal arc welding is the only process approved for the welding of steel castings, forgings, and the obsolete steels S, SU, D, D1 and DW quality. Proposals to use other welding processes may be submitted to MOD for consideration. All consumables selected for use within the scope of this section are to be subject to compliance with 'Fabricators approval' in NES 769. Selection of welding electrodes for the obsolete steels, forgings and castings shown in Section 1., Groups 2, 3 and 4 respectively are to be selected from NES 769 subject to the following requirements:

(1) Electrodes approved for B quality steel up to 12mm thick are to be used for S, SU, DW and A quality steels up to 12mm thick.

(2) Electrodes approved for B quality steel over 12mm thick are to be used for:

(a) the above materials when they exceed 12 mm thick;

(b) Forgings Classes I and II to Adspec 1100, and general purpose castings to DG Ships 8081, of any thickness;

(c) D and D1 quality steel up to 12mm thick. Welding of D and D1 quality steel above 12mm thick is not permitted.

(3) Electrodes approved for QT28 quality steel are to be used for welding Class III forgings to Adspec 1100. Class IV forgings to Adspec 1100 are to be welded in accordance with NES 770.

b. For manual metal arc welding of certain steels both basic (hydrogen controlled) and non-basic coated electrodes are approved. The use of basic coated electrodes is recommended for all repair work where restraint is a major factor or for welding on castings or forgings where the mass of the components will provide a greater heat sink than that associated with nominal plate thickness calculations.

c. When gas or gas mixtures are selected the combination of consumables and gas or gas mixture are to be as stated in NES 769. Shielding gases or gas mixtures are to be of the following quality:

(1) **Argon** The gas is to be a minimum of 99.95% pure.

(2) **Carbon dioxide** The gas is to comply with the requirements for carbon dioxide Type 1 in BS 4105.

(3) **Gas mixtures** The use of gas mixtures is permitted when the mixture is certified as being the correct mixture by the gas supplier.

Note: The use of CO_2 shielding gas will require a heater to be inserted between the cylinder valve and the reducing valve to prevent freezing causing flow blockage at this junction.

d. When welding joints between structural materials of different strengths the selection of welding conditions including pre-heat and electrode baking are to be related to the higher carbon equivalent material but the welding consumable may be selected from those approved for the lower strength material. Where a hydrogen controlled consumable is required for either of the materials involved then the consumable selected is to be of that type.

e. Particular care is to be taken in selecting welding consumables for use with the obsolete structural steels, forgings and casting which may be found on refit of older ships. Many of the castings and forgings in service were supplied prior to the issue of the current specifications. The following factors may increase the risk of weld metal/HAZ cracking:

(1) steels being out of specification chemically;

(2) segregation of chemical elements with high C and S or P increasing the risk of hydrogen induced or hot cracking respectively.

f. It is recommended that chemical analysis be taken in the following circumstances and that the advice of DG Ships be sought if the CE is above 0.7:

(1) S quality steel when welding inserts or joints under high restraint in submarine pressure hulls;

(2) when positive identification of the material to a current specification cannot be made.

g. In the case of steels with proven or suspected high S and P levels it may be necessary to use welding consumables with high Mn content. Where hydrogen induced cracking is experienced or obsolete materials combined with high restraint is expected to cause hydrogen induced cracking it is recommended that the precautions to reduce hydrogen level in electrode coatings normally required for Q1N materials are employed, ie baking electrodes at 400° C to 475° C for between 2 and 3 hours. In addition it is important to ensure that the joint to be welded is carefully cleaned to prevent hydrogen pick-up by contamination from substances that can contain hydrogen, eg scale, rust, grease, moisture etc.

9.2 <u>Pre-heat</u>

a. Pre-heat temperature is defined as the temperature of the base material in the welding region immediately prior to absorption of any heat from the welding process.

b. The pre-heat temperatures to be applied for the welding of MOD(PE) structural steels, castings and forgings within the scope of this Standard are shown graphically in FIGURE 9.1. They apply in the following circumstances:

(1) when using hydrogen controlled processes where the electrode coating or submerged arc flux have been baked in accordance with Clause 8.4a., or where the MIG bare wire welding process is being used;

(2) where the heat input of the welding process is between the range:

1.18kJ/mm to 2.56kJ/mm;

(3) where the joint involved is being welded in the structural sense, as opposed to a repair weld, under normal shipbuilding conditions of fit up and without undue restraint.

c. The curves in FIGURE 9.1 show curves of constant Carbon Equivalent (CE) against temperature and material thickness. To eliminate the need to calculate particular carbon equivalents, steels of similar maximum carbon equivalents have been grouped together. The curves have been plotted to a base of MAXIMUM COMBINED PLATE THICKNESS; this is derived by the sum of the thicknesses involved at the joint as shown in the sketches on FIGURE 7.6. The carbon equivalent formula used for calculation within this Standard is:

$$CE = C + \frac{Mn}{6} + \frac{Ni}{40} + \frac{Cr}{5} + \frac{Mo}{4} + \frac{Si}{24}$$

Note: The thermal dissipation of fillet welds is higher than that of butt welds made from the same thickness material.

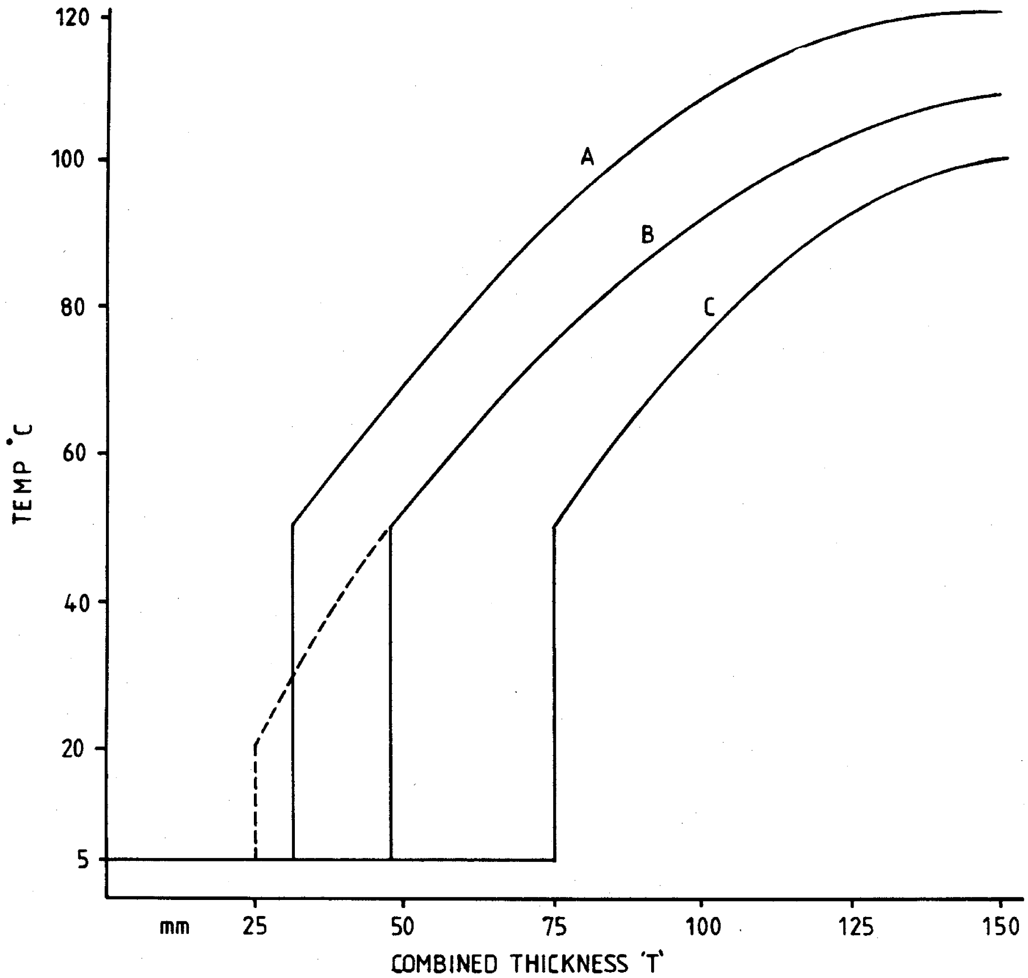
d. Where the base material is dry and the ambient temperature is 5° C or more the materials shown in TABLE 9.1 may be welded without pre-heat up to the COMBINED THICKNESS SHOWN. Where the ambient temperature is less than 5° C and no requirement for pre-heat is stated for the particular material and combined thickness involved (see FIGURE 9.1), then the base material is to be heated by local application of pre-heat until the material is warm and dry within the specified pre-heating area see; Clause 9.3a. Adequate protection is to be provided for the welder and work during periods of inclement weather.

MATERIAL	TYPE OF WELDING PROCESS	
	NOT HYDROGEN CONTROLLED	HYDROGEN CONTROLLED
Mild steel and ‘A’ qual	50mm	75mm
‘B’ qual, Castings and Forgings Class I	25mm butt 38mm fillet	50mm
S, SU, DW qual	12mm	25mm
D, D1 qual	To be welded with LH only	25mm

TABLE 9.1

e. Welding is not to be permitted while one side of the base material is immersed in water without specific MOD(PE) approval.

f. In cases where it is considered impracticable to attain the correct level of pre-heat, proposals to use lower levels of pre-heat balanced by use of proven, very low hydrogen processes or the use of austenitic stainless steel electrodes are to be forwarded to MOD(PE) for consideration.



CURVE A	FOR USE WITH UXW, AD SPEC 1100 FORGINGS CLASS II & III
CURVE B	FOR USE WITH 'B' QUAL, QT 28, AD SPEC 1100 FORGINGS CLASS I AND CASTINGS
CURVE B	FOR USE WITH D.* D1.* S., SU &(DW DOTTED AT ORIGIN, THEN AS CURVE B FULL)
CURVE C	FOR USE WITH MS & 'A' QUAL

* SEE CLAUSE 1202 b (3)

THICKNESS (t) SHALL BE MEASURED AT POSITION 3t FROM THE WELD CENTRE LINE

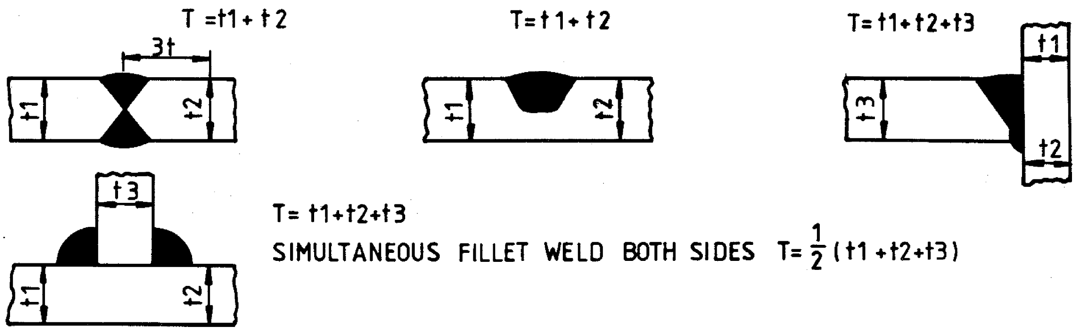


FIGURE 9.1 PRE-HEAT TEMPERATURES FOR USE WITH HYDROGEN CONTROLLED CONSUMABLES

9.3 Application of Pre-heat

a. The area to be pre-heated will depend on the thickness of the parts to be welded. Specifically at least 3T, where T is the thickness of the thicker material, either side of the joint is to be so heated, with a progressive fall off in temperature outside this zone being acceptable. Wherever possible castings or forgings are to be pre-heated in a furnace and local pre-heating confined to those applications where this is impracticable. The pre-heat is to be uniform with sufficient time allowed for the heat to soak through the thickness of the parts being welded. Liberal use is to be made of heat insulating material to prevent heat losses and ensure slow cooling after welding is completed. Where possible it is recommended that pre-heat be continuously maintained until completion of the joint or, where it is necessary to stop pre-heating before completion of the welding, that sufficient weld metal has been deposited to withstand the contractional stress induced by cooling. Full pre-heat is to be attained before welding recommences.

9.4 Pre-heating Methods

a. Pre-heat can be applied by any of the following methods:

(1) **Electrical strip resistance heaters of the contact type** They are particularly suitable for circumferential butt joints. The heaters are to be anchored close to the material and approximately 100mm from and parallel to the joint, covered with a dry insulating material with the terminals carefully insulated to avoid the danger or shock to workmen. There is no interference with the welding arc when using these heaters, thus it is unnecessary to switch off the pre-heat current during welding operations unless the interpass temperature is exceeded.

(2) **Electrical radiant heaters** These may be suitable for pre-heating in box type structure.

(3) **Electrical induction** This may be suited for circumferential butt joints in pressure vessels. The heating current may require turning off during welding to prevent interference with the welding arc.

(4) **Gas strip heaters** Oxy-acetylene, propane, propgas, and a mixture of coal gas and air can be used. The strip heaters can be attached by magnetic clamps or some form of approved temporary attachment.

(5) **Gas torches** These are generally to be confined to local pre-heating for the attachment of fittings and tack welding, or as an accessory to decrease the time required to attain pre-heat temperature on material which is being heated with electric heaters. Care must be taken to avoid excessive temperature differentials since high stresses can be developed, resulting in distortion and broken tack welds. Special adaptors are available for attachment to gas cutting torches for pre-heating purposes.

(6) **Furnace** Pre-heating for castings or forgings.

9.5 Pre-heat Temperature Measurement

a. Pre-heat temperature is to be measured by tempilsticks or other approved means in a sufficient number of positions before deposition of weld metal to ensure that the whole volume of material in the entire welding area (see Clause 9.3a. or details), is up to the required minimum pre-heat temperature without exceeding in the specified maximum. Where possible the temperature is to be measured from the opposite side of the joint to that which is being heated. The above requirement for pre-heat measurement is to apply to the first and all subsequent runs of welding. Tempilsticks are not to be used on fusion faces of the joint or on weld metal which will subsequently be covered by further welding.

9.6 Interpass Temperature

a. Interpass temperature, in a multi-pass weld, is defined as the temperature of a section of the deposited weld metal and adjacent base material immediately prior to welding again at that section.

b. An interpass temperature limit of 250° C is to be imposed during the welding of all materials within the scope of this section. Control of interpass temperature is to be accomplished by proper distribution of welders, the use of welding sequences and by control of pre-heat input. Welding must not continue if the interpass temperature exceeds 250° C. Interpass temperature is to be measured on the surface of the base material on the side from which welding will be performed, within 25mm of the weld joint edge and along the joint within the 75mm of the start of the next weld pass.

9.7 Heat Input

a. The range of heat inputs permissible for welding the materials within the scope of this section are to be strictly in accordance with the range stated against particular consumables. Special restrictions on any of the parameters used for calculating heat input may also be imposed; these limits are shown in NES 769. Heat input control is to be applied to all welding processes. As used in this Standard heat input is the nominal heat input which can be calculated using the formula:

$$\text{Heat input (Joules/mm)} = \frac{\text{Arc volts} \times \text{Amperage}}{\text{Welding speed mm/sec}}$$

b. The heat input can be related approximately to leg length, cross-sectional area and in the case of MMA electrodes, length of deposit from the usable portion of a 450mm electrode, ie 400mm as shown in TABLE 9.2.

HEAT INPUT	LEG LENGTH OF SINGLE FILLET BEAD	CROSS-SECTIONAL AREA	ELECTRODE GAUGE/SIZE			
			3.25mm 10G	4mm 8G	5mm 6G	6mm 4G
kJ/mm	mm	mm2	LENGTH OF DEPOSIT			
1.18	5	15	216mm	292mm	419mm	–
1.77	6	23	140mm	190mm	285mm	419mm
2.17	7	29	115mm	150mm	222mm	368mm
2.56	8	41	101mm	140mm	202mm	305mm

Note: Attention is drawn to the fact that the above figures apply to 400mm of electrode. If a shorter length of electrode is deposited then the above deposit lengths are to be reduced in proportion. The figures in brackets in the above table, under electrode size, are the nearest American electrode sizes. The deposit lengths quoted in the table can also be used for these sizes but adjustment for shorter lengths of American electrodes will be necessary.

TABLE 9.2

c. The amount of weaving of MMA electrodes is to be restricted in order to achieve the above deposition lengths. For welding with the automatic welding processes the welding current, arc voltage and speed of travel are to be adjusted to keep within the heat input rules. They are to be such as to ensure satisfactory running of the electrode wire and produce sound welds of acceptable size and shape. Arc volts are to be measured at the feed rolls and not the power source. Currents and voltages are not to be used if they are outside the electrode manufacturer's recommended range, or such ranges as may be specified by MOD(PE) for particular consumables; see NES 769.

9.8 Weld Deposition Techniques

a. Electrode arc strikes on the base material beyond the fusion face are to be avoided; arc initiation is to be accomplished within the fusion area and in such a manner that:

(1) electrode coatings are not damaged;

(2) stop/start porosity or deep end craters are minimized by use of the 'run back technique'. The 'run back' technique is a means of avoiding porosity and crater cracking which can be caused by the abrupt withdrawal of the welding arc at the end of a weld run. This technique consists of delaying the electrode at the weld end to fill the crater and then welding back along the top of the previously deposited weld for a short distance, thus facilitating the withdrawal of the arc from superfluous weld metal. The superfluous weld metal is subsequently removed.

b. Damage may be caused by stray arcing and care is to be taken to avoid such damage. Stray arcing may be caused by the following occurrences:

(1) contact by the electrode holder to the work piece;

(2) contact between the work piece and the welding earth return lead connection;

(3) contact between the work piece and any part at earth potential.

c. Stray arcing may cause cracking; where evidence of stray arcing is seen the area is to be crack detected and repairs made as necessary.

d. Hydrogen controlled electrodes are to be used with a close arc technique. Due to the limited gas shield evolved with these electrodes increases in arc length will result in atmospheric contamination and porosity.

e. Where possible when using automatic welding processes extension 'run on' and 'run off' plates are to be used. These are to be securely welded to the plate to be welded and grooves are to be made in these extension plates which conform to the actual weld preparation. Where, however, sufficient green material is available at the joint ends or where it is necessary to groove out weld ends to facilitate correct weld sequence at intersecting joints, see Clause 9.12a., then 'run on'/'run off' plates need not be used.

f. The largest practicable cross sectional area is to be attained by root run deposits by use of the highest permitted heat input to minimize the risk of root run contractional cracking or HAZ hydrogen induced cracking. Where due to joint configuration and thickness the weld has to be made under high restraint consideration is to be given to using the block technique. Blocks are to be not less than $^{2}/_{3}$ depth of the weld preparation.

9.9 Cleaning

a. Inter-run cleaning is to be carried out after each weld pass to effectively remove slag. Stop/start or other weld bead irregularities are to be removed prior to the deposition of subsequent weld passes. Where the block technique is used the tails may need to be faired to allow effective joining of adjacent weld blocks.

9.10 No Scallop Technique

a. Where the 'no scallop' technique is used in place of scallops for abutting members crossing butt welds (see Clauses 5.14a. and 5.14b.), the edge preparations, design and welding procedure are to be in accordance with the following:

(1) The edge preparation of the butt weld is to ensure that between ½ and $^{2}/_{3}$ preparation is directly below the abutting member.

(2) Where unprepared fillet welds are involved the design is to be changed to full penetration T butt weld for a length of 150mm each side of the butt weld; see FIGURE 9.2.

(3) Commence welding butt of abutting member by projecting the electrode under the nose of T butt preparation and welding out from both sides. Continue welding until it becomes impossible to project the electrode under the T butt nose. Deposit a transverse weld bead along the root of the T butt and then complete the butt weld on that side; see FIGURE 9.3a.

Note: Positionally, for steels where an electrode is not approved for vertical down applications, on the uppermost side of the passing member welding will commence under the nose of the T butt preparation and progress upwards. On the lower side it will be necessary to commence welding a distance below the passing member and the weld progressed vertically upwards finishing under the nose of the T butt preparation.

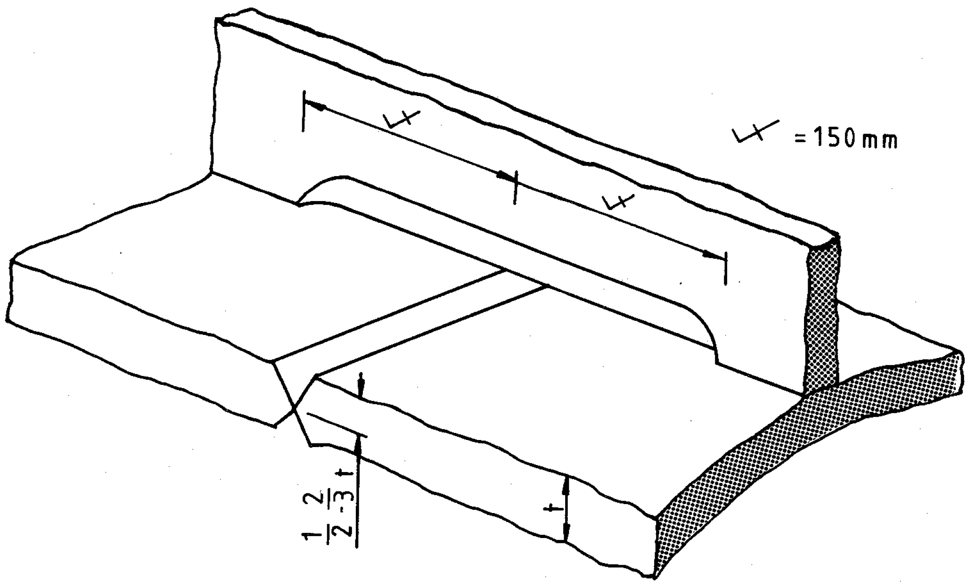


FIGURE 9.2 TYPICAL EDGE PREPARATION

(4) On opposite side of T butt preparation gouge into the root of T butt and deposit a transverse bead in the root. Start on the T butt edge preparation complete this side of the butt in normal manner, see FIGURE 9.3b.

(5) Back gouge back run of butt weld going locally deep in way of T butt, complete butt weld in the normal manner.

(6) Gouge first side of T butt locally in way of plating butt to remove weld metal deposited from (3) and (4) above; subsequently weld the T butt in the normal manner; see FIGURE 9.3c.

(7) Repeat (6) above on second side of T butt; see FIGURE 9.3d.

(8) Non-destructive examination is to be done to establish that the appropriate standard for the particular structure has been achieved. For submarine work ultrasonic examination and crack detection is required.

9.11 Intersecting Butt Welds

a. Care is to be taken at the intersection of butt welds in making T and four way junctions to ensure that the weld deposit in the butt is carried full across the seam and subsequently cut back to the seam preparation; see FIGURE 9.4.

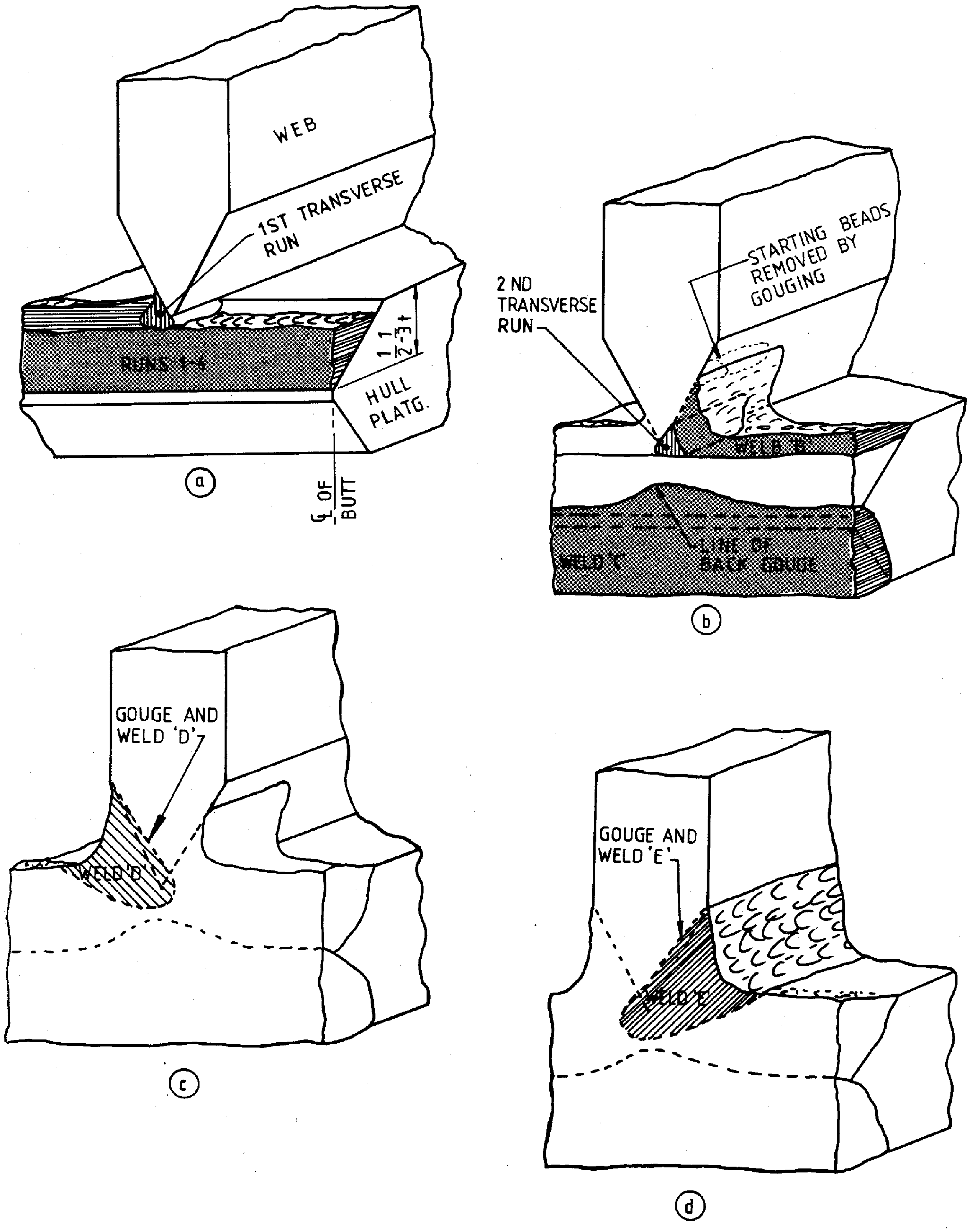

WEB
1ST TRANSVERSE RUN
RUNS 1-6
$1\frac{1}{2}$-3t
HULL PLATG.
℄ OF BUTT
a
2 ND TRANSVERSE RUN
STARTING BEADS REMOVED BY GOUGING
WELD 'B'
WELD 'C'
LINE OF BACK GOUGE
b
GOUGE AND WELD 'D'
WELD 'D'
c
GOUGE AND WELD 'E'
WELD 'E'
d

FIGURE 9.3

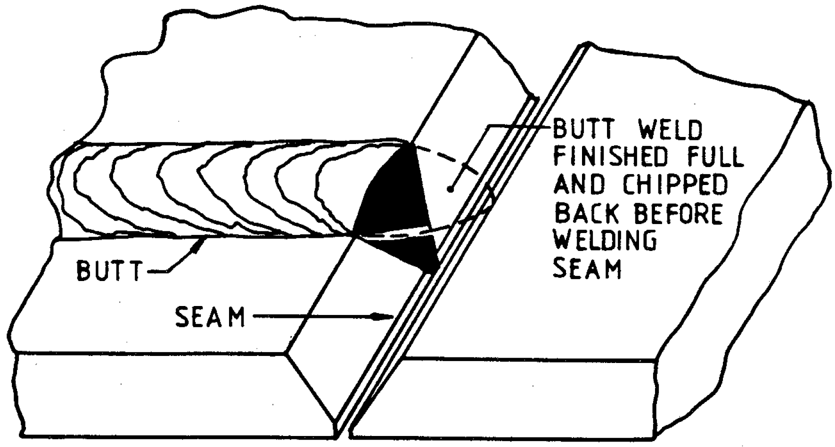


FIGURE 9.4 'T' JUNCTION

9.12 Back Gouging

a. Back gouging is to be done for all butt and full penetration T butt welds except where specifically excluded by approved procedures for one sided welds and square edge two pass welds. It may be carried out by pneumatic chipping, machining, arc air gouging, or grinding. The use of arc air gouging is recommended for speed of working but subsequent grinding may be necessary.

b. Particular care is required in back gouging when it is to be followed by MIG welding. Where pneumatic chipping or arc air gouging is used subsequent grinding will be necessary. In addition where pneumatic chipping is used no lubricant is to be applied at the points of chipping tools and precautions are to be taken to prevent air or water being sprayed on the weld preparation from the working parts of the machine.

c. The back gouged groove is to be semicircular at the root and deep enough to expose solid weld metal free from slag and other contamination. Where root run porosity or piping is encountered this is to be removed. The sides of the excavation may be opened out to facilitate electrode manipulation and prevent side wall undercut or lack of fusion. Details of two types of chipping tool are shown in FIGURE 9.5a and b: the tool shown in 'a' is suitable for use on plating up to 4mm thick, and that in 'b' for heavier material. Diamond pointed tools are not to be used for back chipping or the removal of defective welds. On important work and where a production technique relies on gouging operations to produce the main welding preparation gouging operators are to be provided with suitable gauges defining the required cross-sectional shape.

d. The pre-heat requirements for the particular material involved are to be maintained for arc air or other thermal gouging operations.

e. No formal qualification tests will be stipulated for operators of gouging equipment this factor will be left to the discretion of the Inspecting Authority. It is important that operators are aware of the implications of malpractice and know the procedural requirements for the particular process operated by them.

f. Production use of arc air gouging equipment on submarine structure is to be in accordance with written procedures approved by the Inspecting Authority.

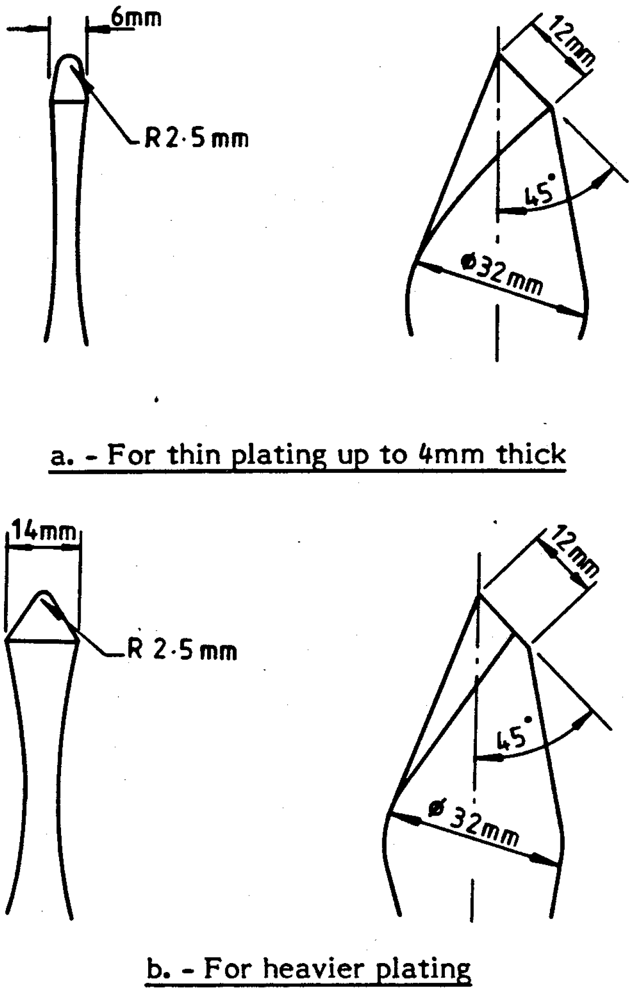


FIGURE 9.5 GOUGING CHISELS

9.13 **Flushing or Weld Dressing**

a. Where requirements exist for weld reinforcement to be dressed smooth or flushed to the level of adjacent material such operations may be done by pneumatic chipping, grinding or by use of arc air carbons. Where arc air carbons are used pre-heat is to be maintained in accordance with Clause 9.12d. Underflushing is unacceptable.

b. Where arc flushing is used on B, UXW and QT28 material removal of weld reinforcement is to be limited to within 3mm of the adjacent base material; the remaining excess reinforcement is to be removed by grinding.

c. No formal qualification tests will be stipulated for operators of flushing equipment: the requirements of Clause 9.12e. are to apply.

d. All arc air flushed welds on submarine pressure hull plating and other important structural members are to be inspected by crack detection methods in accordance with NES 729 and are to meet the acceptance standard of DG Ships/G/10000.

9.14 Post-heat

a. Apart from slow cooling after welding specified in Clause 9.3a. post-heating is not generally required. In certain circumstances such as high restraint or inserts post-heating may be specified. Where specified then it is to be applied to the weld area in the same manner, and to the same temperature as pre-heat. Slow cooling, after post-heat, is required in the same manner as after pre-heat.

9.15 Buttering or Build up by Welding

a. Buttering or build up, but not cladding, will be permitted in the following circumstances:

(1) where necessary to facilitate the joining of structural materials to non-ferrous materials or stainless steels. Each application is to be subject to MOD(PE) approval of the relevant written procedure. Procedural tests may be required;

(2) where necessary to correct oversize root openings or errors in joint preparation. Such buttering is to be done prior to fitting where possible and is not to exceed 10mm thickness on any joint edge. Each application is to be approved by the Inspecting Authority;

(3) where approved by MOD(PE) for the renovation of surface areas where the thickness has been reduced by corrosion; see Section 15.

Note: Requirements for weld cladding are contained in Section 18.

b. All welding deposited for the purpose of buttering is to be deposited in accordance with the full welding requirements of this NES. Buttering done under Clause 9.15a.(1) and 9.15a.(2) is to be considered as part of the final welded joint so far as inspection requirements are concerned. Buttering done under Clause 9.15a.(3) is to be examined in accordance with Section 17.

9.16 Peening

a. Peening of welds is prohibited except where approval has been granted by MOD(PE).

10. WELDING INSERTS

a. This section contains the requirements for welding inserts and other penetrations, with particular emphasis on such work in submarine pressure hulls, containment structure or other structure subjected to diving pressure. The general principles are applicable to similar welds in surface ships. For definitions of insert plates, insert pads, through penetrations and frames see Annex B.

b. The use of fillet welded overlap plates, fillet welded spigoted plates and fillet welded tapered plugs are not permitted without specific MOD(PE) approval. Where it is considered to be essential to use any of these types complete details are to be forwarded to MOD(PE) for consideration.

10.1 Welding Process

a. Welding inserts into submarine structure is to be done by the manual metal arc process only. Proposals to use other welding processes, complete with full procedural detail, are to be forwarded to DG Ships for approval.

10.2 Welding Procedures

a. Written weld procedures are to be produced in accordance with the requirements of Section 4.

10.3 Welding Consumables

a. The selection of welding consumables for use with inserts is to be based on the lowest strength material involved (see Clause 9.1d.), ie when welding a Q1N insert into a QT28 pressure hull, electrodes approved for QT28 may be used. The welding conditions are, however, to be based on the requirements of the material with the highest carbon equivalent, eg Q1N, pre-heat, baking temperature etc.

10.4 Welding Conditions

a. The welding conditions, ie care and baking of electrodes, pre-heat, heat input etc, used for QT35, HY80 or Q1N materials are to be strictly in accordance with NES 770. The welding conditions for other structural materials specified are to be in accordance with this NES.

10.5 Welder Qualification

a. Welders employed welding QT35, Q1N or HY80 inserts are to be fully qualified manual metal arc welders in accordance with NES 770. Welders employed welding other structural steel inserts or penetrations not involving QT35, Q1N or HY80 material are to be qualified in accordance with Section 3.

10.6 Materials

a. It is essential to establish which materials are involved in both inserts/ penetrations and the adjacent structure before welding. This is to be straight forward for new construction vessels but may be more difficult during refit periods. In the latter case refitting authorities are to consult the appropriate design section in Ship Dept to ensure that they are in possession of up to date information.

b. Material identification by chemical analysis is recommended under the circumstances defined in Clause 9.1f.

10.7 Material Examination

a. All new material required for inserts or penetrations are to be ultrasonically examined to ensure freedom from laminations or significant inclusions as defined in DG Ships 86 prior to being worked into a submarine structure. In the case of material which is hot or cold worked and heat treated the examination is to be done before and after such working operations. Where components penetrate submarine structure and are to be welded by full penetration T butt welds, ie hatch coamings, torpedo tube sleeves, periscope wells etc, in addition to the above ultrasonic examination the area in the vicinity (2t) of the T butt weld is to be 100% ultrasonically tested before welding. When an existing insert plate is removed for access purposes the original insert may be refitted except where there is sufficient evidence to expect that the replaced insert plate will be less structurally sound than before removal, or where other overriding factors make it necessary for new material to be fitted.

b. To minimize the risk of producing a less sound structure as a result of refitting an existing insert plate the following non-destructive testing is to be done as soon after removal as possible.

(1) All cut edges, after edge preparation or initial surface dressing, are to be crack detected in accordance with NES 729.

(2) Where frames are joined to the insert plates by full penetration T butt welds, then the toes of such welds are to be crack detected on those welds made to the insert plate and for 300mm in from the frame/stiffener cut edge on the adjacent structure.

(3) The insert and adjacent plating in the vicinity of the T butt welds and for a distance of 300mm in from each cut edge are to be subjected to 100% ultrasonic examination in accordance with DG Ships/PS/9022.

c. Where recordable defects are shown by the examinations in Clause 10.7a. and 10.7b. fuller investigations are to be done to find the full extent of such defects. Where local weld repair action can be taken to remove the defects (see NES 770 for QT35/HY80/Q1N), this may be attempted at the discretion of the Inspecting Authority. Where, however, defects are considered extensive the advice of DG Ships is to be sought regarding repair and replacement or fitting new material.

10.8 Size and Shape of Inserts

a. These factors are important and affect the ease of welding both in regard to the tendency to cracking and deposit soundness. Inserts are generally to be either circular, rectangular with semicircular ends, or rectangular with radiused corners except where an edge of the insert coincides with a seam or butt of adjacent plating. For inserts up to 1.2mm wide the radius of the corners are to be $^1/_8$ the width of the opening or 75mm whichever is the greater. For larger inserts the radius of the corners need not be greater than 150mm. Because the difficulty in making sound welds increases with decreasing diameter, inserts are generally to be not less than 150mm in diameter. Where difficulty is met in accommodating this size smaller inserts may be used with corresponding greater welder skill provided that no insert is less than 100mm in diameter. Where it is impracticable to open up small holes which require blanking to accommodate 100mm diameter inserts DG Ships advice is to be sought.

10.9 Location of Inserts

a. The position of inserts in relation to each other and to other welded joints is important to avoid the build up of residual stress due to the cumulative shrinkage resulting from welds made in the near vicinity. It is also necessary to avoid welds crossing at acute angles. Inserts are to be sited in accordance with the following instructions. Where it is not possible to meet these requirements, full details with alternative proposals are to be forwarded to MOD(PE) for decision:

(1) Wherever practicable inserts are to be located clear of any butt, seam or fillet weld. The distance between inserts and other welds is to be as large as possible and generally not less than 75mm between toes of welds as shown in FIGURE 10.1a. Where this is not possible the insert is to cross the existing weld as shown in FIGURE 10.1b, except that a minimum clearance of 38mm from another weld is acceptable where an obstruction or any other reason would make it extremely difficult to fit a cross-over insert.

(2) As an alternative one side of an insert may be incorporated into an existing butt or seam in the adjacent plating; in such cases the insert is to have square corners at the intersection and the existing butt weld is to be released as shown in FIGURE 10.1c to enable the requirements of welding intersecting butts to be met; see Clause 9.12a.

(3) The fitting of a number of small inserts close together is to be avoided wherever practicable by fitting a large insert to embrace all the holes in that area. The minimum distance generally permitted between any two inserts is 150mm. In practice this is not always attainable; cases exist where it is necessary for the welds of adjacent inserts, or inserts and adjacent penetrations, to intersect. These cases are only permitted with MOD(PE) approval. Where this is the situation it is important to realize that the risk of hydrogen induced cracking and contractional cracking is increased. Special care is required under these circumstances and it is recommended that the following principles are adopted:

(a) The largest insert is to be completely welded first or alternatively adjacent inserts are to be welded at the same time in one operation.

(b) Increase the pre-heat by 20% up to a maximum of 150° C.

(c) Bake electrodes in accordance with NES 770.

(d) Reduce the root gap to the absolute minimum.

(e) Use a block technique particularly at the root with the largest cross-sectional weld deposited within the heat input limit.

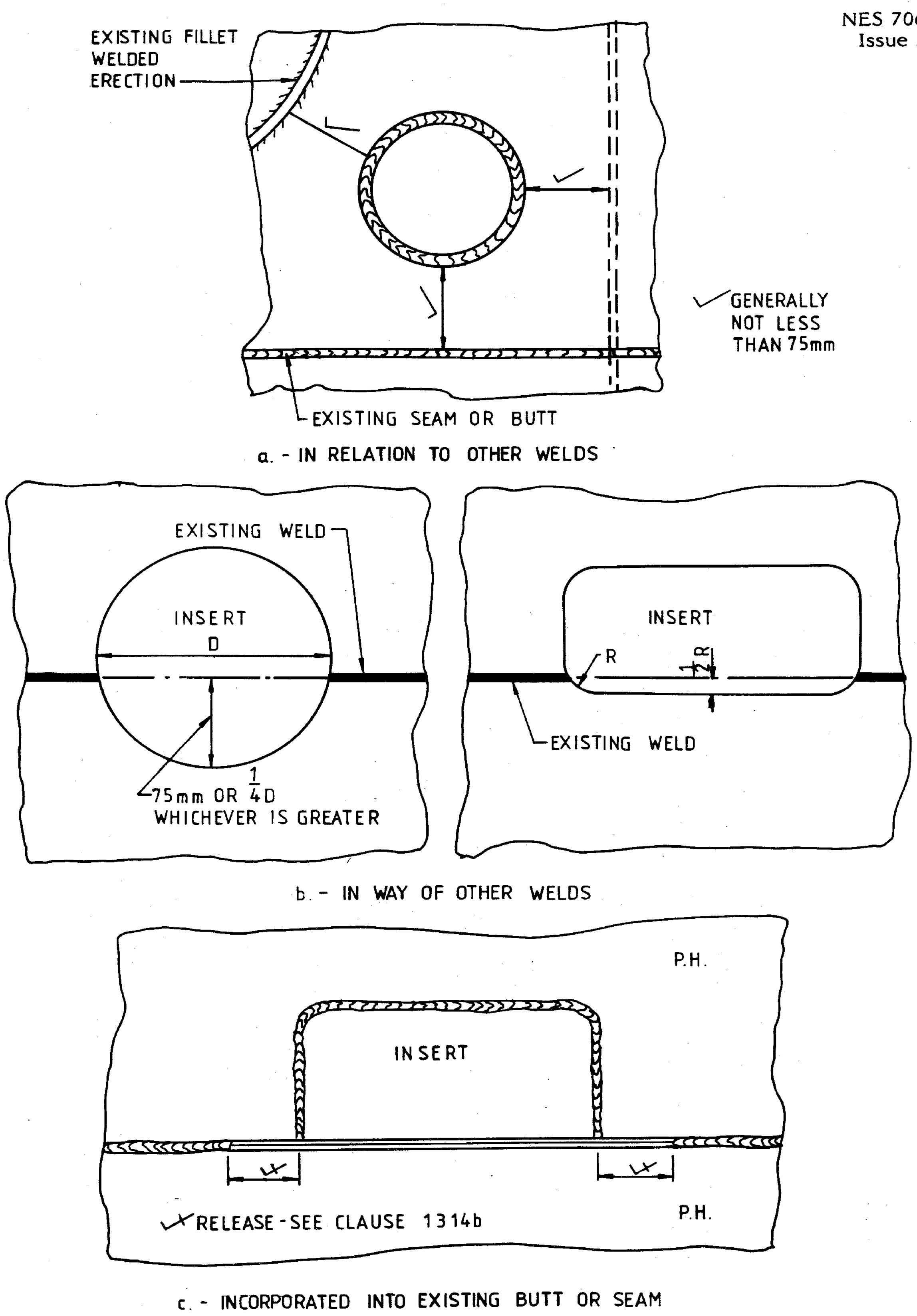


FIGURE 10.1 POSITION OF INSERTS

b. It may be necessary to weld insert pads at the edges of larger insert plates (see FIGURE 10.2), and in such cases the pads are to be welded into the plate before the fitting of the insert plate. Run off plates are to be used when welding the pads into the plate so that the weld ends can be machined back and form the edge preparation of the insert plate. Consideration is also to be given to welding in other insert pads into large insert plates before fitting the latter at ship so that the maximum use of down-hand welding can be employed. Where such action is taken adequate precautions are to be observed to minimize distortion of the insert plate. The photograph, FIGURE 10.3, is an example of this being done for the engine room closure plate of an OBERON Class submarine. Note the method of attaching frames, longitudinal stiffening and the method of securing inserts prior to welding.

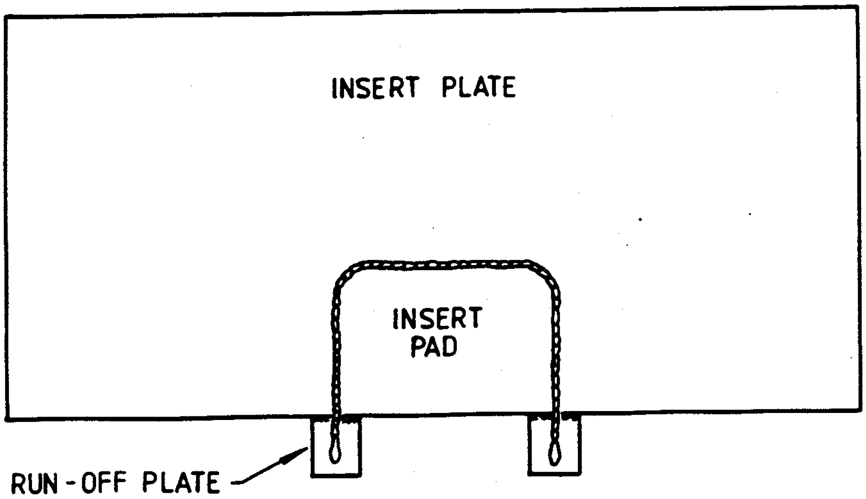


FIGURE 10.2 INSERT PADS AT EDGE OF INSERT PLATE

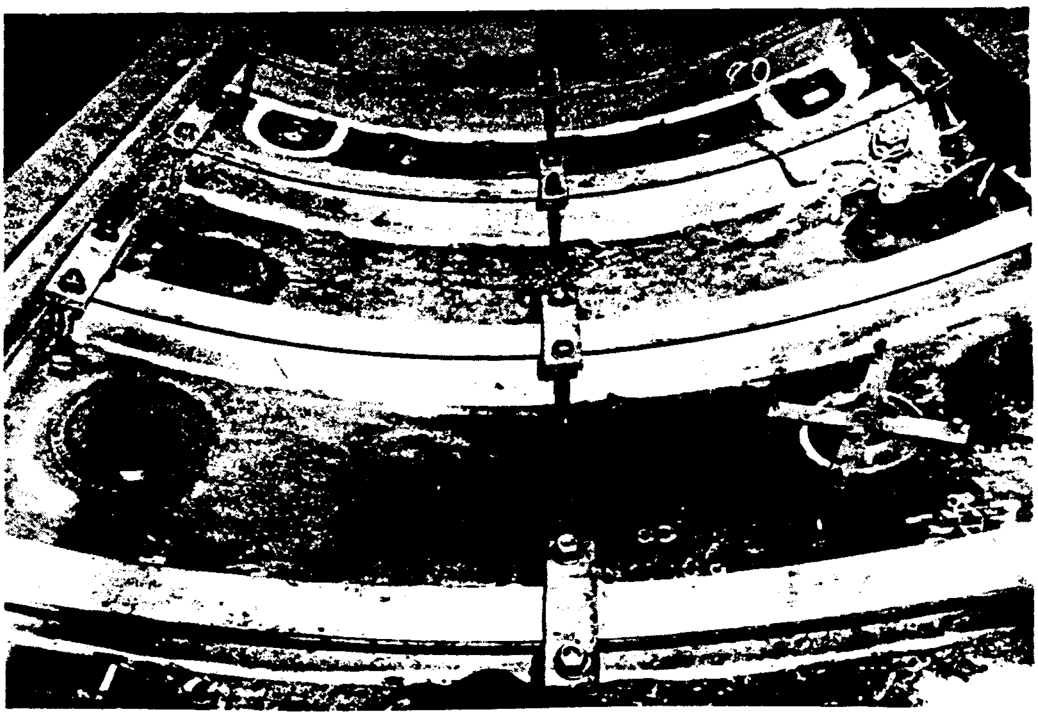


FIGURE 10.3 ENGINE ROOM CLOSURE PLATE

10.10 Edge Preparations

a. Edge preparations are to be in accordance with the general requirements of Section 5. except that when thicker insert pads induce the change from straight sided V joints to U or J then the angle of the U or J is to be increased sufficiently to prevent built-in slag traps or lack of side fusion defects. Particular care must be taken in preparing such joints. Every effort is to be made for inserts to be fitted tight, ie root noses to be in close contact throughout.

b. Where one side has to be welded in the overhead position it may be advantageous to complete or part complete the overhead weld before back gouging, thus providing better conditions for back gouging and possibly facilitating a higher percentage of welding in the flat position. Where such practice is adopted sufficient weld metal must be deposited from the first side to withstand the contraction stress both before and after back gouging. Under normal circumstances about $^1/_3$ of the joint thickness is to remain after back gouging. The positioning of the edge preparation nose will be influenced by this factor; it is therefore essential to resolve the sequence of these operations at an early stage for each insert so that machining of inserts will comply with the requirements at ship. FIGURE 10.4 shows a typical insert pad edge preparation where the edge of the insert pad has been tapered at the correct slope.

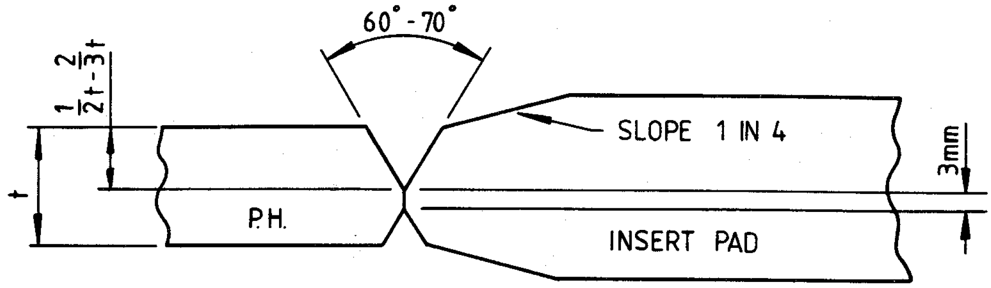


FIGURE 10.4 TYPICAL INSERT PAD EDGE PREPARATION

c. For thick insert pads and through penetrations it is often impracticable for the correct slope, 1 in 4, to be incorporated because in the case of insert pads, the resultant diameter will be unduly large. Tapers greater than 1 in 4 make welding difficult, radiographic interpretation impossible, and creates undesirable sharp changes in section resulting in stress concentrations at the weld toes. Each insert design must aim at attaining the best compromise after consideration of all the above factors. FIGURE 10.5 illustrates an edge preparation for thick inserts which has been found in practice to achieve good results. Alternative solutions are shown in FIGURE 10.6; where these edge preparations are used the side from which back gouging is done is to have a chamber cut as shown so that the joint is clearly visible for back gouging operations.

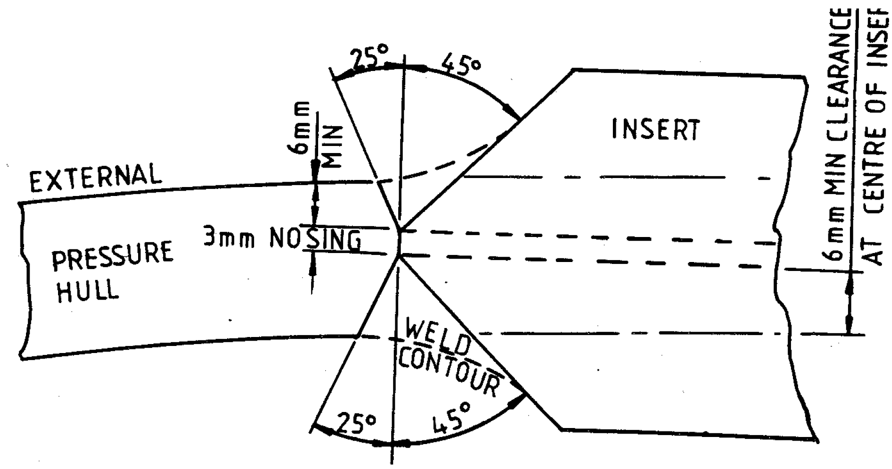


FIGURE 10.5 RECOMMENDED EDGE PREPARATION

d. FIGURE 5.21, FIGURE 5.22 and FIGURE 5.23 in Section 5. show typical edge preparation for T butt welds suitable for through penetrations. Annex F. and Section 5. regarding the risk of lamellar tearing are to be read before welding these joints. Back gouging of penetrations is difficult without cutting into the penetration side wall, leaving a cross-section which can increase the welder's problems; it is therefore recommended that back gouging and thus the subsequent weld back run is arranged to be done in the least difficult position.

e. Finishing or surface weld deposits are to be arranged to blend smoothly into the parent material without excessive weld overfill. Where thick insert pads are fitted without the correct slope at the periphery then weld metal is to be built up to reduce the difference in angle between weld metal and insert pad slope; see FIGURE 10.7.

f. It is a requirement for all insert welds to be dressed to assist in NDT interpretation. Advantage is to be taken of this operation to fair the weld surface into that of the adjacent parent material and the insert.

10.11 Preparing and Erection/Fitting Requirements

a. A higher degree of care is required in producing edge preparations for inserts than for other structural joints. The most accurate methods must be used to achieve the 'fit up' requirements stated in Clause 10.10.a. The general requirements of Clause 7.1a. for methods of producing edge preparations are to be observed but the use of controlled mechanical processes is recommended. Where possible insert pads are to be machined to shape by lathes, shapers, milling machines etc, while the corresponding aperture into which insert pads or penetrations are fitted are to be prepared by drilling/trepanning operations or alternatively machine controlled flame cutting equipment. Even where the edge preparation bevels/angles are subsequently cut by chipping, gouging, or grinding operations, production of the initial hole by mechanized means will assist in attaining an accurate nose to the joint.

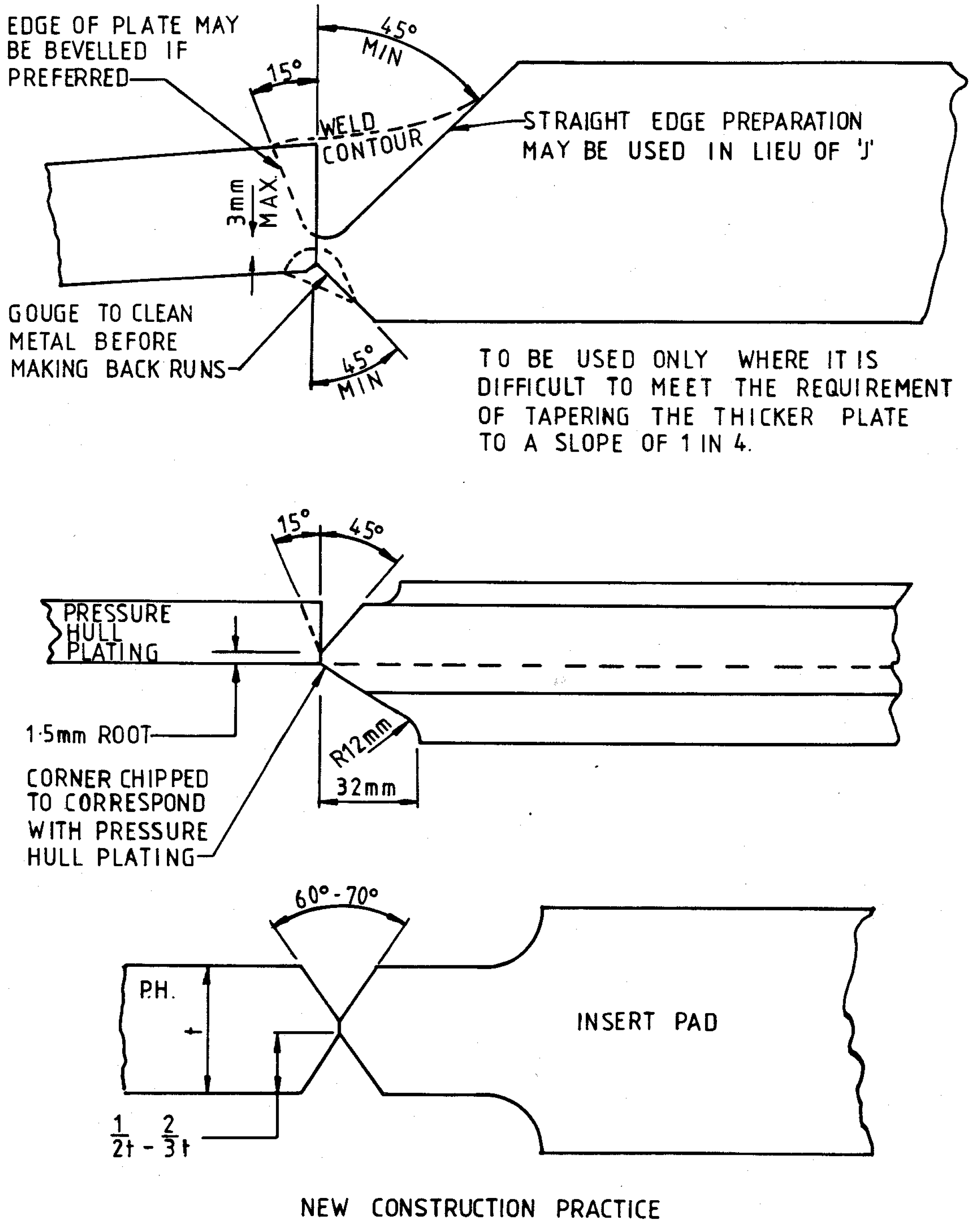


FIGURE 10.6 ALTERNATIVE EDGE PENETRATION

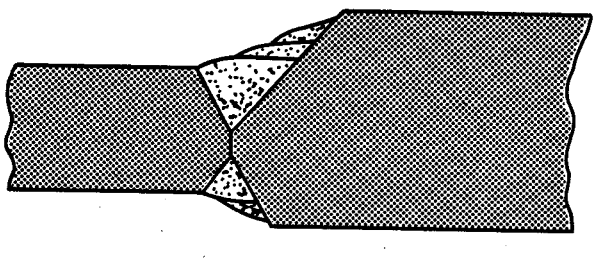


FIGURE 10.7

b. Similar care is required in cutting out insert plates which are subsequently to be replaced. Precautions must be taken to maintain form by the use of local temporary stiffeners, bracing, etc. The cut is to be arranged to be in the middle of original weld metal, where existing inserts are involved, and automatic flame cutting equipment travelling on portable tracks or guides should be used. Radiused corners are to be cut using flame cutting equipment attached to radial arms or other guide devices. Where insert plate corners terminate at existing butt welds (see FIGURE 10.1c), it is recommended that the release of the existing weld, beyond the insert plate dimensions, is done by gouging except that final release of the nose is to be done by mechanical saw or thin grinding disc, care being taken to avoid making a sharp notch at the termination. Extra care is required at these positions when the cold filler technique is used. The removal of a badly corroded plate is to be regarded as the removal of an insert plate except that the frames or other structure crossing such a plate are not to be removed. The redundant plate is to be cut at the periphery and on each side of the frame web or other structure, the surplus metal remaining on the web is to be removed, restoring the abutting member to the correct preparation for subsequent welding.

c. Where it is necessary for structural frames to be removed integral with an insert plate, which is subsequently to be replaced, considerable difficulty may be experienced in actually freeing the unit from the surrounding structure without producing wide cuts in the frames. For that reason, where new inserts are involved, it is recommended that the frames be cut at an angle as shown in FIGURE 10.8.

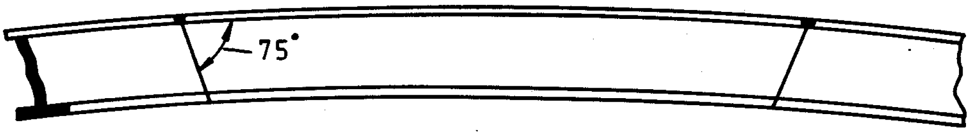


FIGURE 10.8

d. While the above practice will increase the overall width from that of the 'clear opening' the removal and replacement operations are made easier in addition to minimizing the resultant gap in the frame butts.

e. Where, however, existing insert plates are involved and the frames have been 'butted' by some other means then the original arrangements are to be followed, or alternatively, sections of the frames, in way of the insert plate butts, may be made redundant and replaced by new frame inserts as shown in FIGURE 10.9.

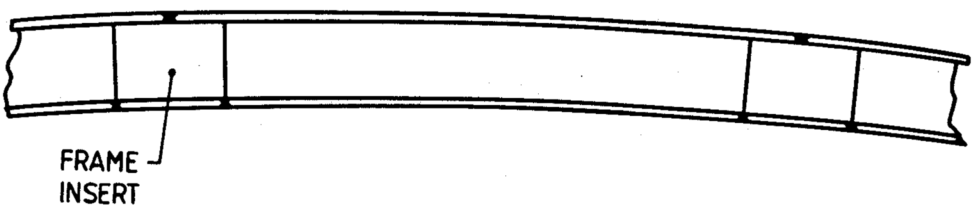


FIGURE 10.9

f. Where it is necessary for insert plates to be replaced with new material and new frames are to be fitted there are two basic methods of replacement:

(1) Frames can be fitted and welded into the existing structure before the insert plate. This method does improve the conditions under which the frame butts are welded.

(2) Frames can be attached to but not necessarily fully welded to the insert plate before fitting at ship. This system makes fitting at ship more difficult, but the addition of the frames or stiffeners may assist in maintenance of form in cases where smaller insert pads are welded into the insert plate prior to fitting at ship.

g. Regardless of the manner in which frames are removed and replaced it will be necessary for the remaining frame ends to be released for a minimum distance of 150mm. Particular care is to be taken where material susceptible to lamellar tearing is involved and it is recommended that the release of such joints is done using grinding equipment and that the ends of such grooves blend smoothly into remaining weld metal.

h. When butting frames in way of insert plates or where butt welds cross the webs of frames it is recommended that the 'no scallop' technique is adopted in accordance with Clause 9.10a. Where the frames are attached by double fillet welds then these are to be converted to full penetration welds for 150mm either side of the position where the 'no scallop' technique is used.

i. Where new frame and insert plates are fitted the attainment of fit up to the required standard can be achieved by preparing the welding edge preparations at ship, careful moulding followed by edge preparation of the new material. In these circumstances it is advisable to leave some green material for final trimming at ship. Where, however, existing insert plates are to be replaced then it will be necessary to reduce the gap between abutting members resulting from the removal cutting operations. This is to be achieved by either 'buttering' one or both edges of the joint or by the 'cold filler' technique as follows:

(1) **Buttering of weld edges** Such buttering is to be carried out using an approved welding procedure, electrode etc for the material involved, and the full welding precautions required for the material in respect of pre-heat, baking of electrodes etc are to be followed. A high standard of welding is required for successful buttering and a minimum of two layers of weld metal are to be deposited. Prior to buttering, the fusion surface is to be dressed free of notches or other irregularities which would otherwise adversely affect the deposition of sound weld metal. Under normal circumstances it should only be necessary to build up the material at, and in the vicinity of, the final edge preparation nose on the plate or frame as applicable.

(2) **Cold Filler techniques:**

(a) The cold filler technique may be used in place of buttering when the total gap resulting from the cutting operation and dressing of the nose is 6mm or less. In such cases the welding edges are to be prepared with up to 6mm root face and an 8mm diameter continuous electrode filler wire fitted between the abutting noses as shown in FIGURE 10.10.

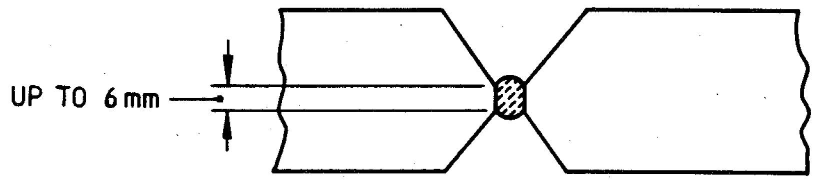


FIGURE 10.10

(3) The electrode filler wire is to be certified low carbon mild steel such as Bostrand S4. This is to be hammered into the root gap and tack welded on the opposite side of the joint from which the first side will be welded.

(4) The first side is to be welded with sufficient depth to withstand contractional stresses before and after back gouging. Back gouging is to be deep enough to completely remove the cold electrode filler wire and penetrate into the root run to expose sound weld metal. The back run and remaining weld metal are then to be deposited in the normal manner.

(5) The cold filler technique will not be permitted on frame butts. Frame butt joints are to be full penetration butt welds. The edge preparations are to be buttered as necessary to achieve the required standard of fit up or alternatively frame or stiffener inserts are to be fitted in accordance with FIGURE 10.9.

10.12 Securing of Inserts Prior to Welding

a. The general requirements of Section 7. are to be followed but wherever possible small inserts are to be positioned and secured by methods which do not involve welding; see photograph FIGURE 10.3. For larger insert pads and plates it is preferred that holding devices which will allow lateral movement are adopted and that tack welding is minimized. Where, however, tack welding is considered necessary the full welding precautions for the material involved are to be taken. Once the main welding has commenced tack welds encountered are to be removed. This may perhaps be arranged by tack welding on the back gouging side so that all tack welds are removed during that operation.

b. Alternatively under certain circumstances tack welds may be replaced by block welds comprising three or four weld layers and between 225mm and 250mm long. Where these welds do not crack during the main welding operation, they may be incorporated in the main weld. The tails of such block welds are to be cleaned out and faired into the normal edge preparations and all such blocks are to be crack detected before being incorporated with the main weld. It is strongly recommended that the main welding of inserts follows very closely after tack welding.

c. Similar care must be taken in securing frames to existing structure prior to welding, precautions must be taken to prevent frames from twisting out of alignment from the correct plane. Suitable temporary stiffening is to be used to provide alignment and maintain the correct relative frame positions.

10.13 Welding Sequences

a. High local stresses obtained when welding inserts can give rise to weld metal cracking. The severity of these stresses and therefore the incidence of cracking will depend on the dimensions of the inserts, the joint preparations and the welding sequence used. Welding sequences are to be evolved and be clearly indicated to the welders. The following information regarding welding sequences is for general guidance. Where fabricators experienced in MOD(PE) work have evolved sequences which have proved satisfactory then such sequences may be used so long as the Inspecting Authority is satisfied that the requirements of this Standard are being met in all other respects.

b. It is important to complete the deposition of root runs without delay or stoppages of work and in general it is recommended that the welding of small inserts is done as a continuous operation. It is particularly important that no stoppages occur until sufficient weld metal has been deposited in the root to avoid the occurrence of contractional cracking. For materials up to 25mm thick four or five weld layers should suffice while for thicker materials, as a general guide, about two thirds of the joint preparation should be aimed for. The largest practicable cross-sectional area, within the applicable heat input rules, is to be deposited for root runs. Hydrogen controlled electrodes are to be used for all small inserts irrespective of the materials involved.

c. Care must be taken to avoid the alignment of weld bead stop/start positions during deposition of subsequent weld layers or in the back run, which will otherwise result in porosity aligned through the weld. In the case of penetrations or inserts where the bore or face must align to a specified datum, regular checks are to be taken during the welding operation and welding sequences adjusted as necessary to maintain the correct alignment.

d. **Small circular insert pads** The recommended sequence of welding for small circular insert pads 150mm diameter or less is shown in FIGURE 10.10a and b. The position of the sectors (1), (2) and (3) for welds being made in the flat or overhead position is immaterial but for welding in the vertical or inclined position the sectors are to be rotated to the position shown in FIGURE 10.11b, weld passes are to be alternately deposited in the order shown until sufficient weld metal has been deposited to allow back gouging and the back run to be welded.

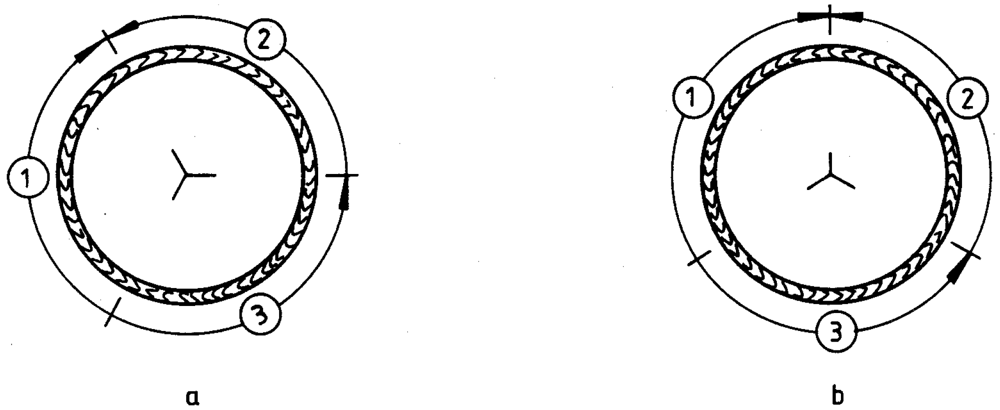


FIGURE 10.11 SMALL CIRCULAR INSERT PADS

e. **Larger circular insert pads** For circular insert pads which exceed 150mm diameter it is recommended that the basic welding sequence is changed from three sectors to quadrants as shown in FIGURE 10.12. Where inserts are to be welded in the vertical or inclined positions the positioning of the welding zones (1) and (2) are to be arranged to be vertical or near vertical. The use of the block technique is advocated; on small inserts this can be achieved by alternately depositing weld passes in (1) and (2) until about two thirds of the joint preparation is filled. On completion of blocks (1) and (2) the tails must be cleaned out and grooved to facilitate joining with blocks (3) and (4). The block welds (3) and (4) are to be deposited in a similar manner to (1) and (2), care being taken to blend the weld beads into the existing blocks. Simultaneous welding of geometrically opposite blocks are to be done wherever the insert is large enough for two welders to be employed. Subsequent weld runs are to follow the same basic sequence but the quadrant is to be rotated as necessary to prevent alignment of stop/start quadrant positions.

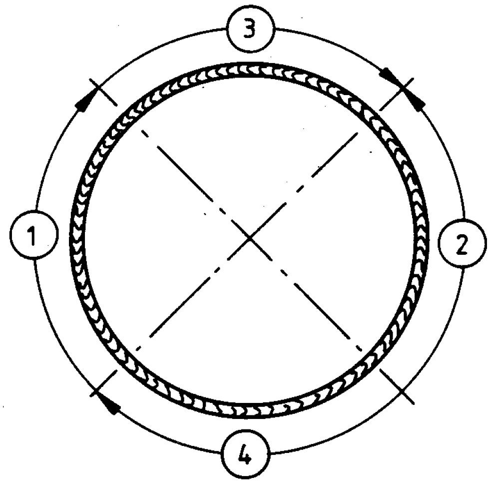


FIGURE 10.12 LARGER CIRCULAR INSERT PADS

f. **Oval or rectangular insert pads** For oval or rectangular insert pads the general principles contained in Clause 10.13e. are to be followed and adapted as shown below:

(1) For small insert pads with semicircular ends the basic welding sequence recommended is shown in FIGURE 10.13.

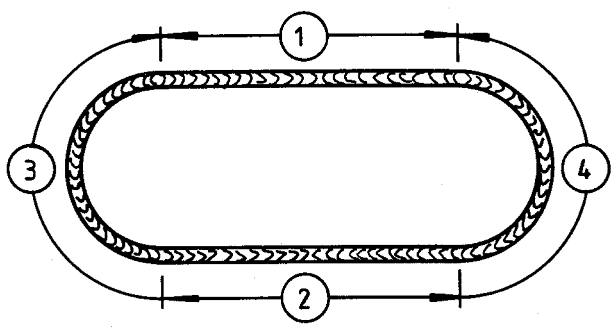


FIGURE 10.13

(2) For rectangular insert pads or small insert plates with radiused corners the basic welding sequence recommended is shown in FIGURE 10.14.

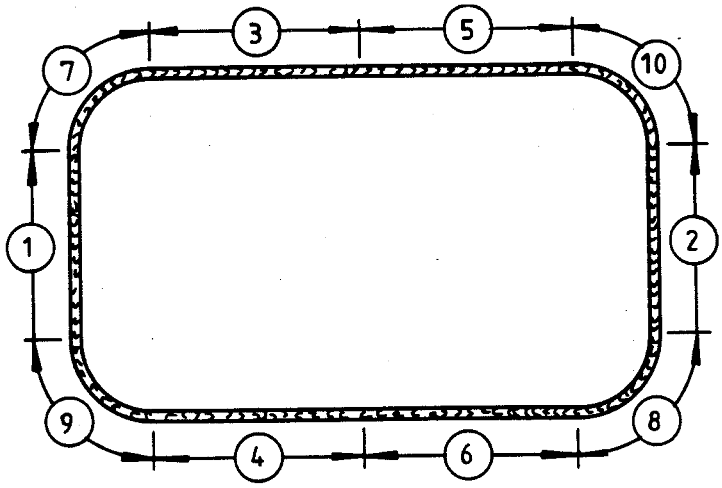


FIGURE 10.14

g. **Insert plates which cross frames but where the frames have not been cut from vessel:**

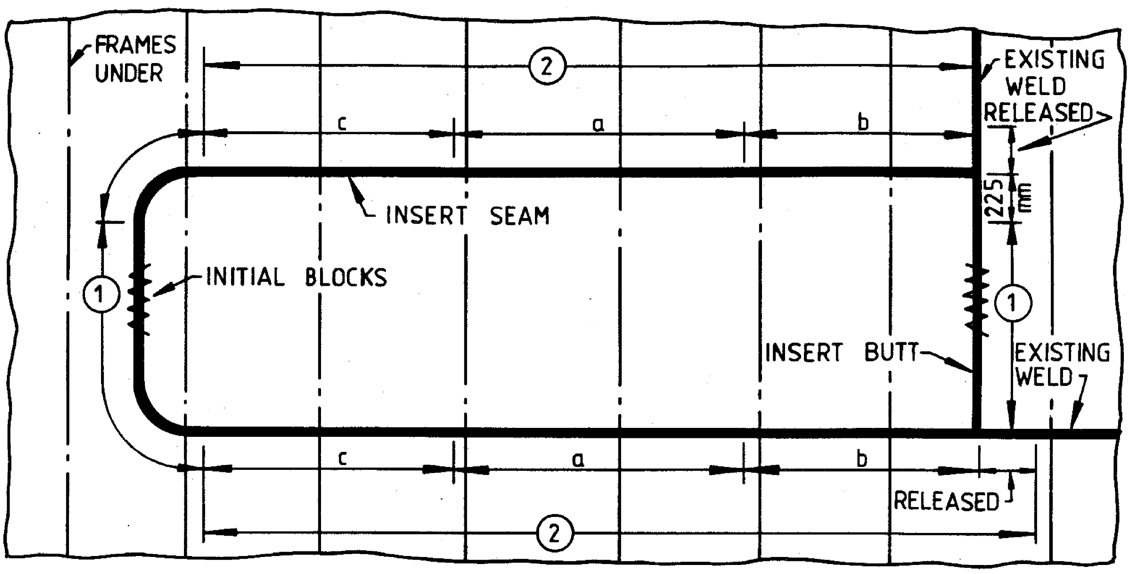


FIGURE 10.15

(1) The insert butts or the shortest sides of the insert plate are to be welded first, both butts are to be welded simultaneously. This is best achieved by starting at the mid-point with block weld welds up to 610mm in length and building up to about two thirds of the edge preparation depth and then working out from the centre block employing four welders, two each end, using the back step block method until the joint is welded to full length.

(2) Where all four corners of the insert plate are radiused then the welding, from the centre, is to continue around the corners for a distance of about 75mm to 100mm along the seam. Where, however, the insert plate butts or seams are continuous with those of adjacent plates then the welding of the insert plate is to be so arranged to meet the requirements stated in Clause 9.11a. for intersecting butt welds. FIGURE 10.15 illustrates this situation.

(3) Where a limit on the length of weld deposit at one butt is set as a result of intersecting butt welds, then the same limit is to be applied on the opposite butt so that each weld is approximately the same length.

(4) Both seams or the longest sides of the insert plate are to be welded in a similar manner to that described above, except that for large insert plates 4mm long it is recommended that each seam be divided into three sections as shown in FIGURE 10.15. Each section is to be welded at the same time by three welders each side, again adopting the central block technique in each section and working out with the back step block method. Particular care is required in joining adjacent blocks. Tee intersections and unwelded corners are to form the third and final stage in welding before back gouging and welding the back run. The back run is to be welded by a similar balanced sequence but care is required to prevent alignment of stop/start positions. Where the ‘no scallop’ technique is being used the welding of the frame in the vicinity of the insert plate butt is to be incorporated as part of the general welding sequence.

(5) In general the welding of frames to the insert plate is to be done following a sequence which aims at balancing the welding on each side of the webs with welding progressing from the mid-points of the insert plate out to the ends. Either the back step block technique or back step skip method may be used; see BS 499, Part 1.

h. **Insert plates where existing or new frames are being replaced in the vessel.** In general it is recommended that frame butts are welded before the insert plate butts as this sequence will reduce the risk of structural distortion. Where, however, fabricated frames are involved and the web is locally removed to provide access to weld the insert plate butt, then so long as the frame table butts are welded first, the web insert may be welded on completion of the insert plate butt welds. Where possible butt joints of the same frame are to be welded simultaneously. Once all frame butts have been welded the insert plate butts and connections of frames to insert plate are to be welded as described in Clause 1340.

10.14 Sequence of Welding Frame Butts

a. **Rolled frames** Some difficulty can be expected in achieving full penetration welds of these butt welds due to the configuration found at the intersection of web with table:

(1) Prepare frame edge as shown in FIGURE 10.16. Note area (X) provides a deep nose.

(2) Weld (1) using a run on plate at edge of table.

(3) Back gouge side (2).

(4) Weld (2) as (2). above.

(5) Back gouge table butt cutting deep at (X) until sound weld metal is found.

(6) Weld (3) using run on/off plates.

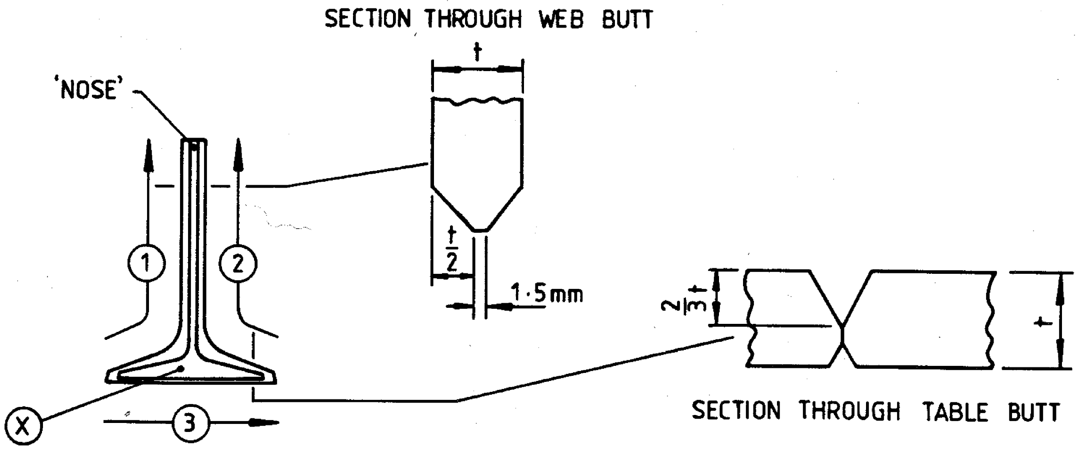


FIGURE 10.16

b. **Fabricated frames** The 'no scallop' technique is recommended for these configurations; a typical arrangement is shown in FIGURE 10.17.

(1) Prepare frame edge as shown in FIGURE 10.17. Weld (1), (1A) and (1B) as normal 'no scallop' technique; use run on/off plates at table.

(2) Back gouge table cutting deep at mid-points.

(3) Weld (2) as (2) above.

(4) Weld (3) back gouge and weld opposite side.

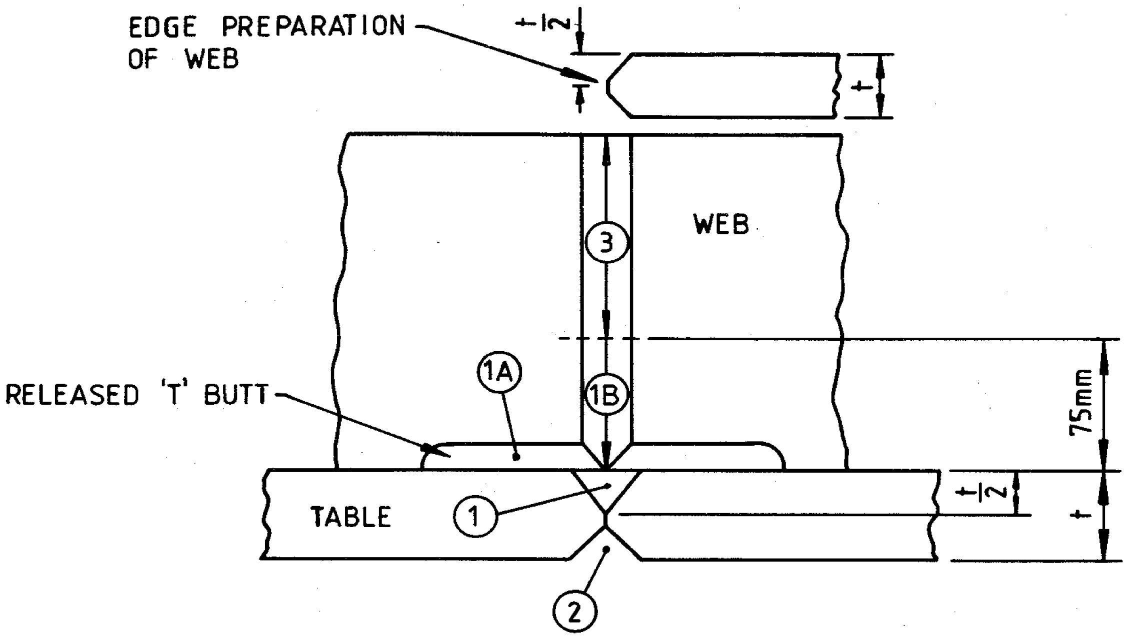


FIGURE 10.17

10.15 Non-destructive Examination and Acceptance Standards

a. Non-destructive examination requirements and acceptance standards are to be in accordance with Section 17.

11. WELDING CASTINGS AND FORGINGS

a. This section contains the instructions for welding the structural steel castings and forgings shown in Section 1. Groups 3 and 4. The general principles if not the actual requirements defined herein may be applicable to British Standard castings or forgings. Where such materials are selected by the designer advice is to be sought from MOD(PE) regarding the degree of compliance that is to be placed on this NES.

11.1 Welding Operations

a. The welding operations which may be encountered are:

(1) structural joining of castings and forgings ie shaft brackets arms to barrel;

(2) repair of casting defects caused during casting manufacture;

(3) repair of pitted or corroded cast or forged components; these instructions are contained in Section 15.

Note: In-service fractures of castings or forgings are not to be repaired without prior consultation with MOD(PE) except as an emergency measure.

b. In the case of Clause 11.1a.(1) and 11.1a.(2), the welding of castings and forgings can be more difficult than rolled steel plate because of the large mass which provides a rapid heat sink, and rigidity which induces a high level of restraint. Successful welding can be further aggravated by the presence of casting defects in the locality of welds. The acceptance standard for castings is such that some physical defects such as areas of shrinkage, blow holes, slag etc which are not in themselves detrimental to the casting may, in the vicinity of welds, initiate unacceptable defects when combined with stresses resulting from welding.

c. **Welding process** Welding of castings and forgings are to be limited to the Manual Metal Arc process. Proposals to use other welding processes, complete with full procedural details, are to be forwarded to MOD(PE) for consideration of approval.

d. **Welder qualification** Welder qualification is to be in accordance with Section 3.

e. **Welding procedures** Written welding procedures are to be produced in accordance with the requirements of Section 4. Pre-production procedure testing may be required see Clause 11.1c.

f. **Welding consumables** Only MOD(PE) approved manual metal arc welding electrodes noted as approved and as stated in NES 769, are to be used for welding castings and forgings. The approved list states for which applications the electrode is suitable, eg as-welded, stress relieved. The selection of welding consumables for use with castings or forgings or the combinations of castings and forgings and other structural steels are to be based on the lowest strength material involved; see Clause 9.1d. Baking, storage and issue of welding consumables are to follow the requirements of Section 8.

g. **Welding conditions** Pre-heat, heat input, interpass temperature and weld bead deposition technique are to be as specified in Section 9. except that where post weld stress relief is not carried out pre-heat is to be maintained for two hours after completion of welding. Selection of welding conditions is to be based on the material with the highest CE. Wherever possible welding is to be done in the flat position.

h. **Heat treatment requirements** Welding is only to be carried out on castings or forgings which have been fully heat treated at the manufacturing stage and after acceptance mechanical testing has been done. The only heat treatment, except for continuation of pre-heat, permitted after weld repair or structural welding of castings or forgings are to be post-weld stress relief which will be permitted in accordance with Clauses 11.2a. and 11.3c. Where required post-weld stress relief is to be done in accordance with Clauses 7.9a. and 7.11a. to 7.11d. the stress relief temperature is to be between 600° C and 650° C.

i. **Edge preparation (Manufacture)** Edge preparations are to be produced in accordance with the general requirements of Clauses 7.1a. to 7.4b. Completed edge preparations are to be crack detected to ensure freedom from surface defects. In important thick structural joints it is recommended that sub-surface inspection is carried out in the near vicinity of the edge preparation to ensure that any defects within the casting acceptance standard are not significant enough to propagate into unacceptable defects as a result of welding.

j. **Welding technique** Balanced welding sequences are to be used to minimize the resultant contractional stresses and distortion these requirements are to be clearly indicated to the welder. Each weld pass is to be deposited to produce the largest cross-sectional area within the heat input limits using the largest practicable electrode size and wherever possible the block technique is to be adopted. Tack welding is to be avoided but where essential tack welds are to be of the same dimensions and are to be deposited using the same procedure as the main weld. Tack welds are not to be incorporated into the main weld unless proven to be crack free. Repair welding by puddling, ie weaving the electrode around the point to be repaired, is prohibited because of the excessive heat input which is generated.

11.2 Structural Welding of Castings or Forgings

a. Where castings or forgings are joined by welding, in the structural sense, to form a fabricated component or composite structure, such as attachment of side plates to a rudder casting, then welded joints may be made up to 50mm thick without subsequent heat treatment except for maintaining the pre-heat for a period of two hours from completion of welding. Where, however, joints in excess of 50mm thick are made then the entire weldment is to be stress relieved after welding.

b. **Edge preparation (Design)** Design of edge preparation is to be in accordance with the general requirements of Section 5. except that every effort is to be made to minimize the volume of weld metal deposited in an endeavour to reduce the resultant contractional stress. Deep narrow grooves are, however, to be avoided because of the increased risk of side undercutting which provides slag traps or cavities. Where it is necessary to produce a full penetration weld from one side then backing bars are to be used or additional material may be cast at the root of the edge preparation; see FIGURE 11.1. In either case the backing bar or additional cast material is to be subsequently removed by machining. One sided welding will only be permitted in accordance with the requirements of Clause 5.4a.

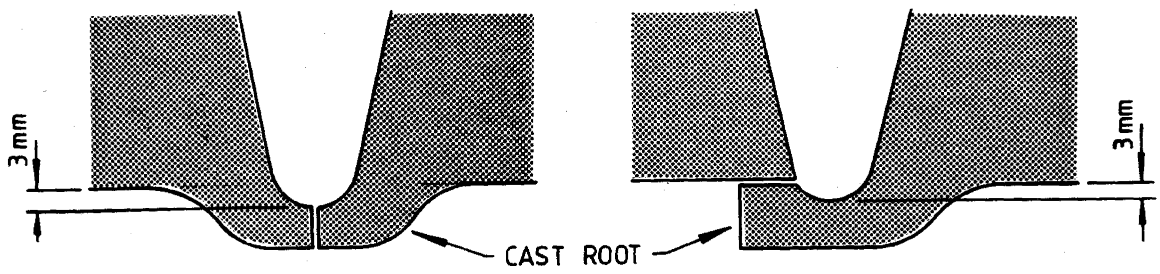


FIGURE 11.1

c. **Non-destructive examination and acceptance standards for structural welding of castings and forgings** The non-destructive examination requirements and acceptance standards for structural welding of castings and forgings are to be in accordance with Section 17.

11.3 Repair by Welding of Castings

a. The requirements regarding acceptance standards for castings and the permitted rectification of defects by welding are contained in DG Ships/PS/9010. The following requirements are additional to those contained under the general requirements of this Section, Clauses 11.1a. to 11.1j.

b. **Welding procedure** Prior to undertaking weld repair of castings a written welding procedure is to be submitted for approval, unless prior written agreement has been reached on standard welding procedures. The Inspecting Authority is to be the approval body for these procedures for all classes of weld repair except for those classified as special repairs. Welding procedures for special weld repairs are to be submitted to MOD(PE) for approval in accordance with DG Ships/PS/ 9010.

c. **Post-weld stress relief** In general post-weld stress relief will be required on all castings with weld repairs which have a depth of 50mm or more and where stated by MOD(PE) for special repairs.

d. **Repair limitations** Repair by welding may be made subject to the limitations stated in DG Ships/PS/9010. The various repair types quoted in that Standard are as follows:

(1) dimensional;

(2) surface defects;

(3) sub-surface defects;

(4) limits on individual sub-surface repairs;

(5) limits on combined weld repairs;

(6) special repairs.

e. **Pre-welding requirements** All areas to be welded shall after excavation meet the general requirements of this NES in respect to cleanliness, access for welding etc. General guidance on methods of excavation, excavation limits, methods of weld deposition can be found in Section 14. Welding is only to take place on sound metal. Suitable non-destructive testing is to be employed before welding to ensure the complete removal of defects which have necessitated the repair action. All surfaces to be welded are to be crack detected in accordance with NES 729.

f. **Non-destructive examination and acceptance standards for repair by welding** Non-destructive examination requirements and acceptance standards for repair by welding of casting defects are to be in accordance with DG Ships/PS/9010.

12. WELDING OF PROTECTIVE PLATING

a. This section contains the instructions and requirements for welding the materials used for protective purposes as shown in Section 4, Groups 5 and 6.

12.1 Current Materials

a. The current materials which may be specified for protective purposes are shown in TABLE 12.1 together with the relevant specification or standard.

MATERIAL	SPECIFICATION
HY80 quality steel	MIL−S−16216 (SHIPS)
Q1N quality steel	DG SHIPS 70
B quality steel	DG SHIPS 1257
Mild steel	DG SHIPS 1207
Stainless Steel	BS 1449 Pt 2, 320S17
Aluminium alloy	BS 1470, NS8

TABLE 12.1

Note: Stainless steel and aluminium alloy are used where non-magnetic properties are required.

b. **Welding and fabrication of current materials** The welding and fabrication of the protective materials shown in Clause 12.1a., TABLE 12.1, shall follow the normal structural requirements applicable to the particular material, ie HY80 and Q1N steels are to be welded and fabricated in accordance with NES 770, while the remaining materials are to be welded and fabricated in accordance with this Standard. Particular attention is to be given to reducing the risk of lamellar tearing where B quality or mild steel is involved as, for the most part, materials used for protective purposes will be of sufficient thickness to provide a high risk of such occurrences; see Clause 5.11a. In addition, reduction in weld sizes may be possible in accordance with Clause 5.12b.

12.2 Obsolete Materials

a. The following obsolete protective materials may be encountered during refits of older vessels. Unless otherwise stated these materials were not made to material specifications with chemical compositions which can be used to assess the weldability; thus the general description of each material has been included. The terms ‘armour plating’ and ‘protective plating’ will be used with the obsolete materials because such terms will be found on older drawings.

b. **Armour plating, 37mm thick and above:**

(1) **Non-cemented (NC quality)** A machinable quality armour plating of homogeneous hardness.

(2) **Cemented (C quality)** Armour plating in which high front surface hardness has been induced by cementation and heat treatment. The front of such plates is normally unmachinable and unweldable.

(3) **Special qualities** Variations on NC and C qualities of plating designed to fulfil special functions. They may possess machinable or unmachinable qualities.

c. **Protective plating, 38mm thick and below:**

(1) Similar to NC armour plating.

(2) **D1HT** A heat treated steel based on the chemical compositor of D1 quality steel; see Section 1. Group 2 for composition. This steel was superseded by UXWHT.

(3) **UXWHT** A heat treated steel based on the chemical composition of UXW steel see Section 1. Group 2 for composition; made in thicknesses of 10mm to 25mm.

(4) **DKM** A nickel chrome steel superseded by NMMQ.

(5) **NMMQ** A non-magnetic machinable quality for use in positions where non-magnetic properties are required; in thicknesses generally not exceeding 25mm.

d. **Armour or protective plating** QT35 steel may be found on certain vessels; this material is no longer specified but where encountered is to be welded in accordance with NES 770.

e. **Welding and fabrication of obsolete materials** Under normal circumstances the obsolete materials used for protective purposes will only be encountered during the refit or modernisation of older vessels and will therefore not be subjected to the normal fabrication operations. This section is therefore limited to welding considerations; for other operations, such as machining, drilling and flame or arc cutting, advice is to be sought from MOD(PE). Welding the obsolete protective materials is to be limited to the manual metal arc process. The welding requirements shown have been evolved and established by experimental evaluation and successful past practice. Adherence to the stated precautions can result in crack free welds and HAZs but the mechanical properties of such joints, with the exception of QT35, will be lower than those normally associated with structural welds. In addition the lack of chemical control in the manufacture of these materials can result in high local segregation of the chemical constituents which can induce cracking notwithstanding that the stated precautions have been followed. For these reasons the amount of welding done is to be minimized to that which is essential and on no account shall the obsolete protective materials be incorporated as main structural members without the approval of DG Ships.

f. The following welding requirements in Clauses 12.2g. and 12.2h. supersede those contained in this NES for structural steel welding but in all other respects the requirements of this NES are to apply.

g. **Armour plating** Welding is to be performed only with the approval of DG Ships. Such approval will normally be limited to thicknesses not exceeding 75mm:

(1) **Non-cemented NC armour** Austenitic electrodes of the 18/8 type to BS 2926 are to be used with a minimum pre-heat temperature of 100° C. The area pre-heated to this temperature is to extend for a distance of 300mm in all directions and be maintained at that temperature during welding. The electrodes are to be treated as a hydrogen controlled electrode for the purpose of baking, holding in quivers etc; see Section 8.

(2) **Cemented C armour** Welding is not permitted.

(3) **Special qualities** Proposals to weld these materials are to be forwarded to DG Ships.

h. **Protective plating** Welding is to be performed only with the approval of DG Ships.

(1) Plating similar to NC armour is to be welded in accordance with Clause 12.2g.(1)

(2) **D1HT** Below a thickness of 10mm Class 6 hydrogen controlled electrodes approved for welding B quality steel are to be used. For thicknesses exceeding 10mm austenitic electrodes of the 18/8 type to BS 2926 are to be used. The minimum pre-heat temperature is to be 100° C.

(3) **UXWHT** There may be considerable variation in composition since the material was accepted only on a Brinell hardness value of 210 to 250, and for this reason greater care is required than for welding UXW steel. Electrodes approved for welding UXW steel are to be used and the degree of pre-heating is to be as shown in TABLE 12.2:

(4) **DKM and NMMQ** Austenitic electrodes of the 18/8 type to BS 2926 are to be used.

MATERIAL THICKNESS	MINIMUM PRE-HEAT TEMPERATURE
10mm	Not required unless ambient temperature is less than 5° C (see Clause 9.2d.).
10mm to 16mm	100° C
16mm and above	120° C

TABLE 12.2

12.3 Stud Welding

a. This is most undesirable on the obsolete protective materials and is not to be done without MOD(PE) approval; such approval will normally be limited to the capacitor discharge equipment. Stud welding on the current protective material will be permitted in accordance with the normal structural requirements for the material involved.

12.4 Non-Destructive Examination and Acceptance Standards

a. Non-destructive examination requirements and acceptance standards are to be in accordance with Clauses 17.3a., 17.3b. and 17.3c.

13. STUD WELDING

a. This section contains the instructions for stud welding to the structural materials shown in Clause 13.5a.

b. For the purpose of this NES the definition of stud welding contained in BS 499 Part 1 is to be used as quoted in Annex B.

c. The arcing time in machine stud welding is of a very short duration, generally a fraction of a second; thus the weld and HAZ is subjected to a rapid quench by the surrounding material, which can result in brittleness or cracking especially in the higher carbon or alloy steels. The application of pre-heat to reduce the rate of quench is a laborious operation and much higher pre-heat temperatures would be required relative to manual metal arc welding before any significant improvements are obtained.

d. In addition to the metallurgical effects, a welded stud forms a geometric discontinuity and is thus a potential crack starter. The resistance to initiation and propagation of cracks is a function of the toughness of the parent material and the depth of the HAZ. It is for these reasons that the use of welded studs, particularly in important parts of the structure, is to be restricted to an absolute minimum.

13.1 Stud Welding Categories

a. Stud welding is divided into two categories:

(1) **Permanent studs** Permanent studs may be welded by either standard or capacitor discharge equipment and by manual metal arc welding.

(2) **Temporary studs** Temporary studs are to be welded by capacitor discharge equipment except as permitted by Clause 7.18a.

b. Where manual metal arc welding of studs is done a high degree of care is necessary to avoid undercut and stray arcing. In such cases the full welding requirements of this NES are to be followed for the base material involved, ie pre-heat, heat-input measured by leg length, size etc.

13.2 Stud Materials

a. The studs are to be of mild steel for attachments to all structural steels unless otherwise stated on approved drawings. Studs for use on stainless steels or aluminium alloys are to be compatible with the base material.

13.3 Welding Procedures

a. Machine stud welding is to be permitted within the limits defined in Clause 13.5a. when approved by pre-production procedure and following written welding procedures in accordance with Section 3. and Section 4.

13.4 Welder Qualification

a. Welders employed on machine operated stud welding equipment are to be qualified in accordance with Section 3.

13.5 Applications

a. Stud welding may be specified to be used on the following materials within the limitations stated:

(1) **Mild steel** Permitted on all thicknesses.

(2) **A and B quality steel** Permitted on all thicknesses but wherever practical to be kept clear of stringer shear strakes, bilge or keel strakes by locating studs on the webs of frames. Temporary studs are not to be welded on the above members except when capacitor discharge equipment is used.

(3) **DW and S quality steels** Permitted on all thicknesses using capacitor discharge equipment and on thicknesses not exceeding 12mm with standard equipment.

(4) **D, D1 and D1HT quality steels** Only permitted when using capacitor discharge equipment.

(5) **UXW quality steel** Prohibited on submarine pressure hull plating except for temporary studs for pre-heat equipment etc when the capacitor discharge equipment is used. Permitted on webs of frames. Where it is not practicable to locate studs on webs of frames then studs may be welded to the frame table.

(6) **QT28 quality steel** To be kept to a minimum particularly on submarine pressure hulls. Where practicable studs are to be located on webs of framing or failing this on the frame tables. Temporary studs may only be welded by the capacitor discharge equipment.

(7) **Protective plating** This is most undesirable on the obsolete protective materials and is not to be done without MOD(PE) approval such approval will normally be limited to the capacitor discharge equipment. Stud welding on the current protective materials will be permitted in accordance with the normal structural requirements for the material involved; see Section 12. for details of material.

(8) **Stainless steel** Permitted on all austenitic stainless steels.

(9) **Aluminium alloys** Permitted on all thicknesses of N5, N5/6 and N8 alloys.

13.6 Stud Welding Requirements

a. Studs are to be welded on surfaces which are clean and free from surface contaminations. No pre-heat is required for machine stud welding unless the ambient temperature is less than 5° C. Where pre-heat is necessary the material is to be heated until warm and dry conditions are achieved. Surfaces in way of studs welded with standard equipment may be lightly countersunk to bright metal. Surfaces in way of studs welded with capacitor discharge equipment are to be lightly ground to bright metal; countersinking is not to be used as this will interfere with the functions of the ‘pip’ on the fusion end of the stud and thus prevent effective welding operations.

b. Prior to the commencement of each working shift or on recommencement of machine stud welding disrupted by other delays, a selection of studs is to be welded to scrap plate to ensure the welding conditions are correct. These studs are to be visually inspected and tested to destruction by hammering. Failure should occur in the stud or base plate and not through weld metal. Where failure occurs through the weld metal the cause is to be established and rectified and the test welds repeated until acceptable results are achieved.

c. It is important to ensure that the earth return lead is effective. This is particularly important for aluminium which is normally insulated from the surrounding structure.

d. Ceramic ferrules are to be used on all studs which exceed 6mm diameter because of the beneficial effect in controlling the arc, concentrating its heat and confining the molten metal to the weld area.

13.7 Removal of Temporary Studs or Redundant Studs

a. Care is to be taken in the removal of all studs. Temporary studs welded by the capacitor discharge process may be knocked off and the previous sites lightly ground. Temporary studs welded by standard equipment or permanent studs made redundant are to be removed by cutting above the parent material; the remaining stub is to be ground flush to the parent material. Defects, ‘pull outs’ gouges, undercut etc revealed by, or resulting from, such operations are to be faired out by grinding providing the depth does not exceed 0.75mm or 10% of the material thickness whichever is the smaller. Where the depth limitations will be exceeded, areas are to be excavated to a sufficient depth to remove all defects and the area rectified by welding in accordance with Section 12.

b. All such flushed areas, regardless of whether or not weld build up was made, are to be proven defect free by magnetic or dye penetrant inspection where the following are involved:

   (1) submarine structure subject to full diving pressure;

   (2) protective plating;

   (3) main structural members in B quality material, ie stringers, sheer, bilge or keel strakes in surface ships.

13.8 Non-destructive Examination and Acceptance Standards

a. Non-destructive examination requirements and acceptance standards are to be in accordance with Section 17.

14. REPAIR BY WELDING

a. This section contains the instructions and requirements for repair by welding of the structural steels, forgings or castings shown in Section 1. Groups 1, 2, 3 and 4, in the following situations.

(1) unacceptable defects in welded joints;

(2) unacceptable defects at sites of prior temporary attachments or stud welds;

(3) unacceptable defects in castings or forgings resulting from manufacturing operations. For repair welding in this category the requirements of Section 11. are to be read in conjunction with the requirements herein.

b. Repair by welding which involves Q1N, HY80 or QT35 steels are to be done in accordance with NES 770.

c. For rectification of surface areas by buttering see Section 15.

d. Repair by welding is more difficult than normal structural welding due to the high degree of restraint that can be present. It is therefore necessary to be more stringent in following the welding precautions which are aimed at minimizing the risk of hydrogen induced or weld metal contractional cracking. These precautions include baking and care of electrodes, pre-heat and heat input control. Due to the isolation of local weld repairs and the relatively small volume of weld metal, cooling rates may be rapid. It is therefore recommended that the welding is done near or at the maximum permitted heat input and that other precautions such as insulation, pre-heat continued after welding, are taken to reduce the cooling rate.

14.1 Rectification Requirements

a. Rectification of unacceptable weld metal or base material defects shall be repaired by welding in accordance with the following requirements:

(1) **Welded joints or defects at sites of prior temporary attachments or stud welds** DG Ships DG/10000;

(2) **Castings** DG Ships/PS/9010;

(3) **Forgings** The Inspecting Authority.

14.2 Welding Procedures

a. Repair by welding is to be done following written welding procedures produced for each repair type or group of repair types. These are to be approved by the Inspecting Authority before repairs are commenced except as stated in Clause 11.3b.

14.3 Welder Qualification

a. Welders employed on repair by welding are to be fully qualified in accordance with Section 3.

14.4 Welding Consumables

a. The welding consumables used for repair welding of weld metal defects are to be of the same classification as that used for the original weld unless otherwise approved by MOD, except that repairs to submerged arc and MIG welds may be done with MOD approved manual metal arc electrodes as shown in NES 769.

b. Welding consumables used for the repair of base material defects, other than weld metal or HAZ defects, are to be selected from those MOD approved manual metal arc electrodes noted as approved for the particular material involved and shown in NES 769. Where under normal circumstances welding consumables other than hydrogen controlled are specified for the material involved and sub-surface defects are to be repaired, then consideration is to be given to using welding consumables of the hydrogen controlled type; see Clause 9.1b.

14.5 Welding Conditions

a. The full welding requirements of this Standard regarding pre-heat, interpass control, heat input, electrode baking etc, are to be complied with during repair by welding. Each weld pass is to be deposited to produce the largest cross-sectional area within the heat input limits using the largest practicable electrode size. Where repair situations are located in areas of high restraint, eg repair of insert or penetration welds adjacent to other main structural welds, consideration is to be given to reduce the moisture content of the electrode to that normally required for welding Q1N material in accordance with NES 770. It is recommended that post-heat, to the same temperature as pre-heat, is continued for a period of 2 hours subsequent to repair by welding on submarine structure and where the base materials combined thickness exceeds 100mm. All repair welds are to be protected from inclement weather and be insulated to reduce the cooling rate. Where possible repair by welding is to be conducted as a continuous operation.

14.6 Location of Unacceptable Defects

a. Considerable care is to be taken in locating the position of unacceptable defects so that rectification action can be taken in the correct place, thus avoiding the additional re-welding necessary where defects are not completely removed at the first attempt. Difficulties may be experienced in deciding such defects. In these cases it is recommended that ultrasonic examination is used to assist in defect location.

14.7 Weld Repair Types

a. For the purpose of this section weld repairs are to be divided into the following categories:

(1) **Surface defects** which include scars and fabrication damage, sites of prior temporary attachments, stud welds or unacceptable undercut;

(2) **Sub-surface defects**

b. **Surface defects** Repair welding of undercut, sites of prior stud welds or temporary attachment surface scars, or surface cracking etc are to be limited to those areas which cannot be dressed smooth by grinding in accordance with DG Ships DG10000 or DG Ships/PS/9010. Where the dimensions of such defects are outside the limits for dressing then repair by welding is to be done. Surface defects are to be removed by grinding, pneumatic chipping, arc air gouging etc in such a manner as to leave a smooth consistent preparation for subsequent welding. Finished preparations are to be suitably examined to ensure defect removal. Weld repairs of surface defects are to be ground flush with the adjacent material, care being taken to prevent the occurrence of under buffing. Repair by welding of fabrication scars is to be done on completion of all fabrication operations.

c. **Sub-surface defects, non-lamellar type** The following information is applied for defects by welding where lamellar tearing is considered not to be a feature of the repair:

(1) The extent of the defective area is to be accurately located and access to the repair area improved as necessary. Thoroughly clean to bare metal the repair area and immediate vicinity.

(2) The defects are to be removed by pneumatic chipping, grinding or arc air gouging.

(3) Careful consideration is to be given to the manner in which excavation of defects is done to minimize the risk of defect propagation. Excavation of the defect is to commence in sound metal at the ends of the defect and proceed from each end towards the centre. Defects close to one another are to be treated as continuous for the purpose of repair.

(4) The extent of gouging is to be such that sufficient margin exists at each boundary to ensure the complete removal of defects. Under normal circumstances excavations to remove defects are to be cut from the side which will involve the minimum excavation depth. For repair by welding of defects associated with welded joints, excavations are not generally to be cut deeper than ½t + 6mm where t represents the thickness of the welded joint. Where, however, defects extend beyond these limits it will be necessary to seal off the defect by weld metal before back gouging from the opposite side. In such cases back gouging is to be sufficiently deep to completely remove the remaining defect.

(5) Excavations are to be finished smooth and terminate in well tapered ends, blending into existing welds where these are present. Completed excavations are to be crack detected to ensure defect removal. Where defects are sealed off for subsequent excavations, during back gouging, sealing welds are to be examined as above to ensure defect arrest.

(6) Repairs of defects are to be done by weld deposition sequences aimed at minimizing contractional stresses. Weld repair surfaces are to be blended into existing welds or base material without excessive reinforcement, and for repair of T butt welds the final profile is to be similar to that shown in Section 5. FIGURE 5.19.

d. **Sub-surface defects, lamellar type** Where repairs to, or in the vicinity of, T butt welds are involved and lamellar defects are evident the following repair technique, known as the ‘two stage buttering technique’ is to be used. It is recommended that this method is always used where full penetration T butt welds in B quality material is involved; the general principles will also be applicable to T welds or corner welds which are designed to be less than full penetration, ie partial penetration T butt welds or large fillet welds. The object of this procedure is to remove the defect from the passing member and to extend the excavation width beyond the final weld toe of the repair T butt weld. The resultant excavation is welded to the surface of the passing member before welding the T butt preparation. This is to ensure that the attachment weld is made on weld metal which is more capable than the passing material of withstanding the through-thickness loadings induced as a result of weld metal contraction.

(1) Improve access to the repair locality as necessary and thoroughly clean to bare metal the repair area and immediate vicinity.

(2) Care must be taken to accurately locate the defect by ultrasonic examination and where possible relate the resultant defect plot to a datum line for subsequent examination proving defect removal and checking final repair. The area examined is to extend for 300mm beyond the length limits at each end. From this information the excavation profile is to be determined. This should evolve a flat based excavation similar to that shown in FIGURE 14.1. The flat base is required to facilitate ultrasonic examination after excavation. The depth of the excavation into the passing member is to exceed the depth of the deepest defect by at least 3mm unless the depth will then exceed ½t + 6mm. Where defects extend beyond that limit then the defects may be sealed by welding and completely removed by back gouging from the opposite side to ensure a full penetration repair. A similar limit is to apply to excavation under the root of T butt welds, and where the defects cannot be removed from one side they are to be sealed by weld metal and removed as necessary by subsequent back gouging.

(3) Excavate defect from the side containing all or the majority of the defects. The use of arc air gouging or pneumatic chipping may increase the risk of defect propagation; where such increase is observed, grinding only is to be used. Commence excavation 75mm beyond the length limits by blending in from existing surface or weld profile and achieve maximum excavation depth within 75mm; continue excavation working towards the mid-position.

(4) The completed excavation is to be of smooth finish and well faired at the ends; where T butt welds are involved sufficient material shall be removed beyond the envisaged final weld repair toe to ensure that this toe is at least 12mm inside the buttered area; see FIGURE 14.2. Crack detect all surface areas of excavation and ultrasonically examine from side opposite the flat base to determine whether defect has been removed, or where part defect remains for removal by back gouging, check for defect propagation.

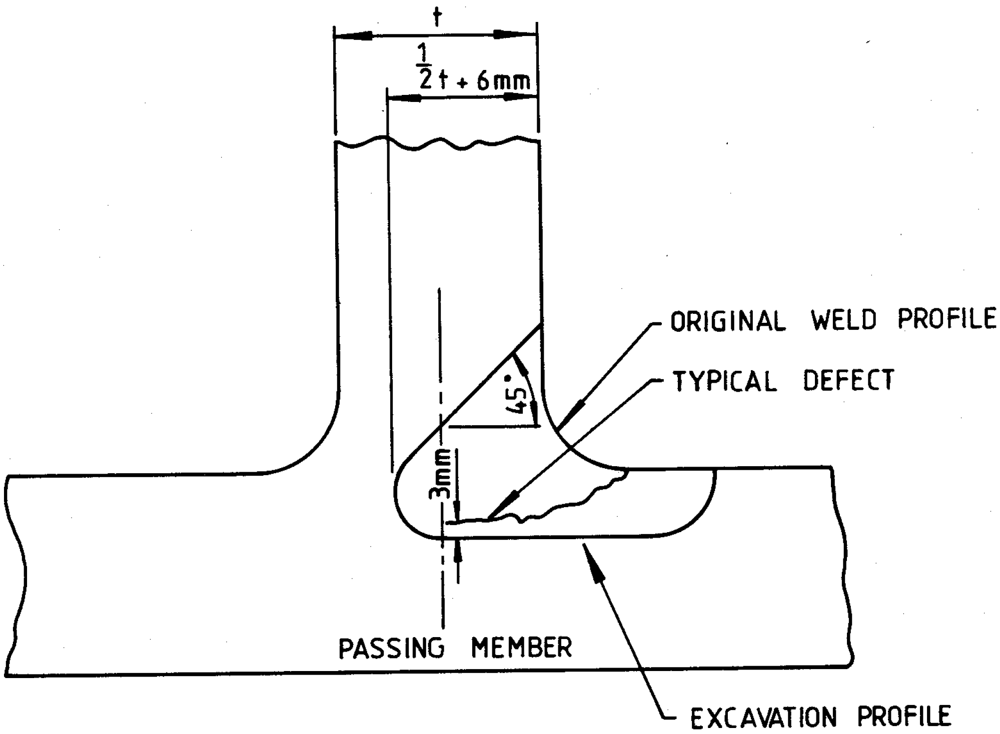


FIGURE 14.1

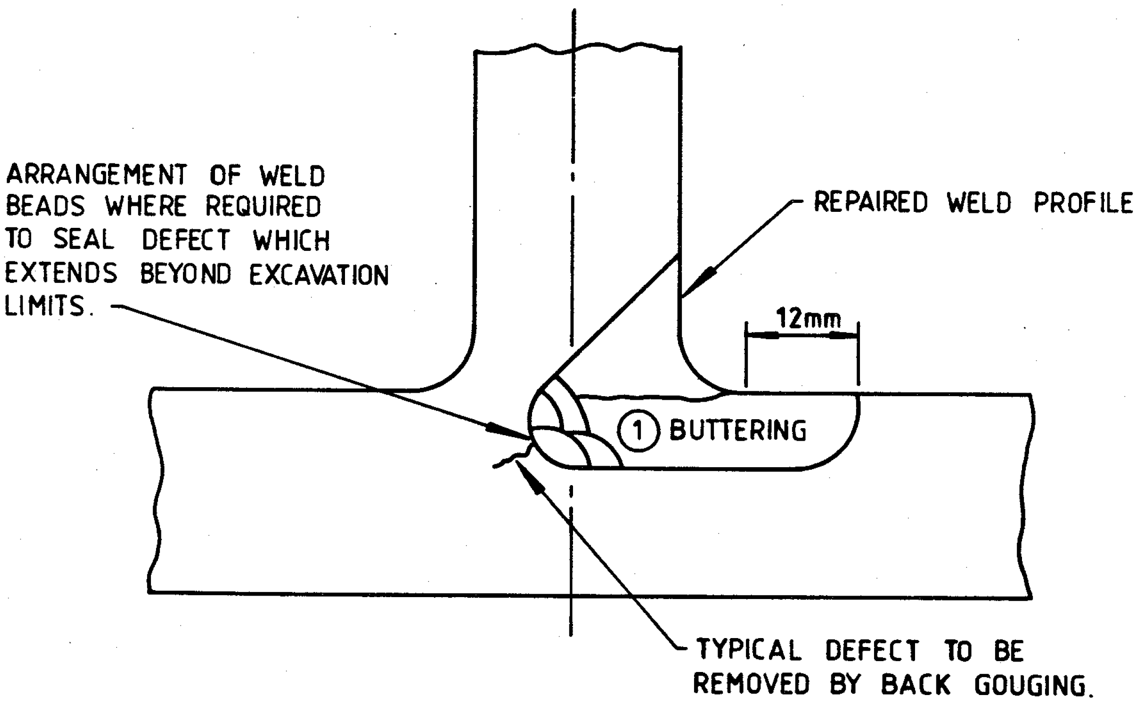


FIGURE 14.2

(5) Welding is to commence by seal welding the excavation ends and where defects are left in the root, for subsequent back gouging, these are to be welded with normally 3 or 4 runs and crack detected to ensure defect arrest. Welding is to continue by weld deposition sequences aimed at minimizing contractional stresses until flush with the passing member surface. Grind such weld surfaces and examine by crack detection and ultrasonics to ensure sound welding and that defect propagation has not occurred. The normal time delay before non-destructive testing may be waived for this 'in process' examination. If the above examinations are acceptable then the T butt weld may be completed in such a way that the final weld toe is at least 12mm in from the outer edge of the buttered position; see FIGURE 14.2. In cases where defects have been sealed, for removal by subsequent back gouging, it is recommended that only two thirds of the T butt weld is completed before back gouging.

(6) Where full penetration repairs are concerned the weld excavation and repair on the opposite side of the T butt are to be completed in a similar manner. Care is to be taken that the excavation completely removes the sealed defect. If all 'in process' examinations are satisfactory then the buttering weld may be completed and if acceptable by crack detection and ultrasonics the T butt weld may be completed. On completion the remaining portion of the T butt on the opposite side may be welded.

14.8 Non-destructive Examination and Acceptance Standards

a. Non-destructive examination requirements and acceptance standards are to be in accordance with Section 17.

15. RENOVATION BY WELDING OF PITTED PLATING, SHAFT BRACKETS, HYDROPLANES ETC

a. This section contains the instructions and requirements for repair by welding of pitted or corroded hull plating, shaft brackets, rudders, hydroplanes etc. These requirements apply to the structural steels, forgings or castings shown in Section 1. Group 1, 2, 3 and 4. The general principles are also to be followed in rectification of pitted or corroded areas on Q1N, HY80 or QT35, except that the actual welding is to follow the requirements of NES 770.

b. Details of other situations and materials, with corrosion or wear damage, eg hydroplane or rudder shaft, operating rods etc which are thought to be suitable for weld repair are to be forwarded to DG Ships for advice and approval.

c. There are several problems associated with renovation of pitted or corroded areas by weld reinforcement. It is relatively easy to restore the surface of a member with weld metal but the structure and the chemical composition of the reinforcement will not be the same as the original material. In addition welding will introduce stresses into the material. The differences in composition and stress levels may result in accelerated corrosion subsequent to such repairs. There is also a danger that cracking of parent material may result from such operations; the risk of cracking is particularly high on the obsolete steels, castings and forgings which may have high carbon equivalents and high sulphur contents. Reinforcements shall therefore only be contemplated where it is absolutely essential to restore the original thickness of the material and where it is uneconomic or impracticable to replace with new material.

15.1 Applications

a. For the purpose of this section applications and repair limitations are divided into the following groups in Clauses 15.1b., 15.1c. and 15.1d.:

b. **Submarine structure subjected to full diving or containment pressure:**

DGSM will provide guidance on the maximum allowable pitting or wastage for each class of submarine.

c. **Submarine structure not subject to full diving or containment pressure and surface ship structure including rudder or stabiliser fin plating** Reinforcement by welding may be done as necessary at the discretion of the Inspecting Authority, but where the rate or extent of corrosion or erosion is considered excessive full details are to be forwarded to DG Ships for decision on what is to be done. Reinforcement by welding is not permitted on D or D1 quality steels which exceed 25mm in thickness.

d. **Cast or forged steel 'A' brackets, see tubes etc** Deep pitting and heavy wastage is to be repaired at the discretion of the Inspecting Authority. In general isolated pitting which is 4.5mm or less in depth, and as a temporary measure only, deeper pitting and heavy wastage may be suppressed by the application of Araldite. Repair welding of components which have been weld metal clad or metal sleeved to obtain improved corrosion/hard facing resistance is only to be permitted with specific approval of DG Ships.

15.2 Welding Procedures

a. Written welding procedures are to be produced in accordance with the requirements of Section 4. These are to be approved by the Inspecting Authority prior to repair by welding.

15.3 Welder Qualification

a. Welder qualification is to be in accordance with the requirements of Section 3., except for welders employed on Q1N, HY80, QT35, or for materials whose CE exceeds 0.7, who shall be fully qualified in accordance with NES 770.

15.4 Welding Consumables

a. The welding consumables used for reinforcement of pitted or wasted areas are to be selected from those MOD(PE) approved welding consumables noted as approved in NES 769 for the particular material involved.

15.5 Preparation of Surface for Weld Reinforcement

a. The area to be welded is to be thoroughly cleaned of all rust, scale, paint and other contaminates. The material surface is to be ground or chipped so that no abrupt discontinuity exists that may give rise to defects in the subsequent weld. In particular edges of pits are to be ground to a smooth contour to give easy entry and exit for the weld passes and to ensure full access to the root of the penetration. Suitable NDT examination is to be made of the weld reinforcement area to ensure that no defects exist in the locality which may propagate as a result of welding. QT35, QT28 and thick B quality material contain lamellar type defects, while castings may contain areas of shrinkage, blow holes, slag etc. Where such defects exist in the near vicinity they are to be removed and the area weld repaired in accordance with Section 14.; where defects exist but cannot easily be excavated and incorporated into the reinforcement area the advice of DG Ships is to be sought.

15.6 Welding Conditions

a. The full welding requirements of this NES regarding pre-heat, interpass control, heat input, electrode baking etc are to be complied with during reinforcement welding. Each weld pass is to be deposited to produce the largest cross-sectional area within the heat input limits using the largest practicable electrode size. Welding is to be protected from inclement weather and precautions taken to provide slow cooling conditions after welding is completed.

15.7 Welding Technique

a. In general weld sequence is to be evolved to minimize the resultant residual stress and minimize the cooling rate. Weld passes are not to be less than 75mm in length and repair by puddling, ie weaving the electrode over and around the point to be repaired is prohibited. Adjacent weld passes are to overlap by up to 50% to reduce the risk of heavy weld metal dilution.

15.8 Surface Finishing of the Reinforced Area

a. On completion of welding the repaired area is to be visually inspected for adequate reinforcement and the absence of undercutting, defects being made good as necessary. When satisfactory the weld reinforcement is to be flushed smooth so as to completely remove the weld bead indentations. The final thickness of plate and reinforcement is not to be less than the original design thickness and not greater than 10% more than the original design thickness. The reinforcement at its periphery is to be carefully blended into the parent plate by grinding. In addition for an area extending about 25mm away from the repair, the parent material itself is to be lightly ground to bright material; every care is to be taken to ensure only a minimum amount of metal is removed.

15.9 Non-destructive Examination and Acceptance Standards

a. Non-destructive examination requirements and acceptance standards are to be in accordance with Section 17.

16. WELDING AND FABRICATION OF ALUMINIUM ALLOYS

a. This section contains the requirements for fabrication and welding of the aluminium alloys approved for structural work.

16.1 Materials

a. Wrought aluminium alloys are grouped into two classes viz: non-heat treatable and heat treatable alloys.

b. **Non-heat treatable alloys:**

(1) Non-heat treatable alloys contain magnesium as the principal alloying element and can be supplied in the as-manufactured condition (M), in the soft or annealed condition (O), or in various degrees of strain hardening (H1 to H8).

(2) These alloys have maximum ductility and minimum tensile strength in the annealed condition and as the degree of strain hardening is increased by cold work the ductility is reduced but the tensile strength is increased.

(3) The strain hardened alloys can be satisfactorily welded but the heat affected zone of the parent plate is reduced in strength to that of the annealed condition.

c. **Heat treatable alloys:**

(1) Heat treatable alloys contain copper, magnesium, silicon and manganese as the main alloying elements, the presence of which, after appropriate heat treatment, gives rise to an increase in strength. Of the six alloys covered by British Standards 1470 to 1475, only two, ie H9 and H30, are suitable for use under marine conditions; the remainder, having copper contents in excess of 0.1%, are susceptible to corrosion.

(2) Welding of these alloys for structural purposes is not normally permitted, as the weld thermal cycle reduces the mechanical properties of the base material to that of the annealed condition.

d. **Approved materials:**

(1) The approved materials for structural work are:

Plate, sheet and strip	BS 1470−NS8
Bars, extruded round the tube and sections	BS 1474−NE8

(2) The materials may be obtained in the M, O or H conditions. The British Standards only specify mechanical properties for the O and H conditions. In the M condition the material acquires some temper from shaping processes in which there is no special control over thermal treatment or amount of strain hardening. Manufacturers may be willing to supply material in the M condition to agreed minimum mechanical properties which are acceptable to the designer; otherwise the O or H conditions are to be specified.

(3) The formerly approved structural aluminium alloys N5 and N6 which may be encountered on existing vessels are to be welded in accordance with the requirements of this section.

(4) Details of chemical compositions and mechanical properties are shown in Section 1. Group 7.

(5) The use of other aluminium alloys may be specified for special applications. Where such alloys are to be used fabrication details are to be stated on the relevant drawings or documents. If welding is involved, details of proposed procedures are to be submitted to MOD DG Ships for approval before production is commenced.

16.2 Welding

a. The major obstacle to welding aluminium alloys is the highly refractory surface oxide film which has a melting point exceeding 2000° C while the material melting point is within the range 580 to 630° C. For welding to be possible the oxide film must be removed by chemical or electrical means assisted by preliminary wire brushing. Oxide removal by chemical means in the form of a flux is employed in oxy-acetylene and metal arc welding but the resultant welds are of such poor quality and low strength that these processes are not approved for structural welding. In addition the flux residuals are extremely corrosive and must be thoroughly removed after welding by vigorous washing in hot water, access to both sides of the joint being essential. Oxide removal by electrical action induced by TIG or MIG welding is more effective and promotes sound welding without the risk of subsequent corrosion.

16.3 Welding Processes

a. For the reasons stated in Clause 16.2a. oxy-acetylene and manual metal arc welding processes are only to be used for work of minor importance or when necessary for essential emergency repairs. The attachment of temporary or permanent fittings of ship structure is not to be regarded as of minor importance.

For all other work the tungsten arc (TIG) or inert-gas metal arc (MIG) processes are to be used except for machine stud welding which may be done in accordance with Section 13. General information regarding TIG and MIG processes is contained in BS 3019 Part 1 and BS 3571 Part 1 respectively.

16.4 Welder Qualification

a. Welder qualification is to be in accordance with Section 3.

16.5 Weld Procedures

a. Written welding procedures are to be produced in accordance with the requirements of Section 4. Where pre-production procedure testing is required then general information etc on conducting such tests is contained in BS 3451.

16.6 Welding Consumables

a. The shielding gas used for TIG and MIG welding is to be Argon. Proposals to use other gases or gas mixtures are to be forwarded to the Inspecting Authority for approval.

b. The welding wire to be used for N8 aluminium alloy is to be NG61: BS 2901; this wire is also suitable for N5, N5/6 and N6 aluminium alloys.

c. For TIG welding it is recommended that the tungsten electrode alloyed with zirconium be used. The addition of zirconium increases the electron emission thus giving better arc striking and arc re-ignition with consequential improved arc stability particularly at low currents. Zirconated tungsten electrodes are specifically designed for ac welding and provide longer life than pure tungsten electrodes. They will carry higher currents and are less likely to give tungsten inclusions in the weld. In preparation tungsten electrodes for ac welding the electrode end is to be pre-chamfered, with a silicon-carbide grinding wheel, at an angle of about 45°, leaving a blunt point of a diameter about half that of the electrode. The size of the tungsten electrode is to be chosen according to the welding current used. Table 5 of BS 3019 gives guidance on such sizes.

d. **Care of welding consumables** Welding wires are to be stored in their wrappings and cartons in a dry atmosphere of even temperature. Partly used reels are to be returned to their cartons and similarly stored. Lengths of filler wire for tungsten arc welding must be thoroughly cleaned with wire wool to give a bright appearance free from grease and surface corrosion. Where degreasing is required the requirements of Clause 16.11a. are to apply.

16.7 Preparation of Materials

a. Plate edges and weld preparation are to be produced by the following methods:

(1) plasma arc cutting;

(2) tungsten arc;

(3) mechanical means, including shearing, planing, milling, sawing or pneumatic chipping without the use of lubrication oil. Grinding by abrasive discs is to be avoided but may be permitted using tungsten burrs. Band saws and circular saws are to be of the skip-tooth type. Care must be taken to avoid the use of tools contaminated by other metals particularly copper or brass. Shearing is normally to be limited to material 6mm thick or less; sheared edges are to be subsequently machined or filed smooth.

b. Prepared edges must be smooth and free from burrs, distortions or other irregularities which may interfere with the attainment of the requisite weld acceptance standard.

16.8 Fabrication

a. Fabrication and erection operations are generally similar to steel work, but are considerably affected by the lighter weight of structure and assemblies, by the greater flexibility of the members and by the larger dimensional changes, about three times that of steel, due to variations in temperature.

b. Aluminium lends itself to high standards of workmanship. During erection the structure must be securely braced using temporary stiffening as necessary.

c. Marking out techniques are similar to those for steel work except that, where subsequent welding is involved, paint, chalk, graphite or other contaminations used for marking must be removed from the fusion areas.

d. Aluminium alloy structures are to be pre-fabricated in order that the maximum amount of welding can be carried out in fabrication shops under favourable conditions. The work is to be arranged so that the maximum amount of welding is done in the flat position.

e. The use of backing bars (temporary) or backing strips (permanent) may be essential especially on thin material. The arrangement of butt joints to fall on other structural members to form a backing strip is to be encouraged as this practice promotes the production of sound porosity free welds and can reduce distortion.

f. Backing bars are to conform with the dimensions shown in Tables 31, 32 and 35 of BS Code of Practice CP 118 and may be made of mild steel, stainless steel or copper and are to be maintained in a clean condition, free from grease, dirt, moisture and rust. Backing strips are generally to be of the same composition as the parent material and are to be continuously fillet welded at the edges. Typical examples of backing strips are shown in Tables 33 and 36 of BS Code of Practice CP 118.

g. Where backing bars or strips are not used then back gouging will be necessary for full penetration welds and is to follow the requirements of Clauses 9.12a. to 9.12c. and 9.12e. but excluding all reference to arc air gouging.

16.9 Joint Design

a. The requirements for each type of joint, ie full penetration butt, T butt, prepared fillet etc, are to be in accordance with the contract documents. Fabricators are to select suitable joint configurations from the undermentioned documents after careful consideration of the various recommendations contained in:

BS 3019 Part 1—TIG;

BS 3571 Part 1—MIG;

BS Code of Practice 118.

b. Structural drawings are to show the size and type of each welded joint. Great care must be taken to ensure that welds are continuous around attachment fittings, brackets, and ends of structural members etc. Intermittent welding is not to be used for work of structural importance because it is liable to suffer from crater cracking and stop-and-start porosity. It may be permitted on work of no structural importance but the preferred method is to use sub-size fillet welds in accordance with Clause 5.12d. Where it is necessary for scallops to be used then care is to be taken at the weld ends to ensure continuous welds at their junctions.

16.10 Erection and Assembly

a. The general requirements of Section 7. regarding the following aspects are to be observed:

(1) dimensional accuracy;

(2) strongbacks;

(3) temporary attachments;

(4) misalignment.

b. Backing bars and strips are to be in close contact with the material along their entire length. Tacking on a more extensive scale than is necessary for steel welding is essential and for material up to 3mm thick spacing should be 50 to 70mm and 100 to 150mm for TIG and MIG welding respectively. For thicker material 50mm tack welds at 225 to 300mm intervals are to be sufficient for MIG welding with about half the spacing for TIG welds. Where material exceeding 4.5mm thick is tack welded, the tack welds are to fully fuse the root face and sides of the '**v**' to a depth of at least $^2/_3$ of the metal thickness.

c. Particular care is to be taken in the welding of temporary attachments and tack welds due to the tendency for crater cracking to occur at stop/start positions. Welding is to be continuous around temporary attachments. Removal and subsequent dressing of temporary fittings are to be done by pneumatic chipping or grinding discs followed by dressing flush by grinding. Such grinding discs are to be made from aluminous oxide and are not to be contaminated by other materials. Prior sites of temporary attachments are to be visually examined to ensure freedom from surface defects or undercut. Tack welds must be either chipped or ground smooth at the ends to facilitate their incorporation in the weld or completely removed if their presence is likely to cause defects in the weld.

16.11 Condition of Fusion Faces

a. The fusion faces of weld joints are to be free from grease, dirt, moisture and excessive oxide film, immediately before welding. This is to be achieved by scratch brushing preceded where necessary by degreasing and/or pickling. In multi-run welds scratch brushing is necessary between runs. Scratch brushing is to be done with mechanical or manual brushes. Stainless steel wire brushes are considered the most suitable; such brushes are not to have been used on other materials. Where degreasing or pickling is used the operations are to be conducted in accordance with BS 3571 Part 1. If the parent material has been painted, anodized or chemically treated, the edges close to the weld and earthing point must be thoroughly cleaned and degreased.

16.12 Weather Conditions

a. Welds are not to be made on wet surfaces. During inclement weather, and especially during periods of high winds, the welder and the work are to be effectively protected. Draughts may break the gas shield, resulting in porous or oxide-covered welds. Simple shields may be used close to the prepared surfaces, eg by laying pieces of angle on each side of the joint in the case of a flat butt weld. Precautions are to be taken to avoid condensation in the inert-gas passages of the welding equipment because this may cause porous welds.

16.13 Pre-heating

a. Although pre-heating is generally unnecessary, it may be needed where the weld is to be made on thick material or where there is a difference in thickness between the two parts to be joined; in such cases pre-heating is to be to the thicker part. The pre-heat temperature is to be sufficient to ensure good fusion between the weld and the parent metal. Where a backing bar or strip is used, local pre-heating may also be required in order to avoid a cold start or in order to remove moisture. In general the application and measurement of pre-heat are to be in accordance with Section 9. The selection of pre-heat temperature, where considered necessary, will depend on the welding process, thickness of material, configuration of the joint and the ambient temperature. For most structural applications a pre-heat temperature of up to 60° C will be sufficient. Pre-heating within the range of 60° C to 240° C is prohibited as heating within this temperature range can impair the corrosion resistance of the joint and base materials. Where special cases of thick material are involved which necessitate a higher pre-heat temperature then this must be controlled above 240° C.

16.14 Electrode Wire Sizes, Welding Conditions and Gas Shield Flow Rates

a. The selection of electrode wire sizes, related welding conditions and argon flow rates are to follow the recommendations of the appropriate sections/tables of BS 3019 for TIG welding and BS 3571 for MIG welding. The use of stringer bead deposition is recommended in multi-pass fillet welds to avoid undercut and concave weld profiles. In TIG welding, to avoid tungsten spatter on the work, the arc is to be struck either on a separate piece of the same material to that being welded or on a carbon block, and the electrode is to be brought to its working temperature before the actual weld is started. Run on and off plates are recommended where possible to avoid crater cracking at the beginnings and ends of welds made with the MIG process. The use of electrical welding start/stop devices are permitted so long as the weld quality is acceptable. A pre- and post-weld purge of argon gas is recommended to ensure adequate shielding from atmospheric contamination at start/stop positions. To minimize the risk of porosity and to obtain maximum penetration with minimum spatter, the visible arc length is to be between 4.5mm and 6mm in MIG welding. This is achieved by using the shortest arc which does not make a crackling sound.

16.15 Weld Repair of Weld Defects

a. Rectification of unacceptable weld metal or base material defects are to be repaired by welding in accordance with the requirements of DG Ships/G/10000. Repair welding is to be done following written welding procedures produced for each repair type or group of repair types. These are to be approved by the Inspecting Authority before repairs are commenced.

b. Considerable care is to be taken in locating the position of unacceptable defects by use of the appropriate NDT method so that rectification action can be taken in the correct place thus avoiding the additional re-welding necessary where defects are not completely removed at the first attempt.

c. The defective area is to be removed by pneumatic chipping or grinding with tungsten burrs, and the faces of the resultant groove are to have an included angle of not less than 60° and are to have a generously rounded root so as to encourage the deposition of a sound, properly fused weld. The groove is to be continued for a minimum of 25mm beyond each end of the defective area and is to be gently scalloped out at the extremities.

d. The repair excavation is to be cleaned and degreased as required by Clause 16.11a. before welding commences.

e. It is recommended that the repair welding is started a short distance, say 25mm, before the start of the excavation and finished a similar distance beyond the end of the excavation. Weld repaired surfaces are to be blended into existing welds or base material without excessive reinforcement; grinding is to be used at start stop positions to remove excessive build up.

16.16 Non-Destructive Examination and Acceptance Standards

a. Non-destructive examination and acceptance standards are to be in accordance with Section 17. except that the normal method is to be radiographic and dye penetrant examination. Special requirements may, however, require the use of ultrasonic examination; in such case, procedures will be evolved in conjunction with, and approved by, DG Ships.

16.17 Shaping and Forming of Plate and Sections

a. Shaping and forming of plate and sections or plate and sections containing welds will be permitted for the N8 aluminium alloys subject to the procedure being approved by the Inspecting Authority. Pre-production tests are to be done which prove that the proposed operations can be done without detriment to the material. Any piece that cracks or fractures because of forming operations are to be rejected. The Inspecting Authority is to have the right to require mechanical testing of pre-production procedure tests to establish that the material properties are in accordance with the appropriate BS specified properties.

b. Fabricators experienced in MOD work with structural aluminium alloys may offer this experience as proof that they have established satisfactory working procedures and that the pre-production testing required by Clause 16.17a. need not be done. The acceptance of such evidence is to rest with the Inspecting Authority.

c. In all forming operations allowance must be made for the considerably greater spring back of aluminium alloys as compared with steel. Every effort is to be made when forming aluminium alloys to ease the material round slowly. Attempts to form these alloys quickly frequently results in cracking. Sharp edged forming tools are to be avoided for the same reasons; radii of forming tools are to be smooth and bend areas of parts are to be free of centre punch marks, scratches etc. All edge burrs are to be removed by filing or grinding before shaping or forming. Owing to the low hardness values of aluminium alloys the surfaces will be more sensitive to blows and scoring than steel surfaces and extra care is necessary in cleaning the tools and machines used in forming operations.

d. **Cold and hot working** The following information in Clauses 16.17e. to 16.18a. inclusive is provided for guidance to fabricators in evolving procedures referred to in Clause 16.17a.

e. **Cold working (Plates)** The normal method of cold forming or shaping is to be by rolling. Pressing may be permitted when done with well radiused smooth tools. In general cold bending of NS8 plate is to have internal radii of bends not less than 1½ to 2T for material up to 6mm thick, and not less than 3T for material over 6mm thick. Where possible forming or shaping is to be carried out perpendicular to the direction of rolling. Shaping and forming by hot working are to be done where satisfactory cold working is not possible or where the internal radii is less than stated above.

f. **Cold working (Sections)** Small sections or bars with little curvature may be formed by cold working but high curvature and heavy sections will require hot work to enable forming to be successful. No definite recommendations of minimum bend radii can be given. These are best determined by procedural testing.

g. **Hot working (plates and sections)**

(1) Heat treatment and hot forming or shaping of the heat treatable aluminium alloys is not permitted without specific MOD(PE) approval.

(2) **Hot working operations** The preferred method for heating of aluminium alloys is by controlled furnace. The working temperature is to be between 450° C and 500° C overheating must be avoided as a high risk of melting will occur where temperatures exceed 550° C. Heating and cooling through the temperature range 60° C to 240° C are to be as rapid as practicable to avoid impairing the material’s corrosion resistance. Where facilities for furnace heating are not available a continuous process of local heating is permitted. Prior to hot working operations the material is to be free from oil, grease, zinc, lead, tin and copper, substances which contain these materials or elements, or other low melting point constituents. Subsequent to hot working the component is to be cooled in still air. It is to be noted that the temperature of aluminium alloys, unlike steel, cannot be judged by sight. During hot working operations the temperature is to be measured by ‘Tempilstiks’ or contact pyrometers.

(3) **Control of heat treatment furnaces** Accurate control of furnace temperatures, within the vicinity of the item being heated, to within ±10° C is necessary during all operations. Temperature measuring equipment is to be provided to indicate the temperature of the item. The temperature of the item is to be the average of the observed temperatures at different locations. When it can be demonstrated that the temperature of the item can be maintained within the required range by controlling the furnace temperature then the average of the pyrometer readings will be accepted. Autographic records are to be made of all heat treatment operations.

(4) **Local heating** Local heating is to be done with coal, oxy-acetylene or propane gas torches. Braziers must not be used for this purpose due to the lack of temperature control. With local torch heating a ‘soft’ flame is to be used and it is essential that the flame is kept moving over a length of about 460mm. At each pass the torch is to be drawn across the bar in small increments until the entire width is covered. Heating is to commence on the thickest part.

(5) **Cold and hot working of weldments (containing welds)** Cold and hot working of weldments containing welds is permitted as for plate sections. All weld reinforcement is to be removed by grinding or machining; where possible such operations are to be at right angles to the axis of the bend.

16.18 Inspection Requirements for Shaped or Formed Materials

a. All surfaces subjected to shaping or forming are to be visually inspected; in addition, welds and HAZ are to be crack-detected. Surfaces so examined are to be smooth, free from indentations, 'orange peel' appearance, cracks or crack-like indications or surface flaking. Significant thinning, more than 10% t or 3mm, whichever is less, of material, in particular in the weld HAZ, is to be cause for rejection.

17. NON-DESTRUCTIVE EXAMINATION OF WELDS

a. This section defines the requirements for non-destructive examination and the appropriate acceptance standards for all production welding within the scope fo this NES. Annex E. contains technical information regarding the various defect types, their causes and significance. Guidance to designers regarding the extent of non-destructive examination and the appropriate acceptance standard for structural welds is contained in DG Ships/G/10000.

17.1 Methods

a. The methods of carrying out non-destructive examination are to be in accordance with NES 729 except for stud welds which shall be examined as defined in Clause 17.5a. Radiography is only to be carried out under the conditions prescribed in accordance with BR 3020. Background information concerning the principals and application of the various non-destructive examination methods is contained in BR 3925.

17.2 Time Delay and Extent of Non-destructive Examination

a. Sufficient time must be allowed between the completion of welding and commencement of non-destructive examination to reduce the risk of delayed cracking, hydrogen induced, remaining undetected in welded joints or weld repairs. In addition the risk of cracking occurring in existing welds in the vicinity of new or repair welding cannot be ignored. To minimize the possibility of such defects remaining undetected the following requirements are to be adopted:

(1) **Time Delay** All welds are to be examined:

(a) after a minimum time delay of 24 hours; or

(b) when the weld area has reached ambient temperature, whichever of the two is the greater time lapse.

The delay period is to be measured from the time when the welding and, where applicable, post-heat treatments have discontinued.

(2) **Extent of Non-destructive Examination** All existing welds within a distance of 150mm are to be visually examined at the same time for surface cracking with the exception of existing weld repairs involving lamellar tearing which are to be examined by both ultrasonic and surface crack detection methods when located within a distance of 300mm from new welding.

17.3 Structural Welds

a. The minimum requirements for the extent of non-destructive examinations will be defined in the Contract Documents.

b. The acceptance standard is to be in accordance with the contract document. Where the acceptance standard is not so stated then the appropriate standard in DG Ships/G/10000 is to apply.

c. Where vessels are being modified or refitted then the welding is to be examined to the same degree and to the same extent as required by Clauses 17.3a. and 17.3b. Where doubt exists DG Ships is to be consulted.

17.4 Welded Inserts and Penetrations

a. The contractual requirements will be as shown in Clauses 17.3a. and 17.3b.; the general requirements are, however, shown in TABLE 17.1 and TABLE 17.2 for guidance to refitting establishments:

<table>
<tr><th>VESSEL</th><th>WELDED ITEM</th><th>RADIOGRAPHY</th><th>ULTRASONIC</th><th>CRACK DETECTION</th></tr>
<tr><td rowspan="4">NUCLEAR SUBMARINES</td><td>Inserts</td><td>100%</td><td>100%</td><td>100%</td></tr>
<tr><td>Penetrations</td><td>–</td><td>100%</td><td>100%</td></tr>
<tr><td>Frames—web to hull or insert</td><td>–</td><td>100%</td><td>100%</td></tr>
<tr><td>Frames—web and table butts</td><td>100%</td><td>100%</td><td>100%</td></tr>
<tr><td rowspan="6">CONVENTIONAL SUBMARINES</td><td>Small inserts</td><td>100%</td><td>100%</td><td>100%</td></tr>
<tr><td>Penetrations</td><td>–</td><td>100%</td><td>100%</td></tr>
<tr><td rowspan="3">Large inserts where the long dimension exceeds 1.2m</td><td>At each corner and at any Tee junction</td><td rowspan="3">100%</td><td rowspan="3">–</td></tr>
<tr><td>At 0.9m intervals at the sides</td></tr>
<tr><td>In areas where ultrasonic methods have located defect indication</td></tr>
<tr><td>Frames—web to hull or insert and web butts</td><td>–</td><td>–</td><td>100%</td></tr>
<tr><td rowspan="3">SURFACE SHIPS</td><td>Small inserts</td><td>100%</td><td>–</td><td>–</td></tr>
<tr><td rowspan="2">Large inserts</td><td>At each corner and at any Tee junction</td><td rowspan="2">–</td><td rowspan="2">–</td></tr>
<tr><td>At one intermediate position on any dimension exceeding 3.65m</td></tr>
<tr><td colspan="5">NOTE: Special requirements may arise when 100% examination of inserts is required for large inserts in surface ships.</td></tr>
</table>

TABLE 17.1 NON-DESTRUCTIVE EXAMINATIONS

VESSEL	ACCEPTANCE STANDARD
NUCLEAR AND CONVENTIONAL SUBMARINES	Class I
SURFACE SHIPS	Class II

TABLE 17.2 ACCEPTANCE STANDARD FOR RADIOGRAPHY

17.5 Stud Welding

a. The non-destructive examination requirements and acceptance standard for welded studs are to be in accordance with the following:

(1) **MMA welds** Visual inspection must show an even weld deposit free from undercut, porosity and cracks.

(2) **Machine welded studs**

(a) **Visual inspection** Must indicate that the entire cross-section of the stud is fixed to the base material and the stud is not situated in a deep crater.

(b) **Bend test** Approximately 5% of all studs are to be tested by bending to an angle of 15° and returning with a device similar to that shown in FIGURE 17.1. If failure occurs in this test, stud welding is to be stopped and all studs welded under similar conditions are to be tested and the conditions causing failure rectified.

17.6 Repair by Welding

a. The non-destructive examination requirements and acceptance standards are to be in accordance with Clause 17.3c. except that repair welds are to be examined 100% by the appropriate methods. Thus the requirements of Clause 17.2a.(1) will apply to all repair welds.

17.7 Renovation by Welding of Pitted Plating, Shaft Brackets, Hydroplanes etc

a. **For submarine structure which is subjected to full diving or containment pressure:**

(1) The ground smooth area (see Clause 15.8a.) comprising the repair area and the adjacent plate is to be examined by crack detection and ultrasonic methods. All unacceptable defects are to be repaired.

(2) The area is to be 100% crack detected and all defects are to be evaluated and repaired in accordance with NES 729 and DG Ships/G/10000.

(3) The area is to be 100% ultrasonically examined in accordance with DG Ships/PS/902. The deposited welding will be acceptable provided it does not show multiple reflections from the reinforcement interface or internal defects equal to or greater than the ultrasonic reference standard quoted in NES 729.

b. **For structure other than above** Ultrasonic and crack detection is to be done at the discretion of the Inspecting Authority.

c. **For shaft brackets, rudders and hydroplanes** 100% crack detection.

17.8 Weld Metal Cladding

a. The non-destructive examination requirements and acceptance standards are to be stated on each weld procedure. Guidance on the general requirements for such applications are contained in Clause 18.16a.

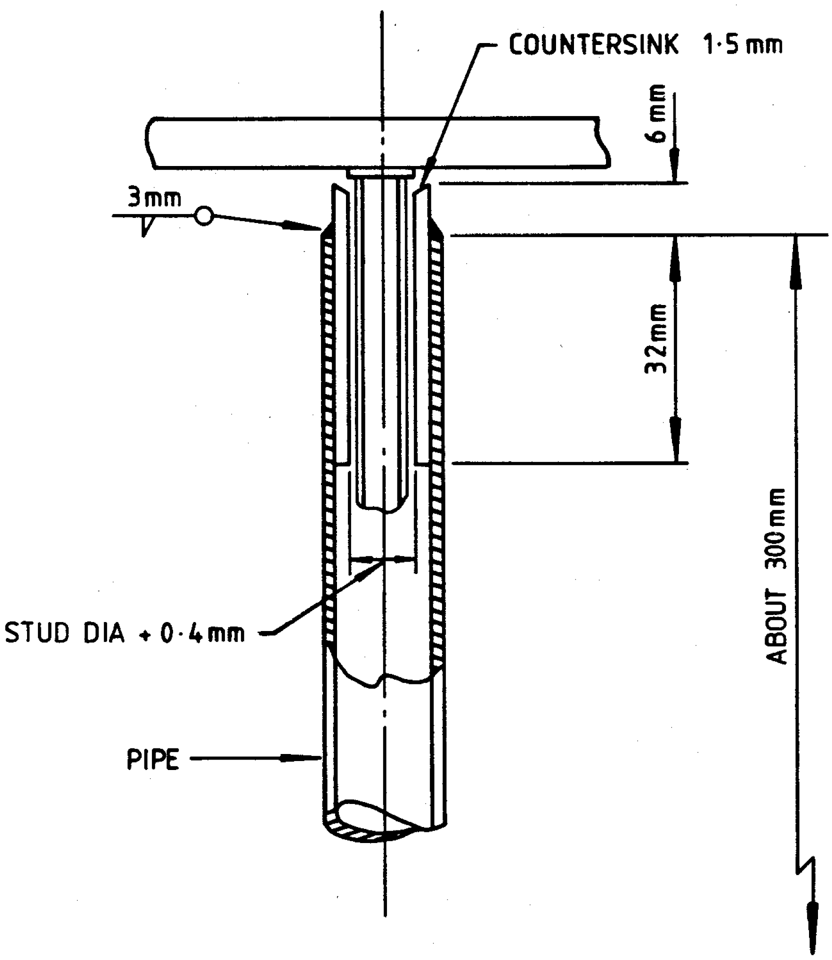


FIGURE 17.1 DEVICE FOR TESTING WELDED STUDS

18. METAL CLADDING

a. This section contains information and instructions regarding the protection of materials covered by this NES against corrosion or wear by the use of metal cladding.

b. Cladding with corrosion or wear resistant materials is used for the protection of vulnerable areas of certain components where the design requirements demand structural strength and long life, or where cladding of a structural material provides an economic advantage.

c. Cladding is also used to provide material compatibility between non-ferrous fittings and ferrous structures, eg nickel aluminium bronze hull connections to submarine pressure hull inserts.

18.1 Areas of Application and Cladding Materials

a. Areas to be clad will be specified in the relevant contract documents.

b. Typical areas currently protected by cladding and the cladding materials used both current and retrospective are shown in TABLE 18.1. The retrospective situation is given to aid those concerned with the repair of existing clad components to emphasize the need for care in establishing the clad and base material concerned. Where positive identification of the materials cannot be achieved by reference to drawings, weld history sheets or other certified documentation a chemical analysis shall be undertaken prior to any repair action.

c. The selection of the cladding material will depend on the primary requirements for corrosion or wear resistance or a combination of both coupled with galvanic compatibility with adjacent materials and back-up systems.

18.2 Base Materials

a. Various base materials may be involved in cladding operations including the current MOD(PE) structural steels in the wrought, forged or cast form. In view of the different base materials which may be involved in cladding operations it is essential for material identification to be established before cladding or cladding repairs are attempted.

b. Rudder stocks, stabilizer and hydroplane operating shafts may be made from a wide range of forged or cast steels, eg BS 970−826940 (EN 26). Other situations require the cladding of steel sleeves which are subsequently shrunk on to the stocks or shafts to be protected.

c. Whilst the primary object of cladding is to provide corrosion/wear resistance such operations must not be undertaken if the process has an adverse effect on the base material properties.

Typical areas clad	Purpose	Cladding Material	
		Current	Historic
Submarines			
Pressure hull hatch coamings and cover seals	Corrosion and wear	Inconel 625/112 (Ni 62%, Cr 22%, Mo 9%, Nb 3.6%)	Deloro Stellite Alloy 'C'; Rockweld Nickel 'C'. 25/20 Stainless Steel.
Pressure hull 'O' seals in hull penetrations, valves and glands	Corrosion	Inconel 625/112	25/20 or 25/15 Stainless Steel.
Bores and faces of hull penetrations in way of Ni Al Br valves	Corrosion	Monel 60/190 Ni 70%, Cu 30%	–
Internal surfaces of cast steel hull valves	Corrosion	Monel 60/190	–
Torpedo tube bow caps, rear doors, flap valves, 'O' ring seals to tube flanges etc	Corrosion and wear	Inconel 625/112	Deloro Stellite Alloy 'C'; Rockweld Nickel 'C'. 25/20 Stainless Steel.
Hydroplane shafts and bearings, operating shafts, pins etc	Corrosion	Deloro Stellite 306 (Ni 5%, Cr 25%, Co balance)	Deloro Stellite Alloy 6.
Rudder stock sleeves, liners and bearings	Corrosion	Deloro Stellite 306	–
Surface Ships			
Rudder stock sleeves, liners and bearings	Corrosion and wear	Deloro Stellite 306	–
Sea tubes	Corrosion	Cu Ni liners	

TABLE 18.1

18.3 Cladding Techniques

a. Clad materials may be secured to the base materials by the following methods:

(1) **Mechanical bond**

Limited to circular shafts or components where either a cast sleeve is shrunk fitted or a weld cladded ferritic sleeve is used for the same purpose.

(2) **Mechanical seal**

Lining or sleeving internal surfaces of bores or external surfaces of penetrations with wrought material or tubes followed by seal welding at the edges. Where wrought materials are formed the resulting seams are welded either as a separate weld during manufacture or as a cladding weld penetrating to structural material during fitting.

(3) **Weld deposition**

The majority of cladding is achieved by fusion welding processes. TABLE 18.2 shows the MOD(PE) approved welding processes for each cladding material.

(4) **Explosion bonding**

The use of this technique is subject to agreement between the fabricator and MOD(PE).

CLADDING MATERIAL	APPROVED WELDING PROCESSES
Monel 70 Ni/30 Cu 60/190	Automatic pulsed MIG/Argon, MMA, TIG/Argon.
Stainless steel 25/20	MMA
Stainless steel 25/15	MIG/Argon, MMA, TIG/Argon
Deloro Stellite Alloy ‘C’	MMA, TIG/Argon, Submerged arc
Deloro Stellite Alloy 306	Auto TIG/Argon, Submerged arc
Deloro Stellite Alloy 6	Auto TIG/Argon
Inconel 625	MIG/Argon, auto TIG/Argon
Inconel 112	MMA

TABLE 18.2

18.4 Fabricator’s Approval

a. Before undertaking production cladding each fabricator is to submit for approval full details of his proposed cladding method and procedures complete with test results. The proposals must aim at achieving weld soundness bond and preservation of the base metal properties. The tests shall include:

(1) hardness plots from the base material through the heat affected zone and cladding which is to be taken from a sectioned specimen;

(2) longitudinal and transverse macroscopic and microscopic examination of sections;

(3) photomacrograph ¢ 10 of sections;

(4) transverse and longitudinal through section side bends: two off, each;

(5) chemical analysis of final machined surface;

(6) non-destructive examination in accordance with Clause 18.16a.

The chemical analysis is not to exceed the requirements of Clause 18.6d. and the acceptance standard for NDE shall be in accordance with Clauses 18.17a.−18.17c.

b. It is the fabricator’s responsibility to evolve the welding procedure from mandatory welding requirements for the base material concerned, using specified cladding requirements and data obtained from pre-production procedural tests.

c. Where the base material is HY 80, Q1N, QT 35, BS 970−826940 (EN 26), similar quenched and tempered steels or has a carbon equivalent exceeding 0.7, the requirements of NES 770 are to apply for written weld procedures and welding parameters. The requirements of NES 706 are to be followed for the steels within the scope of this NES.

18.5 Welder Qualification

a. Production cladding shall be done by qualified welders following approved welding procedures. Where the base material involves HY 80, Q1N, QT 35, BS 970−826940 (EN 26), similar quenched and tempered steels or base materials with a CE exceeding 0.7, then the welders shall be qualified in accordance with NES 770. The qualifying requirements of NES 706 Section 3. are to be invoked for steels within the scope of this NES.

18.6 Technical Requirements

a. Preparation of fusion faces. The area to be clad is to be machined to the specified depth and degree of finish to facilitate cladding to the required thickness. All changes in section shall be smooth transition and corners or recesses shall have a minimum radius of 6mm.

b. Pre-clad examination:

(1) Surface. Prior to weld deposition or bonding, fusion faces shall be examined by dye penetrant or magnetic particle techniques to ensure that the surface is free from crack type defects and that any surface porosity is within the acceptance standard for that material.

(2) Sub-surface. Ultrasonic examination of clad areas is to be carried out on materials susceptible to lamellar tearing to confirm that the base material is sound. Typical susceptible materials are MS, B quality steels, QT 35 and QT 28.

c. Deposit thickness and iron content. The stipulated deposit thickness must be established to ensure that the chemical composition at the final machined clad surface is such that the corrosion/wear resistance is not reduced as a result of iron dilution from the base material.

d. The permitted total iron content at the final machined clad surface must not exceed the following:

Monel	3%
Stellite Alloy ‘C’	14%
Stellite Alloy 306	12%
Stellite Alloy 6	10%
Stainless Steel	Minimum of two layers to be deposited
Inconel 625/112	12%.

e. Practice has shown that it is usually necessary to deposit at least two layers of weld metal, the final machined surface being located in the second layer for the iron content to be kept below the maximum.

f. Where fabricators can demonstrate that the specified iron content can be achieved with one run using low dilution techniques, then approval will be considered by MOD(PE) for that procedure.

18.7 Welding Cleanliness

a. A high degree of care is required to obtain satisfactory weld deposits. Areas to be welded and at least 25mm each side of the weld edges are to be clean, free from oil, grease, paint, rust or other contamination.

b. Grease or oil is to be removed by acetone or similar degreasing agent. Other contamination, ie oxide, rust etc, is to be removed by stainless steel wire brush or aluminium oxide grinding disc. Such implements are not to have been used on other cladding or ferritic materials.

18.8 Welding Consumables

a. The care and storage of welding consumables is to allow the requirements of Section 8. MMA electrodes are to be baked at 150° C for 30 minutes prior to issue and shall be held in heated quivers. Unheated quivers containing silica gel may be used if a daily check is made on the effectiveness of the silica gel. The issue of electrodes is not to exceed the welder’s requirements for the ensuing shift.

b. Lengths of filler wire for TIG welding or cold filler additions must be thoroughly cleaned and where necessary degreased in accordance with Clause 16.6d.

c. Submerged arc fluxes are to be stored under similar conditions to MMA electrodes and baked at 150° C for 30 minutes prior to issue; only sufficient flux is to be issued to welders for the ensuing shift.

d. Submerged arc flux which is reclaimed and filtered to remove slag, dust and other inclusions may be mixed with a minimum of 25% of the original quantity, eg ¼ addition of new flux, and continue to be used so long as the weldability characteristics remain acceptable.

18.9 Welding Conditions

a. In general welding conditions, ie arc volts, current, polarity etc, are to be in accordance with the electrode manufacturer's recommendations except that the heat input shall be within the limits specified for the base material involved.

b. Particular care is required to effectively secure the earth return leads, especially for components which are revolved during weld cladding. Problems of 'arc blow' may be met when welding with dc; this phenomenon may be difficult to resolve and may need some experimenting before the best position for securing the earth return lead is established.

c. Arc ignition may be improved when using MMA electrodes by incorporating a high frequency current into the electrode circuit.

18.10 Deposition Techniques

a. The heat input used must be within the range for the particular base material involved, but is to be as low as possible within the recommended current range to minimise dilution. In addition the first two layers are to be deposited such that each bead of each layer overlaps the previous adjacent bead by between $^1/_3$ and ½ of its width.

b. There are various other low dilution techniques which may be employed to reduce the iron content and risk of cracking, such as cold filler wire additions, oscillating TIG/MIG automatic processes, in addition to pulsed arc welding.

c. Where the base material is HY 80, Q1N, QT 35, BS 970−826940 (EN 26), similar quenched and tempered steels or has a CE exceeding 0.7, the weld bead deposition technique described in NES 770 is to be used at the edges of all cladding.

d. Where possible, run-on and run-off plates are recommended to avoid weld crater defects and to allow the arc to stabilize. A pre- and post-gas purge is recommended for gas shielded processes to ensure adequate protection from atmospheric contamination at start/stop positions. This is essential when run-on run-off plates cannot be used and the weld stops and starts are included in the completed clad weldment. In order to eliminate or minimize weld crater defects the welder/operator is to ensure that the crater is filled and where possible the level of the current is reduced slowly before finally breaking the arc. HF arc initiation procedures are recommended for TIG welding.

e. It may be found beneficial to fit a gas dryer in the supply lines of gas shielded processes to minimize weld metal porosity. Gas supply lines are to be regularly checked for leaks to prevent atmospheric contamination.

18.11 Pre-heat and Interpass Temperature

a. When weld cladding or seal welding liners or sleeves in HY 80, Q1N, QT 35, BS 970−82640 (EN 26), similar quenched and tempered steels or steels with a CE above 0.7, the pre-heat and interpass temperature requirements and methods of measurement shall be in accordance with NES 770 except that after two layers of weld metal have been deposited and if no further weld metal is to be deposited directly onto the base material then the pre-heat may be reduced to 60° C and the interpass temperature increased to 250° C.

b. For other base materials the pre-heat and interpass temperature and methods of measurement are to be in accordance with Section 9. with a corresponding reduction of 50% in pre-heat temperature after the deposition of two weld layers.

c. The methods of pre-heating are to be in accordance with the above respective standards. In circumstances where pre-heating cannot be done by electrical means then gas burners may be used, the flame being neutral or reduced in the reactor and kept moving over the whole of the work area to insure uniform heating.

18.12 Distortion

a. Deposition sequences are to be evolved to minimize the degree of distortion and residual stresses. It may be necessary to use strongbacks to assist in controlling distortion.

b. Where possible strongbacks or other holding devices are to be secured by mechanical means. Where, however, it is necessary to use welded strongbacks it is essential that the securing welds are sufficiently strong and that welding is in accordance with the requirements of this Standard or NES 770 depending on the base material.

18.13 Interrun Cleaning

a. Each weld run is to be effectively de-slagged with clean stainless steel wire brushes, chipping hammers etc. Slag traps, stop/start positions and all weld bead irregularities are to be ground smooth with tungsten burrs, aluminium oxide grinding wheels or other approved processes. The above implements shall not be used on ferritic materials. For surfaces to be dye penetrant examined, light grinding is recommended.

b. Where Monel is involved or the configuration induces high stresses it is recommended that on completion of each weld layer the weld surface is lightly ground and examined by dye penetrant to ensure freedom from cracking prior to depositing the next layer.

c. All dye must be removed with solvent prior to welding local repairs or depositing the next layer.

18.14 Finished Deposits

a. Finished weld deposits are to be examined to ensure a reasonable uniform contour without depressions which could prevent the attainment of the correct thickness of cladding after final machining and that the specified dimensions can be achieved after final machining.

18.15 Rectification of Weld Defects

a. Unacceptable weld metal defects are to be effectively removed by grinding with tungsten burrs or aluminium oxide discs, except for isolated surface porosity which may be locally repaired by TIG welding with or without filler wire additions. Local repair without the addition of filler wire is to be subject to the attainment of the required cladding thickness after final machining.

b. Excavations are to be sufficiently long to permit the achievement of stable arc conditions during repair welding; the excavation ends are to be tapered into the existing sound cladding. Finished excavations are to be checked by dye penetrant examination to ensure defects have been removed.

c. The conditions for repair welding are to be the same as those used during initial deposition in respect of pre-weld cleaning, pre-heat, interpass temperature, deposition techniques etc.

d. The welding process employed is where possible to be the same as that used for the original deposition. Where this is impracticable other welding processes may be employed so long as the fabricator has demonstrated his ability in the pre-production procedure tests with the particular process involved. The welding consumables used must be of the same type except where the TIG process is used for local repairs when the use of lengths of MIG wire or submerged arc wire will be permitted.

e. Where it is necessary for excavations to be made into the base material by more than 10% or 6mm whichever is the greater of the base material thickness then MOD(PE) is to be consulted before proceeding with repair action. Where, however, defect removal is achieved by penetrating the base material by less than 10% or 6mm whichever is the smaller the excavation may be completely rectified by the cladding material.

f. The repair weld surface is to be proud of the existing clad surface and subsequently machined flush.

g. Weld repairs which do not penetrate to the base material are to be examined by dye penetrant and meet the acceptance standard of Clause 18.17b.

h. Weld repairs which penetrate the base material shall be examined by dye penetrant and ultrasonic methods and meet the acceptance standard of Clauses 18.17b. and 18.17c. on completion of welding after final machining and repaired area shall again be examined by dye penetrant and meet the acceptance standard of Clause 18.17b.

18.16 Non-Destructive Examinations

a. The following non-destructive examinations are to be carried out in accordance with NES 729.

(1) Careful visual examination on completion of each weld run and prior to

(2) deposition of each weld bead.

(3) Dye penetrant of the first weld layer where cladding material is Monel or where the configuration will result in high restraint.

(4) Dye penetrant and ultrasonic examination of all clad surfaces after initial rough machining of final layer.

(5) Dye penetrant of all clad surfaces on completion of final machining.

18.17 Acceptance Standards

a. **Visual examination** In accordance with DG Ships/G/10000.

b. **Dye penetrant** In accordance with DG Ships/G/10000.

c. **Ultrasonic** In accordance with DG Ships/G/10000 except that having established the ultrasonic reference standard as defined in NES 729 rejection will be based on defects which show indications in excess of 80% FSD.

ANNEX A.

RELATED DOCUMENTS

A.1 Reference is made to:

		Referred to in Clause
BS 499	Welding, brazing and thermal cutting glossary	6.1a., 13.b.
BS 638	Arc welding plant, equipment and accessories	2.4d.
BS 970	Wrought steels in the form of blooms, billets, bars and forgings	TABLE 1.1
BS 1449; Part 2	Stainless and heat resisting steel plate, sheet and strip	TABLE 1.1, 12.1a.
BS 1470	Wrought aluminium and aluminium alloys. Plate, sheet and strip	TABLE 1.1, 12.1a., 16.1c., 16.1d.
BS 1474	Wrought aluminium and aluminium alloys. Bars, extruded round tube and sections	TABLE 1.1, 16.1c., 16.1d.
BS 1504	Steel Castings for Pressure Purposes	TABLE 1.1
BS 2901	Filler rods and wires for gas-shielded arc welding	16.6b.
BS 2926	Chromium-nickel austenitic and chromium steel electrodes for manual metal-arc welding	12.2g., 12.2h.
BS 3019; Part 1	General recommendations for manual inert-gas tungsten-arc welding. Wrought aluminium, aluminium alloys and magnesium alloys	16.3a., 16.6c., 16.9a., 16.14a.
BS 3451	Methods of testing fusion welds in aluminium and aluminium alloys	16.5a.
BS 3571; Part 1	General recommendations for manual inert-gas metal-arc welding. Aluminium and aluminium alloys	16.3a., 16.9a., 16.11a., 16.14a.
BS 4105	Liquid carbon dioxide, industrial	9.1c.
BS4360	Specification for Weldable Structural Steels	TABLE 1.1
BS CP.118	The structural use of aluminium	16.8f., 16.9a.
MIL−S−16216 (Ships)	Steel plate alloy, structural, high yield strength (HY80 and HY 100)	TABLE 12.1
NES 729	Requirements for Non-Destructive Examination Methods	7.12b., 7.19a., 9.13d., 10.7b., 11.3e., 15.1b., 17.1a., 17.7a., 18.16a., 18.17c.
NES 736	Requirements for Q1 (Navy) Quality Steel	TABLE 1.1

NES 769	Welding consumables for structural steels approval systems	4.a., 4.b., 4.2b., 4.2c., 5.1a., 5.6a., 7.8b., 7.8d., 7.13c., 8.2a., 9.1a., 9.1c., 9.7a., 9.7c., 11.1f., 14.4a., 14.4b., 15.4a., C.8i., D.3c., D.4b., FIGURE 5.7, FIGURE 5.10, FIGURE 5.13, FIGURE 5.14, FIGURE 5.15, FIGURE 5.17, TABLE 8.1
NES 770	Welding and fabrication of Q1N HY80 and QT35 steels	Foreword 2., 3.a., 10.7c., 10.9a., 12.1b., 12.2d., 14.b., 14.5a., 15.a., 15.3a., 18.4c., 18.5a., 18.10c., 18.11a., C.3g., F.5c.
NES 791 Pt 1	Requirement for Weldable Structural Steel Part 1: Mild Steel—Plate, Sections and Bars	TABLE 1.1
DG SHIPS 322	B Quality Steel Plates	TABLE 1.1
DG SHIPS/PS 9010 *(NES 745)	Classification, inspection requirements and acceptance standards for steel and copper based alloy castings	11.3a., 11.3b., 11.3d., 11.3f., 14.1a., 14.7b.
DG SHIPS/G/ 10000 *(NES 773)	Minimum acceptance standards for welded joints in HM Ships and Submarines	5.2(2), 7.19a., 9.13d., 14.1a., 14.7b., 16.15a., 17.a., 17.3b., TABLE 17.2, 17.7a., 18.17a., 18.17b., 18.17c., E.1a.
DG SHIPS 86 *(NES 793)	Ultrasonic acceptance standards for QT28, QT35 and Navy Q1 steels	7.12a., 10.7a.
ADSPEC 1100	General carbon steel forgings	9.1a., TABLE 1.1, FIGURE 7.6
BR 3020	Instructions for radiological protection HM Ships and MOD(N) Units and Establishments	17.1a.
BR 3925	Aids to maintenance, non-destructive inspection methods and equipment	17.1a.

NOTE: *In course of preparation. When published will supersede the related document.

DG SHIPS 137	Thickness measurement of Q1N and similar quality steel plates	7.12b.
DG SHIPS 346	Steel Plate Alloy QT28 quality	TABLE 1.1
DG SHIPS 1207	Mild Steel plates, sections and bars	12.1a., TABLE 1.1
DG SHIPS 1257	B Quality steel plates and sections	7.12a., 12.1a.
DG SHIPS 8081	Carbon steel castings	TABLE 1.1, 9.1a.
DNC/S26	UXW Quality, Steel 'T' sections	TABLE 1.1

ANNEX B.

DEFINITIONS AND ABBREVIATIONS

Fabricator	The term fabricator is to be used to define the Firm, Company, Organization, Establishment or Naval Base working within the scope of this NES.
Inspecting Authority	The term Inspecting Authority is to be used to define those MOD(PE) personnel engaged in ensuring that requirements of this NES are being met by the fabricator.
Insert plates	Inserts required for blanking holes after the removal of redundant equipment, for closing up after the shipping of equipment, for repairs, or for providing additional strength in way of access openings, are to be referred to as insert plates. Such insert plates are to be the same thickness or slightly thicker than the adjacent plating.
Insert pads	Inserts required to facilitate securing of pipe systems, electrical cables or operating gear passing through the hull are to be referred to as insert pads. These will be thicker than the hull plating but tapered at the edges to or near the thickness of the adjacent plating. Castings or forgings which are flanged to provide a welding preparation which is of a similar thickness to the adjacent plating are to be treated as insert pads.
Through penetrations	Those penetrations, ie hatch coamings, torpedo tube sleeves etc, which effectively pass through the plating to form a full penetration T butt joint.
Frame	The term ‘frame’ is to be used to describe those structural members which abut inserts and may be frames, stiffeners, decks, flats or bulkheads.
Stud Welding	The attachment of a stud, or other suitably shaped part, to a metal surface by the production of a weld over the whole of the area of the stud.

ANNEX C.

WELDABILITY OF FERRITIC MATERIALS

C.1 General

a. Weldability, which is defined as the ease of making welded connections free from defects and of adequate strength, depend principally on:

(1) composition of the steel;

(2) amount of hydrogen introduced during welding;

(3) the stress/strain system produced by the degree of restraint within the structure;

(4) the rate of cooling;

(5) the mechanical properties of the deposited weld metal in relation to the parent plate.

b. The tendency to the formation of cracks both in the weld metal and the heat affected zone (HAZ) is the main factor to be considered. A steel of good weldability is one in which, in normal thicknesses, no cracking will occur when using normal methods of welding procedure without pre-heat or other special precautions.

C.2 Cracking

a. Cracking in the weld metal and parent plate can be defined as hot or cold according to the temperature range in which it occurs.

C.3 Hot Cracks

a. Hot cracks or tears, as the name implies, are formed at temperatures above 1000° C. Such fractures are intergranular (at the grain boundaries) and the broken faces are recognizable by the blue tinge appearance caused by oxidation at the formation temperature. These cracks are usually found at weld centre line but may be found in the transverse plane.

b. To examine the mechanism of this type of cracking it is necessary to consider the solidification of the weldpool. FIGURE C.1 shows the solidification pattern of a bead on plate weld. The solidification path in the form of columnar grain growth from the fusion boundary results in growth towards the weld centre line.

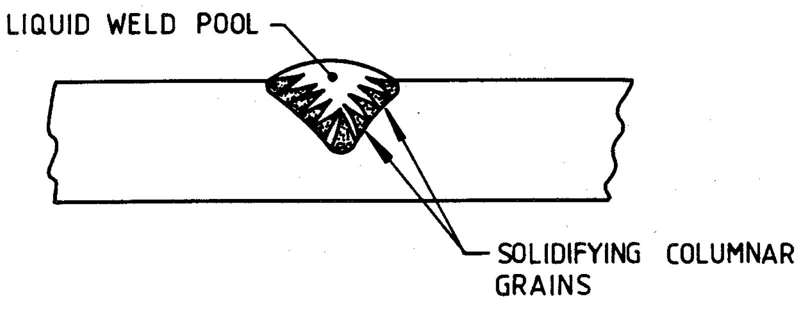


FIGURE C.1

c. Grains from opposite fusion faces of the weldpool and the base therefore terminate at the centre of the weld. The formation of columnar grains by dendrites and early formed crystals are low in carbon (Fe has a higher melting point). Solidification continues with low melting point constituents, such as S and P, being held in the liquid state and finally pushed to the weld middle line causing less ductility. Normal contraction stresses can be sufficient to strain these areas until voids or parting of the grain boundaries causes the birth of a hot crack. Alternatively, segregation of this nature may cause the formation of brittle grain boundary films resulting in loss of ductility and even cracking at lower temperatures.

d. From the above it can be seen that the root causes are: solidification pattern, amount of grain boundary low melting point constituents and/or carbon. For these reasons welding consumables are produced from very low carbon material with S and P kept to a minimum. Mn is beneficial due to the affinity that S has for Mn which combines to form Mn-sulphides, thus ‘balling up’ the liquid films into spheroidal particles which are well distributed in the weld pool and become relatively harmless. A rough guide to the degree of Mn required is that it should be 35 times the S content. In addition the use of weld deposition techniques which minimize the dilution factor, ie the weldpool pick up from parent plate, will assist in avoiding hot cracking in materials with high C and S contents.

e. Steels and, of course, welding consumables developed after DW quality have, by better steel making practice, closer chemical control and heat treatment practices, become almost immune to massive hot cracking of the type described.

f. The above remarks are most pertinent to weld metal but the parent material in the immediate vicinity will liquefy and adjacent to this, in the HAZ, temperatures in excess of some low melting point constituents can occur. This can be aggravated by high welding heat inputs. Hence hot tears can form in a similar manner to that described above; the question of further propagation is related to many variables but in general terms will be a function of the cleanness of the material and degree of local stress. While hot tears are confined to the microscale they do not constitute a significant problem.

g. Hot cracking will not normally occur in welding the current MOD(PE) structural steels where the requirements of this standard of NES 770 are followed. Care is however needed in welding the obsolete steels, castings and forgings.

C.4 Cold Cracks

a. Cold cracks generally occur below 300° C. Two crack types can be defined under the heading of cold cracks: stress induced and hydrogen induced. The former type can occur in isolation while the latter is, for the most part, dependent on the combined effects of both hydrogen and stress.

b. **Stress induced:**

(1) Contraction of weld metal during solidification and subsequent cooling can produce stresses of sufficient magnitude to cause weld metal failure. These cracks may occur as a result of low ductility or grain boundaries or be transgranular in nature as a result of the contractional stress exceeding the capability of the weld metal. The tendency for such cracks increases where the geometry is as shown in FIGURE C.2 with small cross-sectional area root runs and either bad initial ‘fit up’ or existing high structural residual stresses.

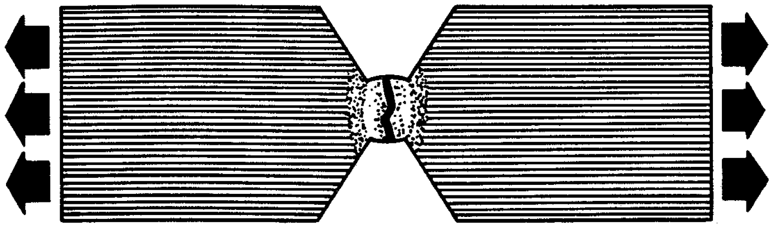


FIGURE C.2

c. The crack will normally be longitudinal and follow the weld centre line; in high strength weld metal, however, transverse root run cracks may also be found. The cause of the high strength failures is not fully understood but may well be hydrogen induced. The precautions to overcome contractional cracking is to ensure reasonable sized root runs are deposited, by adopting the block technique to provide an even larger root cross-section, by balanced sequence of welding and good fit up. The order of assembly should be aimed at allowing each joint to shrink as freely as possible and thus allow weld metal contraction to take place without undue plastic strain. The above precautions will also assist in minimizing the risk of the high strength transverse cracking.

d. **Hydrogen induced:**

(1) One of the most important crack types found in welded joints is known as hydrogen induced or hard zone cracks. Such cracks will not usually occur above 300° C and often appear several hours or days after completion of welding. These cracks may be encountered in weld metal or the HAZ. Typical crack sites are shown in FIGURE C.3.

(a) **Weld metal** Weld metal hydrogen induced cracking is less well understood than HAZ hydrogen cracking. However, the principal cause in addition to hydrogen appears to be a function of the weld metal strength. In the higher strength weld metals large longitudinal tensile stresses are produced as a result of weld contraction. In the presence of hydrogen transverse cracking can occur. Longitudinal cracking may occur in a similar manner where the degree of restraint and contractional stresses are of sufficient magnitude.

(b) **HAZ** The effect of the weld thermal cycle is to produce a HAZ in the parent material, adjacent to the weld, that is harder and less ductile than the unaffected parent material. This in itself may be unacceptable but if enough hydrogen is trapped in the area with residual stresses then hydrogen induced cracking may occur. This form of cracking tends to follow the fusion line.

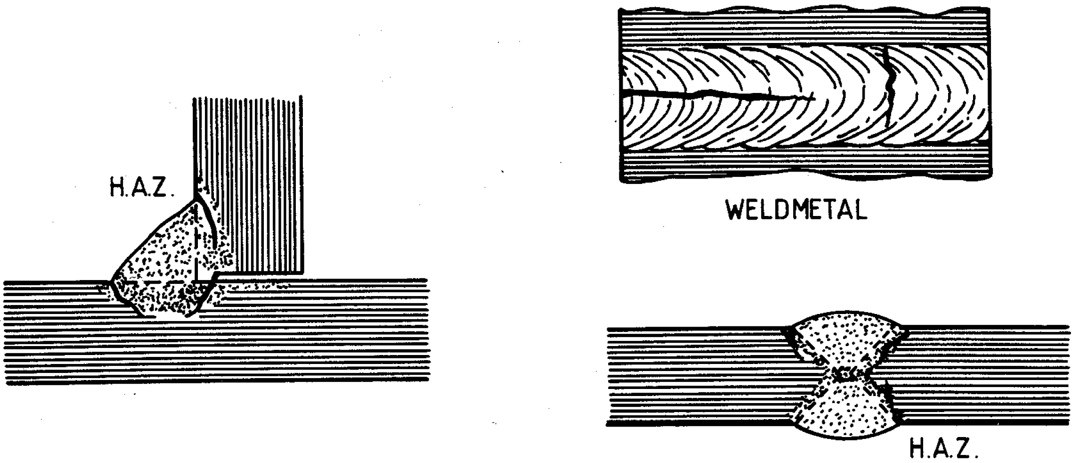


FIGURE C.3 TYPICAL CRACK SITES

(2) The following factors are responsible for hydrogen cracking and the control of these features will prevent cracking of this type:

(a) hydrogen;

(b) the degree of stress in the joint, ie the residual stress due to welding and the stress due to initial restraint;

(c) the crack susceptibility of the micro structure, produced in the HAZ by the composition of the steel and its rate of cooling; produced in the weld metal as a function of strength.

C.5 Hydrogen

a. It is important to understand the principles of hydrogen ingress so that this can be related to the other variables associated with hydrogen induced cracking.

b. The solubility of hydrogen in steel at ambient temperature is very low; this increases as the temperature is raised and for the same temperature is more soluble in Austenite than in transformed products. Thus the welding cycle, at elevated temperatures, facilitates the rapid ingress of hydrogen.

c. Hydrogen can be introduced into the weld by several modes.

d. Water vapour will, as a result of the heat from the welding arc, transform into atomic hydrogen. Water vapour can be picked up from:

(1) rain or humidity of the atmosphere;

(2) dirt, rust etc held in edge preparations;

(3) electrode coating, fluxes and shielding gases.

e. Assuming efficient pre-weld cleaning is done the main source of hydrogen comes from that inherent in the electrode coating, fluxes or shielding gases, and humidity absorbed from the surroundings.

f. The solubility drops during solidification cooling and markedly on transforming from Austenite. In addition only small amounts of hydrogen are needed to depress the end of the austenite transformation temperature, the final transformation taking place at about 300° C. Under rapid cooling rates insufficient time will be available for hydrogen to diffuse, thus a supersaturated solution results in the weld and HAZ. Given sufficient time the hydrogen will diffuse from the weld and HAZ until equilibrium conditions are restored. However, where a susceptible micro structure exists with residual stress the excessive hydrogen present can lead to spontaneous cracking as shown in FIGURE C.3.

C.6 The Degree of Stress in the Joint

a. Residual stresses, in a particular weld joint, are induced by two principal causes:

(1) **pre-weld restraint:** ie heavy sections and joints of high rigidity, existing fabrication restraint developed by other welds and fabrication work;

(2) **welding stresses:** after the (peak) welding temperature the contraction of the weld metal is restrained by the surrounding parent material. Due to the lower strength of the weld metal at elevated temperatures and the small mass of heated metal compared to the weldment as a whole, most of the contraction is absorbed by plastic straining of the weld metal. The final magnitude of the residual stresses will depend on many factors including, weld metal strength, degree of pre-weld restraint, fit up, size of weld beads etc. Weld metal residual stresses, in the as-welded condition, can, however, be at or exceed the material's yield strength.

b. The precautions outlined under Contractional Cracking are to be observed to minimize residual stresses.

C.7 The Crack Susceptibility of the HAZ Micro Structure

a. The extent of the metallurgical changes and the crack susceptibility in the HAZ resulting from the welding thermal cycle will mainly depend on the following characteristics of the parent material:

(1) hardenability;

(2) degree of hardness induced.

b. Hardenability, in this case, is defined as the ease and depth to which hardened HAZ are formed. Rapid cooling rates will be required to produce a hardened micro structure in a steel with a low hardenability whereas a material with high hardenability will transform to a hardened HAZ even at slow cooling rates.

c. Both hardenability, hardness and hence cracking susceptibility rise with increasing carbon and alloy content; thus the tendency to cracking increases markedly with carbon above 0.2%. The relative effect of other alloy additions can be expressed by the carbon equivalent formula. There are many variations on this and the results can only be used as a guide:

$$CE = C + \frac{Mn}{6} + \frac{Si}{24} + \frac{Ni}{40} + \frac{Cr}{5} + \frac{Mo}{4}$$

d. This simple means provides a guide to the crack susceptibility for a particular material; it will be shown later how this factor is considered in relation to the other variables to determine the precautions necessary to avoid hydrogen induced cracking.

C.8 Precautions to Avoid Hydrogen Induced Cracking

a. The ways of minimizing hydrogen induced cracking are:

(1) pre-heat to reduce the cooling rate;

(2) post-heating to reduce the cooling rate;

(3) restrict hydrogen availability;

(4) control arc heat input;

(5) minimize restraint.

b. The degree to which the above need be applied in any particular case will depend on the hardenability and therefore the alloy composition (ie carbon equivalent) of the steel being welded.

c. Steels with a CE up to about 0.45 can be welded without special precautions against cracking with combined joint thickness up to about 50mm. By using hydrogen controlled consumables or bare wire processes the combined joint thickness can be increased to 75mm. With thicker materials or materials with higher CE susceptible micro structures will form. In welding such materials a more controlled cooling rate must be achieved, in the first place to obtain the least hardened structure and secondly to provide more time for hydrogen diffusion through the critical temperature zone. Heat input control related to thermal dissipation can be used to produce the desired cooling curve at the upper temperature ranges, which will control the final hardness. There are, however, limits to the amount by which heat input can be increased (to obtain impact properties) and it is necessary to decrease the cooling rate at the lower end, in the vicinity of 300° C. This is done by raising the temperature of the base material by pre-heat such that on cooling after welding the shape of the cooling curve is drawn out through the 300° C zone, allowing more time for hydrogen diffusion. Alternatively post-heat can be used for the same purpose, but in most cases post-heat is confined to those circumstances where the risk of cracking is considered very high. Slow cooling must follow these operations, the cool down to ambient being retarded by use of suitable shielding or insulation.

d. The benefits of pre-heat are three-fold: it reduces the cooling rate of both weld and HAZ and thus accelerates hydrogen diffusion from those areas; in addition it tends to reduce the shrinkage stresses. The application of pre-heat will therefore reduce the tendency for cracking in both weld and HAZ. In practice the selection of pre-heating to avoid HAZ cracking is related to:

(1) chemical composition (parent material);

(2) material thickness;

(3) welding processes;

(4) arc heat input;

(5) degree of restraint.

e. The level of pre-heat required for MOD(PE) structural materials has been derived from considerable experimental work done at NCRE. Special tests have been devised which incorporate the above variables such that the pre-heat level to avoid cracking can be established and related directly to CE and the material thickness. From this information curves of constant CE plotted against combined material thickness and temperature have been produced. These curves make allowance for normal shipyard fit up and restraint and are reproduced in Section 9. of this NES.

f. Production ‘feedback’ has shown that the specified pre-heats are sufficient to prevent hydrogen induced cracking when used as part of a weld procedure which is satisfactory in other respects.

g. The specified pre-heat temperatures are based on the use of normal ferritic welding consumables. Reductions in the level of pre-heat required for a particular application can be considered; one special case is the use of Austenitic electrodes. Austenitic weld metal has a greater solubility for hydrogen than ferritic weld metal thus reducing the amount of hydrogen available to be absorbed by the HAZ. However, there are a number of objections to the use of austenitic electrodes and specific guidance is to be sought from DG Ships if it is proposed to make use of them where the situation is not already approved within this NES.

h. Restricting the availability of hydrogen is achieved by use of hydrogen controlled electrodes or processes. Hydrogen controlled electrodes are formulated to minimize the amount of moisture in the coating, and part of the manufacturing process involves high temperature baking prior to the electrode being packed. Hermetically sealed packages are not specified so electrode coatings can absorb excessive moisture unless stored under warm dry conditions. To ensure that these electrodes have not absorbed excessive moisture during the holding period, requirements exist for pre-weld drying or baking, the degree of heating being related to the CE of the material to be welded. Similar precautions are necessary for other hygroscopic consumables, such as submerged arc fluxes or coated continuous electrode wire. Bare wire consumables are not inherently hygroscopic but hydrogen can be evolved from grease or other surface contamination; it is therefore essential to inspect and clean wire surfaces as necessary. Shielding gases may contain moisture; where such gases are procured under BS specifications the probability of moisture contamination is low. Gas hoses and connections within the supply system are, however, to be checked for leaks to prevent atmospheric entrainment and subsequent contamination. Additionally it is important to prevent high winds from diminishing the effectiveness of the gas shield.

i. The precautions defined in Section 8. of this NES regarding the care and storage of welding consumables are aimed at reducing the hydrogen content to acceptable levels. Care must, however, be taken to prevent hydrogen ingress from rust and production arisings by cleaning weld joints prior to welding.

j. Heat input resulting from the arc energy will influence the required level of pre-heat; high heat input will provide more heat per unit mass than low heat inputs. High heat inputs will cause a corresponding reduction in the cooling rate. This factor is taken into account in determining the specified pre-heat temperatures. In addition to the influence that heat input will have on the selection of pre-heat temperatures the attainment of the required weld metal properties will be impaired by heat inputs which fall outside certain limits. For these reasons arc heat input limits are placed on all welding consumables approved by MOD(PE). These limits are shown against each consumable in NES 769. The means of calculating nominal arc heat inputs is shown in Section 9. of this specification and NES 770. Where welds are deposited within the specified limits a high confidence level can be placed on the attainment of weld soundness and the required mechanical properties from the joint as a whole.

ANNEX D.

DISTORTION

D.1 General

a. This Annex aims to provide general background information for designers and fabricators regarding the problem of welding distortion. The basic causes, contributory factors, means of control, and corrective measures are reviewed.

b. All metals expand when heated and providing there is freedom for dimensional changes to take place will return to their original shape on cooling. The application of heat in welding is of a local nature; there is therefore little possibility of free expansion and contraction being achieved. On heating, free expansion is restricted by the cooler parent material thus a large proportion of the volume increase takes place at the free surface of the weld. On cooling contraction tends to take place in all directions but is restricted by the steep thermal differentials at the fusion boundaries. At elevated temperatures, in the cooling cycle, the above restrictions cause some plastic flow to take place, but at lower temperatures the cooling metal obtains strength resulting in the formation of stresses. Part of these stresses find relief in distortion; the remaining stresses become residual.

c. Heat other than that produced by the welding process can influence distortion. Pre-heat is an example, and care is needed to ensure that the application of pre-heat does not induce pre-weld distortion or cause root gaps to open.

d. In addition residual stresses in plates and sections resulting from fabrication operations, gas cutting, shearing or working, and the stresses inherent from the material manufacturing processes tend to be locally relieved and re-distributed by welding. This can cause such members to distort in a manner which cannot be solely attributed to weld metal contraction.

D.2 Forms of Distortion

a. To understand the mechanism of distortion it is necessary to consider the fundamental dimensional changes that occur as a result of welding. The dimensional changes can be divided into three principal movements:

(1) transverse;

(2) longitudinal;

(3) rotational, which is normally associated with (1) and (2).

b. **Transverse:**

(1) Transverse contraction occurs perpendicular to the longitudinal axis of the weld. If a weld is made between two plates free to move the plates will be drawn together by the transverse contraction of the weld metal. The root gap between the plates will narrow and close in advance of the arc when using MMA processes and where sufficient length of butt is available the plates may ‘scissor’ or overlap each other; see FIGURE D.1.

(2) In using higher heat input processes, such as submerged arc or automatic MIG the plates will contract behind the arc but open ahead of the arc increasing the root gap; see FIGURE D.2.

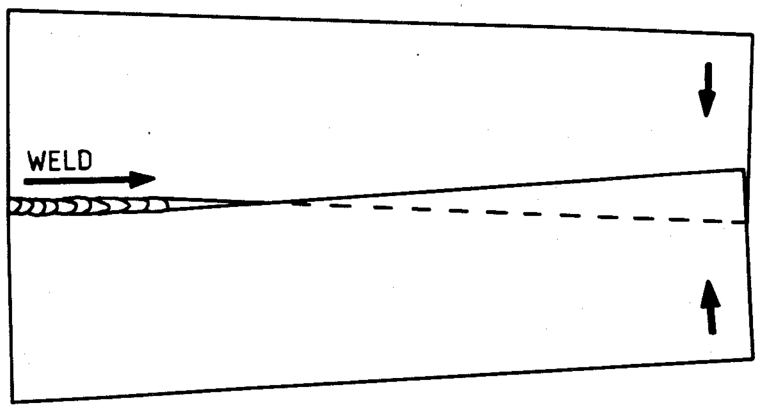


FIGURE D.1 SCISSOR

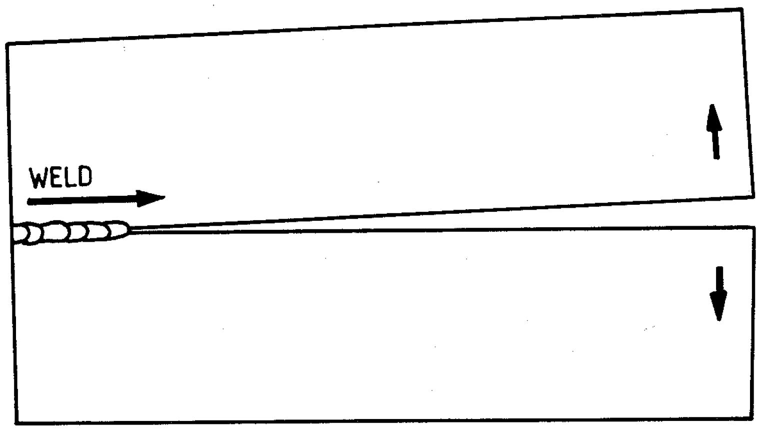


FIGURE D.2

(3) Where welds are adequately tacked or block welded at intervals the transverse contractional stress is partly absorbed by the parent plate as residuals.

(4) The lateral contraction caused in the width of the assembly will be in the order of 1.5mm for each butt weld. Where the root gap is wider than specified there will be additional shrinkage.

(5) Transverse contraction will only occur in isolation when the weld metal is deposited symmetrically about the neutral axis of the joint in one pass, such as square edge submerged arc or electro-slag welding. More often the weld is made up of several passes which are not symmetrical about the neutral axis, thus inducing angular distortion both in the longitudinal and transverse direction. Ignoring for the moment the longitudinal aspects, in welding a butt joint the root run will pull the plates together with little tendency to cause angular rotation where the deposit is near the neutral axis. The next run deposited on top of the root run tends to contract but is resisted by the first run. Thus as the second run contracts it creates a 'pull' at the weld face and the resistance of the first run creates a hinge about which angular rotation occurs. Additional runs are restrained by the previously deposited weld metal and are situated at a greater distance from the neutral axis providing a larger lever, thus tending to increase the forces causing angular rotation; see FIGURE D.3.

(6) A similar situation exists with T joints. In the case of a simple fillet weld, the contractional force from the root run will pull the plates together and due to the location, remote from the joint neutral axis, will cause angular rotation; see FIGURE D.4. This distortion will increase in proportion to the number of weld runs deposited and distance from the joint neutral axis.

(7) Angular distortion will increase in amount per run if larger electrodes are used but not in direct proportion to the increase in volume of metal deposited. Larger electrodes require less runs for a given weld size and should therefore produce less distortion.

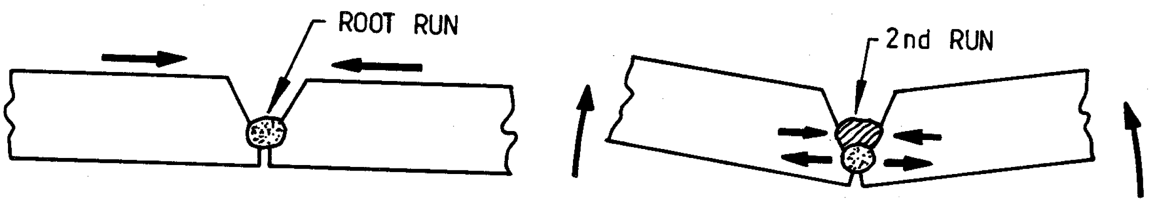


FIGURE D.3 THE HINGE MECHANISM

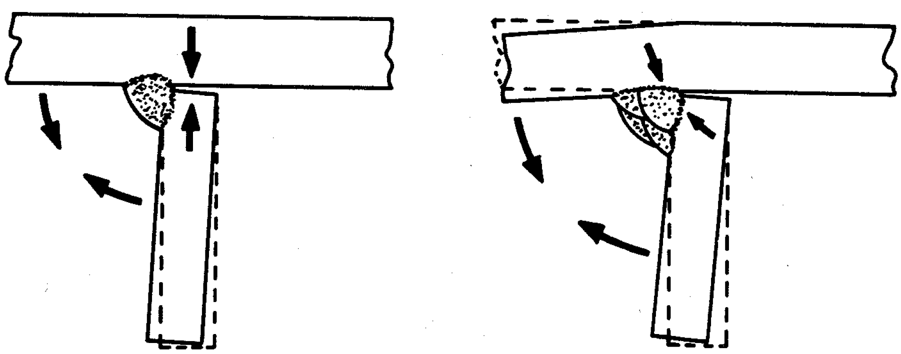


FIGURE D.4 ANGULAR ROTATION OF FILLET WELD

c. **Longitudinal:**

(1) Longitudinal contraction occurs parallel to the longitudinal axis of the weld. Where welds are deposited in one pass and are symmetrical about the neutral axis the resultant contraction will cause a reduction in longitudinal dimension. This reduction will be in the order of 3mm per 3m of welded joint. In general, however, the deposition of individual weld runs are separated from the joint neutral axis, therefore weld contraction in the longitudinal direction will cause angular distortion in the form of bowing.

(2) The greater the distance from the neutral axis the higher the degree of resultant distortion; see FIGURE D.5.

(3) It is the cumulative effect of the three fundamental forms of distortion that result in the general distortions found in welded structures. Panel bowing and buckling are typical examples of the resultant distortions.

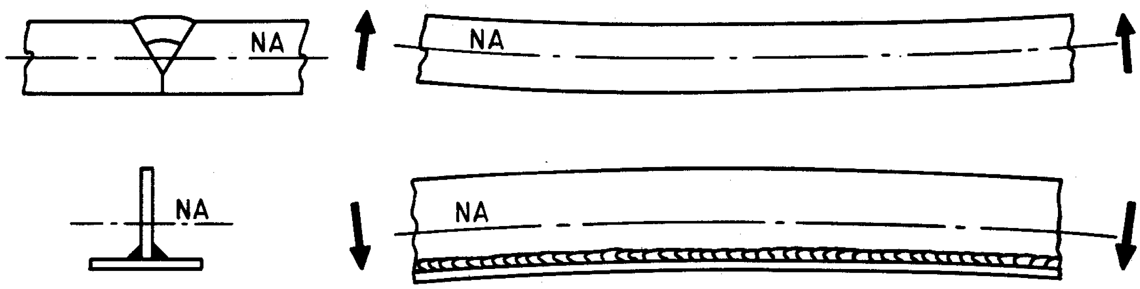


FIGURE D.5 LONGITUDINAL BOWING

D.3 Factors Contributing to the Degree of Distortion

a. The principal factors which affect the amount of distortion are:

(1) material properties;

(2) heat input;

(3) rigidity;

(4) type of joint.

b. **Material properties:**

(1) Different metals expand by different amounts when heated, and the coefficient of expansion of both weld and parent materials have an important influence on distortion. The coefficient of contraction is the reverse of thermal expansion. Thus aluminium alloy, with a coefficient of thermal expansion of about 200% that of steel, is more prone to distortion than mild steel.

(2) The relative weld metal/parent metal strengths will also affect the degree of distortion. Over matching weld metal strength will induce more strain in parent material than undermatching situations where the weld metal has a greater ability to deform without distorting the parent material. On MOD work the use of undermatching weld metal is limited to special cases and is prohibited without prior approval. The use of the lowest strength weld metal within a particular approved group is however recommended.

c. **Heat input:**

(1) The heat developed by the welding arc is approximately the arc voltage ¢ amps ¢ rate of travel. In general the lower the heat input and the more uniform the heat flow, the less will be the distortion. The total heat input required will depend on the material to be welded, the amount and position of welding and the welding process. Positional welding generally results in increased losses by spatter and is carried out at slower rates resulting in increased heat input.

(2) Automatic arc welding makes possible the use of high welding speeds and the distortion obtained with these processes are less than that resulting from MMA welding for two reasons:

(a) A greater volume of weld metal can be deposited in one pass (so long as the heat input limits of NES 769 are not exceeded) than is possible by MMA welding, thus reducing the number of passes required to complete a given joint.

(b) The progressive, intermittent contraction by cooling weld and plate, which occurs in MMA welding during the interval between the deposition of each electrode, is eliminated.

(3) In manual welding, each electrode deposited creates its own system of thermal disturbance. The systems of thermal disturbance increase with the number of electrodes used and this causes a complex stress system. Automatic welding, being a continuous process, produces a more uniform and simple system of disturbance than can be obtained by irregular application of heat by manual welding.

(4) An attempt to compare systems of isothermals produced by manual and automatic welding is shown in FIGURE D.6. The smooth isothermal contour in automatic welding will produce more uniform expansion and contraction, and this will be helpful in reducing distortion.

(5) It can also be seen from the temperature distribution how the mechanism of opening or closing the edge preparation in front of the arc operates, as shown in FIGURE D.1 and FIGURE D.2.

(6) Increasing the size of electrode will increase the speed of welding by allowing the use of increased current and for manual welding can also improve the continuity of welding by increasing the length of deposited weld metal from each electrode.

(7) The use of low heat input processes, such as short circuiting MIG or pulsed arc MIG, favour less distortion.

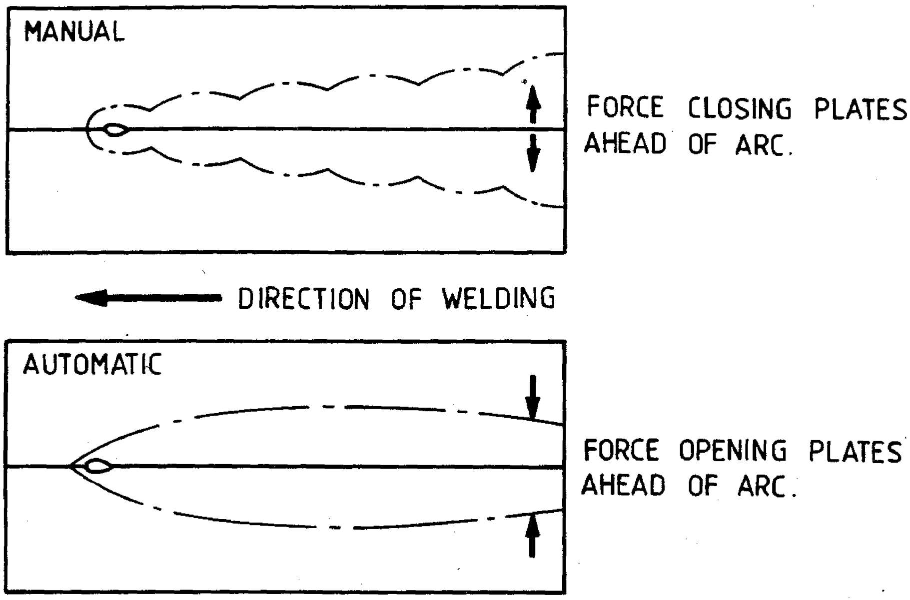


FIGURE D.6 ISOTHERMALS PRODUCED BY MANUAL AND AUTOMATIC WELDING

d. **Rigidity:**

(1) The degree of restraint imposed during welding, by either the rigidity of the structural parts involved or the use of holding devices, has a considerable bearing on the resultant distortion. The greatest distortion occurs when the parent metal is free to follow the shrinkage movement of the weld and the least where little movement of the parent metal can take place.

(2) It would therefore appear that the simple solution would be to aim at rigid joints, but if there is complete restraint the weld and parent material become increasingly stressed during cooling, increasing residual stresses and the risk of cracking. For these reasons the use of holding devices to attain rigidity must be carefully considered. In addition the controlled free movement of component parts can be used to advantage in reducing the final level of distortion.

e. **Type of joint and welding sequence:**

(1) The type of joint designed has a definite influence on the degree of distortion likely to occur. In general edge preparations which are not symmetrical about the neutral axis will induce more distortion than symmetrical preparations and as the volume of weld metal increases the tendency to distort will increase.

(2) Effective joint design must be supported by weld deposition sequences which aim at balancing the overall contractional stresses on each side of the joint neutral axis.

D.4 Control of Distortion

a. The basic methods which may be used to control distortion are:

(1) design;

(2) assembly sequence;

(3) welding sequence;

(4) forcible restraint;

(5) pre-setting;

(6) thermal stress relief.

b. **Design:**

(1) It is generally agreed that the most economical design for a welded structure is one that requires the least number of parts and a minimum of welding; such a design also assists in reducing distortion.

(2) The type of joint preparation is important, particularly for unrestrained butt welds, because the joint preparation can influence the degree of angular distortion. The ideal situation would be for a square edge preparation filled by one pass such as is possible with electro slag/gas processes (only permitted on MOD(PE) work with special permission). Development work is in hand for one sided welding with submerged arc welding for commercial shipbuilding but these techniques are not yet approved for MOD(PE) work. Square edge butt weld preparations with one pass each side is the nearest approach to the ideal. This preparation is approved for MMA welding of material up to 5mm thick; greater thicknesses may be welded with the submerged arc process. The use of the latter is to be encouraged wherever the mechanical properties of the base material can be achieved. NES 769 lists the approved consumables and the permitted material thicknesses which may be welded in this manner.

(3) Great material thicknesses need to be welded by multipass techniques which requires the use of some form of edge preparation providing access for the electrode. In single V and U preparations the welding is not balanced about the neutral axis and angular distortion will increase with plate thickness and number of weld runs in the joint. The effect on angular distortion is less for U preparations due to the smaller volume of weld metal compared to the V preparation on material thicknesses exceeding 19mm.

(4) Symmetrical double V and U preparations offer advantages over one sided preparations where it is possible to deposit the weld runs alternately from the first and second sides so that angular distortion is balanced on each side of the joint. This practice becomes impracticable where back gouging is required as it is necessary to deposit more than one weld pass from the first side before back gouging operations can be safely done, thus inducing angular distortion from the first side welded. As a rough guide about twice the volume of weld metal is required on the second side welded to correct the original distortion. It can be seen that the available volume on the second side is insufficient for this to be achieved other than on relatively thin material where the added volume from back gouging becomes significant. To achieve the required volume balance it becomes necessary to offset the joint nose such that a $^{1}/_{3}$ to $^{2}/_{3}$ double V or U preparation evolves. This preparation can be successfully employed on materials which are free to move in an angular direction; see welding sequences. Where the production programme dictates that one side is completely welded before back gouging, the $^{2}/_{3}$ volume must be the second side welded.

(5) Other circumstances exist in thicker materials and restrained or rigid welds where completion of welding from the first side would be unacceptable because of the degree of residuals induced, or the spring back when temporary holding devices are removed. In such cases the nose of the V or U edge preparation should be offset sufficiently to facilitate the $^{1}/_{3}$ to $^{2}/_{3}$ volume requirement about the neutral axis of the joint in the vicinity of the mid-portion; see FIGURE D.7.

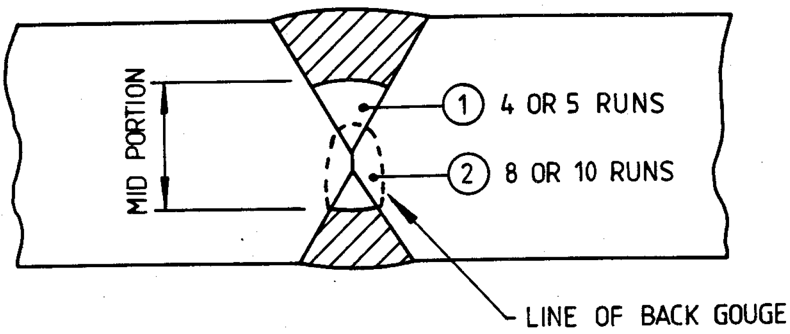


FIGURE D.7

(6) Having completed the root runs and initial welds from the back gouged side the joint should have sufficient rigidity to prevent a high degree of distortion by completing the outer portions in a balanced manner.

(7) T joints present similar problems except that it is normally more practicable to arrange for balanced weld depositions to be made on each side of the joint. Section 5. deals with the selection of joint preparations.

(8) Distortion can be minimized by balanced weld deposition and by specifying the minimum weld size consistent with the strength requirement. The use of sub-size fillet welds is particularly useful in reducing panel distortion on thin structure.

(9) Distortion cannot be controlled solely by good design and well chosen joint detail, but these methods do reduce the magnitude of the problem and make it easier during fabrication to apply practical measures to minimize the problem.

c. **Assembly sequence**

(1) The control of distortion is one of the factors to be considered in the assembly sequence. The fabrication and welding processes, the physical size of component parts of a structure, and the lifting/handling facilities of a particular fabricator's plant all dictate to one degree or another the final breakdown of the structure into two and three dimensional pre-fabrication units.

(2) To optimize the control of distortion, careful consideration must be given to the breakdown of the ship hull into 'ship units' and the associated 'sub-units'. It is general practice to make dimensional allowances on both ship and sub-units by leaving 'green material' at the edges of abutting members to allow for accurate fitting and thus compensate for overall shrinkage.

(3) There are no objections to 'ship units' being joined by straight butts which circumscribe the hull in one line. In fact this practice will facilitate accurate fitting and the balanced sequence of welding necessary to minimize angular distortion of entire units. The straight line butt method will also enable some pre-setting of units where the total weld volumes are not symmetrical about the neutral axis of the ship; see FIGURE D.8.

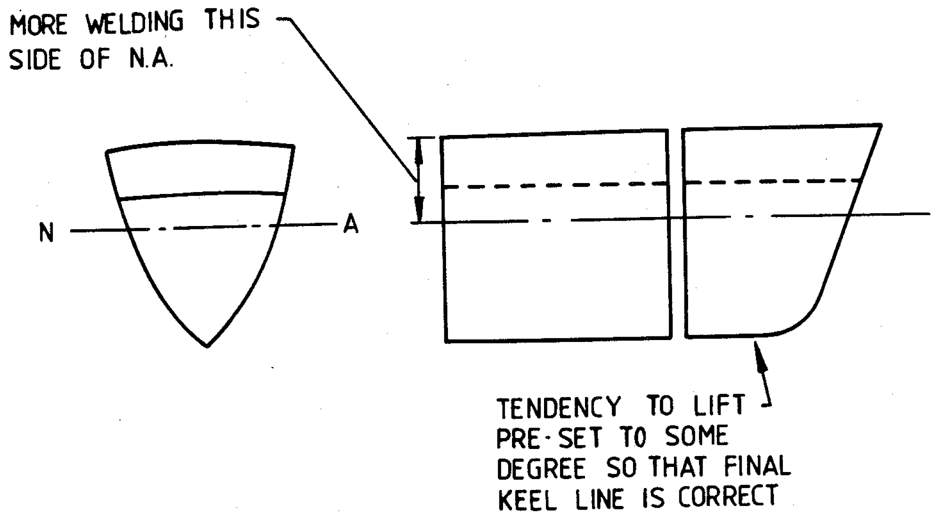


FIGURE D.8

(4) The 'fit up' of the butts joining adjacent units is most important; excessive root gaps or irregular root openings will result in more than normal contraction thus causing a higher level of distortion.

(5) The assembly sequence of the sub units must also make provision for the overall shrinkage resulting from welding. To minimize the final distortion it is generally necessary to allow as much freedom of lateral movement to take place between adjacent parts, but at the same time reduce the influence of those parts being welded on adjacent members. The following examples of welding assemblies are intended to give guidance and illustrate the principles involved.

(6) **Flat stiffened panels** The largest possible plates are to be used to reduce the volume of weld metal required. There are two basic approaches, defined in (7). and (a).

(7) **Weld flat plates first and then add stiffeners** See FIGURE D.9.

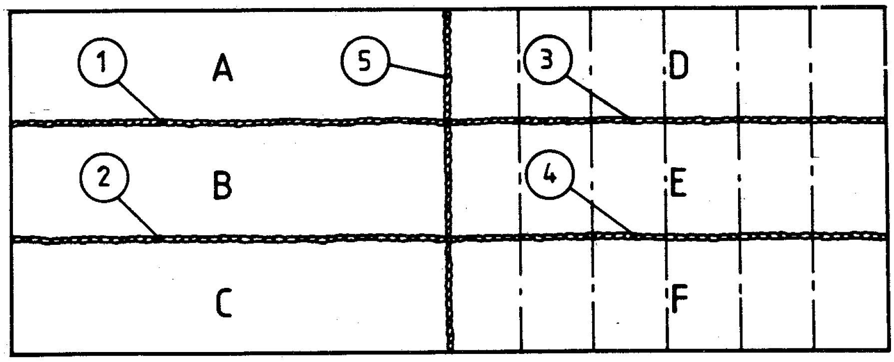


FIGURE D.9

(a) The concept is to weld adjacent plates in an individual manner completing the back runs at the same time such that the addition of a single plate at a time progressively increases the basic panel size. This method confines contractional influence to the butt being welded without affecting the panel as a whole. Using controlled welding sequences and by adopting $^1/_3$ to $^2/_3$ techniques, plates need not be restrained in the transverse direction but can be allowed to distort in an angular manner. Welding the $^2/_3$ joint side subsequently can be controlled to bring the panel flat. Some form of longitudinal restraint may be needed in the vicinity of the butt.

(b) For the panel shown in FIGURE D.9 the assembly sequence would be as shown: 1, 2, 3, 4 and finally 5.

(c) On completion of welding the panel the stiffeners are added and welded in a balanced sequence. Where deep frames or girders are involved advantage can be obtained by welding the intersections of framing to form an 'egg box' structure prior to erection on the panel. Clamping the egg box to the flat panel will result in a final weldment where only the attachment welds will interact on the panel as a whole, as opposed to all welds interacting where the assembly sequence tacks plates and stiffeners together from the onset.

(8) **Flat plates and stiffeners assembled together**

(a) This practice requires the plates to be restrained to prevent angular distortion but wherever possible transverse lateral movement should be permitted. This can be achieved by securing the stiffeners, girders etc to the panel plates by bridges which will hold the plate flat but allow the individual plates to move in a lateral plane without influencing to a large extent the panel as a whole. (More effective methods such as hydraulic jacks or magnets are available in modern shipyards.) The concept of welding one butt at a time as in FIGURE D.9 is still considered valid.

(b) On completion of welding the butts the stiffeners should be welded in a balanced manner, followed by inverting the panel to back gouge and complete the welding from the second side. In this case the welding is to commence at the mid point and work outwards, as free movement of individual butts is prevented.

(9) With both the above methods in (7). and (a)., less distortion will result by the use of automatic welding processes. A variation on the above methods, which will facilitate the use of automatic welding unencumbered by stiffeners, is to restrain the flat plates to the welding grid by clamps, etc, then add the stiffeners after welding the butts on the second side.

(10) Where MMA welding is used it is recommended that the butt weld is stopped short of the free edges to help effective joining to adjacent weldments. The need for run on/off plates makes this practice impracticable where automatic welding is involved.

(11) The assembly of the smaller components of a sub-assembly such as girders, frames, etc nearly always involves the welding of a flange or rider to a flat plate. Where the depth and thickness of the flat plate is large in relation to the flange or rider then the rigidity of the flat plate is to be sufficient to prevent serious distortions so long as the welding of the resultant tee joint is done in a balanced manner. Some precautions may, however, need to be taken to restrain the flat plate from bowing or buckling. In the case of flat plates which are small in relation to the flange or rider then bowing as shown in FIGURE D.10 must be expected.

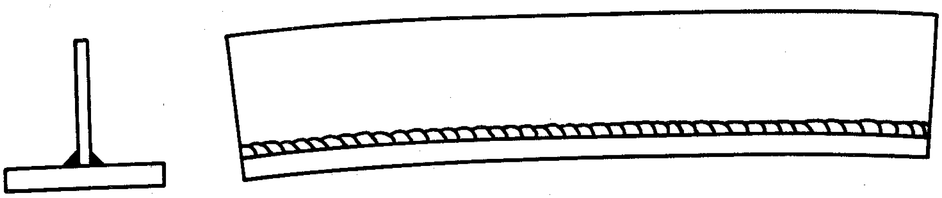


FIGURE D.10

(12) The means of minimizing this form of distortion are dealt with under welding sequence, holding devices, or pre-setting. Alternatively beams or girders etc may be permitted to distort and subsequently straightened by cold work within the limits stated in Section 7. The problem concerning frames and girders can of course be alleviated by use of suitable extruded or rolled sections.

d. **Welding sequences:**

(1) The sequence of welding will have little effect on the final magnitude of stress but careful distribution of the contractional stress induced by welding can be employed to advantage in reducing distortion. Both sequence of assembly and welding must be complementary to each other in avoiding unacceptable distortions.

(2) As previously stated, under assembly, the first consideration should be to permit each part freedom of movement in one or more directions for as long as possible, thus ensuring that the joints which undergo the greatest contraction are welded first without influencing other members.

(3) The second consideration is to balance the welding about the neutral axis of the joint/unit/ship, or to deliberately use asymmetrical weld volumes and allow free transverse angular distortion so that the required final shape is achieved, ie $^1/_3$ to $^2/_3$ technique.

(4) The manner in which welding progresses along the joint can be controlled to modify the inherent stress systems produced; which for MMA welding tends to close plates ahead of the arc with the reverse occurrence by automatic welding.

(5) Welding sequences, such as the backstep and skip sequences, are practicable for manual and semi-automatic welding. In the back-step sequence (see FIGURE D.11), weld metal is deposited in increments, usually of length equal to that deposited from one electrode, such that each increment is deposited in a direction that is opposite to the general direction of welding. In this arrangement a contracting weld is opposed by one which is expanding, so tending to balance the stresses. The skip technique (see FIGURE D.11), is used to obtain a more uniform distribution of heat.

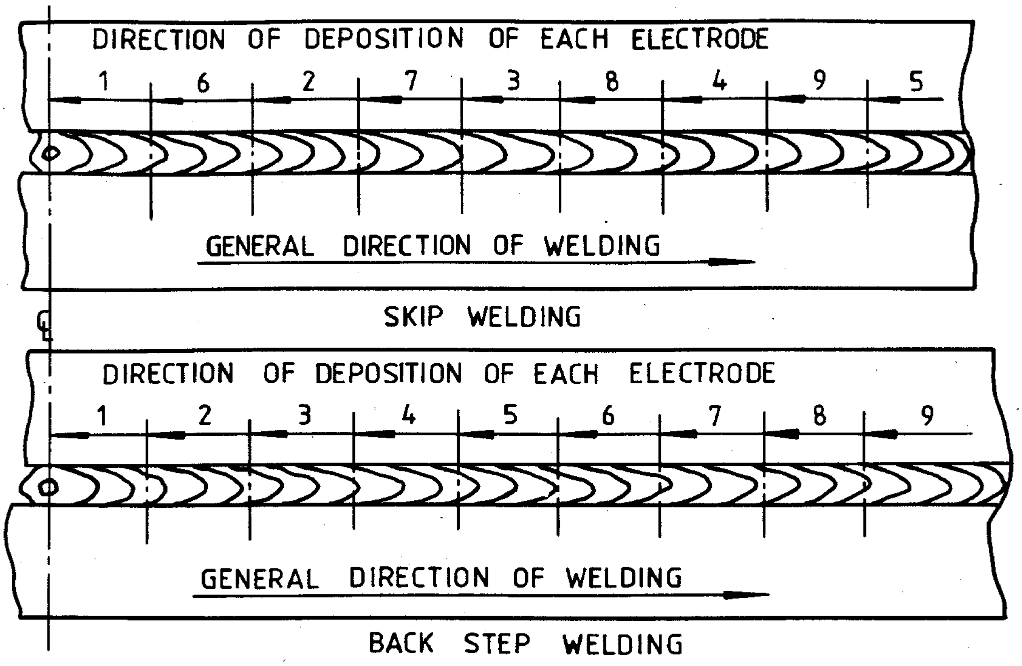


FIGURE D.11 BACK STEP AND SKIP SEQUENCES

(6) An extension of these methods can be used in long runs of automatic welding by depositing runs of about 1.5m or 1.8m long similar to that described above; this action will prevent a tendency of the plates to open ahead of the arc.

(7) **The block technique** This technique is explained in Annex B. applicable to welding inserts and penetrations. The basic use of large block welds at pre-determined positions is a useful means of making joints contract in an even manner and subsequently make the joint more rigid and less liable to distort in an angular manner. It is recommended that this method is adopted in securing adjacent hull units; see FIGURE D.12.

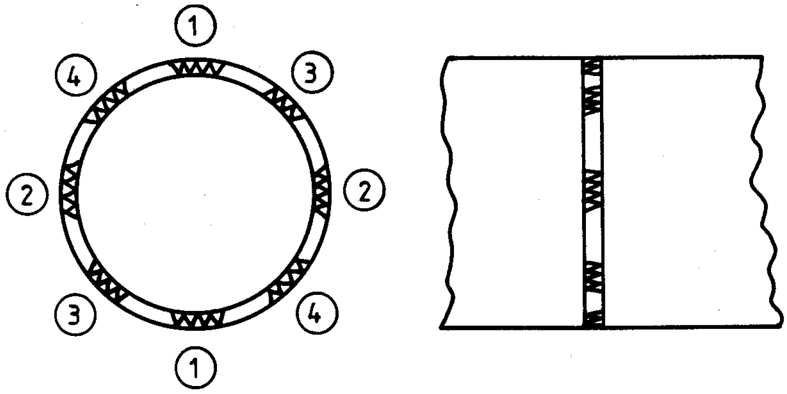


FIGURE D.12 SUBMARINE HULL UNITS BLOCKING

(8) In welding stiffeners, frames, girders, etc to panels of plating it is important to balance the welding about the neutral axis of the joint. Minimum distortions will probably result from simultaneous welding at each side of the joint and by use of automatic welding processes. With MMA welding the use of the skip technique is recommended.

(9) Opinion seems divided regarding the point at which welding should commence in welding a number of individual stiffeners or an egg box structure to a panel. FIGURE D.13 shows one approach with the welding commencing at the mid-point and working out to the edges. An alternative method is to start at one end and work towards the opposite side. Whichever method is used it is important to secure the stiffeners by bridges or other holding methods such that lateral movement is permitted as opposed to securing the stiffeners by tack welds. Securing stiffeners by tack welding will result in individual welds influencing the weldment as a whole, particularly in the case of egg box structures.

e. **Forcible restraint:**

(1) The restraint may be due to the nature of the component or be deliberately applied as in the case when fairing aids or holding devices are employed. Forcible restraint can be an effective means of reducing distortion, but the greater the restraint the greater the magnitude of stresses during and after welding. The increased stresses during welding will increase the tendency to cracking and unless balanced sequences are employed distortion may occur after the restraints are removed. Fairing aids, such as strongbacks, holding devices etc as shown in Section 7., can be used to combat angular distortion but allow lateral contraction to take place.

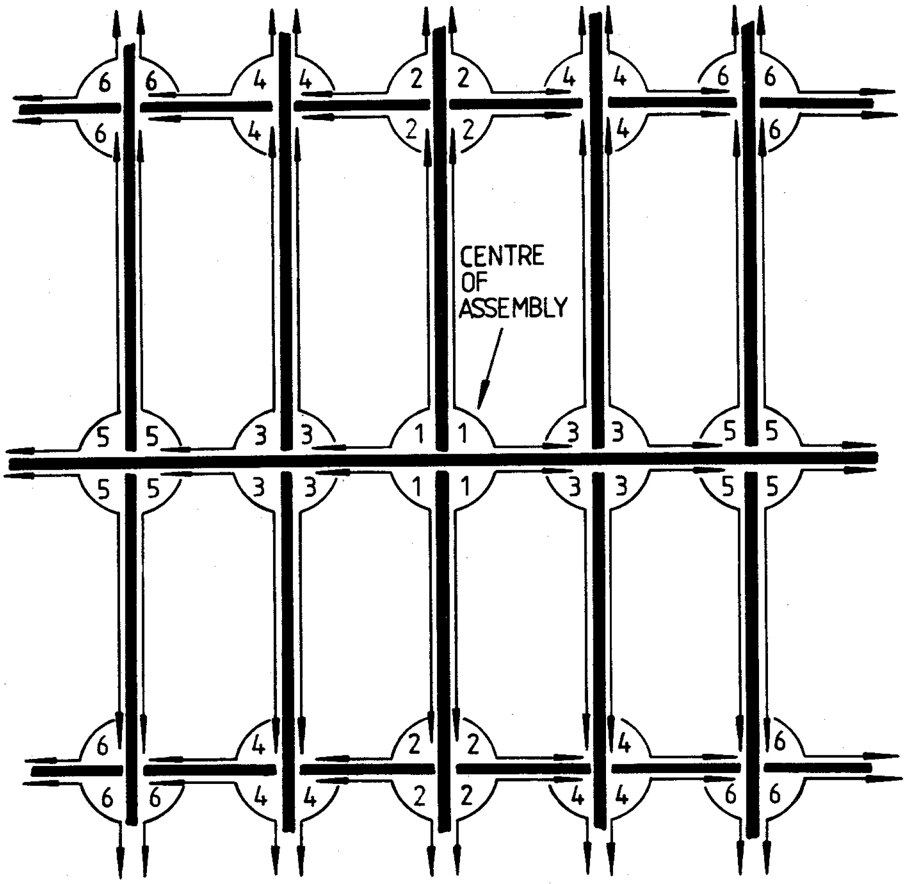


FIGURE D.13 SEQUENCE FOR WELDING STIFFENERS TO PLATING

(2) Individual components can be secured as shown in FIGURE D.14 such that the combined rigidity is better able to withstand the contractional tree resulting from welding. This method will also make the welding symmetrical about the combined neutral axis during the welding operation.

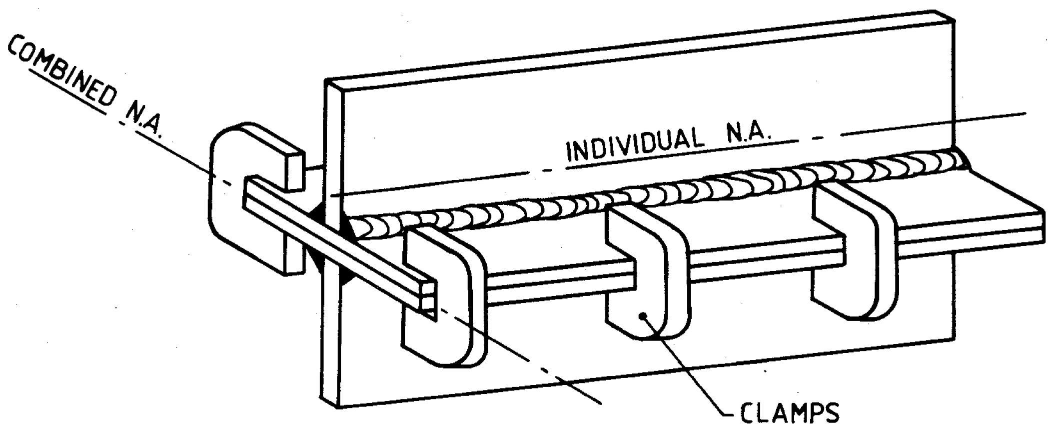


FIGURE D.14 BACK-TO-BACK CLAMPING

(3) An extension to this method is to support the ends of the component to facilitate easy turning of the assembly such that a balanced welding sequence can be used with welding in the flat position; see FIGURE D.15.

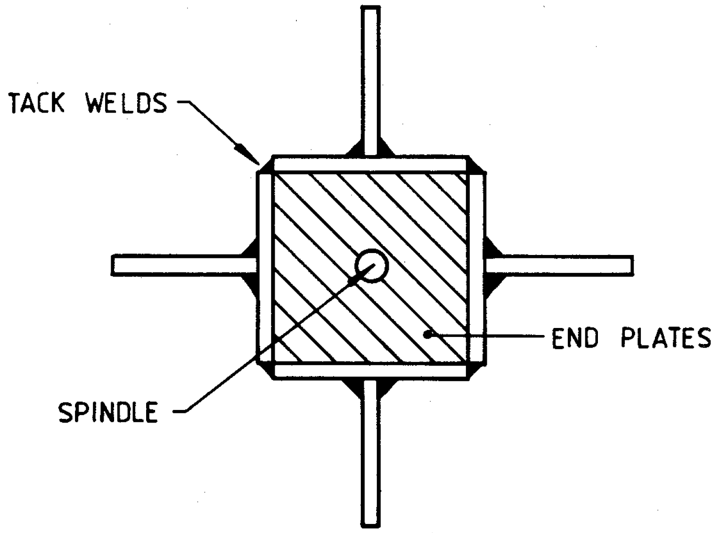
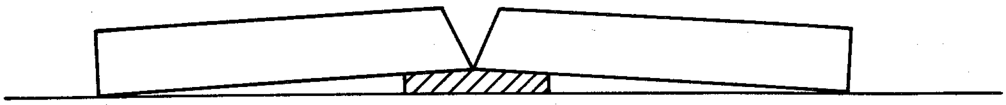


FIGURE D.15 FOUR BAR COMBINATIONS

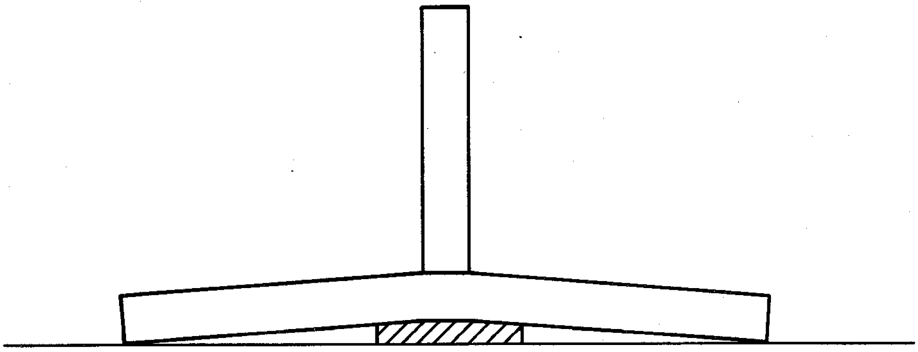
f. **Pre-setting:**

(1) Pre-setting involves estimating the amount of distortion likely to occur as a result of welding and then assembling the job with the members pre-set to compensate for the distortion. This method can only be used on relatively simple fabrications, but can also be used to advantage in welding main hull units together see; FIGURE D.8. For the most part pre-setting is limited to angular distortion. Simple examples of the pre-setting method as applied to fillet and butt welds are shown in FIGURE D.16.

(2) The amount of preset required varies according to the plate thickness, plate width and the welding procedure. For this reason it is advisable to establish the amount by experiment otherwise it is only possible to make an 'intelligent guess' at the allowance.



PRE - SETTING OF BUTT JOINT



PRE - SETTING OF TEE FILLET JOINT

FIGURE D.16 EXAMPLES OF PRE-SETTING

g. **Thermal stress relief**

(1) This may be employed to reduce the shrinkage stresses to prevent distortion occurring after the removal of holding devices, etc, or before machining operations to prevent distortion occurring during the re-distribution of residual stresses as a result of dimensional changes during machining.

(2) Stress relief will not remove distortions which have already occurred and may in fact increase existing distortion. For these reasons stress relief is only to be used for components which require a high level of machining and where dimensional stability is essential. The rules governing stress relief treatment are contained in Section 7.

D.4.1 Correction of Distortion

a. Parts of a fabrication which have buckled or otherwise changed shape to unacceptable limits can be corrected by the following methods:

(1) cold working;

(2) hot working;

(3) flame or thermal straightening.

b. The rules governing these operations are contained in Section 7. Cold and hot working is permitted in accordance with the requirements of Clauses 7.6a. and 7.7a., while correction by flame or thermal straightening is to be in accordance with Clause 7.14b.

c. The principles involved in thermal straightening are reviewed to provide general guidance; it is to be noted that considerable care and experience is required in correcting distortions by these methods.

d. The reduction of distortion by flame straightening relies on the rapid heating of a small area such that the cooler material in the vicinity prevents free expansion of the heated zone. On cooling, the heated zone tends to contract in all directions thus inducing contractional stresses which can result in local change in shape; see FIGURE D.17.

e. This mechanism can be used to advantage at distortion ‘high areas’ or areas of ‘excess metal’ to induce flattening by shrinkage; see FIGURE D.18.

f. The operator must be able to recognize the ‘high areas’ and exercise judgment as to the location and amount of heat needed.

g. The application of heat is restricted to gas flame torches. The application of heat by the deposition of weld beads on the surface of the material to correct distortion is not permitted.

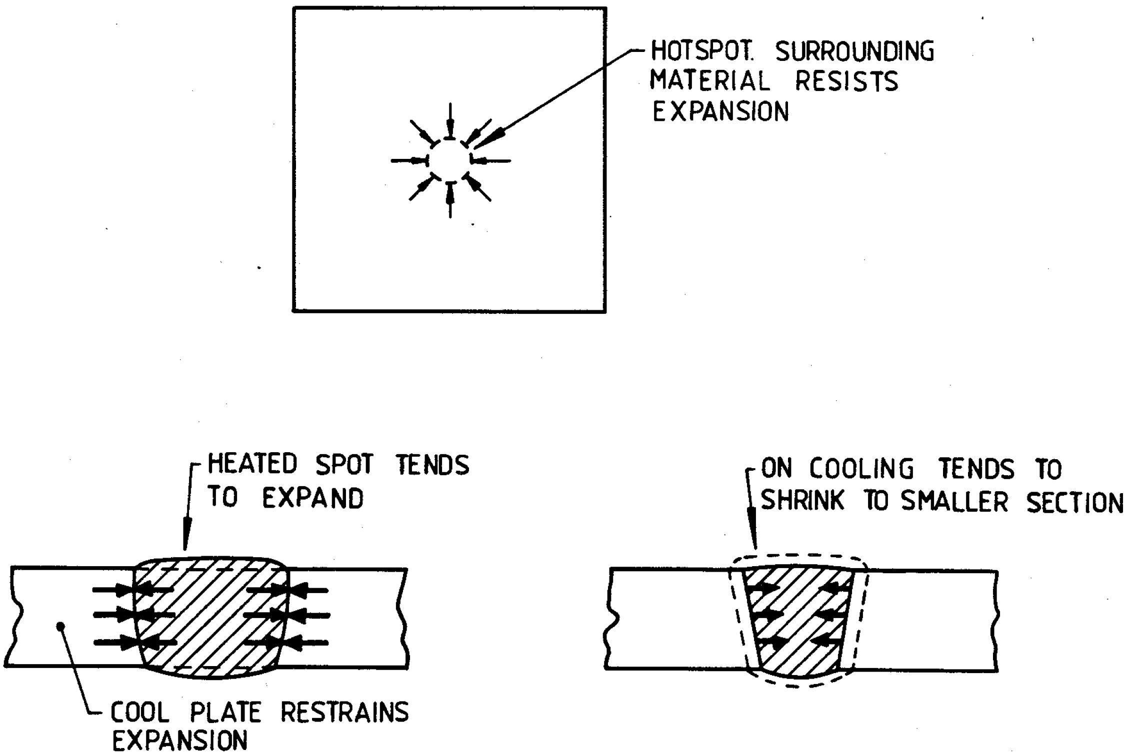


FIGURE D.17

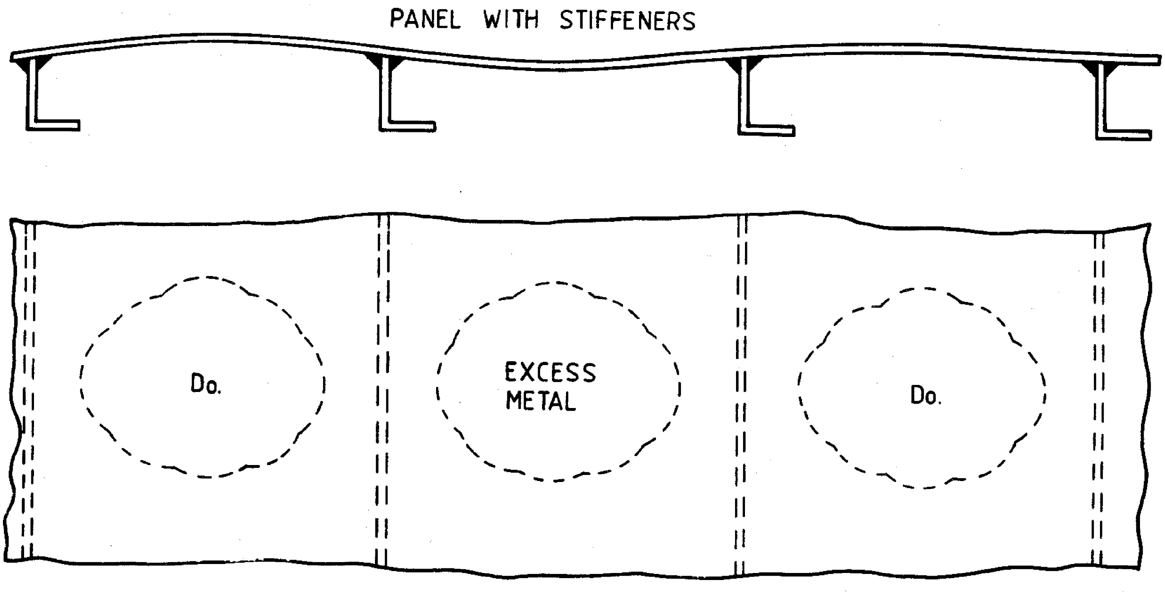


FIGURE D.18

h. A high temperature is not required when flame straightening, but a large torch is to be used. The efficiency of the process depends upon the attainment of a steep temperature gradient and a large torch is required for rapid heat input to build up sufficient temperature differential.

i. The temperature used must ensure the attainment of maximum contractional stress in the heated zone without significantly changing the material properties of the weldment. Excessive temperature leads to overheating and the impairment of the material properties, in particular notch toughness. For these reasons the maximum temperature to be used, on those MOD materials where flame straightening is permitted, is not to exceed 650° C (see Clause D.3c.).

j. It is good practice to proceed cautiously when flame straightening, periodically allowing cooling to take place and checking the reduction in distortion. To reduce the time involved water cooling is permitted on mild steel, but not on other materials. Water cooling is best achieved by use of an atomized spray fed from the air main.

k. The location and size of the heated areas can only be determined by experience taking into account the degree of distortion, material thickness, restraint etc. The following examples are included to show the principals involved:

(1) Spot heating to reduce panel buckling (FIGURE D.19), aimed at causing uniform contraction throughout the entire spot heated area.

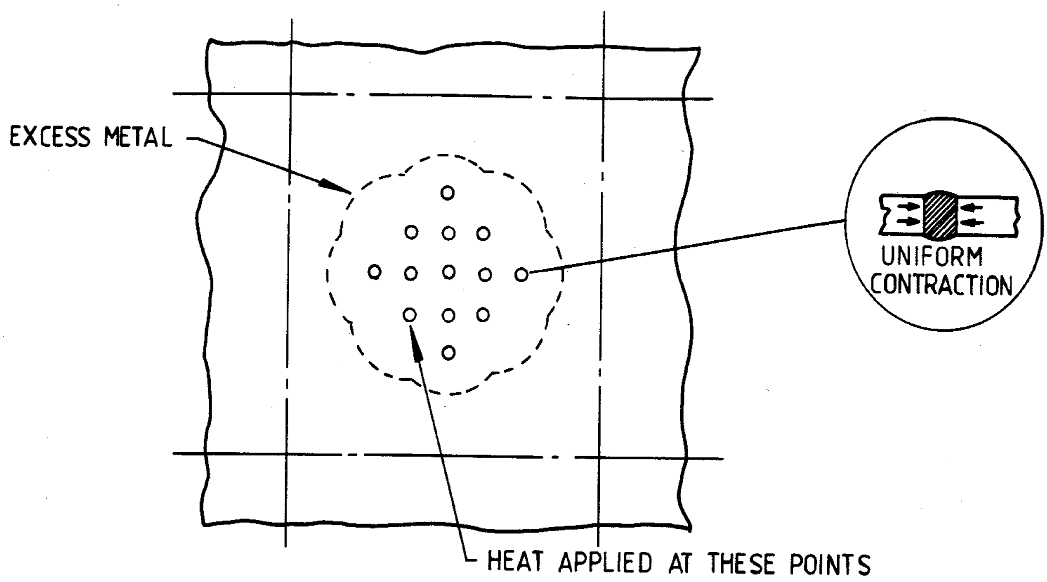


FIGURE D.19

(2) Line heating to reduce angular distortion, aimed at causing asymmetrical contraction by producing a wedged shaped heated zone as shown in FIGURE D.20. The speed at which heating progresses must be regulated for the correct temperature to be attained but sufficiently fast to attain the required wedge shape.

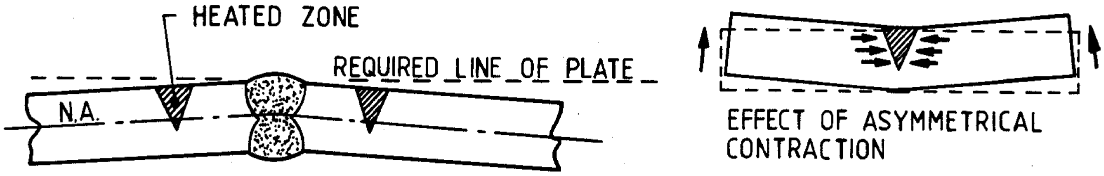


FIGURE D.20

(3) Wedge heating to reduce bowing of beams or frames; see FIGURE D.21. In this case the heat must evenly penetrate through the thickness and proceed from the base of the wedge towards the apex. It may be beneficial to use heat from both sides to ensure an even penetration of heat. The mechanism relies on the asymmetrical contraction which causes a greater shrinkage at the base of the wedge than at the apex in addition to the heated zone being located on one side of the neutral axis.

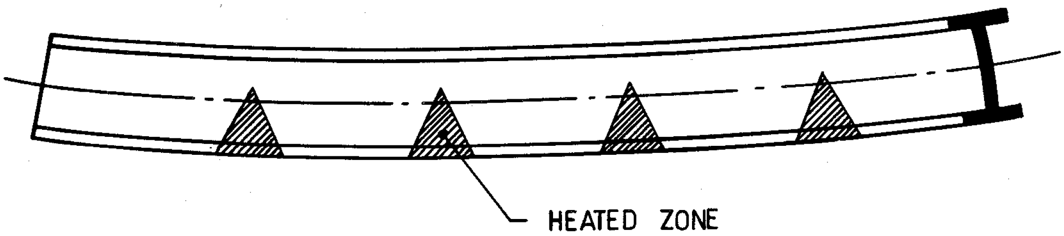


FIGURE D.21

l. There are many variations on the above methods which may be found beneficial, in particular the use of force in conjunction with flame heating may assist in attaining the required dimensional changes to correct distortion. Where force is applied, in the form of jacks, bottle screws etc, then care is to be taken to ensure that the limits for strain imposed for cold work are not exceeded; see Clause 7.6a.

ANNEX E.

WELDING DEFECTS

E.1 General

a. The purpose of this Annex is to provide background information concerning the types of welding defects encountered in structural welding. The various defect types are defined. Notes on the possible causes, effect of service performance and preventive measures are set out for general guidance. This information is not to be interpreted as superseding or modifying in any way the existing MOD Acceptance Standards for Structural Welding, in DG Ships/G/10000 or such other standards that may be specified.

b. Drawings illustrating the appearance of defect indications on radiographs and other sketches are diagrammatic representations only, and as such are intended to be complementary to the definitions.

E.2 Incomplete Root Penetration (Lack of Root Fusion)

a. **Definition** Lack of union at the root of the joint. In a butt weld the image appears in the radiograph as a dark line along or near the centre of the weld image; see FIGURE E.1 and FIGURE E.2.

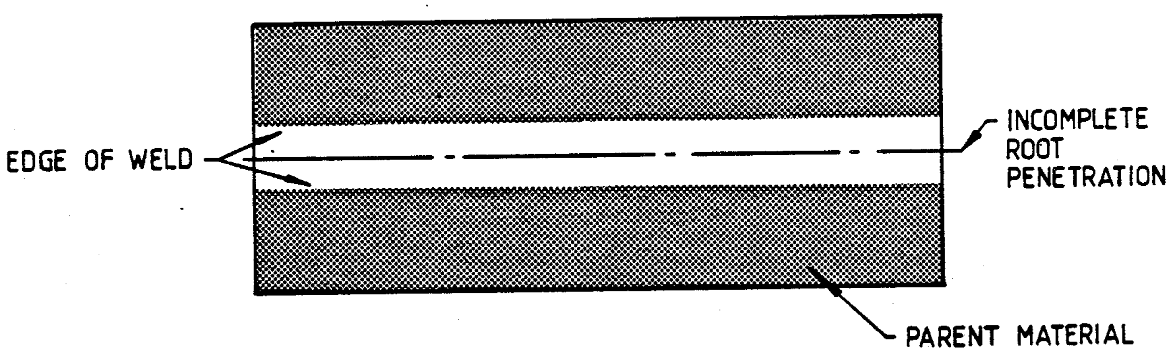


FIGURE E.1 RADIOGRAPHIC IMAGE

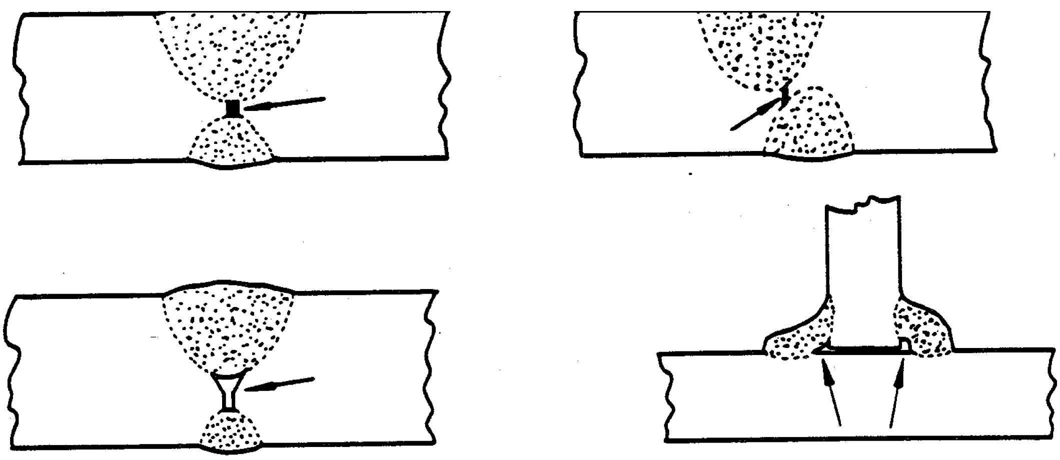


FIGURE E.2 PHYSICAL IMAGE

b. **Cause**

(1) Wrong edge preparation:

(a) root face too large;

(b) preparation too narrow preventing access to root.

(2) Gauge of electrode too large preventing access to root.

(3) Low current preventing penetration.

(4) Long arcing or arc voltage set too high on automatic welding equipment.

(5) Wrong polarity when using dc.

(6) Offset welds in butt joints welded from both sides.

(7) Ineffective back gouging.

c. **Effect on service performance**

(1) **Static loading** If service conditions are above the Nil Ductility temperature of the steel and weld metal, incomplete root penetration may be evaluated by its position in the structure, extent and stress carried. Under static loading conditions it can often be accepted.

(2) **Dynamic loading** The effect under dynamic conditions of loading is dictated by the notch ductility of the steel and weld metal in relation to the service temperature. The higher the transition temperature the more serious is the defect. If the loading conditions and/or the consequence of failure cannot be precisely evaluated then the defect must be repaired.

(3) **Fatigue** Knowledge of the effect of fatigue is based mainly on small scale laboratory specimens and the application of this knowledge demands precise information of the loading conditions of the real structure. When this information is not available the defect must be repaired.

d. **Preventive measures** Establish the cause by historical analysis of the possible causes and take the necessary action to prevent re-occurrence.

E.3 Lack of Fusion

a. **Definition**

(1) Lack of union in a weld:

(a) between weld metal and parent metal;

(b) between parent metal and parent metal;

(c) between weld metal and weld metal.

(2) In a radiograph of a butt weld the image appears as a faint dark line with sharply defined edges, which may be broken or continuous. This defect is sometimes not shown on a radiograph depending on the beam direction relative to the defect orientation. When inter-run lack of fusion occurs as shown in FIGURE E.4b it might not be indicated on the radiograph.

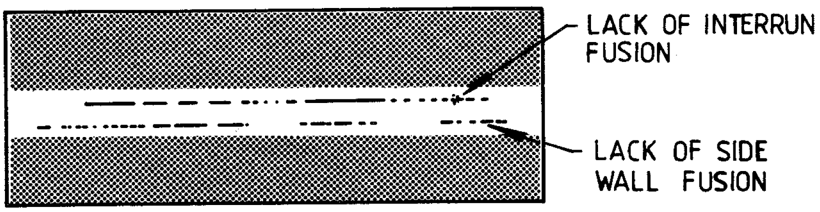


FIGURE E.3 RADIOGRAPHIC IMAGE

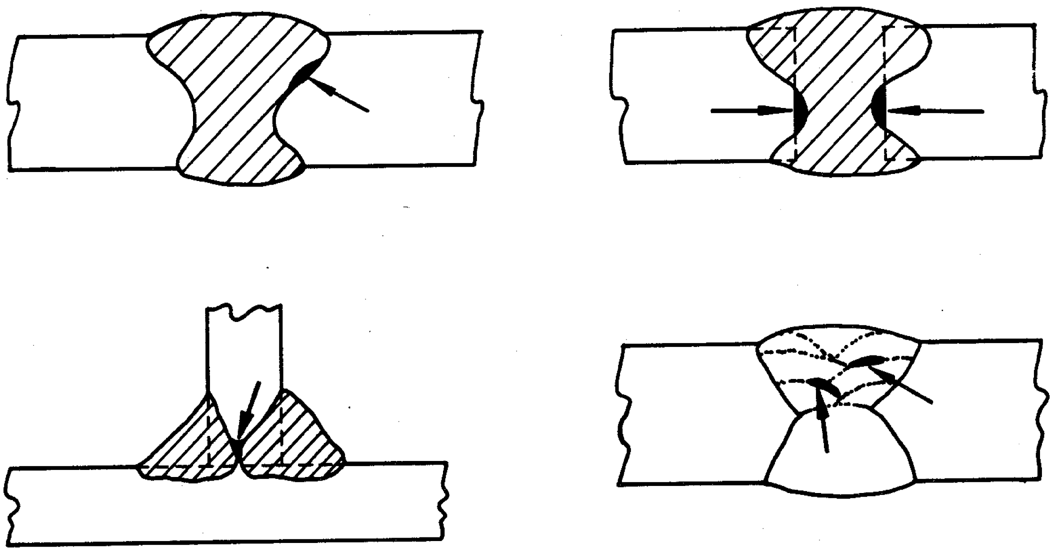


FIGURE E.4 PHYSICAL IMAGE

b. **Cause**

(1) Wrong edge preparation or poor access conditions preventing proper manipulation of the electrode.

(2) Current too low, failure to properly fuse with parent plate.

(3) Overlaying on convex beads in multipass welding.

(4) MMA current too high leading to excessive speed of travel and failure to sufficiently heat the parent plate.

(5) Long arcing with MMA electrodes or too high arc voltage with automatic welding.

(6) Presence of oxide, slag and mill scale, which will prevent fusion.

(7) Arc blow.

(8) Finger shaped penetration with the MIG process resulting in 'cold lapping' at the root.

(9) Incorrect angle of electrode relative to joint cross-section.

(10) Ineffective removal of oxide film in aluminium welding.

(11) Cold lapping in Pulsed MIG and Short-Circuiting Arc.

c. **Effect on service performance**

(1) The remarks under lack of penetration apply equally to this defect. The main difference is that lack of penetration usually occurs in the centre of the weld whereas lack of fusion can occur near the plate surface. Because of this the defect may be in a more highly stressed area and in general, therefore, this defect may be more serious than lack of penetration.

d. **Preventive measures**

(1) Establish the cause and rectify as necessary; in particular avoid deep narrow edge preparations on small inserts which hamper the welder from attaining the correct electrode angle to the fusion faces.

(2) Where weld beads are inherently convex dress out to provide better shape for subsequent passes or investigate alternative approved electrodes with improved profile. In aluminium welding, improve the means of removing oxide film prior to welding.

NOTE: Complete oxide removal will only be attained where the fusion face is subjected to the arc action.

E.4 Inclusions

a. **Definition**

(1) **Isolated inclusions** Slag or other foreign matter entrapped during welding. The defect is usually more irregular in shape than gas pores. The radiographic appearance of the defect may show variations in density within the image itself, which may be light if it is a metallic inclusion or dark if a non-metallic inclusion. A large isolated inclusion appears in the radiograph as a dark or light shade of irregular contour.

(2) **Linear inclusions** An inclusion of linear form situated parallel to the weld axis. This appears in the radiograph as a dark band with irregular edges along the weld, often occurring in a long continuous line. It is sometimes found along both edges of a weld in two roughly parallel lines, ie ‘tram lines’.

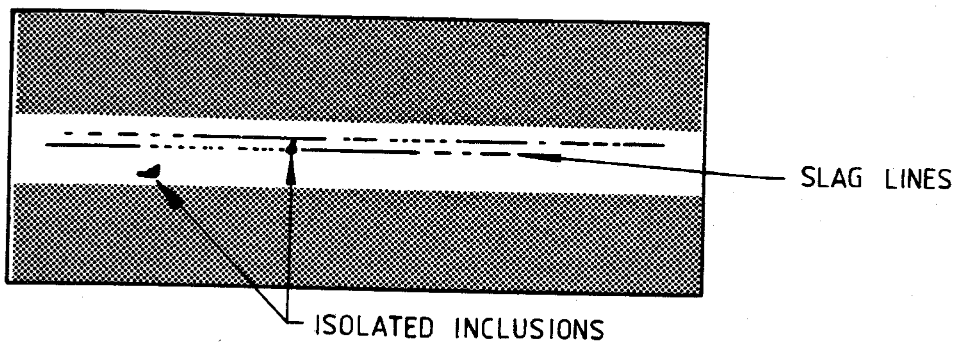


FIGURE E.5 RADIOGRAPHIC IMAGE

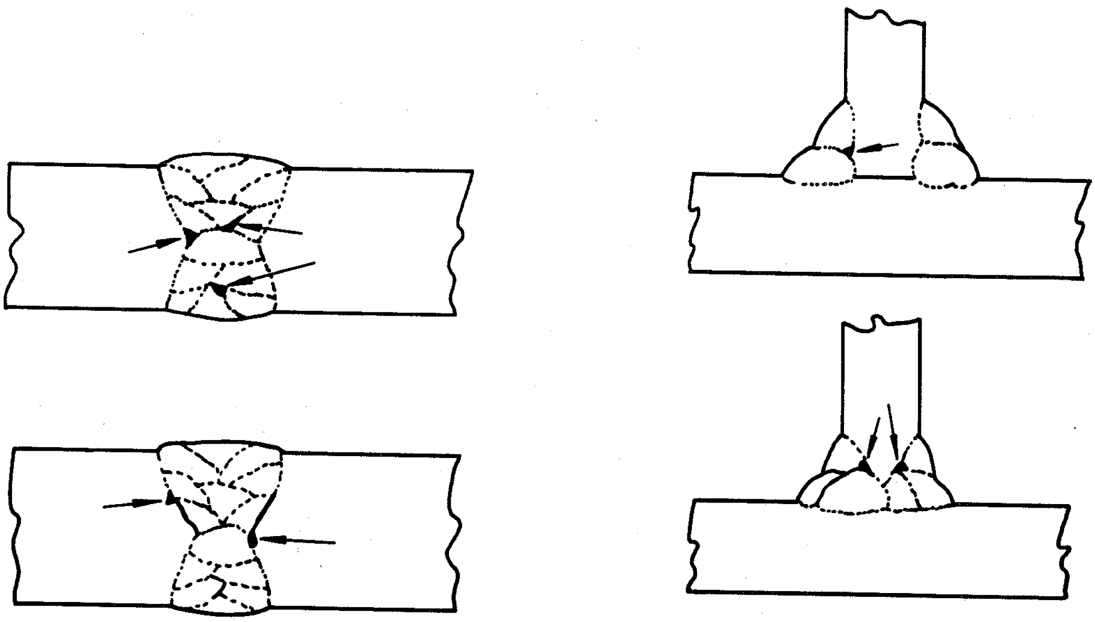


FIGURE E.6 PHYSICAL IMAGE

b. **Cause**

(1) Generally slag, but could be heavy mill scale or other foreign matter.

(2) Lack of cleanliness.

(3) Failure to properly de-slag between runs.

(4) Narrow edge preparation and/or bead convexity providing slag traps.

(5) Inter-run undercut providing slag traps.

(6) Operator failing to control slag during welding.

(7) Tungsten inclusions in aluminium welding.

(8) Ineffective oxide removal from surface of aluminium welds in multipass welds.

c. **Effect on service performance:**

(1) **Static loading** Finely dispersed small patches are not serious. The acceptance of larger patches depends on evaluation of the position of defect, extent, stress, transition temperature of steel and service temperature of weldment.

(2) **Dynamic loading** Finely dispersed small patches are not likely to be serious. Larger patches and particularly linear inclusions can be serious. Evaluation depends on loading conditions and notch ductility of steel.

(3) **Fatigue loading** Accurate analysis of effect is virtually impossible due to variety in size, shape and position of defect. The effect is, however, always bad and could well result in premature failure.

d. **Preventive measures**

(1) Establish the cause and rectify as necessary. In particular, check that the edge preparation is wide enough to provide the welder with sufficient access and that the electrode deposit is not excessively convex.

(2) Ensure that welders effectively remove slag and provide the best available equipment for this purpose. Dress out slag traps before allowing welding to continue.

E.5 Piping and Porosity

a. **Definition**

(1) Entrapped gas during the solidification of molten metal in the form of small bubbles or elongated in a tubular form. This appears on the radiograph as a sharply defined shadow of circular contour or if elongated a dark circular contour with a tail. Large porosity, where the largest dimension exceeds 3 mm, or elongated porosity are assessed as non-metallic inclusions for MOD(PE) acceptance standards.

(2) Aligned porosity or piping are usually indicative of lack of root fusion or root penetration although these defects cannot be seen in the radiograph.

b. **Cause**

(1) Gas entrapped; the main sources of gas are:

(a) electrode coating or flux;

(b) the atmosphere;

(c) contaminants on joint such as moisture, paint, scale, oxide, low melting point constituents etc;

(d) direct entrapment of shielding gas in MIG welding.

(2) Damp electrodes or flux.

(3) Contaminated electrode wire, particularly with aluminium welding.

(4) Incorrect use of hydrogen controlled electrodes, permitting atmospheric contamination. (Gas shield from hydrogen controlled electrodes is sparser than with rutile electrodes, thus the use of a short arc technique is essential.)

(5) Too rapid cooling of the joint preventing escape of gas through the surface, ie speed of travel too fast or current too low.

(6) High sulphur content of plate or core wire.

(7) Too high current in MIG welding of steel.

(8) Inadequate shielding in MIG welding/TIG welding due to:

(a) insufficient flow of gas;

(b) dispersal of gas shield by external draughts;

(c) pre-weld gas purge/post-weld delay in gas flow not working;

(d) air entering gas lines.

(9) Root runs, exposed at the back to atmosphere are prone to produce porosity/piping. Thus back gouging must be sufficiently deep to remove these defects.

(10) Stop/start positions before arc stability is attained.

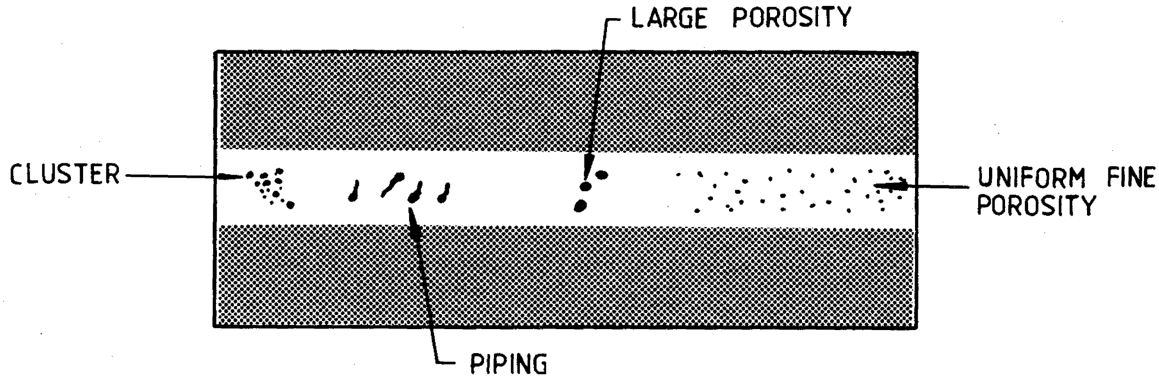


FIGURE E.7 RADIOGRAPHIC IMAGE

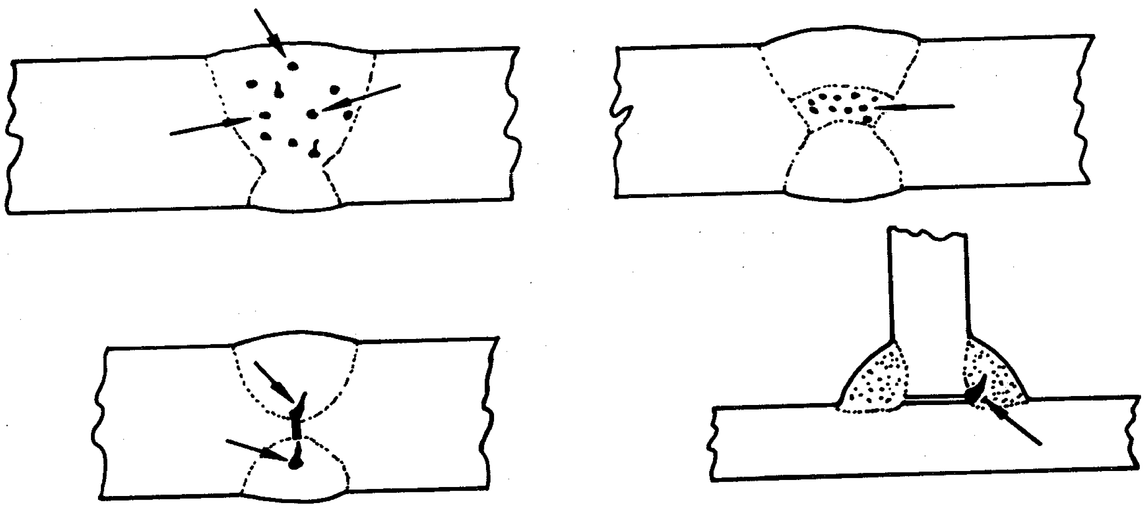


FIGURE E.8 PHYSICAL IMAGE

c. **Effect on service performance**

(1) **Static loading** Not serious unless it is gross porosity (Aero Chocolate).

(2) **Dynamic loading** Finely dispersed porosity not serious. Clusters of heavy pipes or porosity could be serious, particularly if sited on or close to the surface in tension.

(3) **Fatigue loading** Only finely dispersed porosity may be accepted provided that it does not appear on the surface of the weld either naturally or as a result of machining or grinding.

d. **Preventive measures**

(1) Piping and porosity, in particular the latter, is probably the most common defect. The possible causes are numerous; it is therefore essential to carry out careful analysis in determining the type and cause. The three main defect types are:

(a) stop/start porosity;

(b) root porosity/piping;

(c) general porosity.

(2) Stop/start porosity in MMA welding can be minimized by the start/finish technique, ie delay at start position until arc stability and effective gas shielding is attained, and the ‘run back’ practice before extinguishing the arc. In MIG welding the pre/post gas purge also becomes important. With submerged arc welding the elimination of this defect is almost impossible, thus the use of run on/off plates is essential. In some cases it becomes necessary for stop and start positions to be gouged out to remove defects and facilitate blending in or joining weld beads. It is also important to avoid alignment of stop/start positions through the weld depth.

(3) Aligned root porosity or piping is always indicative of lack of root penetration or fusion; it is therefore necessary to check that the root face of the edge preparation is not greater than the penetrating power of the particular process or alternatively that back gouging is being properly done. Contamination of the root fusion faces by paint, rust etc can also result in this defect.

(4) General porosity can be caused by many factors; joint cleanliness and effective gas shielding are essential. Cleanliness of aluminium welding wires and joints is very important. Porosity in welds made from properly baked hydrogen controlled electrodes is usually caused by long arcing. In gas shielded welding it may be necessary to provide screening if external draughts are present and to increase the gas flow, and to check against leaks in the gas shield system. The use of a gas lens in the welding torch is a means of obtaining a better gas shield flow. Dampness or moisture can be an important contributory factor in all welds but of critical importance with aluminium welding; such moisture should be removed by lightly pre-heating before welding.

E.6 Weld Metal Cracking

a. **Definition**

(1) A linear discontinuity produced by fracture. Cracks may be longitudinal, transverse, edge, crater, centre line or fusion zone.

(2) Cracks are revealed in a radiograph as fine dark lines but these may sometimes be diffused, tortuous, and often discontinuous. The detection of a crack is dependent on its orientation relative to the source of radiation.

(3) Divergence from the optimum orientation results in a broadening of the indications which may become difficult to recognize or become entirely lost.

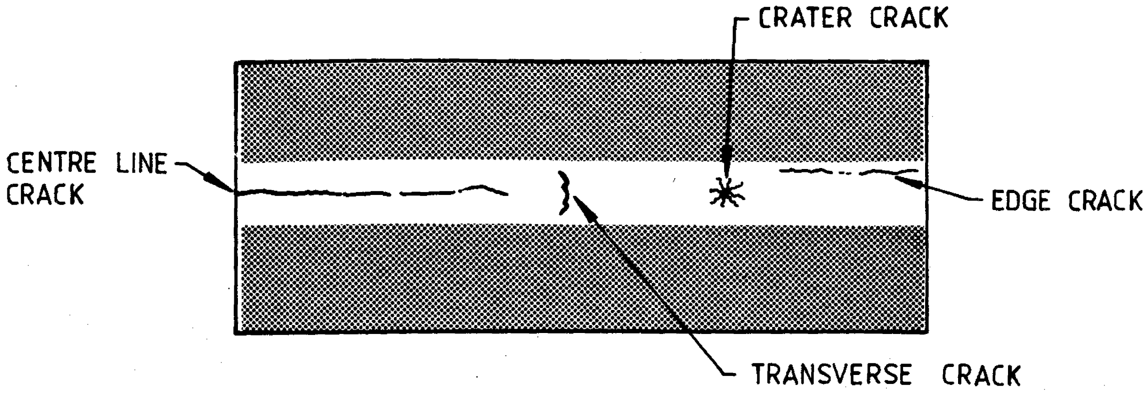


FIGURE E.9 RADIOGRAPHIC IMAGE

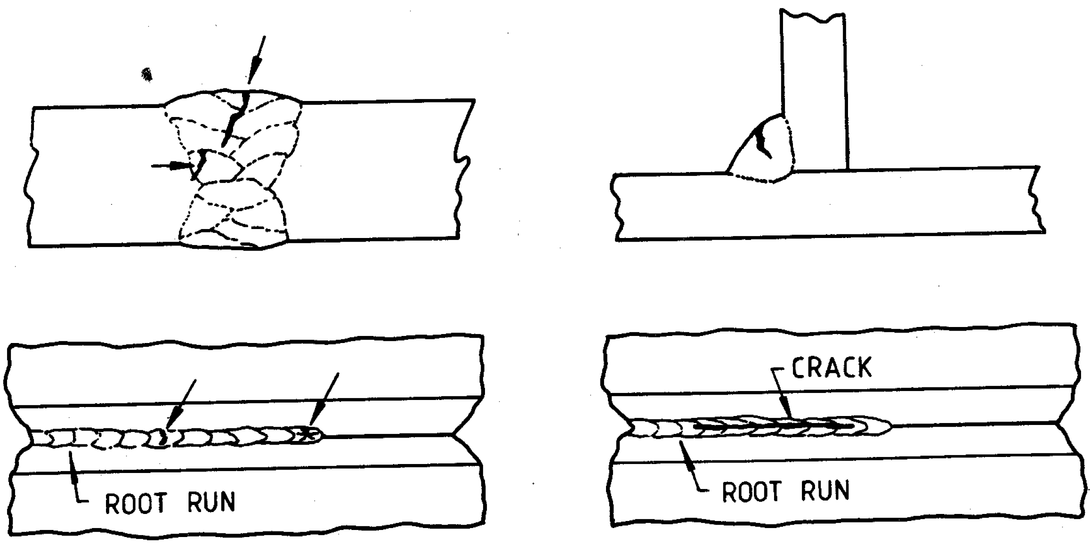


FIGURE E.10 PHYSICAL IMAGE

b. **Cause**

(1) Crater cracking; extinguishing the arc too quickly on completion of weld bead or stray arcing.

(2) Transverse cracking in steel usually hydrogen induced with higher strength weld metals; see Annex C.

(3) Centre line or edge cracking in steel; hot cracking, contractional cracking or hydrogen induced; see Annex C.

(4) Weld metal cracking in aluminium alloy occurs as contractional cracking in joints of high restraint which is aggravated by deposition of small weld beads. Hot cracking is not usually encountered when the approved filler wires are used; however, contamination by low melting point constituents can cause this defect. Crater cracking frequently occurs, and short or intermittent welds are to be avoided where possible.

c. **Effect on service performance**

(1) **Static loading** Must be evaluated according to its extent, position, and transition temperature of the steel vis-a-vis service condition. May or may not be serious.

(2) **Dynamic loading** Effect depends on size, location, and loading but even for small cracks prudence demands that it be repaired.

(3) **Fatigue loading** Effect depends on location of crack, eg middle of weld or plate surface, but is always bad. All cracks must be regarded as serious defects shortening fatigue life.

d. **Preventive measures**

(1) It is important to establish the type of cracking and the probable cause. Annex C. explains the principal causes and precautions associated with weld metal hot and cold cracking of ferritic materials. Crater cracking in both steel and aluminium welding can be avoided, in the former case by welder technique, delaying withdrawal of the electrode from the arc until the weld pool has been built up, or by the run back technique. A similar technique is to be employed in welding aluminium in addition to the post-weld purge. Certain MIG equipments are fitted with a programmed arc delay mechanism.

(2) Aluminium weld metal cracking can be avoided by ensuring that sufficient sized weld beads are deposited in joints of good fit up. In addition joint cleanliness is essential. Where cracking is persistent check that the correct filler wire is being used.

(3) In both steel and aluminium welding balanced welding sequences are to be evolved to minimize the contractional stresses.

E.7 Cracking in Parent Plate

a. **Definition**

(1) A linear discontinuity produced by fracture. Cracks may be longitudinal, transverse, edge fusion line, root or under bead.

(2) Cracks are difficult to detect by radiography on fillet or Tee butt welds. In these configurations surface cracks can be found by crack detection methods. Sub-surface defects can be indicated by ultrasonic examination of Tee butt welds but examination of fillet welds by this method is difficult. HAZ cracks in butt welds will normally be shown by radiography as for weld metal cracks.

(3) HAZ hydrogen induced cracking is not to be confused with lamellar tearing; see Annex F for the latter.

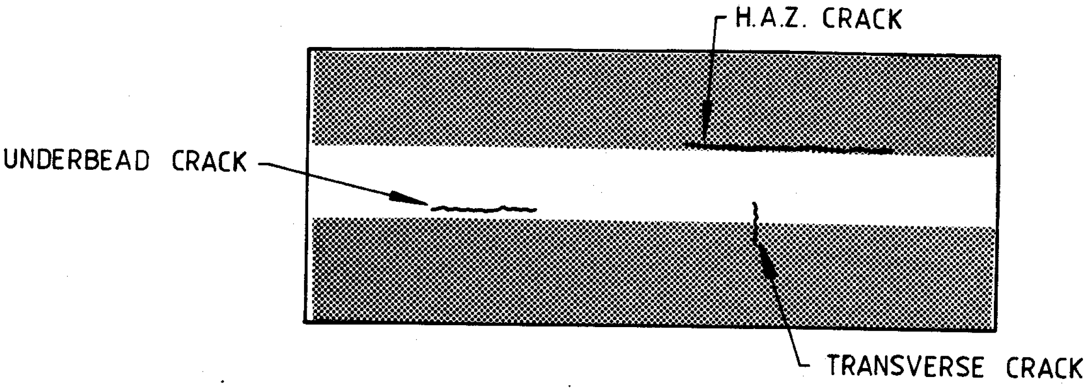


FIGURE E.11 RADIOGRAPHIC IMAGE

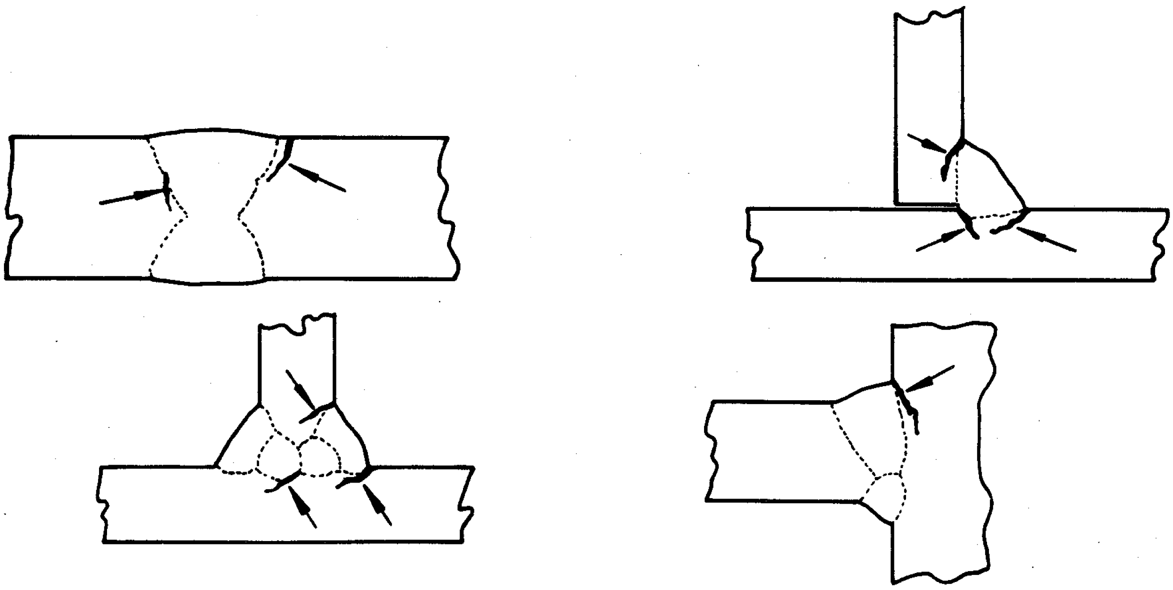


FIGURE E.12 PHYSICAL IMAGE

b. **Cause**

(1) In ferritic materials, these cracks are normally hydrogen induced or a form of hot cracking in areas of the HAZ heated above the solidification temperature of some low melting point constituents, ie S in the older obsolete steels.

c. **Effect on service performance**

(1) The remarks for weld metal cracking generally apply but in addition it must be noted that under bead cracks, appearing at or near the surface could be more serious in effect due to their position.

d. **Preventive measures**

(1) It is important to establish the type of cracking. Where hot cracking is suspected the chemical analysis of the filler material and parent material must be checked, high sulphur content being a likely cause. Where high sulphur levels are involved in the parent plate, electrodes with high manganese can, in conjunction with a welding technique minimizing the dilution factor, be a satisfactory method of avoiding the defect.

(2) Annex C. explains the principal causes and precautions aimed at minimizing HAZ cracking.

(3) The approved aluminium alloys do not normally suffer from HAZ cracking.

E.8 Undercutting

a. **Definition**

(1) An irregular groove at the toe of a weld deposit in parent material or in previously deposited weld metal due to welding.

(2) It appears in the radiograph as a dark irregular band, in a position adjacent to the toe of a weld run or as slag lines if situated sub-surface at the fusion face of the edge preparation.

NOTE: Undercutting the fusion faces in a multi-pass weld can lead to linear slag inclusions.

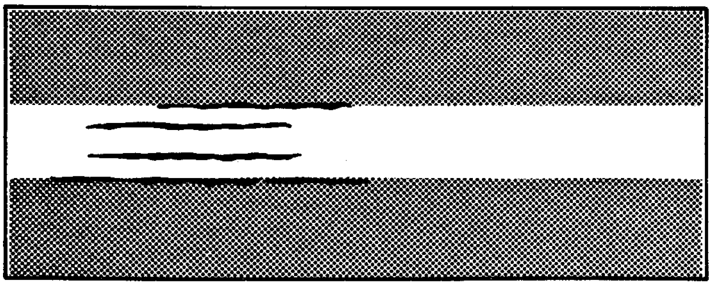


FIGURE E.13 RADIOGRAPHIC IMAGE

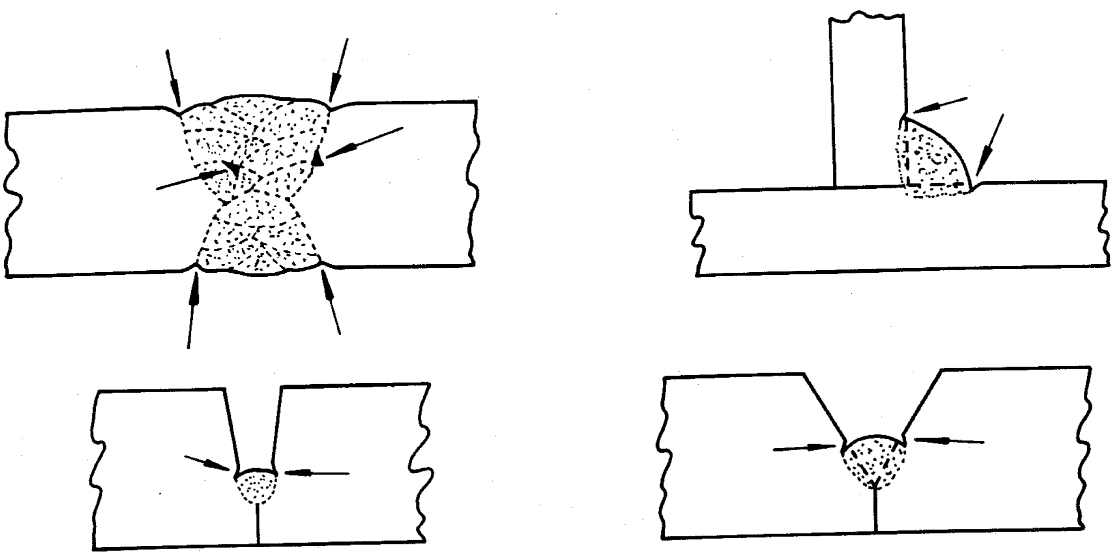


FIGURE E.14 PHYSICAL IMAGE

b. **Cause**

(1) Excessive current.

(2) Incorrect angle of electrode.

(3) Allowing too much heat to build up in heavy runs.

(4) Damp electrodes.

(5) Rust and mill scale on plate.

(6) In joints of thick to thin materials build up of heat in thin material can cause undercutting.

(7) Narrow edge preparation.

(8) Too rapid a speed of travel.

c. **Effect on service performance**

(1) **Static loading** Must be assessed according to the stress at the toe of the weld and the transition temperature of the steel. Unlikely to be serious in normal design.

(2) **Dynamic loading** Serious since it occurs where there is a stress concentration due to a geometric and metallurgical notch, and where, under bending, the stress will be high at the surface.

(3) **Fatigue loading** As for dynamic loading. Undercutting can appreciably reduce fatigue life.

d. **Preventive measures**

Check:

(1) Condition of electrodes.

(2) Operator's manipulation of electrode.

(3) Size of deposit (and therefore heat input) particularly adjacent to the upper member of the horizontal-vertical welds.

(4) Condition of plate surface.

(5) Current conditions.

(6) That edge preparation is sufficiently wide to allow electrode manipulation.

E.9 Spatter

a. **Definition**

(1) Globules of metal expelled during arc welding onto the surface of the parent metal or weld. Spatter appears in the radiograph as small light spots. It is generally in the image of the parent material but may be in the image of the weld.

(2) A special case occurs in TIG welding where the tungsten spatter gives very light images. Where this occurs within the weld image care is essential to confirm that it is on the surface and not in the weld metal.

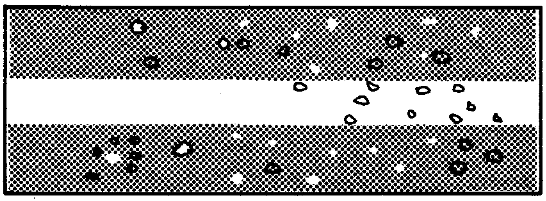


FIGURE E.15 RADIOGRAPHIC IMAGE

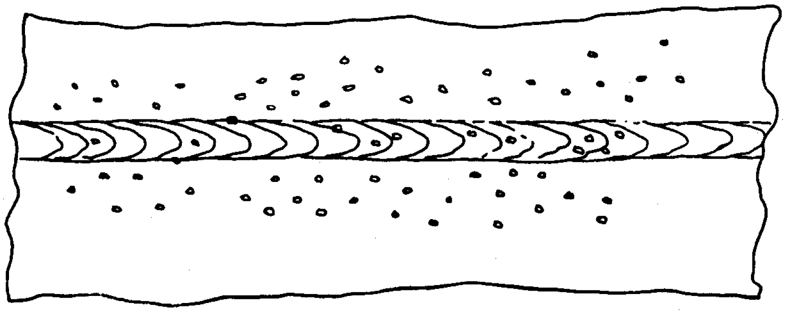


FIGURE E.16 PHYSICAL IMAGE

b. **Cause**

(1) Excessive current.

(2) Damp electrodes.

(3) Incorrect current settings in MIG welding (inductance too low).

c. **Effect on service performance**

(1) No effect on strength of joint, except in TIG welding where it is to be evaluated as inclusions, but leads to subsequent breakdown of paint coatings and therefore must be prevented or removed. It is to be removed from fusion faces since it may induce areas of lack of fusion.

d. **Preventive measures**

(1) Check arc current, condition of electrodes and operating settings of MIG equipment for compliance with procedure.

E.10 Dimensional Defects

a. **Definition**

(1) Distortion; see Annex D.

(2) Misalignment of butt welds.

(3) Weld size.

(4) Weld shape. Excessive concavity or convexity, overlap and the free edge of a plate being melted off in a lap joint, are particular examples of incorrect shape.

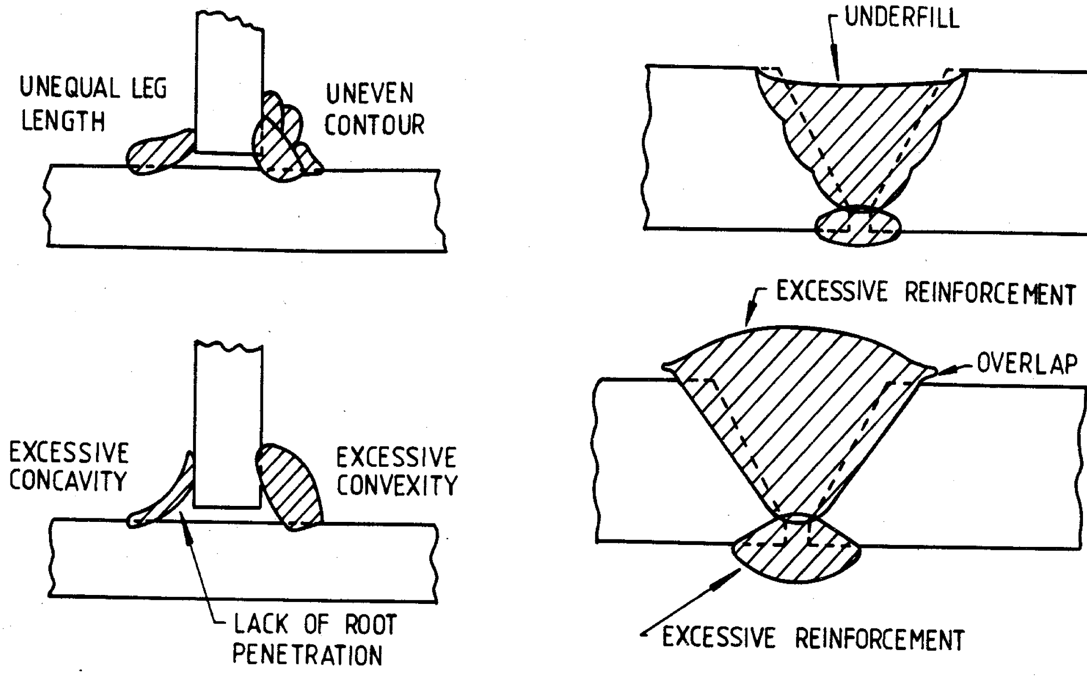


FIGURE E.17 PHYSICAL IMAGE

b. **Cause**

(1) **Distortion** Failure to adopt satisfactory weld sequences and/or balanced edge preparations; see Annex D.

(2) **Misalignment of butt welds** Results from bad fit-up.

(3) **Weld size** Depends on the joint preparation; the gauge of electrode or filler wire, the current and speed of welding, and communication of the relevant information to the welder.

(4) **Weld shape** Satisfactory weld shape depends on welder skill, the electrode and welding process being used and arc voltage and current. The profile of the individual passes of multipass welds can have considerable effect on subsequent passes. Lack of welder access and vision.

c. **Effect on service performance**

(1) **Static loading** Generally not serious except in welds where the following defects can lead to the joint failing to meet its designed strength due to reduction in the throat thickness:

(a) unequal leg length;

(b) overlap;

(c) convex fillet bead leading to poor root penetration;

(d) concave fillet bead;

(e) underfill of butt welds.

(2) **Dynamic loading** Could be serious.

(3) **Fatigue loading** Badly shaped fillet welds and/or overlap can seriously shorten fatigue life. Excessive reinforcement can cause surface notch effect which will shorten fatigue life.

d. **Preventive measures**

(1) In general terms the above defects can all be avoided by adequate supervision and procedural adherence. Where MMA electrodes are used by qualified welders within the approved limits satisfactory weld size/shape will be attained. With the semi-automatic or automatic welding processes the welding conditions related to the actual joint preparations must be evolved by pre-production procedural testing; thereafter these conditions must be followed.

(2) Dimensional defects can be detected by the use of visual inspection aided by suitable gauges. This is an important part of NDT and must not be overlooked. Welds of incorrect size or shape are to be corrected by the deposition of additional weld metal and/or grinding.

ANNEX F.

LAMELLAR TEARING

F.1 General

a. The purpose of this Annex is to provide information for designers and fabricators aimed at minimizing the occurrence of lamellar tearing in welded structures.

F.2 Description

a. Lamellar tearing is a mode of cracking which occurs in the parent plate beneath T-butt and fillet welds and at corner welds. The defect is mostly found in rolled steel plate fabrications greater than 20mm thickness.

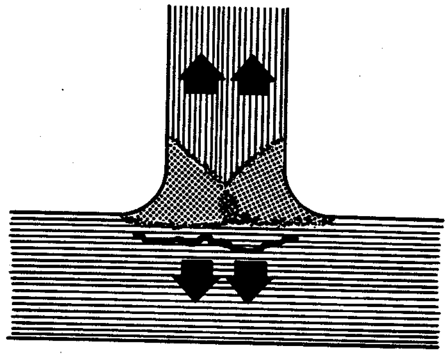


FIGURE F.1 TYPICAL LAMELLAR TEAR

(1) Lamellar tearing is characterized by its orientation and stepped appearance with long horizontal portions and short vertical steps. Often located just outside the HAZ parallel to the weld fusion boundary and plate surface. It can be completely sub-surface or break surface at weld toes. The fracture faces are fibrous, woody and typical of low ductility fractures.

(2) In some cases cracking may be extensive, extending for several feet and being readily visible on plate edges or at weld toes. In some instances complete detachment may take place causing typical ‘pull out’ fractures.

F.3 Causes

a. For lamellar tearing to occur the following conditions must be satisfied:

(1) The material must be susceptible to tearing, eg in FIGURE F.1 the horizontal plate must have poor ductility in the short transverse (through the thickness) direction.

(2) The weld orientation must be such that the strains act through the joint, across the plate thickness, ie the fusion boundary is roughly parallel to the plate surface.

(3) Strains must develop in the short transverse direction of the plate. These strains arise from weld metal shrinkage in the joint but can be greatly increased by strains developed from reactions with other joints in restrained structures. Alternatively fabrication, eg forming or bending, and thermal stresses, can develop the necessary strains.

b. **Material susceptibility**

(1) It is now generally accepted that the main reason for the poor short transverse properties is a function of the inclusion content of the plate. The inclusion content of the original ingot depends on numerous factors such as the type of steel making practice, deoxidation, composition, position in ingot etc. The inclusions are usually formed during solidification of the ingot, in the form of spheres, entectic film or small angular particles.

(2) When the ingot is rolled to form steel plate the inclusions deform into plates or discs parallel to the plate surface. High concentrations of elongated inclusions are responsible for the poor short transverse ductility.

(3) Susceptible MOD(PE) materials are: thick MS, B quality, QT28 and QT35; of these B quality and QT35 have the highest susceptibility.

c. **Weld orientation** Lamellar tearing occurs at certain critical joints usually within large welded structures involving a high degree of stiffness and restraint. Typical tearing situations are shown in FIGURE F.2 to FIGURE F.5.

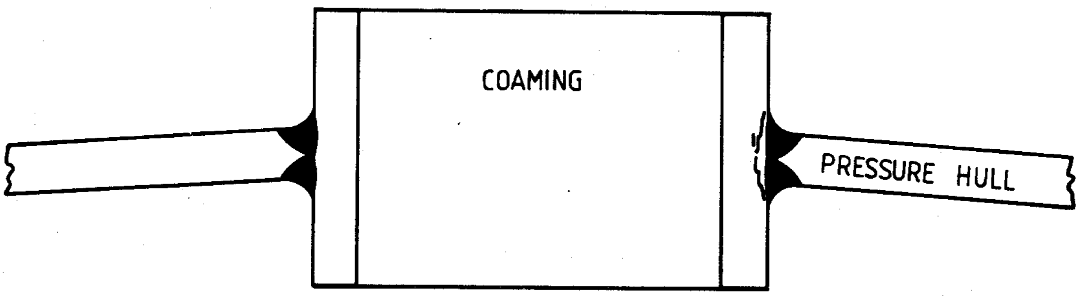


FIGURE F.2 COAMING IN P.H. T BUTT WELD

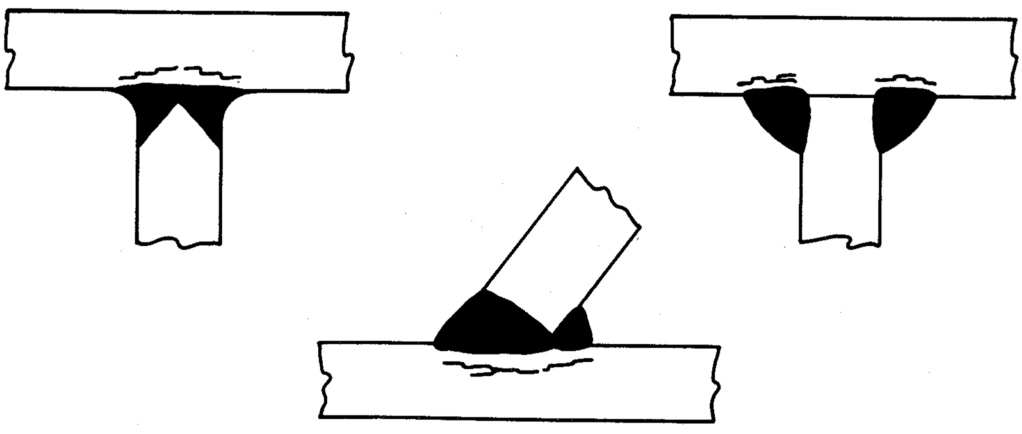


FIGURE F.3 T BUTT JOINTS

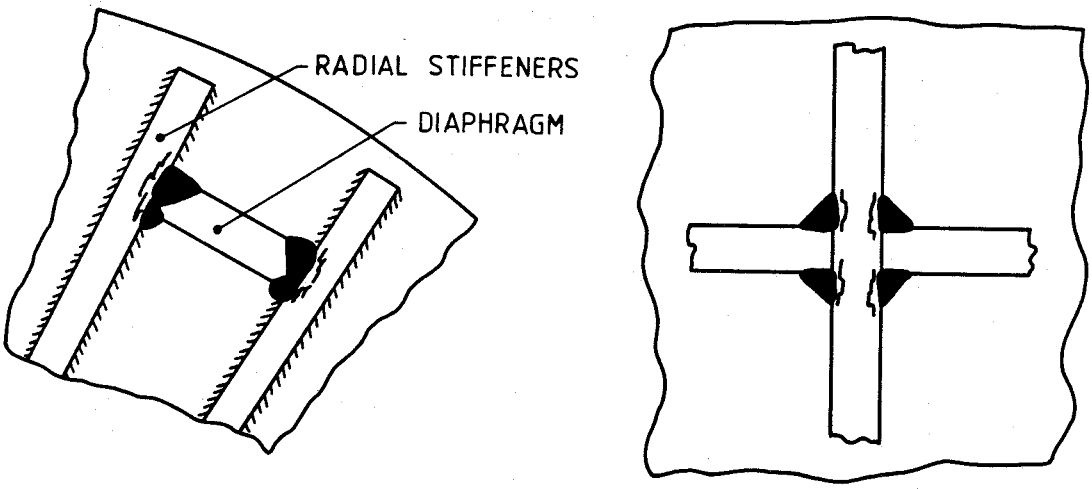


FIGURE F.4 INTERSECTING STIFFENERS

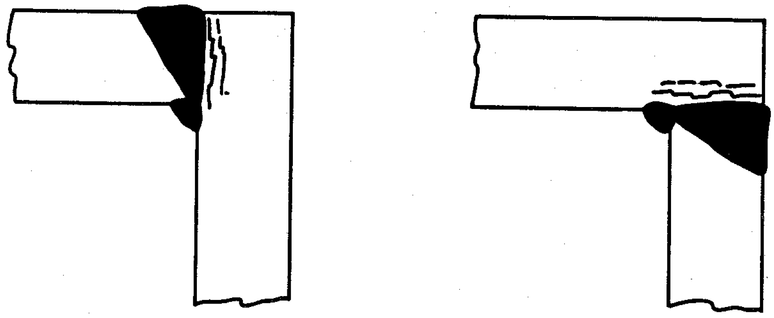


FIGURE F.5 CORNER OR FLANGE TO ROLL UP JOINT

d. **Strains:**

(1) It can be seen from the typical crack situations that the welds apply through thickness strains in the passing members resulting from weld metal contractional stresses. These stresses are aggravated in the presence of existing residual stresses and structural rigidity and further aggravated as the thickness of the material increases.

(2) In many cases the problem can be overcome at the design stage, in the first place by using a material which is not susceptible to lamellar tearing and secondly where other factors dictate the selection of susceptible material, by minimizing the degree of through thickness loading by careful selection of joint design.

(3) When designing attachment T joints it is not always necessary to match the joint strength to that of the parent material. In such cases providing it does not infringe any instructions regarding the minimum size of a single weld bead or temper bead technique the throat thickness of the weld may be reduced consistent with the degree of strength required, thus reducing the weld metal volume and subsequent contractional stresses.

(4) The following factors must be considered relative to the other requirements for weld soundness and strength aimed at attaining the best compromise. T joints with single or double sided full penetration butt welds are high risk configurations. Balanced double fillet weld joints do not give such severe problems, but this only provides a marginal improvement where thicker materials are involved. Hence where it is necessary for full penetration welds to be made in highly restrained positions, eg hatch coaming or penetrations in submarine pressure hulls, consideration should be given to using a material with a small risk of lamellar tearing, eg HY80, NQ1, or perhaps advantage can be taken of using one of the welding techniques explained in paragraph F.4c.

(5) Where corner welds or flanges to large pipes or 'roll ups' are involved considerable reduction in the risk of lamellar tearing can be attained by placing the edge preparation in the material subjected to through-the-thickness loadings; see FIGURE F.6. In this configuration the weld tends to seal the 'end grain' of the material.

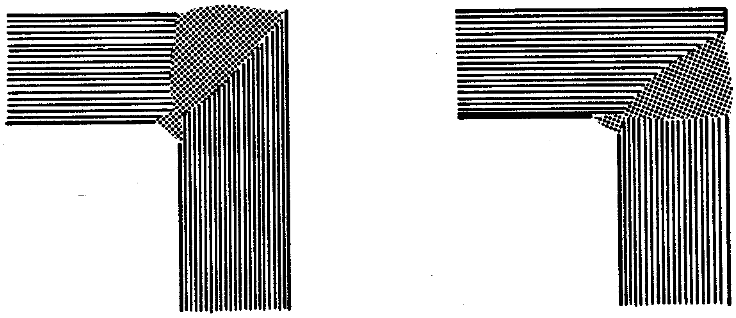


FIGURE F.6

(6) More fundamental design changes can be adopted, such as the use of extruded sections, castings or forgings to replace T butt welds as shown in FIGURE F.7. This avoids the occurrence of through-the-thickness loadings.

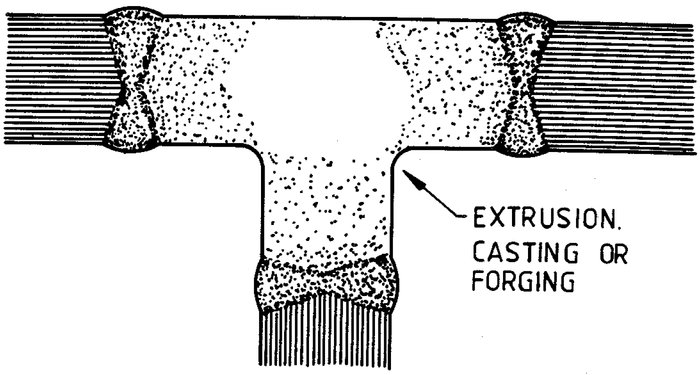


FIGURE F.7 AVOIDING THROUGH-THE-THICKNESS LOADINGS

F.4 Welding Factors

a. The choice of welding processes, welding parameters, consumables and techniques can influence the incidence of lamellar tearing. The approved welding processes for MOD(PE) work, MMA, MIG and submerged arc processes can all cause lamellar tearing. There is some evidence of a lower risk when using high heat inputs but this is probably small within the approved heat input limits imposed on MOD(PE) approved consumables.

b. The use of the lowest strength weld metal within the approved group for the material involved can be a significant means of reducing the degree of strain developed by a particular joint and thus reduce the risk of lamellar tearing. In certain circumstances the use of under-matching welds can be considered; however, this practice is only to be adopted with prior MOD(PE) approval.

c. A number of welding techniques can be applied as precautionary measures in order to minimize the risk of tearing. The use of these techniques is normally limited to high risk situations where no better alternative is available.

d. **Buttering**

(1) One or more layers of weld metal is deposited on the surface of the passing member prior to erecting the abutting member. Where possible the layer should extend for 12mm beyond the final weld toe, see FIGURE F.8 so that the stress at the weld toe is applied to weld metal which will absorb a proportion of the strain, thus reducing the effect on the parent material.

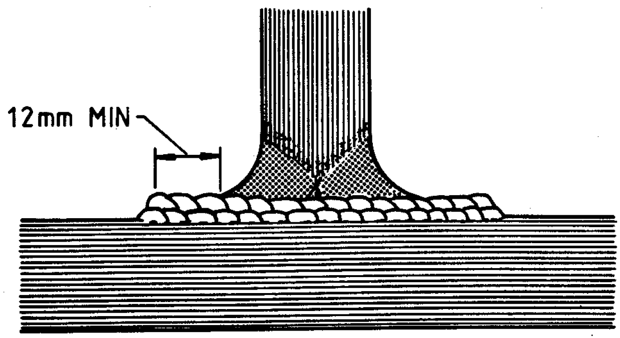


FIGURE F.8 SURFACE BUTTERING

(2) An extension to surface buttering is to groove at the surface of the passing member and fill this with weld metal prior to securing the abutting member as shown in FIGURE F.9.

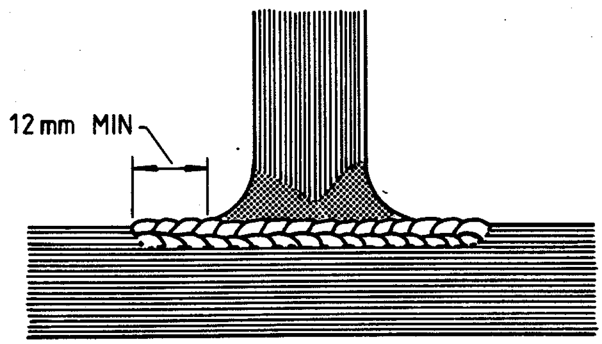


FIGURE F.9 GROOVE BUTTERING

e. **In situ Buttering**

(1) A modification to buttering the passing member before joining the abutting member is in FIGURE F.10 where the joint is erected in the normal way but the weld deposition sequence proceeds in three or more distinct layers. This method is not as successful as that described in paragraph F.4d. in preventing lamellar tearing, the last layer being deposited remote from the passing member. Both sides of the weld should be done in a similar sequence and best results will be achieved by simultaneous deposition or a balanced sequence which will minimize the angular distortion and accompanying high stresses at weld toes.

(2) This technique, in principle, relies on minimizing the strain in the parent material.

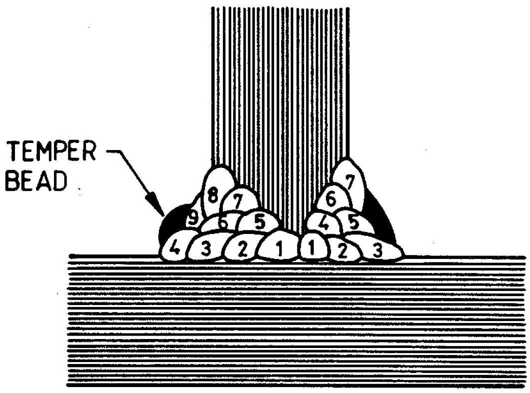


FIGURE F.10 IN SITU BUTTERING

F.5 Notes on NDT and Weld Repair Action

a. Where lamellar tears break surface these can be detected by visual, dye penetrant, magnetic particle or AMLEC examinations. Detection by surface inspection methods must be interpreted with care, to avoid the risk of confusion with other forms of cracking. Unless the tear is of the ‘pull out’ type, sub-surface examination must be done to obtain more positive evidence to determine the defect type.

b. The orientation of lamellar tearing is usually such that radiographic examination is impossible. The only satisfactory method of sub-surface inspection is ultrasonic examination; nevertheless care in interpretation is essential to avoid confusion between clusters or inclusions, microstructural bands, and actual fracture faces. Therefore, ultrasonic equipment must be calibrated and used in accordance with the relevant specifications. Particular attention must be taken to determine the position and extent of the defect indication in relation to the plate surface and weld fusion boundary to avoid confusion with lack of root fusion or other weld metal defects. In addition the weld procedure history is to be consulted to eliminate the possibility of other forms of cracking, ie HAZ hydrogen induced.

c. Once positive identification of lamellar tearing has been made the defect is to be repaired in accordance with Section 14. of this Standard or Section 15 of NES 770.

d. Pre-erection ultrasonic examination of susceptible material in the locality of T or corner welds in important structure is recommended in certain circumstances; see Section 8. The detection of unacceptable lamellar defects in the parent material at an early stage in the production programme can provide time for replacement material to be used, the weld to be re-sited in clear material, or allow plate repair by one of the buttering techniques.

e. Because of the present inability of ultrasonic examination to measure the extent and distribution of micro-inclusions, which in themselves can cause lamellar tearing, freedom from risk of lamellar tearing cannot be guaranteed.

ANNEX G.

STATEMENT OF TECHNICAL REQUIREMENTS

TITLE: ....

REFERENCE: ....

NOTES

1. This Check List is to ensure that certain aspects of this Naval Engineering Standard are consulted when preparing a Statement of Technical Requirements for a particular application.
2. Clauses where a preference for an option is to be used or where specific data is to be added are included in the Check List.
3. Each item is to be marked either

√ = included

NA = not applicable

CHECK No	CHECK	CLAUSE No	√ or NA
1	Where special NDT requirements are required over and above those specified, by the Contract Documents, these are to be indicated on drawings.	6.3a.	
2	Final dimensional accuracy is to be stated in the Contract Documents.	7.15a.	
3	Areas to be weld metal clad.	18.1a.	

ALPHABETICAL INDEX

A

B

C

D

E

F

G

H

I

J

M

N

P

Q

R

S

T

U

V

W

Inside Rear Cover

Defence Standards are Published by and Obtainable from:

Defence Procurement Agency
An Executive Agency of The Ministry of Defence
Directorate of Standardization
Kentigern House
65 Brown Street
GLASGOW G2 8EX

DStan Helpdesk

Tel 0141 224 2531/2
Fax 0141 224 2503
Internet e-mail enquiries@dstan.mod.uk

File Reference

The DStan file reference relating to work on this standard is D/DStan/69/02/706.

Contract Requirements

When Defence Standards are incorporated into contracts users are responsible for their correct application and for complying with contractual and statutory requirements. Compliance with a Defence Standard does not in itself confer immunity from legal obligations.

Revision of Defence Standards

Defence Standards are revised as necessary by up issue or amendment. It is important that users of Defence Standards should ascertain that they are in possession of the latest issue or amendment. Information on all Defence Standards is contained in Def Stan 00-00 Standards for Defence Part 3 , Index of Standards for Defence Procurement Section 4 'Index of Defence Standards and Defence Specifications' published annually and supplemented regularly by Standards in Defence News (SID News). Any person who, when making use of a Defence Standard encounters an inaccuracy or ambiguity is requested to notify the Directorate of Standardization (DStan) without delay in order that the matter may be investigated and appropriate action taken.