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PROCESS OF EXTRUDING STEEL

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This invention relates to new steel having improved physical and mechanical properties and residual stress characteristics and it relates also to a new and improved method for producing same.

This application is a continuation-in-part of our copending application Ser. No. 293,433, filed on June 13, 1952, now abandoned and entitled, "Improved Metallurgical Process and Steel Products Produced Therefrom."

As defined in the aforementioned copending application, the specific invention herein resides in the improvement of the mechanical and physical properties of steel and more particularly in the method for minimizing the development of residual stresses in the steels. These improvements are secured by reaction at elevated temperature as the steel is advanced through a die to effect reduction in cross-sectional area. As the result of the control of such residual stresses as are developed in steel upon working, as in the manner described, it has become possible to reduce warpage and the development of cracks in products fabricated of such steels and it has become possible also to control the type and magnitude of the stresses developed more desirably to conform the warpage and cracking characteristics, if any remain, to the requirements for the particular products which are fabricated of the steels.

It is known that in working steels, as by drawing, stresses of considerable magnitude may be introduced, depending upon the amount of draft and chemistry of the steel. The presence of residual stresses in steel products has an important influence in processing the steel into the finished product and the residual stresses existing also have considerable influence on the specification of certain materials for particular uses and applications. As a result the present day practice has evolved where heavy drafts are employed very infrequently in an effort to minimize the residual stresses, especially the circumferential stress which can result in longitudinal cracking of the drawn bars unless the stresses are relieved by some subsequent treatment. Such cracking of the bars might occur immediately as the bar leaves the die, during subsequent processing into a finished product, in finished stock storage or in final assembly of a finished product in which the steel unit may form an essential part. Such breakage in use not only forms a source of embarrassment to the supplier and damages the reputation of the manufacturer but, from a practical standpoint, unnecessarily markedly increases the cost of materials by reason of the scrap involved.

In an attempt to control and minimize the harmful effect of residual stresses, the drawn steel members are often submitted to a separate stress relieving treatment as by furnace treatment at some appropriate temperature below the lower critical temperature. It is, of course, highly desirable to produce drawn steels wherein the residual stresses are controlled and minimized without the limitations of special die practices with or without subsequent stress relieving treatments. Thus it would be possible to

make use of the high strength in readily available steels which result from heavy drafts without the attendant high cost of manufacture and the limitations in techniques and machinery capable of being used.

Attempts have been made to control and to reduce the development of hoop or cracking stresses as an incidence to the drawing operation and attempts have also been made to control the longitudinal or warping stresses as an incidence to the drawing operation. In one method described in the Landis and Sims Patent No. 2,589,881, a particular combination of drawing dies are used to take an abnormally heavy draft and an extremely light draft in a predetermined sequence. In another method described in the British Patent No. 423,868 a combination of drawing steps, in a predetermined sequence, is employed in conjunction with normal cold working so as to, in effect, minimize the stresses which control the degree of warpage. In general, the art tends to ignore the residual stresses or else relies on a plurality of die combinations or subsequent processing operations with or without subsequent heating as a stress relieving treatment to minimize or control the residual stresses in the final product.

This invention has for its object to provide a new and improved method for the reduction and control of residual stresses formed in steel during working operations, such for example as by drawing the steel through a die to effect reduction in cross-sectional area.

Another object is to provide a method which avoids the multiple steps, the multiple drawing operations or limitations with respect to draft of the prior art processes and which in a simple and economical manner obtains the objective of controlled residual stresses and/or lower levels of stresses formed in drawn steel products.

A further object is to provide a method for the production of steel characterized by new and improved physical and mechanical properties and wherein residual stresses of low and controlled values are embodied into the steel as an incidence to the drawing operation.

A still further object is to provide a new and improved method for drawing steel whereby residual stresses are minimized and controlled during the drawing operation thereby to achieve the desired reduction in cross-sectional area while, at the same time, introducing new and improved strength and physical properties into the steel product including, in particular, residual stress control thereby to achieve in one operation that which has heretofore required a number of steps, and has never to the present been achieved, as regards the improved physical and mechanical properties of the steel.

In general it is an object of this invention to provide a method of working steels of the type described which prevents warpage or cracking of the worked or drawn product.

A further object is to produce a product and to provide a method for producing same with gross compressive stresses in outer areas of the steel member whereby the product is characterized by better structural fatigue properties.

In the aforementioned copending application description includes a new and improved process for working non-austenitic steels having a pearlitic structure in a matrix of free ferrite to produce products characterized by physical and mechanical properties which have not heretofore been available in steels of the type described and which approach the properties of heat treated steels and alloy steels sufficiently closely to enable substitution of these low cost and readily available steels for the more expensive and less available metals and alloys. In brief, the described improvements in steel products are achieved by drawing the steel at elevated temperatures considerably above room temperature but at a temperature below

the lower criitcal temperature for the particular steel composition. In general, for steels of the type described, the improvements in physical and mechanical properties are achieved by heating the steel substantially uniformly to a temperature within the broad range of above 200° F. to about 1100° F. and preferably within the ranges of 600–850° F. and 850–1100° F. depending upon the type of properties which it is desired to be developed in the steel.

By drawing steel at a temperature within the range described, marked improvements may be secured in tensile strength and in the important property of proportional limit. These improvements in strength properties are available at normal drafts as well as with abnormally heavy drafts. In general, it has been found that the degree of improvement is proportional to the amount of draft at the elevated temperature whereby exceptionally high strength values can be secured in steel products drawn with abnormally heavy reduction in cross-sectional area.

The further important advance in the art embodying the features of this invention resides in the discovery that the residual stresses, as measured by warping value of the processed steel, can be minimized and almost completely controlled by the appropriate combination of draft and temperature of working as related to a particular chemistry of steel. By proper selection of temperature and draft, it is possible in a single operation to secure marked improvements in physical and mechanical properties and also to reduce the scope and character of the residual stresses thereby to avoid the possibility of failures occurring in the finished product subsequent to the drawing operation and further to make the product still more useful and more easily fabricated into finished products without excessive scrap or limitation with respect to the machining operations and the techniques for forming the steel into a finished product.

As used herein, the term "warping value" is an indication of the concentration and character of the longitudinal stresses present in steel. In the test for warping, test pieces are sloted through a diameter for a distance of about 8 inches in the event that the test piece has a diameter of 2 inches or less and for a distance of about 10 inches if larger than 2 inches in diameter. The length of the slot is recorded and the maximum diameter perpendicular to the slot is also measured. The difference between the diameter before slotting and after slotting comprises the flare caused by the presence of residual stresses. The flare is considered positive, indicating tensile stresses in the outer area of the material, if the bar expands on slotting and negative, indicating compressive stresses in the outer area of the material, if the ends move towards the cut through the diameter. The warping values determined for evaluation are calculated from the following equation:

$$\text{Warping value} = \frac{100 \times \text{original diameter} \times \text{flare}}{(\text{Slot length})^2}$$

Typical of the steels with which the improvements in physical and mechanical properties are capable of being developed in accordance with the practice of this invention are steels which can be strain hardened and which will harden by some mode of precipitation at temperatures below the lower critical temperature for the steel. If the steel shows hardening because of precipitation or other re-arrangement, then it becomes possible to improve the strength properties and the combination of strength and elastic limit by the practice of this invention wherein the steel is worked as by drawing or extrusion at elevated temperatures to effect reduction in cross-sectional area. Thus it is possible to distinguish the steels which may be employed in the practice of this invention over other steels such as the hard to draw high speed steels or carbon tool steels of the type described in the Kronwoll Patent No. 2,400,866.

The non-austenitic steels having a pearlitic structure in a matrix of free ferrite are characteristic of the steels which may be employed in the practice of this invention.

With steels of the type described, it has been found that drawing steel at elevated temperatures to produce new and improved physical and mechanical properties in the steel has no effect on the warping values of the steel after drawing until a temperature of about 650° F. is reached. At this point up to the lower critical temperature for the particular steel composition, the warpage values or the residual stresses in the steel produced begin to fall off. Marked reduction to exceptionally low values occurs when the steel is drawn at temperatures above 850° F. The critical temperature relationship for reduction of residual stresses after drawing, as indicated by a reduction in warping values, appears to be independent of steel composition for normal drafts. However, the temperature level at which the residual stresses are desirably affected varies somewhat with the amount of draft.

The marked reduction in warpage value which occurs when drawing at temperatures above 650° F. and preferably above 850° F. permits the production of drawn steel products having improved physical and mechanical properties with residual stress values as low or lower than values which have heretofore resulted from processing subsequent to drawing, as by heat treatment, to achieve a lowering of the residual stress values. It is believed that this novel combination of increased strength with reduced residual stresses and the attendant low warpage values represents an important advance in the art of processing steels for use in the manufacture of various products.

It has been found further and it is another important concept of this invention that high compressive stresses instead of tensile stresses may be formed in the outer areas of the drawn steel product, as indicated by a negative warpage test of the drawn steel, when the steel is drawn through a die at a temperature above 800° F. and preferably above 850° F., depending upon the amount of reduction, followed by rapid cooling of the drawn bar, as by means of a water spray or quench. In this respect again, composition bears little influence on the formation of negative warpage values but the temperature at which negative warpage values are secured varies somewhat inversely with the amount of reduction of cross-sectional area in drawing. For example, the development of negative warpage values in the outer area of the steel rod or bar begins at temperature levels of about 800–850° F. with drafts of about 36 percent, at about 850–875° F. with 19 percent draft, and about 900° F. with 12 percent draft. The compressive stresses existing in the surface portions of the steel following drawing at the temperature levels defined appear chiefly when the material is rapidly cooled to a lower temperature level immediately after drawing. In the event that the drawn product is allowed to cool slowly, as in air, negative warpage values are in general no longer available. This does not suggest that compressive stresses are not introduced by drawing at such elevated temperatures without subsequent rapid cooling but it appears that such compressive stresses might be insufficient to give negative warpage values. Instead, a general low level of residual stresses exist in the drawn metal. The compressive stresses in the steel can be accentuated, if desired, by rapid cooling or quenching above about 850° F.

High compressive stresses in the surface portions of the bars are extremely advantageous in increasing the torsional fatigue value of the drawn material at any particular strength level. By drawing at a temperature above 850° F. and rapidly cooling the drawn product, as previously described, it is believed that steels can be produced having high compressive stresses in the surface portion.

The novel concepts of this invention may be illustrated by the following examples of steel compositions in which the major ingredients other than iron are set forth:

EXAMPLE 1

A hot rolled steel having the following composition and of a non-austenitic type having a pearlitic structure in a matrix of free ferrite was advanced through a drawing die to effect reduction in cross-sectional area. Reductions of 12, 19 and 36 percent were taken in 5/8 inch round.

Steel composition:

0.48 percent carbon
1.50 percent manganese
0.03 percent phosphorus
0.27 percent sulphur
0.30 percent silicon
0.005 percent nitrogen

Before advancing the steel bars to the drawing die to effect the desired reduction in cross-sectional area, the bars were heated at various temperatures ranging from room temperature of about 75° F. to a temperature of 900° F.

The warping values calculated for each of the conditions are listed in the following table:

Table 1.—Warping values of steel at various temperatures with 12, 19 and 36 percent reductions in cross-sectional area

Temperature of steel drawn (° F.)	Warping Values		
	12% reduction	19% reduction	36% reduction
Room temperature	+0.29	+0.38	+0.46
250	+0.33	+0.37	+0.57
490	+0.41	+0.41	+0.50
640	+0.45	+0.38	+0.20
740	+0.33	+0.20	+0.08
790	+0.26	+0.03	+0.01
850–900	+0.02	+0.05	−0.15

As would be expected, it will be apparent that the amount of the residual longitudinal stress produced in the steel by drawing at room temperature is related to the amount of deformation as measured by the reduction in cross-sectional areas. With light drafts of 12 percent the longitudinal stress as indicated by the warping value increases with drawing at elevated temperature until the steel is preheated to a temperature in excess of about 650° F. Thereafter the warping values fall off slowly and then more rapidly at temperatures in excess of 800–850° F. until a warping value of almost zero concentration is reached at about 900° F. With greater drafts of 19 percent and 36 percent, the warping values remain substantially the same or may increase in some instances, however at temperatures in excess of 650° F. the warping values for steel given a 19 percent reduction begin to drop markedly until substantially zero warping value is reached at about 850° F. With still larger drafts, the warping values rise to higher levels at temperatures below 500° F. but then begin to fall as the steel is heated for drawing at higher temperatures. Substantially zero warping values are reached at about 800–850° F. and negative warping values, indicating the existence of compression forces in the surface of the drawn product, are secured at temperatures in excess of 800–850° F. It will also be evident from the table that the temperature at which reduction in stress values begins to take place is a combined effect of draft and temperature. The decrease in the longitudinal stress for the 12 percent reduction occurs at approximately 690° F. while the decrease for a 19 percent reduction is about 650° F. and for a 36 percent reduction about 550° F.

EXAMPLE 2

A hot rolled open hearth steel of the following composition was processed as by drawing 5/8 inch diameter bars through dies to achieve 19 percent reduction in cross-sectional area.

Steel composition:

0.08 percent carbon
0.75 percent manganese
0.12 percent phosphorus
0.27 percent sulphur
0.01 percent silicon
0.015 percent nitrogen

One group of bars were drawn at a temperature of about 75° F. and other bars were heated to temperatures of about 250°, 400°, 560°, 690°, 740°, 850°, 1035° and 1200° F. before drawing. Some of the bars were air cooled while others were given a water spray upon issuing from the drawing die to cool the bar rapidly down to room temperature. The warping values determined from the various specimens are listed in the following table:

Table II.—warping value of steel bars drawn at various temperatures with a 19 percent reduction in cross-sectional area

Temp. of steel drawn (° F.)	Warping Values	
	Air Cooled	Water Spray
Room temperature	+0.33	+0.33
250	+0.31	+0.30
410	+0.28	+0.27
590	+0.30	+0.25
690	+0.25	+0.20
740	+0.12	+0.05
850	+0.03	−0.05
1,035	+0.02	−0.14
1,200	+0.03	−0.15

It will be observed from the results secured in the series of tests of Example 2 that the residual forces remain at a rather high level whether or not the metal is rapidly cooled after drawing until the metal is drawn while heated at a temperature in excess of 650° F. Thereafter increased reduction in warpage values appears to result by rapidly cooling the drawn metal issuing from the drawing die and negative warping values, indicative of the existence of compressive stresses in the surface portion of the steel, begin to exist in steel products drawn at temperatures in excess of 800–850° F. and which have been rapidly cooled.

EXAMPLE 3

A hot rolled non-austenitic steel of the following composition having a pearlitic structure in a matrix of free ferrite was processed by drawing through dies to achieve a 19 percent reduction in cross-sectional area.

Steel Composition:

0.17 percent carbon
0.75 percent manganese
0.03 percent phosphorus
0.04 percent sulphur
0.08 percent silicon
0.005 percent nitrogen

One group of bars were drawn through the die at room temperature while others were heated to various temperatures to about 1035° F. Some of the bars were allowed to air cool subsequent to drawing while others were rapidly cooled by water spray immediately after issuing from the drawing die.

Table III.—warping values of steel bars drawn at various temperatures with a 19 percent reduction in cross-sectional area

Temp. of steel drawn (° F.)	Warping Values	
	Air Cooled	Water Spray
Room temperature	+0.27	+0.28
260	+0.22	+0.20
410	+0.27	+0.20
560	+0.23	+0.18
690	+0.21	+0.14
860	+0.10	−0.14
1,035	+0.04	−0.08

It will be apparent from the above that the conditions existing in Example 2 are paralleled by the warping values secured under similar conditions with a steel composition of the type employed in Example 3.

These advantages in stress conditions are capable of achievement in addition to the improvements in mechanical and physical properties secured, as heretofore described, by working steel at elevated temperature. The existence of these conditions may be illustrated by comparison of the physical specimens produced in accordance with Example 3 as set forth in the following table:

Table IV.—physical properties of steel given 19 percent reduction in area at various temperatures

	Temperature at drawing					
	Room temperature	260° F.	410° F.	560° F.	690° F.	860° F.
Tensile strength (1,000 p.s.i.)	87.8	88.2	95	96.8	102.2	100
Yield strength (1,000 p.s.i.)	87.2	87.4	94.1	96.3	101.2	97.4
Proportional limit (1,000 p.s.i.)	65	63.6	71	79.8	81	76.8

The residual stress characteristics in steel may also be expressed as a "warpage factor," which in the following examples was determined by a standard warpage test using a 10 inch specimen with an 8 inch slot. The "warpage factor" gives the overall stress characteristics of the steel including the compressive stresses and the tensile stresses effective through the cross-section of the specimen. When measured from the standpoint of warpage factor, it will be apparent from the following data taken on steels of still different chemistries, that the same reactions exist with respect to a marked reduction in the intensity of the existing stress values when the steel is drawn at a temperature in excess of 850° F. In the following tables of results, the described improvements secured in the physical and mechanical properties of the drawn steel at such elevated temperatures will also be set forth.

EXAMPLE 4

A non-austenitic low allow steel having a pearlitic structure in a matrix of free ferrite and of the following composition was processed by drawing through dies to achieve a 5 percent reduction by drawing a ⅝ inch steel bar down to approximately 39/64 inch or about a 1/64 inch draft, and a 30 percent reduction by drawing the ⅝ inch steel bar to about 17/32 inch or nearly a 3/32 inch draft at various temperatures. Prior to drawing, the bars were heated in a lead furnace except for those bars drawn at temperatures above lead furnace temperature. These were heated in an electric furnace. Use was made of a drawing speed of about 10 feet per minute and lubricant No. L571 of the Sinclair Oil Company was applied to the surfaces of the bar for drawing.

Steel Composition:
- .42 percent carbon
- .87 percent manganese
- .016 percent phorphorus
- .026 percent sulphur
- .29 percent silicon
- .87 percent chromium
- .20 percent molybdenum

Table V.—5 percent reduction

	Tensile strength, p. s. i.	Yield strength, p. s. i.	Elong. 1⅜", percent	Warpage Factor
Hot rolled material	146,250	102,000	17.5	+.016
Temp. of Draw, °F.:				
160	158,000	131,750	7	+1.100
450	166,000	148,500	9.5	+.628
570	161,000	145,000	10	+.750
730	149,000	137,500	14.5	+.659
830	140,000	125,000	16.5	+.470
880	135,000	116,000	19	+.376
1,100	144,500	96,250	19	+.007

Table VI.—30 percent reduction

	Tensile strength, p. s. i.	Yield strength, p. s. i.	Elong. 1⅜", percent	Warpage Factor
Hot rolled material	146,250	102,000	17.5	+.016
Temp. of Draw, °F.:				
250	179,500	131,250	8	+.459
480	197,750	147,250	9	+.392
560	198,250	180,000	7	+.386
720	169,500	147,250	12.5	+.374
760	168,000	142,250	13	+.377
820	151,250	134,000	16.5	+.210
880	150,500	139,500	17.5	+.141

EXAMPLE 5

Hot rolled non-austenitic steel bars having the following composition were drawn at various temperatures to effect a 5 percent reduction in cross-sectional area by drawing a bar of ⅝ inch down to approximately 39/64 inch or 1/64 inch draft, and the bars of the same chemistry were also given a 30 percent reduction by drawing the ⅝ inch bars down to about 17/32 inch or nearly a 1/32 inch draft.

Steel composition:
- 0.50 percent carbon
- 0.78 percent manganese
- 0.01 percent phosphorus
- 0.02 percent sulphur
- 0.30 percent silicon
- 1.01 percent chromium
- 1.12 percent vanadium

Table VII.—5 percent reduction

	Tensile strength, p. s. i.	Yield strength, p. s. i.	Elong. 1⅜", percent	Warpage Factor
Hot rolled material	92,000	45,000	29.0	−.010
Temp. of Draw, °F.:				
280	101,625	91,250	20.2	+.505
320	93,750	82,500	25.5	+.550
430	92,500	83,750	25.5	+.544
500	92,750	84,500	23.0	+.465
590	92,750	88,750	22.0	+.395
700	103,750	100,000	16.5	+.397
790	97,750	88,750	20.0	+.282
910	96,000	78,500	23.0	+.075
980	88,500	79,000	28.0	+.162

Table VIII.—30 percent reduction

	Tensile strength, p. s. i.	Yield strength, p. s. i.	Elong. 1¾", percent	Warpage Factor
Hot Rolled Material	92,000	45,000	29.0	−.010
Temp. of Draw, ° F.:				
220	106,500	96,750	17.2	+.152
320	106,250	102,000	14.5	+.155
420	107,000	100,500	16.0	+.119
500	115,000	111,000	13.0	+.119
590	118,750	112,500	12.5	+.103
690	123,500	121,000	12.5	+.077
820	117,750	112,500	14.0	+.027
1,000	110,250	97,500	19.0	+.006

EXAMPLE 6

Hot rolled non-austenitic steel bars having the following composition were drawn at various temperatures to effect a 5 percent reduction in cross-sectional area by drawing a bar of ⅝ inch down to approximately 39/64 inch or 1/64 inch draft, and the bars of the same chemistry were also given a 30 percent reduction by drawing the ⅝ inch bars down to about 17/32 inch or nearly a 1/32 inch draft.

Steel composition:

.39 percent carbon
.76 percent manganese
.015 percent phosphorus
.019 percent sulphur
.28 percent silicon
1.80 percent nickel
.76 percent chromium
.25 percent molybdenum

Table IX.—5 percent reduction

	Tensile strength, p. s. i.	Yield strength, p. s. i.	Elong. 1¾", percent	Warpage Factor
Hot Rolled Material	98,250	60,000	29.0	+.042
Temp. of draw, ° F.:				
145	112,000	102,250	16.7	+.967
290	108,125	99,750	20.3	+.822
430	115,500	104,500	19.0	+.650
520	116,000	110,500	13.0	+.600
590	121,250	119,500	13.0	+.584
700	120,500	117,000	12.5	+.512
780	119,250	110,000	16.0	+.382
950	112,875	88,750	19.5	+.101

Table X.—30 percent reduction

	Tensile strength, p. s. i.	Yield strength, p. s. i.	Elong. 1¾", percent	Warpage Factor
Hot Rolled Material	98,250	60,000	29	+.042
Temp. of Draw, ° F.:				
210	123,750	106,500	14.5	+.316
350	135,750	125,500	12.5	+.258
420	143,500	141,000	9.5	+.226
520	135,500	134,500	11.5	+.212
580	143,250	142,000	10	+.171
690	134,750	127,000	10	+.194
820	132,000	120,500	11	+.102
1,000	133,750	119,000	11	.00

From the data set forth in Tables V to X of Examples 4 to 6 it will be apparent that the warpage factors in the steel products are reduced materially when the temperature of the steel drawn exceeds 850° F. The marked reduction in warpage factor indicates either the neutralization of the stresses existing in the steel or reduction in the intensity of the stresses existing throughout the cross-section of the steel. It is highly likely, as previously pointed out with reference to the comparison between quenching and not quenching of the steels drawn at elevated temperature, that compressive stresses exist in the outer portions of the steel which are reacted by working upon drawing and that such compressive stresses neutralize the tensile stresses in other portions of the steel to provide a product having low warpage factor. In any event, it has been found that steels which have been worked as by drawing or extrusion to effect reduction in cross-sectional area when heated to a temperature in excess of 850° F. provide improvements with respect to the end products that are formed thereof in the elimination of warpage and cracking.

In general, it will be apparent that marked reduction in residual stresses, as measured by the warpage tests, in drawn steel products is available by drawing at elevated temperatures limited to temperatures above 640° F. and preferably above 850° F. for the development of compressive stresses up to the lower critical temperature for the steel composition. It will be apparent also that such improvements in the stress characteristics of the steel are achieved at temperature levels within the range at which improvements in physical and mechanical properties may be secured as by working the steel such as in an extrusion or drawing operation at an elevated temperature below the lower critical temperature for the steel composition.

It will also be apparent that compressive forces, advantageous in increasing torsional fatigue substantially can be achieved for the first time by the introduction of compressive stresses in the outer surfaces of the drawn steel products by drawing the steel at elevated temperatures in excess of 850° F. and immediately cooling the bars rapidly by quenching or spraying, preferably with water. In some instances bars with compressive stresses on the surface may be produced in accordance with the practice of this invention, by drawing at elevated temperatures without rapid cooling of the type described although these stresses may not be strong enough to produce negative warpage values.

It will be evident from the description that there is provided herein a new and novel metallurgical process for producing steel products embodying low stress values, at least as low as values secured by cold drawing at room temperature followed by a separate step of stress relieving by furnace treatment. Thus it is possible, in accordance with the practice of this invention, to achieve the desired marked reduction of the stress factors in a single processing step without limitation as to draft. By the metallurgical process described herein, it is also possible, by proper selection of temperature of the steel drawn, to produce a new steel product having compressive stresses in sufficient amount in the surface portion thereof whereby improvements are available with respect to the subsequent fabrication of the steel into various products. These advantages and stress conditions are capable of achievement in addition to the improvements in the physical and mechanical properties secured, as previously described.

The method of heating the steel to the desired temperature of drawing is unimportant. Heating may be achieved by any number of ways well known in the art, such as by an electric furnace, resistance heating or the like. For example, the steel may be heated by means of a salt bath which may advantageously be used also to coat the metal with a lubricant and otherwise condition the surface of the steel for drawing, as described in the copending application of Nachtman, Ser. No. 286,039, filed May 3, 1952, wherein description is made that, in the past, the metal has been prepared for deformation to produce a better finish in a cold finishing operation by treating the surface of the metal first with an acid to remove scale, followed by a rinse to remove acid, followed further by liming to protect the surface and to prepare the surface for subsequent application of lubricant prior to cold working or drawing. The improvement described in the aforementioned copending application resides in the development of a process wherein the various steps of descaling, washing, liming and lubricating are provided in a single step wherein the steel is treated with a molten bath of sodium hydroxide and a reducing agent wherein the steel is descaled by chemical reduction and wherein the steel is heated to the desired temperature

for advancing the steel through the die to effect reduction in cross-sectional area in accordance with the practice of this invention. Instead of applying molten salts for purposes of lubrication, use may be made of conventional lubricating compounds.

It will be understood that changes may be made in the details of processing and in the manner of heating and cooling of the steel during working as by drawing or extrusion without departing from the spirit of the invention, especially as defined in the following claims.

We claim:

1. The method of processing a hot rolled steel of the non-austenitic type having a pearlitic structure in a matrix of free ferrite which hardens when worked at a temperature between 850° F. and the lower critical temperature for the steel composition, comprising the steps of descaling the steel and lubricating the surfaces of the steel and drawing the steel through a drawing die to effect reduction in cross-sectional area while the steel is at a temperature above 850° F. but below the lower critical temperature of the steel composition whereby the drawn steel is characterized by improved physical and mechanical properties and low residual stresses.

2. The method of working steel of the non-austenitic type having a pearlitic structure in a matrix of free ferrite and which hardens when worked at a temperature between 850° F. and the lower critical temperature for the steel composition to improve the physical and mechanical properties thereof, comprising the steps of drawing the steel through a drawing die to effect reduction in cross sectional area while the steel is at a temperature in excess of 850° F. but below the lower critical temperature for the steel composition, and quenching rapidly to cool the steel immediately after drawing whereby compressive stresses are formed in the drawn steel in sufficient concentration to provide negative warping values in the steel product.

3. The method of processing a hot rolled steel of the non-austenitic type having a pearlitic structure in a matrix of free ferrite and which hardens when worked at a temperature between 850° F. and the lower critical temperature for the steel composition, comprising the steps of descaling the steel and lubricating the surfaces of the steel and extruding the steel through a die to effect reduction in cross-sectional area while the steel is at a temperature above 850° F. but below the lower critical temperature for the steel composition whereby the extruded steel is characterized by improved physical and mechanical properties and low residual stresses.

4. The method of processing steel of the non-austenitic type having a pearlitic structure in a matrix of free ferrite and which hardens when worked at a temperature between 850° F. and the lower critical temperature for the steel composition comprising the steps of extruding the steel through a die to effect reduction in cross-sectional area while the steel is at a temperature in excess of 850° F. but below the lower critical temperature for the steel composition, and quenching rapidly to cool the steel immediately after extrusion whereby compressive stresses are formed in the steel in sufficient concentrations to provide negative warpage values in the steel product.

5. The method of processing a hot rolled steel which strain hardens and which hardens by some mode of precipitation when worked at a temperature within the range of 850° F. to the lower critical temperature for the steel composition, comprising the steps of descaling the steel and lubricating the surfaces of the steel and drawing the steel through a drawing die to effect reduction in cross-sectional area while the steel is at a temperature above 850° F. but below the lower critical temperature of the steel composition whereby the drawn steel is characterized by improved physical and mechanical properties and low residual stresses.

6. The method of processing a hot rolled steel which strain hardens and which hardens by some mode of precipitation when worked at a temperature within the range of 850° F. to the lower critical temperature for the steel composition, comprising the steps of drawing the steel through a drawing die to effect reduction in cross-sectional area while the steel is at a temperature in excess of 850° F. but below the lower critical temperature for the steel composition, and quenching rapidly to cool the steel substantially immediately after drawing whereby compressive stresses are formed in at least the surface portion of the drawn steel.

7. The method of processing a hot rolled steel which strain hardens and which hardens by some mode of precipitation when worked at a temperature within the range of 850° F. to the lower critical temperature for the steel composition, comprising the steps of drawing the steel through a drawing die to effect a light reduction in cross-sectional area while the steel is at a temperature above 850° F. but below the lower critical temperature for the steel composition, and quenching rapidly to cool the steel substantially immediately after drawing whereby the steel is characterized by improved physical and mechanical properties and compressive stresses are formed in the steel in sufficient concentration to provide negative warpage values in the drawn steel.

8. The method of processing a hot rolled steel which strain hardens and which hardens by some mode of precipitation when worked at a temperature between 850° F. and the lower critical temperature of the steel composition, comprising the steps of descaling and lubricating the surfaces of the steel and advancing the steel through a die to effect reduction in cross-sectional area while the steel is at a temperature above 850° F. but below the lower critical temperature for the steel composition whereby the physical and mechanical properties of the steel are improved.

9. The method of processing a steel which strain hardens and which hardens by some mode of precipitation when worked at a temperature between 850° F. and the lower critical temperature of the steel composition, comprising the steps of advancing the steel through a die to effect reduction in cross-sectional area while the steel is at a temperature above 850° F. but below the lower critical temperature for the steel composition, and quenching rapidly to cool the steel immediately after the steel is advanced through the die whereby compressive stresses are formed in the steel and whereby mechanical and physical properties of the steel are improved.

10. A steel product having improved mechanical and physical properties and low warpage value produced by the method of claim 8.

11. A hot rolled steel product having improved mechanical and physical properties and compressive stresses in the surface portion in sufficient concentration to provide negative warpage values in the steel product produced by the method of claim 9.

12. In a metallurgical process for producing the properties of cold finished, hot rolled steel bars having improved mechanical and physical properties and wherein the hot rolled steel bars strain harden and harden by some mode of precipitation when worked at a temperature within the range of 850° F. to the lower critical temperature for the steel composition, the steps of descaling the steel bars and lubricating the surfaces of the steel bars, and advancing the steel bars through a die to effect reduction in cross-sectional area while the steel is at a temperature above 850° F. but below the lower critical temperature for the steel composition whereby the physical and mechanical properties of the steel are improved.

13. In a metallurgical process for producing the properties of cold finished, hot rolled steel bars having improved mechanical and physical properties and wherein the hot rolled steel bars strain harden and harden by some mode of precipitation when worked at a temperature within the range of 850° F. to the lower critical tem-

perature for the steel composition, the steps of descaling the steel bars and lubricating the surfaces of the steel bars, and drawing the steel bars through a draw die to effect reduction in cross-sectional area while the steel is at a temperature above 850° F. but below the lower critical temperature for the steel composition whereby the physical and mechanical properties of the steel are improved.

14. In a metallurgical process for producing the properties of cold finished, hot rolled steel bars having improved mechanical and physical properties and wherein the hot rolled steel bars strain harden and harden by some mode of precipitation when worked at a temperature within the range of 850° F. to the lower critical temperature for the steel composition, the steps of descaling and lubricating the surfaces of the steel bars, advancing the steel bars through a die to effect reduction in cross-sectional area while the steel is at a temperature above

850° F. but below the lower critical temperature for the steel composition, and quenching rapidly to cool the steel immediately after advancement through the die whereby compressive stresses are formed in the steel and whereby mechanical and physical properties of the steel are improved.

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