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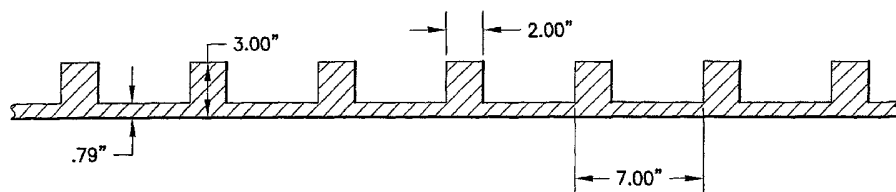
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[Continued on next page]

(54) Title: METHOD OF MANUFACTURING NEAR-NET SHAPE ALLOY PRODUCT



(57) Abstract: A method of producing a heat treatable metal product having the ordered steps of providing an ingot of a heat treatable metal alloy; rolling the ingot to a flat product; removing material from the product to achieve a near-net shape of a desired final shape; and solution heat treating the product. The product is stretched to the desired final shape and aged to achieve the desired mechanical properties.

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METHOD OF MANUFACTURING NEAR-NET SHAPE ALLOY PRODUCT

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] The present invention relates to a process for manufacturing metal alloy plate product in a near-net shape prior to heat treatment. More particularly, the invention relates to the production of a metal alloy product in which a metal alloy plate or sheet is produced in dimensions that are similar to the desired final dimensions of the product, then heat treated, stretched and aged.

Description of Related Art

[0002] Aluminum alloys are extensively used in aircraft and automobiles as well as other products that benefit from the unique combination of properties such as low weight (compared to ferrous alloys), high strength, fracture toughness, and corrosion resistance. Aircraft and automotive structural components are typically produced from a sheet or plate to which additional structural members are attached. For example, the upper and lower wing panels of an aircraft are typically produced from aluminum alloy plate (referred to as the skin) which is reinforced by extruded components (referred to as stringers). The stringers are fixed to the skin by fasteners such as rivets.

[0003] Aluminum aircraft components produced from flat rolled products are traditionally manufactured from direct chill cast ingots that may be several feet thick. The ingot is then hot-rolled to a preliminary plate or sheet thickness. Subsequent cold rolling may be performed prior to heat treating, stretching and artificial or natural aging. Prior to the artificial aging step, the mechanical properties of the alloy such as yield strength and fracture toughness are improved by solution heat treating the alloy at elevated temperatures which alters the microstructure of the solute components in the alloy. The metal is then quenched to lock in the microstructure of the alloy achieved during solution heat treatment. After heat treatment, the material is stretched, artificially or naturally aged and machined or chemically milled to its final shape.

[0004] Some final products (e.g. aircraft wing ribs) have relatively thick cross-sections of up to ten inches thick that are machined from plate. For these thick gauge applications, the ingot is hot-rolled, solution heat treated and quenched. Rapid quenching immediately following solution heat treatment is desirable for rapid locking of the elements needed for strengthening in the microstructure. A slow quench rate risks loss of mechanical properties.

However, the quench rate is dependent on the plate thickness. As the thickness of the plate increases, the quench rate for the plate decreases which results in lower achievable mechanical properties. Moreover, some aluminum alloys have mechanical properties that are readily lost if rapid quenching is not performed. It would be desirable to produce such alloys in thick cross-sections utilizing high quench rates to take advantage of improved mechanical properties. However, the product thickness has been limited by the quench sensitivity of those alloys and slower quench rates. Increasing the quench rate or reducing the cross section thickness, will result in improved mechanical properties.

[0005] Accordingly, a need remains for a method of producing heat treatable metal product at gauges at which the quench rate is acceptable.

SUMMARY OF THE INVENTION

[0006] This need is met by the method of present invention for producing a heat treatable metal product. According to one aspect of the invention, an ingot of a heat treatable metal alloy such as aluminum alloy in the F temper (the temper of the alloy as fabricated) is rolled to a flat product. Material from the flat product is removed to achieve a shape similar to the desired final (net) shape, referred to herein as the near-net shape. The near-net shaped product is solution heat treated and stretched. The stretching step flattens, stress relieves and brings the shape to the desired final dimensions. The stretched product is then artificially aged. Suitable alloys for use in the present invention are aluminum alloys including alloys of the Aluminum Association (AA) series 2XXX, 6XXX and 7XXX. The final product may be an aircraft component such as a wing panel or an automotive component.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] Fig. 1 is a cross section of a component produced according to the present invention;

[0008] Fig. 2 is a plot of electrical conductivity for the lower surfaces of plates produced according to the present invention and control plates;

[0009] Fig. 3 is a plot of electrical conductivity for the upper surfaces of plates produced according to the present invention and control plates;

[0010] Fig. 4 is a plot of tensile strength for plates produced according to the present invention and control plates;

[0011] Fig. 5 is a plot of fracture toughness for plates produced according to the present invention and control plates, both in the T7651 temper; and

[0012] Fig. 6 is a plot of fracture toughness for plates produced according to the present invention and control plates, both in the T7451 temper.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT(S)

[0013] The present invention includes a method of producing heat treatable metal products having a superior combination of properties and economies of production. The invention may be used with various alloy systems including aluminum, magnesium, copper and other alloys which rely on heat treatment for precipitation of solute for strengthening purposes, referred to herein as a "heat treatable metal alloy". The present invention is especially useful for AA 2XXX, 6XXX and 7XXX series aluminum alloys.

[0014] According to the present invention, a heat treatable metal alloy product is produced as an ingot by direct chill casting or the like. The term ingot is meant to include other bulk metal products. The metal alloy ingot is rolled into a flat product. Material from the flat product is removed resulting in a shape of the product that is near-net to a desired final shape. By the phrase "near-net shape" it is meant that the product is dimensionally similar to the dimensions of the desired final shape. Material removal may be accomplished by various techniques including via machining. The near-net shaped product is then solution heat treated and quenched. Solution heat treatment may be performed in any type of solution heat treat furnace using either a spray or an immersion quench system. The orientation of the product in a solution heat treat furnace may be selected to account for potential quench distortion and equipment design.

[0015] By removing material so that the product achieves a near-net shape, the product is thinner and the quench rate for the product is higher than the quench rate for an ingot or a traditional flat product. Accordingly, superior properties are achievable in a product produced according to the present invention due to the opportunity for high quench rate.

[0016] The solution heat treated product is then stretched to achieve the desired final dimensions for the product. The phrase "final dimensions" refers to the dimensions of the product after practicing the present invention, which may not necessarily be the ultimate dimensions of a completed component. Further altering of the product dimensions may occur depending on the end use for the product. Stretching of a product reduces the residual stresses in the product, provides flatness to the product, and may improve metallurgical properties of the product in certain alloys. By removing material so that the product achieves a near-net shape prior to solution heat treatment, the stretching process is facilitated due to the smaller volume of the product being stretched. Typically, stretching decreases the

dimensions of the stretched product by about 1.25% in each of the product thickness and the product width, i.e. has a target stretch of about 2.5%. The step of removing material so that the product achieves a near-net shape should take into account the decrease in the thickness and width of the product during stretching. For example, the dimensions of the product in its near-net shape should be 1.25% larger in each of the product thickness and the product width so that the stretching step results in the desired the final dimensions.

[0017] Finally, the stretched product which is in its desired final shape is aged such as via artificial aging. Traditionally, artificial aging is performed on a plate or sheet product. By artificially aging a product produced according to the present invention which has a significantly thinner cross-section than conventional aged products, the artificial aging process may be performed more rapidly in both the heat up of the product and the cool down of the product providing greater control and consistency.

[0018] Although the invention has been described generally above, the particular examples give additional illustration of the product and process steps typical of the present invention.

EXAMPLES

[0019] Two ingots of Aluminum Association alloy 7085 each weighing approximately 19,000 pounds were randomly selected from existing commercial stock. The ingots referred to as Ingot A and Ingot B were chosen from different casting campaigns. Alloy 7085 has the composition limits shown in Table 1.

TABLE 1

ELEMENT	MIN	MAX
SILICON	--	0.06
IRON	--	0.08
COPPER	1.3	2.0
MANGANESE	--	0.04
MAGNESIUM	1.2	1.8
CHROMIUM	--	0.04
ZINC	7.0	8.0
TITANIUM	--	0.06
ZIRCONIUM	0.08	0.15
OTHER IMPURITIES, EACH	--	0.05
OTHER IMPURITIES, TOTAL	--	0.15
ALUMINUM	REMAINDER	

[0020] Ingots A and B were scalped and homogenized using standard fabrication practices and procedures. Both ingots were hot rolled into plates 3.5 inches thick by 74 inches wide by 600 inches long using standard hot rolling temperatures and pass schedules. Each of the two 3.5 inch x 74 inch plate pieces were cut in half along its length to yield two sets of two 300 inch long plates. One plate from Ingot A and one plate from Ingot B were processed according to the present invention to produce plates having integrally formed stringers on a web (referred to as ISP plates). The two ISP plates were machined from the F temper down the full length to produce the cross section configuration shown in Fig. 1 and are referred to as ISP A plate and ISP B plate. The other plates from each of Ingots A and B were processed in their original configurations as control plates and are referred to as Control A plate and Control B plate.

[0021] All four plates were solution heat-treated in a horizontal furnace and spray water quenched in accordance with AMS (American Metals Society) 2772 guidelines. The ISP plates A and B were solution heat treated with the stringers oriented up. All plates were stretched to a target of 2%.

[0022] To check for quench efficiency, the plates were scanned using eddy current to evaluate the surface electrical conductivity uniformity. Fig. 2 shows the % IACS (International Annealed Copper Standard) electrical conductivity across the width (longitudinal transverse direction) of bottom sides (lower surface during quenching) of the ISP A and B plates (smooth side, without the machined stringers) and of the Control plates A and B. Fig. 3 shows the % IACS electrical conductivity for the top sides of the plates (upper surfaces during quenching). The data for the top side of the ISP plates was taken on stringers at the edge of the plates (Edge Stringer) and on stringers midway across the plates (W/2 Stringer). The data for the top side of the control plates was taken at halfway across the width of the plates (W/2). For the bottoms of the plates and the top sides of the plates, the % IACS electrical conductivity for the ISP plates was uniformly lower than for the control plates. Lower % IACS electrical conductivity is indicative of higher quench rate. As such, product with thinner cross sections than conventional products can be produced according to the present invention at higher quench rates.

[0023] Prior to artificial aging the four plate sections, each plate was again cut in half to yield a piece of plate approximately 150 inches long. The 150 inch plates were aged to each of T7651 type temper and T7451 type temper. Two control plates and two ISP plates were aged to each temper condition. Upon completion of the artificial aging, the plates were sectioned for mechanical property testing. To ensure an accurate comparison between the

control plate properties and the ISP plate properties, special care was taken to keep all of the test plane references relative to the original rolled plate thickness. This was important to eliminate variability in test results associated with chemical composition or grain structure gradients through thickness. Tensile strength testing was performed on the webs of the ISP and control plates from each of Ingots A and B at a plane halfway through the thickness of the plate web ($t/2$) at width locations of the plate edge (Edge) and midway across the plate ($W/2$). Fracture toughness testing was performed at planes of halfway through the thickness of the plate web (Web/2), one quarter through the thickness of the stringer ($t/4$) and halfway through the thickness of the stringer ($t/2$) at several locations across the plate including the plate edge (Web Edge), the stringer edge (Stringer Edge), midway across the plate in the web (Web $W/2$), and midway across the plate in the stringer (Stringer $W/2$). Test locations for the control plates were made in the locations of the solid (non-machined) plates as if the control plates had been machined to include stringers and web so that the comparison between ISP and control plates was referenced from the same position in the original ingot.

[0024] Fig. 4 shows the longitudinal transverse tensile strength data in KSI units (ultimate yield strength or UTS and tensile yield strength or TYS) for the ISP and control plates produced from Ingots A and B, aged to T7651. The ISP plate strengths are generally equal to or slightly above the control group.

[0025] Fig. 5 shows the fracture toughness for the ISP and control plates produced from Ingots A and B aged to T7651, and Fig. 6 shows similar data for plates aged to the T7451 temper. The ISP plates generally exhibited 10% to 20% higher fracture toughness than the control plates in all locations for both tempers.

[0026] It should be appreciated that the present invention allows for machining (or other material removal) of bulk metal into a near-net shape prior to solution heat treatment, stretching and aging with superior properties in the final product compared to conventionally manufactured product that is machined after aging.

[0027] The present invention provides economical benefits in the production of aluminum alloy products. Productivity may be increased due to higher quench rates and shorter aging practices of the near-net shape product with concomitant energy savings.

[0028] In addition, certain aluminum alloy products with complicated shapes have not previously been produced from flat-rolled wrought products. Extrusion, forging and casting processes are typically employed to manufacture such products and those processes do not always impart the mechanical properties achievable with wrought products. However, by using the method of the present invention the shapes of extruded, forged or cast products may

be manufactured in a wrought product by removing material from a flat-rolled (wrought) product to achieve a near-net shape prior to solution heat treatment.

[0029] Further potential benefits of the present invention include reduced weight of components and manufacturing cost savings for the end use customer. The total weight for structural components may be reduced by manufacturing product according to the present invention. Fasteners and other related structural members required for joining components to each other are minimized or avoided when the product is machined to its near-net shape as an integrally manufactured product. For example the stiffening members (e.g. stringers) of an aircraft wing panel may be integrally produced with the skin using the method of the present invention. The opportunity for cost savings to the end use customer may include reduced process time to achieve the final part configuration (e.g. less machining or chemical milling time) and reduced process scrap.

[0030] It will be readily appreciated by those skilled in the art that modifications may be made to the invention without departing from the concepts disclosed in the foregoing description. Such modifications are to be considered as included within the following claims unless the claims, by their language, expressly state otherwise. Accordingly, the particular embodiments described in detail herein are illustrative only and are not limiting to the scope of the invention which is to be given the full breadth of the appended claims and any and all equivalents thereof.

WHAT IS CLAIMED IS:

1. A method of producing a heat treatable metal product comprising the ordered steps of:
 - (a) providing an ingot of a heat treatable metal alloy;
 - (b) rolling the ingot to a flat product;
 - (c) removing material from the product to achieve a shape near-net to a desired final shape;
 - (d) solution heat treating the product;
 - (e) stretching the product to achieve the desired final shape; and
 - (f) aging the product.
2. The method of claim 1, wherein the metal alloy is an aluminum alloy.
3. The method of claim 1, wherein step (c) comprises machining the product to achieve the near-net shape.
4. The method of claim 2, wherein the aluminum alloy is selected from the group consisting of AA series 2XXX, 6XXX and 7XXX.
5. The method of claim 2, wherein the flat product is in the F temper.
6. The method of claim 2, wherein the final product is a component of an aircraft.
7. The method of claim 6, wherein the component is a wing panel.
8. The method of claim 7, wherein step (c) comprises machining the near-net shape of a skin and stiffening members in the wing panel.
9. A heat treated metal component produced according to the method of claim 1.

10. The heat treated metal component of claim 9, wherein said product is a component of an aircraft.

11. The heat treated metal component of claim 10, wherein the component is a wing panel.

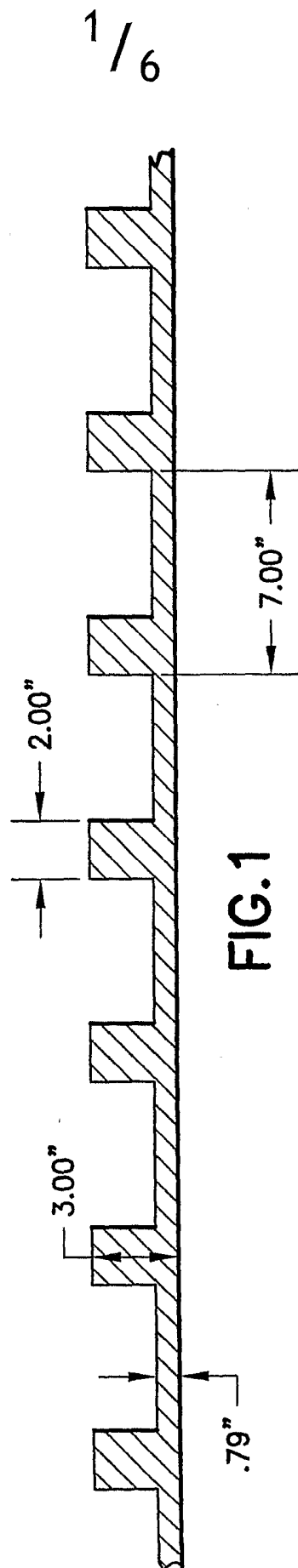


FIG. 2
Electrical Conductivity of Plate Bottom Side in
Longitudinal Transverse Direction Across Plate

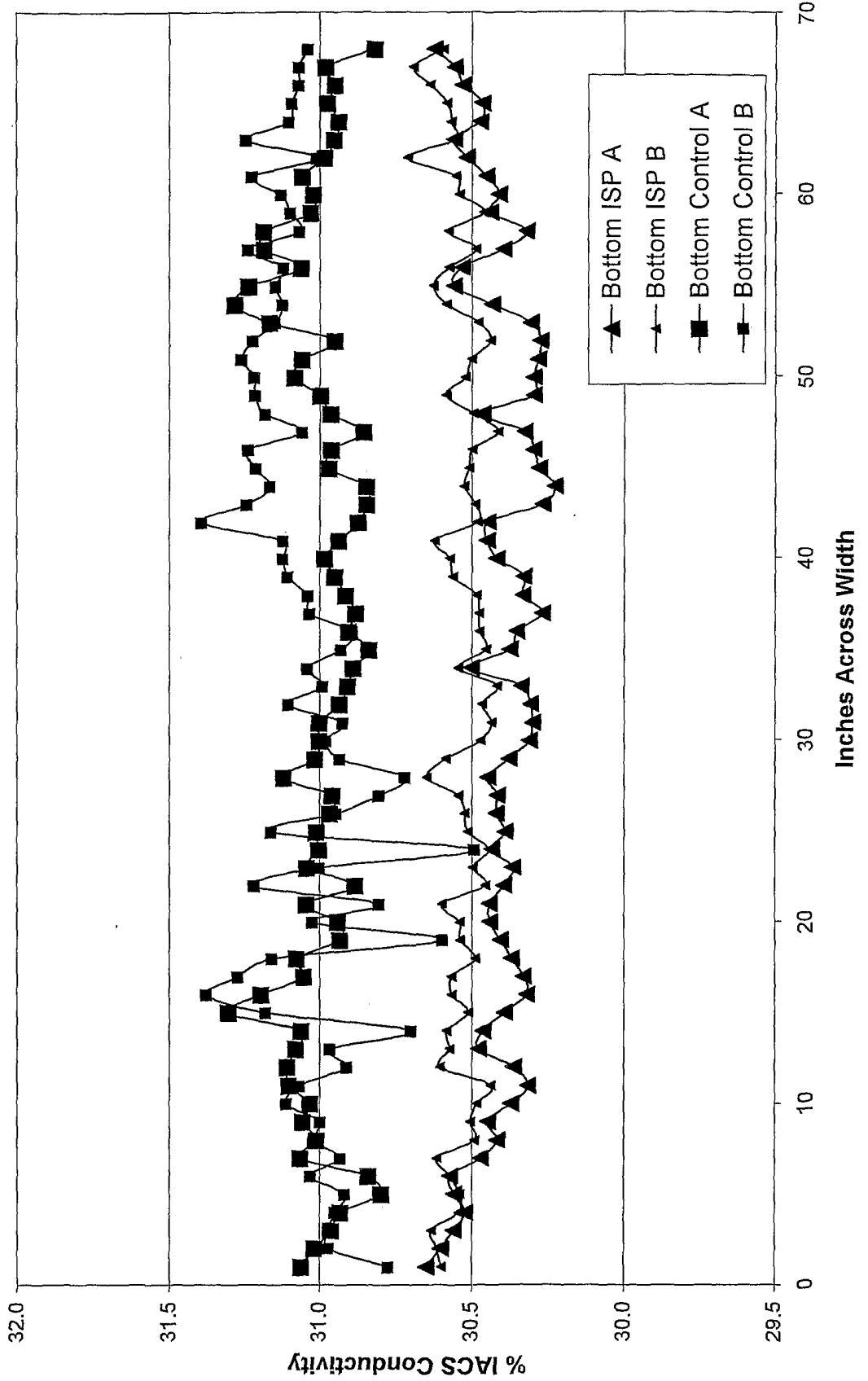


FIG. 3
Electrical Conductivity of Stringer/Upper Side in the
Longitudinal Direction Down the Length of Plate

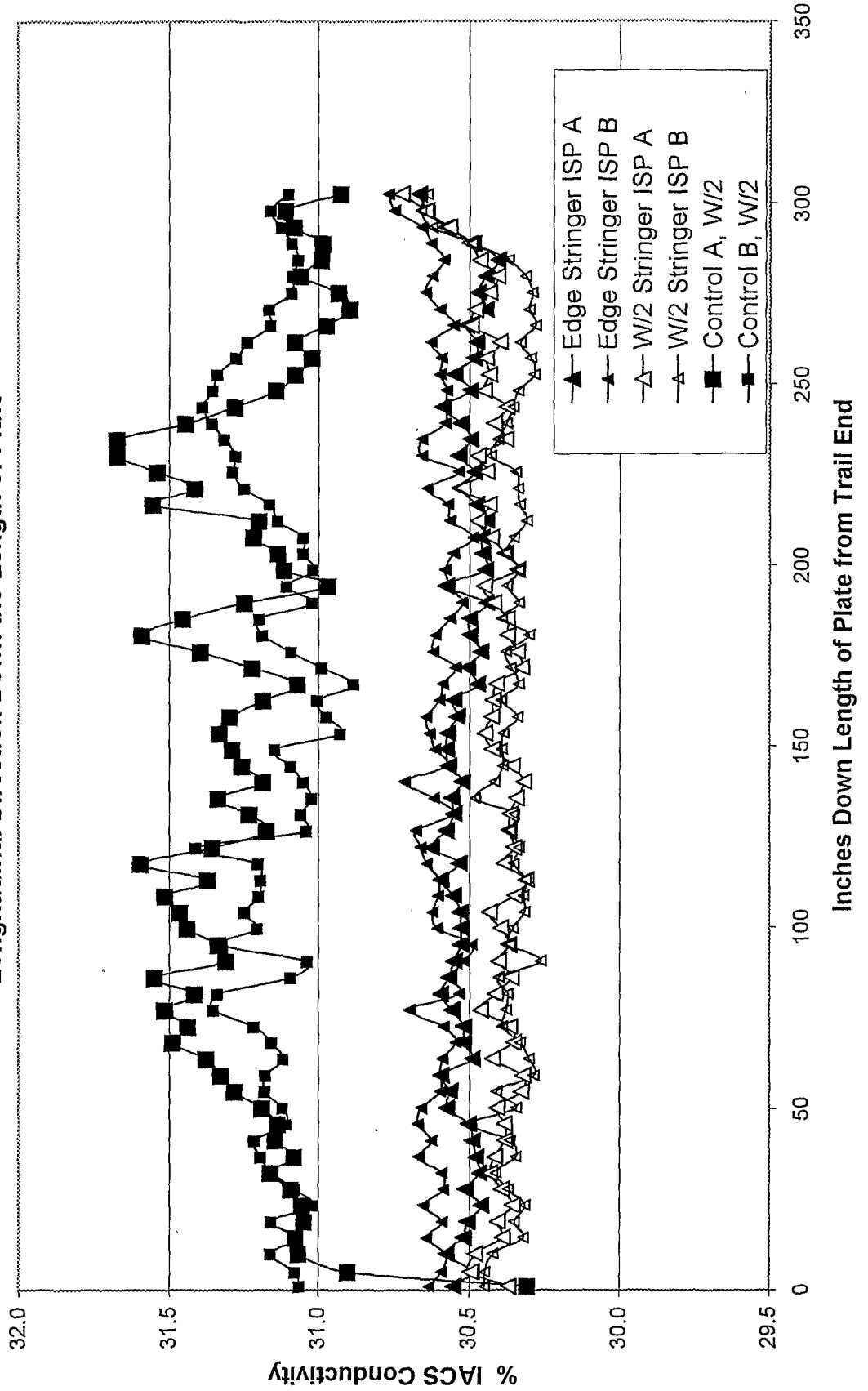
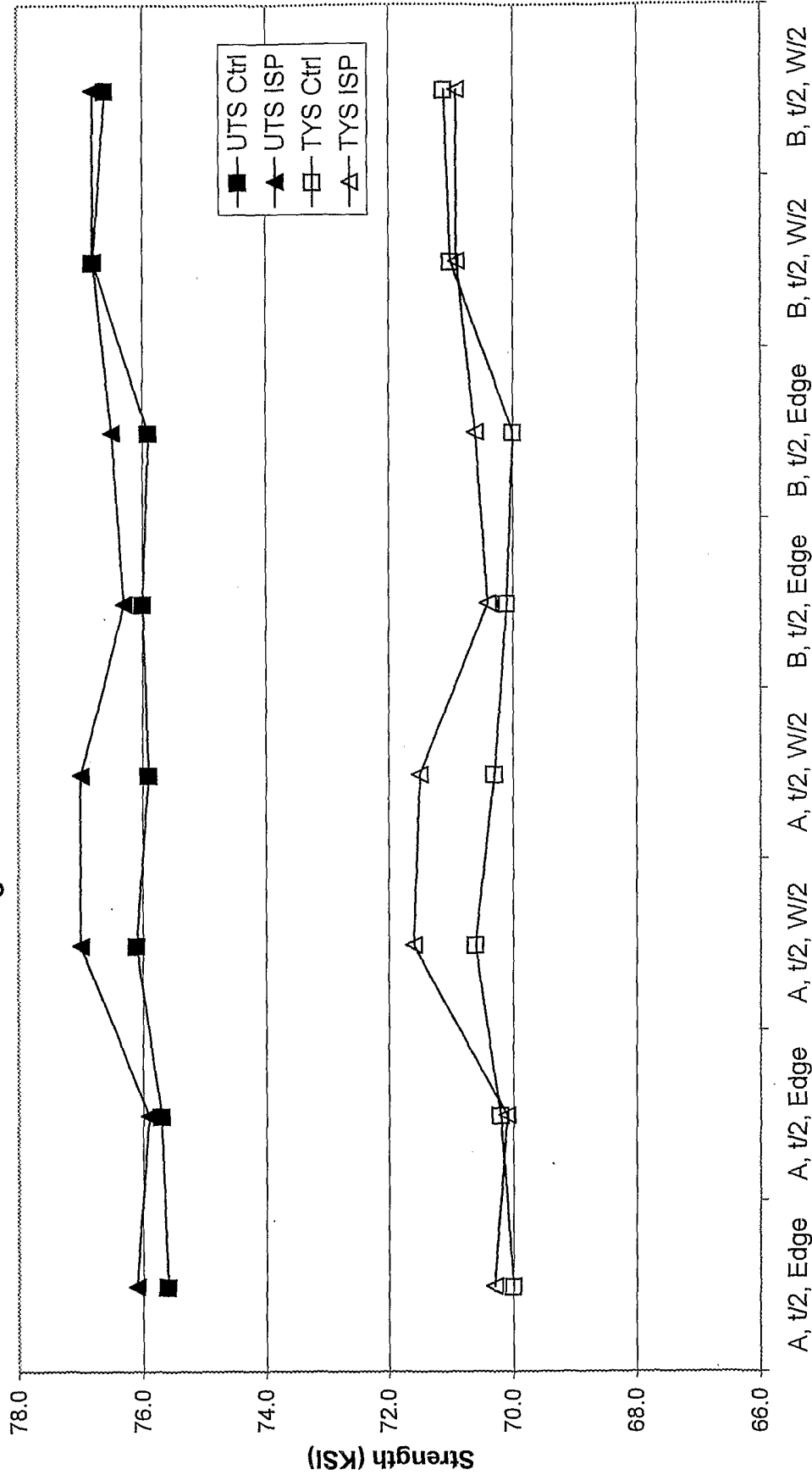
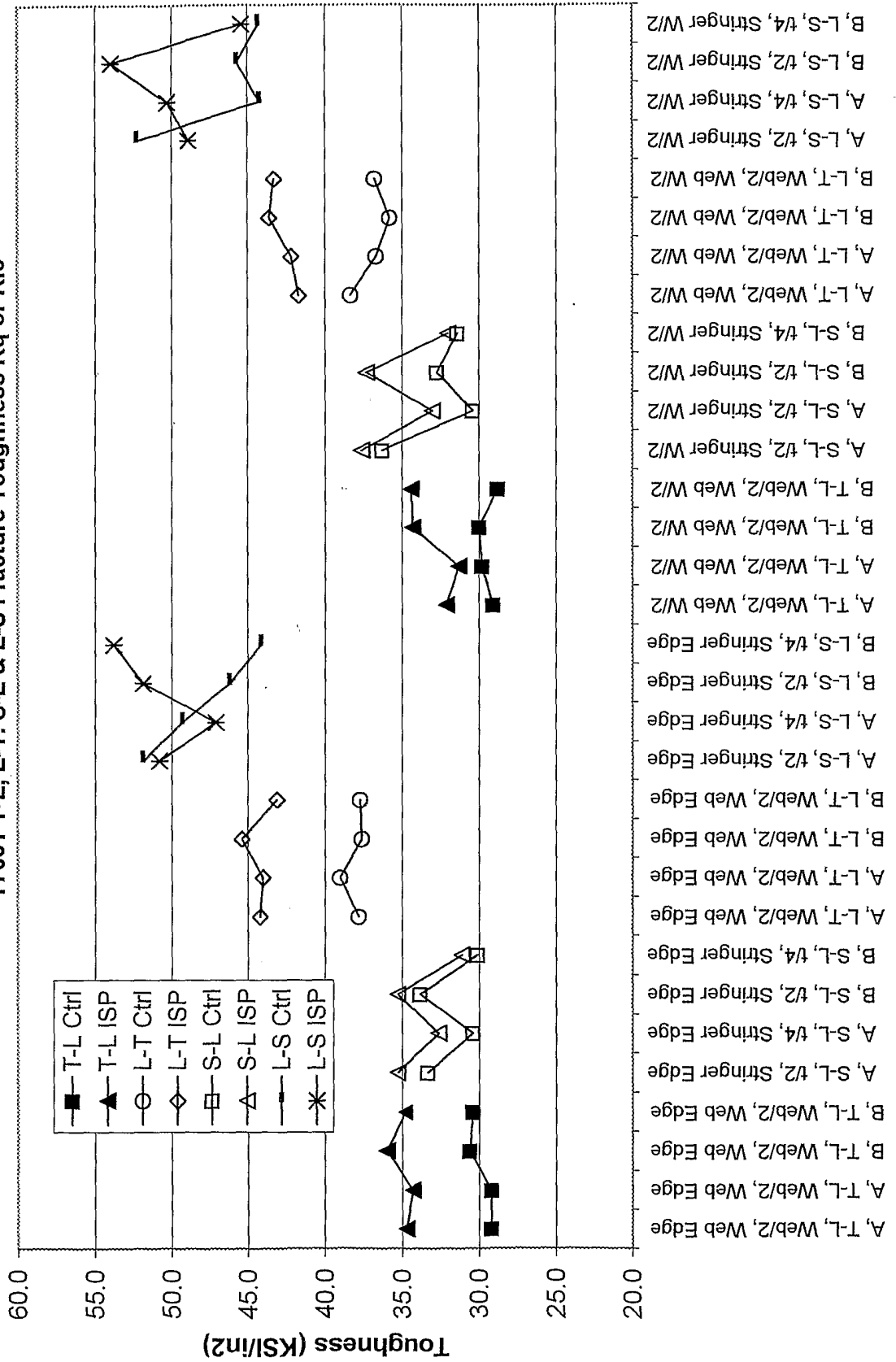


FIG. 4
T7651 Longitudinal Transverse UTS & TYS



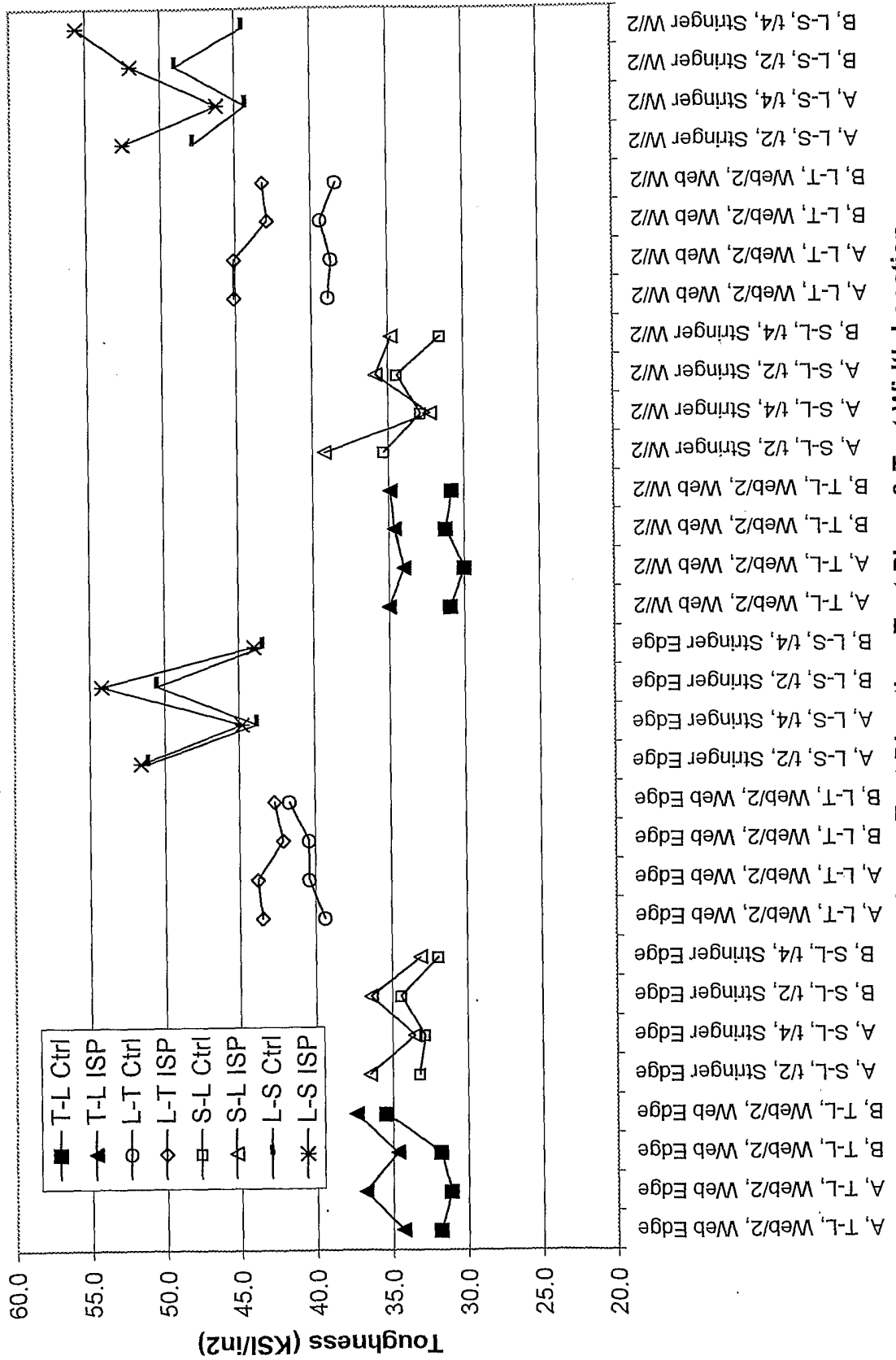
Source Ingot, Test Plane and Test Width Location

FIG. 5
T7651 T-L, L-T, S-L & L-S Fracture Toughness K_q or K_{Ic}



Source Ingot, Test Direction, Test Plane & Test Width Location

FIG. 6
T7451 T-L, L-T, S-L & L-S Fracture Toughness K_q or K_{1c}



6/9

Source Ingot, Test Direction, Test Plane & Test Width Location

INTERNATIONAL SEARCH REPORT

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A. CLASSIFICATION OF SUBJECT MATTER IPC 7 C22F1/04 C22F1/05 C22F1/057		
According to International Patent Classification (IPC) or to both national classification and IPC		
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Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practical, search terms used) EPO-Internal		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Information on patent family members

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