United States Patent [19]

Jones et al.

[11] **3,908,431**

[45] **Sept. 30, 1975**

[54] **STEELS AND METHOD FOR PRODUCTION OF SAME**

[75] Inventors: **Samuel H. Jones**, Flossmoor; **James M. McNeany**, Park Forest South, both of Ill.

[73] Assignee: **LaSalle Steel Company**, Chicago, Ill.

[22] Filed: **May 7, 1974**

[21] Appl. No.: **467,639**

[52] **U.S. Cl.** .... **72/364;** 148/12 B
[51] **Int. Cl.²** **B21C 9/00**
[58] **Field of Search** .... 148/12 B; 72/364

[56] **References Cited**

UNITED STATES PATENTS

1,928,727	10/1933	Johnson	148/12
2,281,132	4/1942	Young	148/12
3,580,746	5/1971	Behar	148/12

Primary Examiner—Lowell A. Larson

[57] **ABSTRACT**

Improved steels and method for the manufacture of same, wherein an elongated steel workpiece is subjected to the steps of cold drawing to pre-strengthen the steel, straightening the workpiece and then rapidly heating the workpiece to a temperature within the range of 500°F to the lower critical temperature of the steel in less than 10 minutes. Steels produced in accordance with the present invention have high tensile strength, high yield strength and low residual stresses.

20 Claims, 7 Drawing Figures

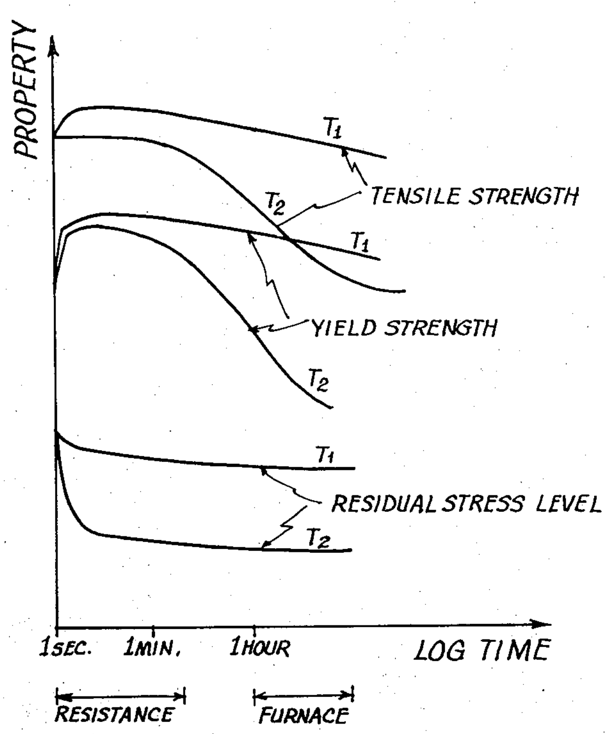


FIG. 1

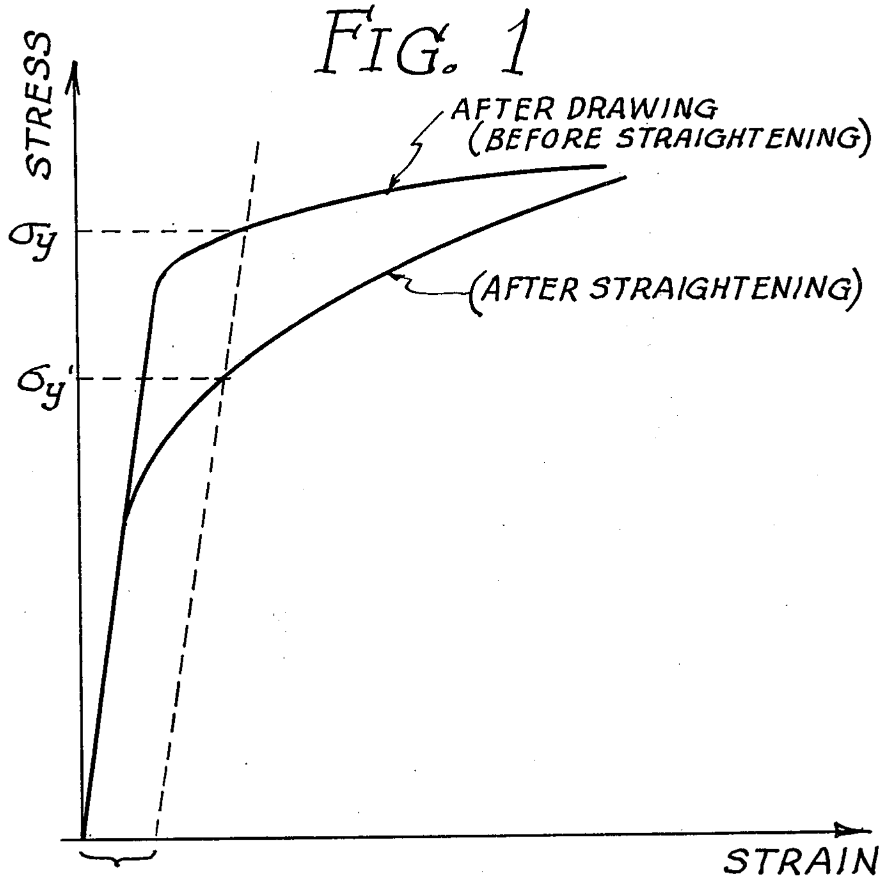


FIG. 3

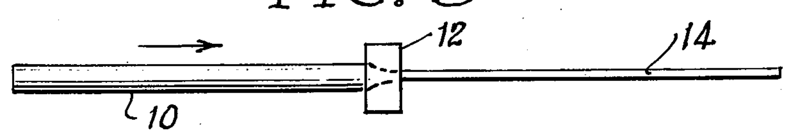


FIG. 4

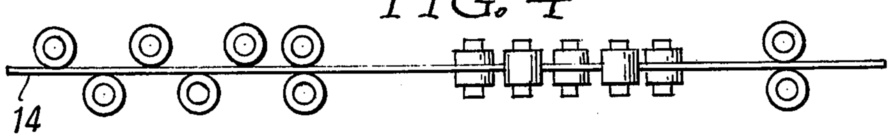


FIG. 5

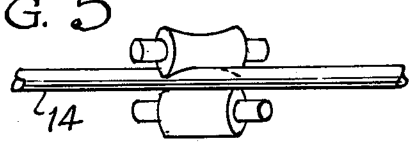


FIG. 6

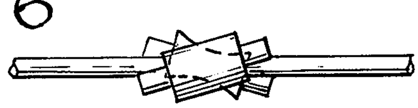


FIG 2

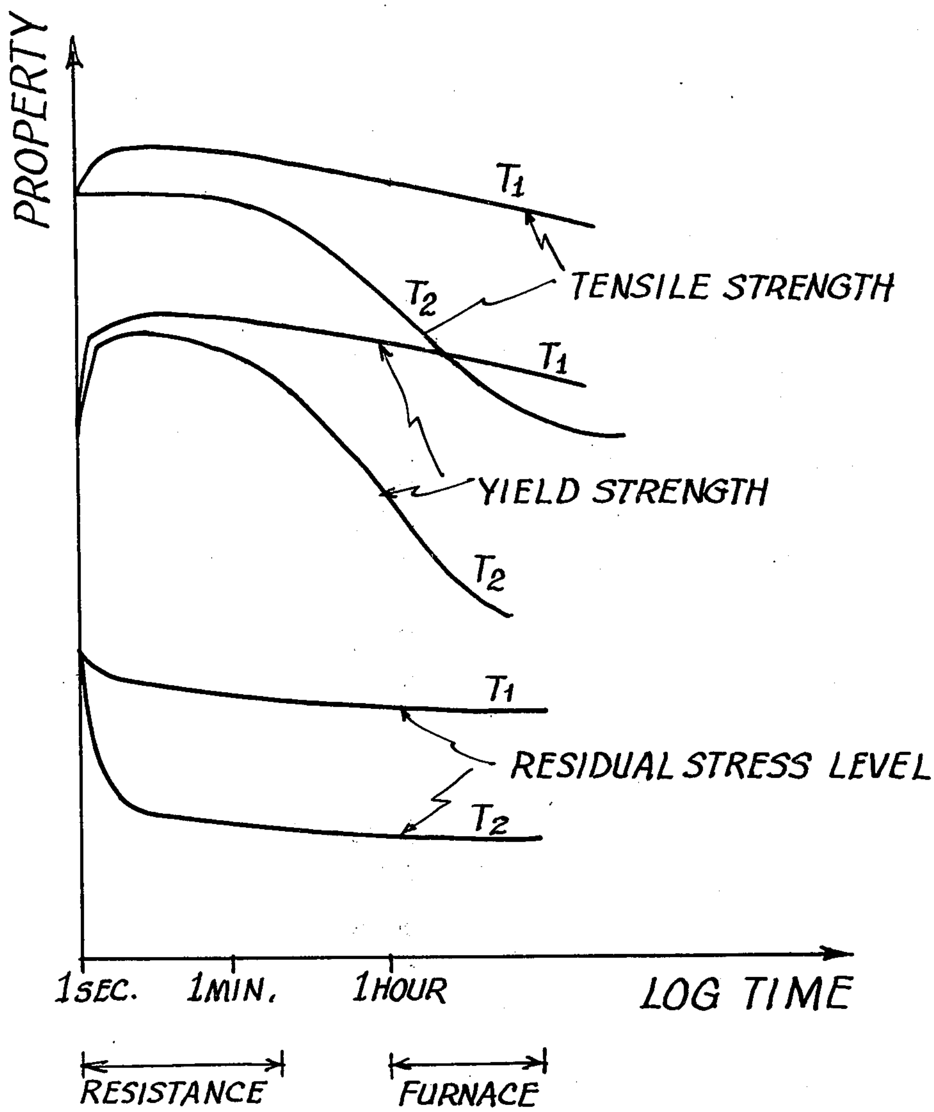
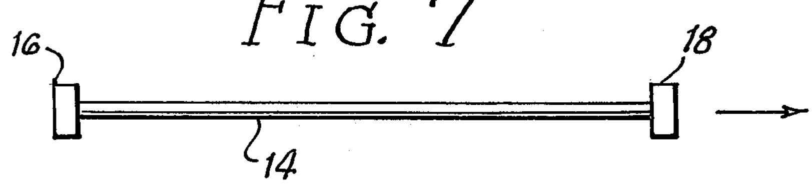

PROPERTY
T1
TENSILE STRENGTH
T2
T1
YIELD STRENGTH
T2
T1
RESIDUAL STRESS LEVEL
T2
1 SEC.
1 MIN.
1 HOUR
LOG TIME
RESISTANCE
FURNACE

FIG. 7


16
18
14

STEELS AND METHOD FOR PRODUCTION OF SAME

This invention relates to pre-strengthened, stress-relieved elongated steel products, and more particularly to steels having high tensile strength, high yield strength and a low level of residual stresses.

As is well known to those skilled in the art, pre-strengthened cold finished steel bars are characterized by a combination of high strength with good machinability and thus, usable parts can be manufactured from the steel bars by various machining operations without the need for subsequent heat treatment steps.

Up to the present, pre-strengthened cold finished steel bars or rods were generally produced by cold drawing a bar or rod through a die while effecting a relatively large reduction in the cross-sectional area of the bar or rod. The cold drawing operation is then followed by a straightening operation in which the bar or rod is passed through a plurality of rollers which successively bend the bar or rod through decreasing arcs to effect a straightening of the bar or rod. Straightening apparatus for this purpose are well known to those skilled in the art and include Lewis straightening equipment and Medart straightening equipment. It has been found desirable to follow the straightening operation by a stress relieving operation to provide a higher level of yield strength in the bar or rod as well as a somewhat reduced level of residual stresses.

The stress relieving operation is usually carried out in a batch or continuous furnace maintained at a temperature within the range of 500° to 1200°F. Uniformity, from the standpoint of uniformity of a single bar and uniformity from bar to bar processed in a furnace is an important consideration in maximizing the yield strength while minimizing the residual stress level. It has been found that the uniformity of the resulting bar or rod is directly related to the degree of temperature uniformity maintained during the heating process. Production furnaces used in the commercial manufacture of stress relieved bars and rods are, due to economic necessity, charged with several tons of bars at a single time so that the desired uniformity can be achieved only by maintaining the bars at the proper temperature for several hours, usually of the order of five hours or more. Even with such a long residence time of the bars in the furnace, it is difficult to achieve ideal uniformity with respect to both the temperature at which the bars are maintained and the time during which the bars are maintained at the desired temperature and still achieve economical production rates.

It is an object of the present invention to provide a method for the manufacture of stress relieved pre-strengthened steel workpieces, such as bars, rods and the like, which overcomes the foregoing disadvantages, and it is a more specific object of the invention to provide a method for the manufacture of stress relieved prestrengthened steels having high tensile strength, high yield strength and a low level of residual stresses.

It is another object of the present invention to provide a method for the manufacture of stress relieved, prestrengthened elongate steel workpieces, in which the method can be carried out quickly to produce stress relieved products in an economical manner, and which can be carried out to provide improved uniformity in the heating operation, both from the standpoint of a single workpiece and from workpiece to workpiece.

These and other objects and advantages of the invention will appear more fully hereinafter, and for purposes of illustration, but not of limitation, an embodiment of the invention is shown in the accompanying drawings in which:

FIG. **1** is a graph illustrating the relationship of stress and strain for steel workpieces before and after straightening;

FIG. **2** is a graph illustrating the effects of the time during which a steel is subjected to an elevated temperature stress relieving operation, with tensile strength, yield strength and residual stress levels;

FIG. **3** is a schematic illustration of a cold drawing operation;

FIG. **4** is a schematic illustration of a straightening operation using a Lewis straightener;

FIGS. **5** and **6** illustrate the operation of a Medart-type straightener, and

FIG. **7** illustrates the preferred stress relieving operation carried out in accordance with the practice of this invention.

The concepts of the present invention reside in the discovery that the tensile and yield strengths of a steel can be maximized and the residual stress levels can be minimized where an elongate steel workpiece is subjected to the steps of cold working to prestrengthen the steel, then straightening the steel, followed by stress relieving at an elevated temperature where the stress relieving operation is performed by heating the workpiece rapidly to the desired temperature, generally within 10 minutes. It has been found that elongate steel workpieces produced in this manner provide greater product uniformity, improved machine-ability and significantly lower levels of residual stresses.

As is illustrated in FIG. **1** of the drawing, which is a graph of stress versus strain, cold drawing of a steel workpiece provides a proportional increase in the stress as the strain on the workpiece is increased until the elastic limit of the steel is reached. At this point, the curve levels off to provide a more gradual increase in stress as the strain, to which the bar is subjected, is increased. However, the straightening operation referred to above provides a somewhat different effect. As shown in FIG. **1** of the drawing, the relationship of stress with strain for a steel workpiece which has been first subjected to cold drawing and then subjected to straightening is somewhat different from that of a steel workpiece after drawing but before straightening. As is shown by the lower curve in FIG. **1**, the relationship of stress with strain for a workpiece which has been cold drawn and then straightened is linear until the elastic limit is reached and then the stress increases more slowly with increasing strain. Thus, the cold drawing operation operates to increase the strength of the steel, but also to impart to it residual stresses. The straightening operation, on the other hand, serves to rearrange or redistribute the residual stresses, but results in a decrease in the yield strength of the resulting workpiece. As is shown in FIG. **1**, the yield strength, i.e. the stress at which the metal will develop a strain of 0.2% is, Σ_y. The value of the yield strength Σ_y for the workpiece, which has been subjected to cold drawing, is higher than the yield strength Σ_y' for the workpiece which has been subjected to cold drawing and then straightening.

The purpose of the stress relieving operation described above is to cause the yield strength to increase. There is shown in FIG. **2** of the drawing a series of curves illustrating the effect of an elevated temperature stress relief operation on the properties of tensile strength and yield strength as a factor of the logarithm of the time during which the heat treatment is carried out. For each property, there are shown two curves, one for a temperature T_1 (of the order of 600°F), and the other for a temperature T_2 (of the order of 900°F). As can be seen from these curves, both the tensile strength and the yield strength of a steel workpiece which has been subjected to cold drawing and then straightening decrease as the elevated temperature stress relief operation is carried out, and the rate of decrease in the tensile strength and the yield strength increases with the time of heat treatment. In the case of the residual stress level, however, the rate at which the residual stress level is decreasing is much faster. In accordance with the practice of this invention, the use of a rapid uniform heating step in the stress relieving operation serves to provide generally the same reduction in the residual stress level, but serves to maximize the tensile and yield strengths by limiting the time during which the workpiece is subjected to the elevated temperature. In other words, by the use of a rapid uniform heating step the stress relieving operation is carried out before a rapid decrease in the tensile strength and yield strength of the material can occur.

In accordance with the practice of the present invention, an elongate steel workpiece, which may be in the form of a rod, a bar or the like workpiece of repeating cross-section, is subjected to a cold working operation, preferably cold drawing, to effect a reduction in the cross-sectional area of the workpiece sufficient to provide a measurable increase in the strength of the workpiece. The cold drawing operation can be carried out in accordance with conventional techniques as illustrated in FIG. **3** of the drawing in which the elongate workpiece **10** is simply advanced through a reduction die **12** to form a prestrengthened workpiece **14.** As used herein, the term "cold drawing" refers to a drawing operation carried out at a temperature below the lower critical temperature for the steel. After the cold drawing operation, the workpiece is subjected to a straightening operation in which reverse bending of the workpiece is performed, preferably by progressively bending the workpiece through decreasing deflections to provide a straightened workpiece. For this purpose, use can be made of a conventional Lewis straightener which is schematically illustrated in FIG. **4** of the drawing, or use can also be made of a Medart straightening machine shown schematically in FIGS. **5** and **6** of the drawing. Such straighteners are themselves conventional and operate to straighten the workpiece by bending the workpiece in decreasing amounts to produce a straightened workpiece.

In accordance with the preferred practice of the present invention, rapid heating of the workpiece to effect the strain relief operation is preferably carried out by direct resistance heating. An electric current is passed through the workpiece whereby the electrical resistance of the workpiece to the flow of current causes rapid heating in the workpiece. The workpiece is preferably connected to a source of electric current with the connections being made at both ends so that the current flows completely through the bar. Since the current flows uniformly through the bar, the temperature of the bar increases uniformly, both axially and radially. In this way, the interior as well as the exterior of the workpiece is heated simultaneously without introducing thermal strains. In the preferred practice of the invention, use can be made of a low frequency electric current or preferably direct current. It is thus possible to heat a large workpiece in a very short time simply with the use of sufficiently large power levels.

One suitable means for heating the workpiece **14** by electrical resistance is schematically illustrated in FIG. **7** of the drawing. As shown in this Figure, electrical contacts **16** and **18** are positioned in contact with the workpiece **14** whereby the flow of current between the two contacts **16** and **18** passes through the entire length of the workpiece **14.** It is generally preferred to subject the workpiece **14,** during the time of the heating operation, to tension to compensate for thermal expansion of the workpiece and to avoid buckling in the workpiece while at an elevated temperature. The slight tension exerted on the workpiece during the stress relieving operation thus serves to preserve the straightness of the workpiece and effects no plastic deformation of the workpiece. The stress relief operation is somewhat time and temperature dependent.

It has been found that when use is made of electrical resistance heating to carry out the stress relieving operation on the workpiece, slightly higher temperatures, for example from **50** to **200**°F higher, are required to achieve the same mechanical property level as compared to typical furnace heating because of the relatively slow rates of change of these properties at a given temperature. However, because of this and because of the reduction in residual stress occurring much faster, substantially lower levels of residual stress are achieved. It is essential to the practice of this invention in producing a workpiece having a high tensile strength, a high yield strength and a low residual stress level to carry out the heating operation uniformly and rapidly. In general, heating times required to achieve the desired temperature of less than 10 minutes, and preferably 15 to 120 seconds, are sufficient. Additionally, it may be desirable to maintain the workpiece at the desired temperature for one second to five minutes. The temperature, to which the workpiece is heated, is generally within the range of 500°F to the lower critical temperature for the steel, and preferably from 500° to 1300°F. It is believed that the somewhat higher heating temperature employed in accordance with the invention is due to the fact that the entire heating operation is performed so rapidly and uniformly as compared to the several hours heating employed in conventional furnaces.

It is known to the art to heat metal wire after it has been drawn to normalize the strains in the wire. For example, reference can be made to Young, U.S. Pat. No. 2,281,132. However, Young does not straighten the wire prior to normalizing the strains and, therefore, does not incur the difficulty in decreased yield strength, contrary to the present invention.

The present invention is applicable to the treatment of a variety of steels, including carbon and low alloy steels, such as carbon steels containing 0.10 to 0.75% by weight carbon, and low alloy steels containing 0.10 to 0.75% by weight carbon.

The invention is particularly well suited in the production of rods and bars formed of AISI/SAE grade 1144, 4142 and 4142H steels, as well as grade 4142 and 4142H steels which contain additives to improve machinability. In general, such steels contain

0.10 to 0.75 % by weight carbon,
0.50 to 1.50 % by weight manganese,
0.01 to 0.07 % by weight phosphorus,
0.01 to 0.50 % by weight sulfur,
0 to 1.50 % by weight chromium,
0 to 0.50 % by weight molybdenum, and
0.10 to 0.80 % by weight silicon,

with the remainder of the steel being iron and its usual impurities.

Having described the basic concepts of the invention, reference is now made to the following examples which are provided for purposes of illustration, and not of limitation, of the practice of this invention.

EXAMPLE 1

A group of 1144 steel hot rolled bars, all from the same heat, was processed by descaling, drawing through a die to a relatively large reduction, and then straightening on a rotary Medart straightener. The group of bars was then split into two sub-groups; the first sub-group was processed in a roller hearth furnace for 5 hours while the second sub-group was stress relieved by resistance heating utilizing heating times of 60 to 90 seconds. The resultant mechanical strength properties were as follows:

	Furnace (875°F)	Resistance (900°F)
Tensile Strength, psi	121,000	127,000
Yield Strength, psi	101,000	113,000
Elongation, %	12	10
Reduction of Area, %	32	27
Hardness, Rc	23	23

All bars were then straightened and subsequently tested for machinability on 1 inch RAN, 6-spindle National Acme Automatic Screw Machine. Each condition was run for an eight hour test at predetermined speeds and feeds to produce test parts.

The results of the tests showed that the resistance stress relieved material was clearly superior in the two parameters observed: drilling characteristics and part growth. While it was necessary to change the drills three times during the eight hour run with the furnace treated material, the resistance heated steel ran the entire eight hours with the same set of drills. Similarly, the part growth (which is related to tool wear) for the resistance heated steel was only 0.0008 inches as compared to 0.0015 inches for the furnace treated material.

A further interesting observation was made during the course of this test concerning the uniformity of the two conditions of material. Extensive sampling and hardness testing of both conditions showed the furnace treated material to have a hardness spread of 6 *Rc* points, whereas the spread in hardness for the resistance treated material was only 4 *Rc* points. Apparently, the uniformity of the resistance heated steel is significantly better than the furnace treated equivalent.

EXAMPLE 2

Another group of 1144 steel bars, all from the same heat, was processed in the same manner as described in Example 1 to provide the same mechanical properties. The furnace temperature in this Example was 850°F and the temperature to which the bars were

heated by resistance was 1030°F. The two conditions were then tested relative to one another on what has historically been a critical machining application involving very light surface removal cuts with a form tool as well as a long center drilling. The critical parameter was the life of the form tool on the automatic screw machine as measured by the number of parts produced at the time of failure.

The results of this test showed that the resistance stress relieved material produced 1290 parts prior to form tool failure, whereas the furnace treated material produced only 970 parts. It may be concluded, therefore, that the resistance stress relieving treatment resulted in a 33% increase in the life of the form tool in this operation.

EXAMPLE 3

A third group of 1144 steel bars, all from the same heat, was again produced in the same manner as previously described, with a furnace temperature of 900°F and a resistance heating temperature of 1050°F, to obtain the same mechanical properties. The two treatment conditions were then tested on a Pratt and Whitney lead screw cutting machine which was set up to cut a 1 inch – 5 Acme screw thread.

Distortion due to residual stresses in pre-strengthened cold finished steel bars is a major problem for manufacturers of lead screws. The measure of this distortion is the lead error in one foot. A lead error of less than 0.0003 inches in one foot is generally considered to be excellent, and is usually obtained by grinding after a rough and finish cut.

The following lead error measurements were taken after one full depth cut in one pass for the two stress relieved conditions:

a. Furnace stress relieved—0.0012 inch in one foot.
b. Resistance stress relieved — 0.00005 inch in one foot.

These results are phenomenal in light of the fact that the two conditions were both produced to 125,000 psi tensile strength and that the only difference between the two is the method of heating used to produce them. The results indicate that the resistance stress relieved bars had over an order of magnitude lower residual stress level than the furnace treated bars.

It will be understood that various changes and modifications in details of procedure, operation and use may be made without departing from the spirit of the invention, especially as defined by the following claims.

We claim:

1. A method for the manufacture of stress relieved, pre-strengthened elongated steel workpieces comprising the steps of cold working a workpiece formed of a carbon or low alloy steel to pre-strengthen the workpiece, straightening the workpiece by reverse bending and rapidly heating the workpiece to a temperature within the range of 500°F to the critical temperature of the steel in less than 10 minutes whereby the workpiece is stress relieved such that high levels of mechanical properties are maintained with low levels of residual stress.

2. A method as defined in claim **1** wherein the workpiece is heated by passing an electrical current through the workpiece.

3. A method as defined in claim **1** wherein the workpiece is heated to a temperature within the range of 500° to 1300 °F.

4. A method as defined in claim **1** wherein the workpiece is heated to the desired temperature within 1 second to 5 minutes.

5. A method as defined in claim **1** wherein the workpiece is straightened by advancing the workpiece through a Lewis straightener.

6. A method as defined in claim **1** wherein the workpiece is straightened by advancing the workpiece through a Medart straightener.

7. A method as defined in claim **1** wherein the steel is a carbon or low alloy steel having a carbon content within the range of 0.10 to 0.75% by weight.

8. A method as defined in claim **1** wherein the steel is a AISI/SAE 1144 steel.

9. A method as defined in claim **1** wherein the workpiece is drawn to reduce the cross-section of the workpiece and to increase the tensile strength of the workpiece.

10. A method as defined in claim **1** wherein the workpiece is subjected to cold drawing.

11. A method as defined in claim **1** wherein the cold working is a cold drawing operation carried out at a temperature below the lower critical temperature for the steel.

12. A method as defined in claim **1** wherein the workpiece is heated at a rate substantially uniform over the cross-section thereof.

13. A method as defined in claim **1** wherein the straightening is carried out by passing the workpiece between a plurality of rollers to bend and straighten the workpiece.

14. A pre-strengthened, stress relieved steel workpiece formed of a carbon or low alloy steel prepared by the method of claim **1**.

15. A steel as defined in claim **14** wherein the steel contains 0.10 to 0.75% carbon by weight.

16. A steel as defined in claim **14** wherein the steel is a AISI/SAE 1144 steel.

17. A steel as defined in claim **14** wherein the steel contains 0.10 to 0.75% by weight C, 0.50 to 1.5% by weight Mn, 0.01 to 0.07% by weight P, 0.01 to 0.50% by weight S, 0 to 1.5% by weight Cr, 0 to 0.50% by weight Mo and 0.10 to 0.80% by weight Si, with the remainder being iron and its usual impurities.

18. A pre-strengthened, stress relieved steel workpiece formed of a carbon or low alloy steel prepared by the method of claim **2**.

19. A method for the manufacture of stress relieved, prestrengthened elongate steel workpieces comprising the steps of cold drawing a workpiece formed of a carbon or low alloy steel at a temperature below the lower critical temperature for the steel to prestrengthen the workpiece, passing the workpiece between a plurality of rollers to bend and straighten the workpiece, and passing an electric current through the workpiece to heat the workpiece substantially uniformly across the cross-section thereof to a temperature within the range of 500°F to the lower critical temperature of the steel in less than ten minutes whereby the workpiece is stress relieved such that high levels of residual stress.

20. A method for the manufacture of stress relieved, prestrengthened workpieces comprising the steps of cold working the workpiece formed of a carbon or low alloy steel to prestrengthen the workpiece, and rapidly heating the workpiece to a temperature within the range of 500°F to the lower critical temperature of the steel in less than ten minutes whereby the workpiece is stress relieved such that high levels of mechanical properties are maintained with low levels of residual stress.

* * * * *

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,908,431 Dated September 30, 1975

Inventor(s) Samuel H. Jones and James M. McNeany

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

In column 8, line 25, after "levels", please insert -- of mechanical properties are maintained with low levels --

Signed and Sealed this

fifteenth **Day of** *June 1976*

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents and Trademarks