March 18, 1952 C. E. SIMS ET AL 2,589,881

METHOD OF PRODUCING STEEL PRODUCTS AND ARTICLES

Filed Feb. 18, 1950 2 SHEETS—SHEET 1

FIG. 1

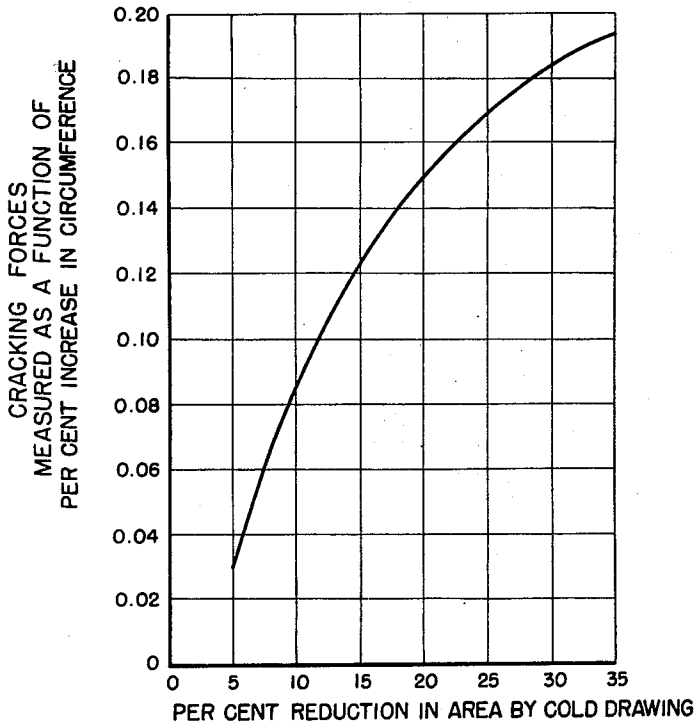

FIG. 2

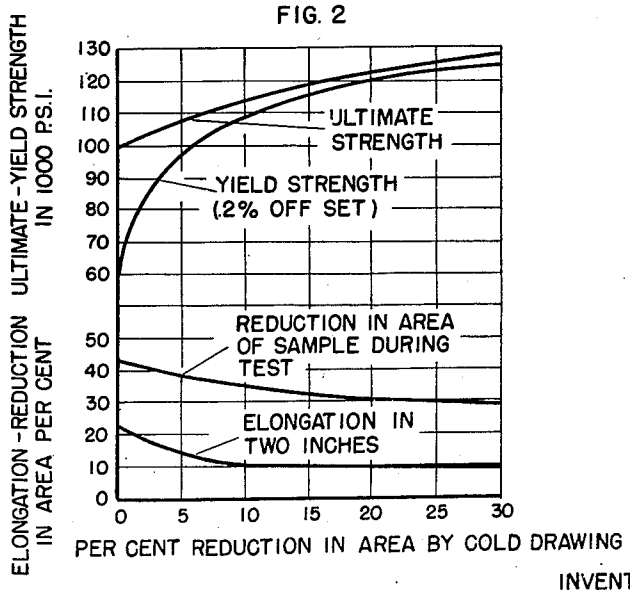

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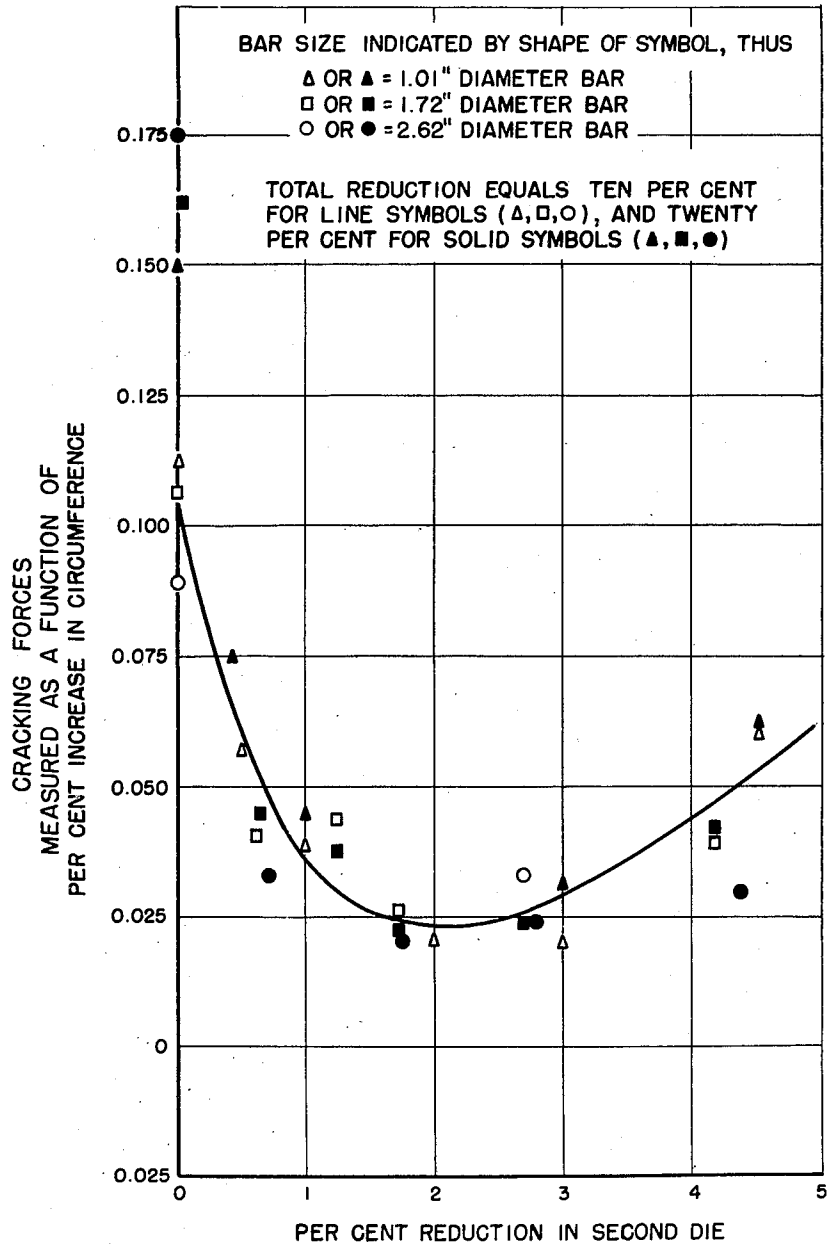
FIG. 3



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2,589,881

METHOD OF PRODUCING STEEL PRODUCTS AND ARTICLES

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Application February 18, 1950, Serial No. 144,908

11 Claims. (Cl. 148—12)

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This invention relates to improved methods of producing steel products and articles, more particularly to methods for producing economically and with a minimum of scrap loss steel products of the cold worked type having highly desirable physical properties such as high tensile strength, satisfactory ductility, etc., and also having exceptional machinability and wearability. This application is a continuation-in-part of a prior application Serial No. 773,230 filed September 10, 1947, now abandoned, in the names of the present inventors.

In United States Patent No. 2,320,040, issued May 25, 1943 in the name of H. N. Landis and entitled Steel Product and Method for the Manufacture Thereof, there are described and broadly claimed methods of producing improved steel products having, among others, the above mentioned highly desirable characteristics. The methods described and claimed in the said Landis patent basically comprise cold working a non-austenitic steel containing a normal pearlitic and ferritic structure, i. e., non-austenitic steel having a pearlitic structure in a matrix of free ferrite at abnormally heavy drafts to effect an area reduction preferably in excess of 20 per cent depending upon the original cross section of the article, and then heating the cold worked steel to a temperature beyond the precipitation or age hardening range but below the temperature at which substantial recrystallization begins to occur. Although these methods are fully operative to produce the improved steel products disclosed in the patent, difficulties have been encountered in employing the methods on a commercial basis to draw steel bars due to the fact that cracking of the bars after or during the drawing operation and prior to the heating step is found to occur in too high a percentage of cases to permit economical operation. The cracks in question are radial cracks extending from the surface to the center, and usually for the whole length of the drawn bar. In severe cases the crack may extend through the whole diameter, but in either case the value of the bar as a commercial product is completely destroyed and it has only a scrap value. When a bar cracks in this manner, the crack opens up as a narrow segment, and the diameter and circumference of the bar are both increased.

The increase in circumference upon opening of the crack indicates that severe residual stresses of magnitudes greatly in excess of the stresses produced by cold working at normal drafts, i. e., at 13 per cent or less depending upon the diameter of the bar, and in the form of circumferential tensile hoop stresses in the surface layers and compressive stresses at the center, are relieved in the act of cracking. These stresses are the primary force behind the cracking, but generally no cracking occurs unless there are present stress raisers of one form or another to initiate the cracking.

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It has been found that the cracks usually open up shortly after a stress raiser has passed through the die. Common stress raisers are guide marks, guide scratches, fins, overfills, seams, slivers, impurity concentrations, or some other form of notch, which stress raisers are present at least to some degree in most hot rolled stock. The cracks, after initiating at a stress raiser, progress along the bar in both directions. For example, if the surface defect or stress raiser that initiates a crack is located adjacent the middle of the bar, the crack, after initiating at that point, progresses toward both ends of the bar at a rapid rate. Occasionally, bars do not crack until after the entire bar has left the die.

Strenuous attempts have been made to control and minimize cracking losses and have resulted in changes in composition of the metal, variations of the die design, improving lubricants, machining the bars before cold drawing, restricting the drawing operation to light drafts only, and numerous other practices. While it has previously been suggested (British Patent No. 423,868) that an exceedingly light draw or skin pass may be employed in combination with normal or less than normal drafts for the purpose of superimposing in additive fashion the stresses produced during the light draw on those produced during the normal draw, so as to in effect modify the original stresses and the internal stress pattern set up in the bars by the normal draw, no practical way has heretofore been proposed for producing the improved steel products having the enhanced physical properties disclosed in the said Landis patent, while minimizing or eliminating the scrap loss due to cracking. The importance of this problem becomes apparent at once when it is considered that, in practicing the methods of the said Landis patent, while the losses from lot to lot will vary widely, such losses from cracking may run as high as 100 per cent on certain lots of steel.

It is accordingly an object of the invention to provide a method for producing steel of the cold worked type having highly satisfactory physical

characteristics and in which scrap loss due to cracking is minimized.

It is another object of the invention to provide a method of producing steel bars by cold working with reductions of such an order that the resulting articles have materially increased strength and hardness resulting from this reduction and at the same time are free from dangerously large cracking stresses.

A further object of the invention is to provide a method of producing steel articles by cold working, wherein an article of high tensile strength, yield strength and hardness is produced that is particularly adapted to machining operations.

In practicing the method of the present invention in one form, an improved steel product is produced by cold working a non-austenitic steel of the type having a pearlitic structure in a matrix of free ferrite to effect an abnormally heavy reduction and to set up in the steel stresses of a magnitude which will, in the presence of a stress raiser, cause cracking of the steel following release of the cold working forces and then, prior to the release of the hoop stresses, further cold working the steel to effect a sufficiently light reduction to reform the hoop stresses to stresses which are incapable of producing cracking of the thus worked steel. If desired, the thus worked steel may then be heated to a temperature beyond its age hardening range but below the temperature at which substantial recrystallization begins to occur.

Other objects of the present invention will become apparent from the following detailed description when read in conjunction with the accompanying drawings, in which:

Fig. 1 is a graph representing the relationship of the percentage reduction in area effected by a single die to the circumferential or hoop stresses present in the cold drawn metal bar;

Fig. 2 is a graph showing the effect upon the ultimate strength, yield strength, reduction in area, and elongation of a bar produced by different degrees of cold reduction; and

Fig. 3 is a chart showing the residual forces in various sized bars after having been cold worked in accordance with the methods of the present invention.

The present invention will be described in connection with the cold drawing of steel bars in order to produce improved steel products of the character hereinbefore mentioned. It has been found that, upon initiation of a crack (as hereinbefore described) due to the presence of a stress raiser in the bar, the crack proceeds along the bar toward the die, but the progress of the crack is arrested a short distance in front of the die and thereafter progresses only at about the same rate as the rate of drawing. The distance in front of the die at which the progress of the crack is arrested will vary with the particular metal composing the bar and with the speed of drawing, and is believed to correspond substantially to the point at which the internal stresses are released from the containing effect of the working forces exerted by the die. In accordance with the present invention, cracking of the bar after a greater than normal reduction and prior to the heating step is eliminated entirely or substantially reduced by drawing the bar through a low reduction die prior to the release of the bar reducing forces exerted by the high reduction die. Preferably the high reduction die and the low reduction die are arranged in tandem with one another and so spaced that the low reduction die is effective

to reform the stress pattern in the bar prior to release of the bar reducing forces. Thus the tensile hoop stresses created by the abnormally heavy reduction in the first die and potentially capable of causing cracking following release of the bar reducing forces are reformed in the second or low reduction die before cracking can occur. In other words, the second die destroys the stress pattern set up by the first die and imposes its own characteristic stress pattern which is independent of the stress pattern set up by the first die. The bars having the stresses thus relieved may then be heated in the manner hereinbefore described to produce the desired cold worked steel bars having enhanced physical characteristics.

In practicing the present method to produce improved steel products of the above indicated character, the steels employed as starting materials are preferably non-austenitic and preferably have a pearlitic and ferritic grain structure. The bars employed are preferably hot rolled, and in the preferred form of the invention have substantially the following chemical composition:

Sulphur, .175% to .400%
Manganese, 1.00% to 2.25%
Phosphorus, 0.00% to 0.10%
Carbon, 0.30% to 0.55%
Silicon, 0.10% to 0.40%

the balance being substantially all iron. The rolled bars are passed through the first or heavy die, which effects a greater than normal reduction in area, i. e., preferably in excess of 20 per cent depending upon the original size of the bar being drawn, and which is effective to set up tensile hoop stresses within the bar potentially capable of producing cracking of the bar upon release of the bar reducing forces exerted by the high reduction die, and the reduced bar is then passed through the second or light reduction die, which is effective to produce only a small further reduction of the bar, i. e., from 0.33 per cent to 5 per cent, and preferably about 2 per cent, the second die being so located as to act on the reduced bar prior to release of the forces exerted by the heavy reduction die. The spacing of the second die from the first die so as to insure that cracking will not occur varies as heretofore indicated, and for steel of the above referred to type, when drawn at a speed of from 20 to 80 feet per minute, the spacing or critical distance between the dies has, in the absence of special stress containing means, been found to be a maximum of about two inches and preferably should be about one-half inch. The second die reforms the stress pattern in the bar, as heretofore pointed out, thus eliminating the cracking problem, and the bars are then heated to a temperature beyond the precipitation hardening range but below the temperature at which substantial recrystallization begins to occur, i. e., preferably above 550° F. but below 1000° F.

In the event that the relatively close spacing of the heavy and light reduction dies is found to be undesirable or impractical in certain instances, means such as pressure rollers or non-reducing but force exerting dies having substantially the diameter of the heavy reduction die may be positioned at the exit face of the heavy reduction die for the purpose of containing the tensile hoop stresses in the bar and preventing re'ease thereof for any desired distance beyond the exit face of the heavy reduction die, and the second or low reduction die may be positioned

adjacent the exit end of such stress containing means. The important factor is that the second or low reduction die be brought into play to reform the internal stress pattern before release of the stress containing forces.

Referring now to the drawing, Fig. 1 graphically shows the high stresses raised within a bar when cold drawn through a die at various amounts of reduction. The abscissa represents the percentage reduction in area effected by cold drawing, and the ordinate represents the hoop stresses or cracking forces measured as a function of the percent increase in circumference of a test piece after slotting. The percent increase in circumference represented in Fig. 1 was obtained by cutting one-half inch long discs off the test bar after it was drawn and measuring the expansion of the circumference after slotting the one-half inch long disc to the center. To obtain the data for Fig. 1, a ⅞ inch diameter bar was drawn through a 15 degree conical die, the bar being composed of a steel conforming to the specification of .08 to .13% carbon, .60 to .90% manganese, .09 to .13% phosphorous, .10 to .15% sulphur, and the balance iron. It is seen from an examination of Fig. 1 that the internal or residual stresses as indicated by the cracking forces measured as a function of the percent increase in the circumference of the test disc after slotting increases rapidly as the cold reduction is increased from 5 to 20 per cent so that at 20 per cent the percent increase in diameter is almost five times as great as at 5 per cent. Although the large reductions which are employed in carrying out the present invention and which are greater than normal produce cracking forces as shown in Fig. 1, which are potentially capable of causing cracking of the bar, reductions of this high order are necessary in order to produce the desired physical characteristics in the finished bar. Fig. 2, for example, shows the effect of different percentages of reduction upon the ultimate strength, yield strength (two per cent offset), reduction in area, and elongation. The bars tested for the purpose of obtaining the data of Fig. 2 were of a diameter of 1.5 inches and were composed of approximately 0.45% carbon, 1.50% manganese, 0.02% phosphorus, 0.25% sulphur, 0.15% silicon, and the balance iron.

The normal commercial reduction employed in the cold drawing of steel bars is about $\frac{1}{16}$ inch, and consequently the normal reduction in cross-sectional area of a 1.5 inch diameter bar is about 9 per cent. The elongation and reduction in area, which are a measure of the ductility of the bars tested, show in Fig. 2 a rather sharp decline up to 9 to 10 per cent. At the same time the yield strength increases very rapidly, a fact of considerable practical importance because strength requirements necessitate that this factor be taken as a measure of the strength of the metal. As shown in Fig. 2, ultimate strength increases gradually up to 30 per cent reductions. The advantage of the greater than normal reductions employed in practicing the present method is at once apparent from the fact that both the reduction in area and the elongation properties are almost constant from 10 to 30 per cent reduction of the tested bars. whereas the strength of the bars increased at substantially a steady rate. Consequently the high reductions effect increased strength with almost no additional loss in ductility.

A direct comparison of the advantages of the present method of producing steel bars with the prior method disclosed in the said Landis Patent No. 2,320,040 may be had by comparing Fig. 3, showing the stresses produced in practicing the present invention, with Fig. 1, which illustrates the stresses produced by employing the single high reduction draw of the said Landis patent. The abscissa in Fig. 3 represents the percent reduction in cross-sectional area effected by the second or low reduction die employed in practicing the methods of the present invention, and the ordinate, as in Fig. 1, represents the cracking forces measured as a function of the percent increase in circumference produced by slotting to the center a one-half inch long segment of the drawn bar. The bars tested to obtain the data for Fig. 3 were the same composition as those tested for the data presented in Fig. 1. As indicated in Fig. 3, the open symbols represent those tests wherein a 10 per cent total reduction was effected and the solid symbols represent those tests wherein a 20 per cent total reduction was effected. The reduction produced by the first or high reduction die can be obtained by subtracting the percent reduction in the second die from the total percent reduction. The bar size is indicated by the shape of the symbol. Thus a triangle indicates a 1.01 inch diameter bar, a square indicates a 1.72 inch diameter bar, and a circle indicates a 2.62 inch diameter bar.

Referring now to the solid triangle symbols shown in Fig. 3, it is seen that the residual stresses produced by drawing a 1.01 inch diameter bar through successive high and low reduction dies, in accordance with the present invention, decrease most rapidly where there is from 0 to 1 per cent reduction in the second or low reduction die, and are at a minimum when there is between about 1¾ per cent to 3¾ per cent reduction in the second die. An examination of the other symbols on the chart of Fig. 3 will show that the same general curve is followed throughout, so that from the data it may be concluded that there is always a certain range of reduction in the second or low reduction die where the residual stresses in the drawn bar are at a minimum for any given metal.

As above stated, normal drafts constitute about $\frac{1}{16}$ inch reduction in diameter, which will range from about 4 per cent reduction in cross-sectional area for a 3 inch diameter bar to about 12 per cent for a bar 1 inch in diameter. In Fig. 1, normal reduction of about 13 per cent on this ⅞ inch bar produced residual stresses sufficient to increase the circumference of the bar by 0.106 per cent upon making a slot test as above described. At 20 per cent reduction, the stresses in the bar caused 0.15 per cent increase in the circumference of the bar upon slotting. Considering now Fig. 3, a 1.01 inch diameter bar on which a normal reduction is about 12 per cent, showed zero stress after a 20 per cent total reduction, when it was passed through two dies, the second one of which effected a reduction of about 2 per cent. Further examination of Fig. 3 discloses that none of the bars tested, wherein the second pass or reduction varied from about 0.33 per cent to about 5 per cent, contained residual stresses at a total reduction of 10 per cent or 20 per cent, as great as the stresses raised at normal reduction of the ⅞ inch bar in Fig. 1. At or about 2 per cent reduction in the second die, the stresses reach a minimum for all of the bars shown in Fig. 3, and are very low when the second reduction is from 0.5 per cent to about 4.5 per cent. Although the different sized bars in Fig. 3 reached mini-

mum stress at about the same percentages of reduction in the second die, the data for all of the bars indicate that a minimum exists for every bar and that the percent reduction on the first die does not materially affect this minimum. The invention is most advantageously practiced, therefore, by providing second dies, or follow-up dies, which will achieve these minimum stress points for the particular bar being reduced.

In practicing the present invention, the first or abnormal reduction of the steel is beyond the critical reduction limit or cracking limit of the particular steel being reduced, and the upper limit of reduction is set by commercial practicability, i. e., that point at which the steel being reduced will respond to commercial methods or apparatus. Reductions as high as 32 per cent have been successfully effected without cracking, by employing tandem reductions as herein described. The degree to which the reduction effected by the second die will reform the stresses produced by the first die will vary with the angle of the second die, but for a given die and a given metal all sizes of bars will reach the minimum stress level at about the same percent reduction in the second die. As previously indicated, the second reduction of the bar must be effected before release of the working forces exerted by the first die, since otherwise the formation of cracks may be initiated before the bar reaches the second die and thus render the second die ineffective.

While particular embodiments of the invention have been described, it will be understood, of course, that the invention is not limited thereto since many modifications may be made, and it is therefore contemplated by the appended claims to cover any such modifications as fall within the true spirit and scope of the invention.

What is claimed and desired to be secured by Letters Patent is:

1. The method of treating non-austenitic steel of the type having a pearlitic structure in a matrix of free ferrite to produce an improved steel product; which method comprises cold working the steel to effect an abnormally heavy reduction and to set up in the steel hoop stresses of a magnitude which will, in the presence of a stress raiser, cause cracking of the steel following release of the cold working forces, containing said hoop stresses against release, and, while said hoop stresses are contained against release, further cold working the steel to effect a sufficiently light reduction to reform the said hoop stresses to stresses which are incapable of producing cracking of the thus worked steel.

2. The method of treating non-austenitic steel of the type having a pearlitic structure in a matrix of free ferrite to produce an improved steel product; which method comprises cold working the steel to effect an abnormally heavy reduction and to set up in the steel hoop stresses of a magnitude which will, in the presence of a stress raiser, cause cracking of the steel following release of the cold working forces, containing said hoop stresses against release, further cold working the steel while said hoop stresses are contained against release to effect a sufficiently light reduction to reform the said hoop stresses to stresses which are incapable of producing cracking of the thus worked steel; and then heating the steel to a temperature beyond its age hardening range but below the temperature at which substantial recrystallization begins to occur.

3. The method of treating non-austenitic steels of the type having a pearlitic structure in a matrix of free ferrite to produce an improved steel product; which method comprises cold working the steel to effect an abnormally heavy reduction and to set up in the steel hoop stresses of a magnitude which will, in the presence of a stress raiser, cause cracking of the steel following release of the cold working forces; and, prior to the release of said hoop stresses set up by said cold working, further cold working the steel to effect a light reduction of about 0.33 per cent to 5.0 per cent to reform the said hoop stresses to stresses which are incapable of producing cracking of the thus worked steel.

4. The method of treating non-austenitic steels of the type having a pearlitic structure in a matrix of free ferrite to produce an improved steel product; which method comprises cold working the steel to effect an abnormally heavy reduction and to set up in the steel hoop stresses of a magnitude which will, in the presence of a stress raiser, cause cracking of the steel following release of the cold working forces; further cold working the steel, prior to the release of said hoop stresses set up by said cold working, to effect a light reduction of about 0.33 per cent to 5.0 per cent to reform the said hoop stresses to stresses which are incapable of producing cracking of the thus worked steel; and then heating the steel to a temperature beyond its age hardening range but below the temperature at which substantial recrystallization begins to occur.

5. The method of treating non-austenitic high sulphur manganese-sulphur steel having substantially the following chemical analysis: sulphur .175%–.400%, manganese 1.00%–2.25%, phosphorus 0.00%–0.10%, carbon 0.30%–0.55%, silicon 0.10%–0.40%, the balance being substantially all iron to produce an improved steel product, which method comprises cold working the steel to effect an abnormally heavy reduction and to set up in the steel hoop stresses of a magnitude which will, in the presence of a stress raiser, cause cracking of the steel following release of the cold working forces; and, prior to the release of said hoop stresses set up by said cold working, further cold working the steel to effect a sufficiently light reduction to reform the said hoop stresses to stresses which are incapable of producing cracking of the thus worked steel.

6. The method of treating non-austenitic high sulphur manganese-sulphur steel having substantially the following chemical analysis: sulphur .175%–.400%, manganese 1.00%–2.25%, phosphorus 0.00%–0.10%, carbon 0.30%–0.55%, silicon 0.10%–0.40%, the balance being substantially all iron to produce an improved steel product, which method comprises cold working the steel to effect an abnormally heavy reduction and to set up in the steel hoop stresses of a magnitude which will, in the presence of a stress raiser, cause cracking of the steel following release of the cold working forces; and, prior to the release of said hoop stresses set by said cold working, further cold working the steel to effect a light reduction of about 0.33 per cent to 5.0 per cent to reform the said hoop stresses to stresses which are incapable of producing cracking of the thus worked steel.

7. The method of treating non-austenitic high sulphur manganese-sulphur steel bars having substantially the following chemical analysis: sulphur .175%–.400%, manganese 1.00%–2.25%, phosphorus 0.00%–0.10%, carbon 0.30%–0.55%, silicon 0.10%–0.40%, the balance being substantially all iron to produce an improved steel bar

product, which method comprises cold drawing a steel bar to effect an abnormally heavy reduction and to set up in the steel bar hoop stresses of a magnitude which will, in the presence of a stress raiser, cause cracking of the steel bar following release of the cold working forces; then, prior to the release of said hoop stresses set up by said abnormal cold drawing, further cold drawing the steel bar to effect a sufficiently light reduction to reform the said hoop stresses to stresses which are incapable of producing cracking of the thus worked steel; and then heating the steel bar to a temperature beyond its age hardening range but below the temperature at which substantial recrystallization begins to occur.

8. The method of treating non-austenitic steels of the type having a pearlitic structure in a matrix of free ferrite to produce an improved steel product; which method comprises cold working the steel to effect an abnormally heavy reduction and to set up in the steel hoop stresses of a magnitude which will, in the presence of a stress raiser, cause cracking of the steel following release of the cold working forces; and, before the cold worked steel has progressed a distance not substantially greater than two inches from the point of said cold working, further cold working the steel to effect a sufficiently light reduction to reform the said hoop stresses to stresses which are incapable of producing cracking of the thus worked steel.

9. The method of treating non-austenitic high sulphur manganese-sulphur steel bars having substantially the following chemical analysis: sulphur .175%–.400%, manganese 1.00%–2.25%, phosphorus 0.00%–0.10%, carbon 0.30%–0.55%, silicon 0.10%–0.40%, the balance being substantially all iron to produce an improved steel bar product, which method comprises cold drawing the steel bars to effect an abnormally heavy reduction and to set up in the steel bars hoop stresses of a magnitude which will, in the presence of a stress raiser, cause cracking of the steel bars following release of the cold working forces; then, before each heavily reduced steel bar has progressed a distance not substantially greater than two inches from the point of said abnormal reduction, further cold working the steel bar to effect a light reduction of about 0.33 per cent to 5.0 per cent to reform the said hoop stresses to stresses which are incapable of producing cracking of the thus worked steel bar; and then heating the steel bars to a temperature beyond its age hardening range but below the temperature at which substantial recrystallization begins to occur.

10. The method of treating non-austenitic steel bars of the type having a pearlitic structure in a matrix of free ferrite to produce an improved steel bar product; which method comprises cold working the steel bar to effect an abnormally heavy reduction and to set up in the steel bar hoop stresses of a magnitude which will, in the presence of a stress raiser, cause cracking of the steel bar following release of the cold working forces, containing said hoop stresses against release, and while said hoop stresses are contained against release, further cold working the steel bar to effect a sufficiently light reduction to reform the said hoop stresses to stresses which are incapable of producing cracking of the thus worked steel bar.

11. The method of treating non-austenitic steel bars of the type having a pearlitic structure in a matrix of free ferrite to produce an improved steel bar product; which method comprises cold drawing the steel bar to effect an abnormally heavy reduction and to set up in the steel bar hoop stresses of a magnitude which will, in the presence of a stress raiser, cause cracking of the steel bar following release of the cold working forces, containing said hoop stresses against release, and while said hoop stresses are contained against release, further cold drawing the steel bar to effect a sufficiently light reduction to reform the said hoop stresses to stresses which are incapable of producing cracking of the thus worked steel bar.

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MAURICE N. LANDIS.

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
2,320,040	Landis	May 25, 1943

FOREIGN PATENTS

Number	Country	Date
423,868	Great Britain	Feb. 11, 1935