Jan. 18, 1966 M. W. TUFTS 3,230,118

METHOD OF DEVELOPING HIGH PHYSICAL PROPERTIES IN FERROUS MATERIAL AND PRODUCT PRODUCED THEREBY

Filed Aug. 15, 1961

Fig. 1.

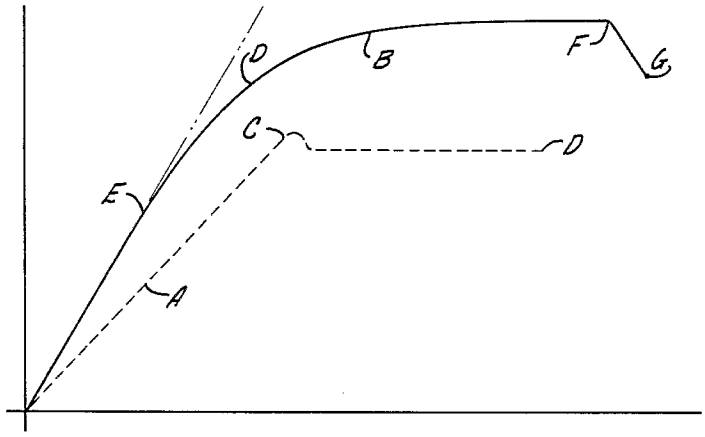


Fig. 2.

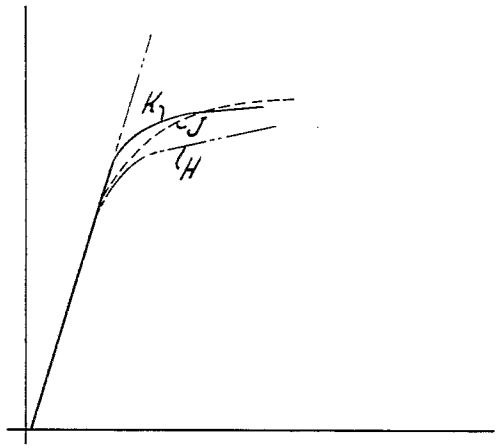
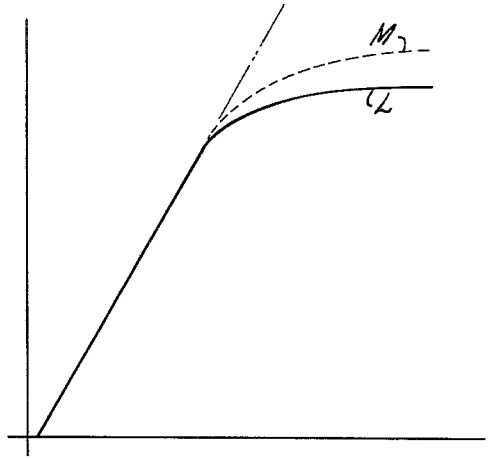


Fig. 3.



INVENTOR.
Marshall W. Tufts,
BY Parker & Carter
Attorneys.

United States Patent Office 3,230,118 Patented Jan. 18, 1966

3,230,118

METHOD OF DEVELOPING HIGH PHYSICAL PROPERTIES IN FERROUS MATERIAL AND PRODUCT PRODUCED THEREBY

Marshall W. Tufts, Crete, Ill., assignor, by mesne assignments, to Screw and Bolt Corporation of America, Pittsburgh, Pa., a corporation of Pennsylvania

Filed Aug. 15, 1961, Ser. No. 131,557
7 Claims. (Cl. 148—12)

My invention relates to ferrous materials having improved physical properties and to a method of improving the physical properties of ferrous materials. It is specifically directed to a method of improving the physical properties of ferrous materials that respond to strain-hardening or precipitation-hardening of some nature while maintaining the hardness at least substantially constant, or, alternately, while reducing the hardness.

It is well known that the physical properties of many ferrous materials, such as carbon steels, can be improved by heat treatment. To the best of my knowledge an increase in physical properties by heat treatment is always accompanied by an increase in hardness. In applications in which hardness is the limiting factor, such as applications in which machinability is important, the known methods of improving the physical properties are of little benefit.

My invention, in its broadest aspect, consists essentially of stressing, at least once, ferrous materials that respond to strain-hardening or precipitation-hardening of some nature to at least a point at which, upon release of the stress, a permanent set or plastic deformation is imparted to the steel. The stressing operation may optionally be performed in conjunction with a cold working operation, generally one in which a change in the cross section configuration of the material is achieved, such, for example, as a cold drawing operation. If a cold working operation is employed, it may precede or follow the stressing operation.

Alternately, the ferrous material may be stress relieved in conjunction with the stressing, or stressing and cold working operations. The stress relieving should be carried out at a temperature below the recrystallization temperature of the ferrous material in its unstressed condition. The stressing, cold working if employed, and stress relieving need not occur in any particular sequence although the advantages of the invention will not be achieved if the ferrous material is first stress relieved and then stressed obviously. It will often prove to be more expedient to first stress and then stress relieve, and this is the preferred method. It is quite within the scope of my invention however to simultaneously stress and stress relieve the material in one operation.

Further, more than one stress relieving operation may be employed. If a plurality of stress relieving operations are employed, they may be used after each preceding stressing and/or cold working operation, or after only selected preceding operations.

My invention will best be understood from the following description which, when read in light of the accompanying drawings, will illustrate several methods by which it may be carried out. In the accompanying drawings,

FIGURE 1 is a diagrammatic representation of the range of plastic deformation on representative stress-strain curves;

FIGURE 2 is a stress-strain curve of a C–1018 type steel; and

FIGURE 3 is a stress-strain curve of a 4140 type steel.

For purposes of convenience my invention will be described in terms of treatment of bar stock. It should be understood that the scope of the invention is not limited to bar stock. The physical properties of ferrous material

of almost any type and cross-sectional configuration, regular or irregular, can be improved if the material can somehow be subjected to sufficient stresses.

For purposes of this description and claims the terms "permanent set" and "plastic deformation" refer to a condition of the material in which it has been stressed to a point such that, upon release of the stress, a permanent set or plastic deformation will have been imparted to the material. The magnitude of plastic deformation need not be equivalent to the deformation during stress. The material will be considered to have a permanent set if it does not return to its original condition upon release of the stress.

In materials in which the yield joint is readily discernible, the lower end of the range of plastic deformation may be equated roughly to it, but as is well known the yield point is not readily discernible in many types of conventional materials, such as cold drawn bar stock.

The upper end of the range is defined by that point on a stress-strain curve beyond which rapid loss of strength is produced by continued application of stress. When speaking of bar stock, for example, the upper end of the plastic deformation range would be that point at which the material begins to neck down.

FIGURE 1 illustrates diagrammatically the plastic deformation range on two typical steels.

Curve A represents the stress-strain curve of 4140 hot rolled carbon steel bar stock having the following approximate analysis:

C	.40
Mn	.86
P	.015
S	.025
Si	.25
Cr	.93
Mo	.20

Curve B represents a steel which has been hot rolled, cold drawn and stress relieved prior to being treated in accordance with my method.

In the steel of curve A the lower end of the plastic deformation point would be approximately at point C, which is roughly the yield point of the steel. The upper end of the plastic deformation range would be represented by point D, which is the breaking point of the steel. The plastic deformation range would therefore extend from C to D along the abscissa.

The yield point of the steel represented by curve B is not readily discernible. If the steel were stressed in the range represented, roughly, between E and D, upon removal of the stress the steel would return at least partially to its original condition. Since the yield point is not readily discernible, the lower end of the plastic deformation range cannot be pinpointed on the curve but can be described as the point beyond which the steel will not return to its original condition. The upper end of the range would be represented by point F, since that part of the curve between F and G represents the necking-down of the steel before it fractures at G.

My invention can best be visualized from data derived from tests run on conventional types of bar stock.

Table I shows to what extent the physical properties of 4140 bar stock was improved with a constant stress relieving temperature. The particular stock tested had the following approximate analysis:

C	.40
Mn	.86
P	.015
S	.025
Si	.25
Cr	.93
Mo	.20

In each instance specimens approximately 3 feet long x 5/8 inch in diameter were first stressed to a point in the plastic deformation range and thereafter stress relieved. Following these two steps the indicated tests were run to evaluate the physical properties.

Table I

	T.S.	Y.S.	EL. 2"	R.A.	Hardness, B.H.N.	Normal Hardness Equivalent to Achieved Physicals
Q.&T. 1,180° F	143,800	136,800	19.4	57.5	279	
Q.&T. 2% S_r 600°	146,200	133,800	20.0	56.5	271	294
Q.&T. 4% S_r 600°	149,400	149,400	17.7	57.5	271	301
Q.&T. 6% S_r 600°	163,600	152,900	16.6	54.3	286	327
Q.&T. 8% S_r 600°	174,100	168,500	16.6	47.9	286	353

In its quenched and tempered condition, the steel had a yield strength of 136,800 p.s.i. whereas after it was stressed 8 percent and then stress relieved at 600 degrees F. the yield strength was increased to 168,500 p.s.i., an increase of approximately 26 percent in terms of the original yield strength. In the foregoing table and throughout the specification the magnitude of stress is expressed in terms of increase in length over the original length of the specimen. The increase in length will of course be accompanied by a reduction in cross sectional area. Unless otherwise indicated, all materials having a definitely discernible yield point were stressed beyond it. The length of time the specimen was subjected to the stress relieving temperature was based on conventional industry practice. Usually the bars were stress relieved approximately one hour per cross-sectional inch, with approximately a 50 percent safety factor.

The last two columns should be compared with the strength columns. The hardness, expressed in terms of Brinell hardness numbers, BHN, an untreated specimen in its quenched and tempered condition was 279. In the remainder of the specimens the hardness remained constant within experimental error. This occurred despite

the fact that the physical properties, for example the yield strength, increased appreciably. The last column indicates the hardness normally required to reach the physical properties achieved by the combination stressing and stress relieving operations specified in column 1.

In Table II the improvement in physical properties achieved by subjecting specimens of 4140 bar stock to gradually increasing stress relieving temperatures while maintaining the stress approximately constant are tabulated.

Table II

	T.S.	Y.S.	EL. 2"	R.A.	Hardness, B.H.N.	Normal Hardness Equivalent to Achieved Physicals
Q.&T. 1,180° F	143,800	136,800	19.4	57.5	279	
Q.&T. 6% S_r 200°	155,200	155,200	16.5	52.8	286	311
Q.&T. 6% S_r 400°	166,100	157,000	16.0	54.9	286	336
Q.&T. 6% S_r 600°	163,600	152,900	16.6	54.3	286	327
Q.&T. 6% S_r 800°	152,200	149,400	19.7	54.9	294	301

The figures show that the combination of stressing followed by stress relieving increased the strength of the steel over its quenched and tempered condition. Temperatures of 200° F. to 800° F. were effective, with maximum improvement occurring at about 400° F. Again a comparison of the values in the last two columns indicates that the increase in physical properties was achieved with practically no increase in hardness.

In Table III the increase in physical properties to be expected when my method is used in conjunction with a conventional cold drawing and stress relieving operation is illustrated.

Table III

	T.S.	Y.S.	EL. 2"	R.A.	Hardness, B.H.N.	Normal Hardness Equivalent to Achieved Physicals
H.R. 1/16"CD—600°	190,000	176,200	7.5	44.8	381	
H.R. 6% S_r: 400°—1/16"CD 600°	230,300	212,300	7.0	37.3	264	451

In this table the first $1\frac{1}{16}$", 3' specimen of hot rolled 4140 bar stock was subjected to a cold drawing operation which reduced its diameter $\frac{1}{16}$", and then stress relieved at 600° F. The second specimen, which was identical in chemical composition to the first, was first stressed 6 percent and stress relieved at a temperature of 400 degrees

F. before the cold drawing and final stress relieving operation. The additional steps produced more than a 21 percent increase in tensile strength and almost a 21 percent increase in yield strength. In this instance, the hardess of the specimen dropped markedly. This is important because it makes possible the use of material for a given application whose initial hardness is too high and strength too low for the application.

In Table IV the effect of varying both the amount of stress and the stress relieving temperature is indicated. A C1144 type steel having the following composition was tested: C .42, Mn 1.57, P .016, S .290.

Table IV

	T.S.	Y.S.	EL. 2" percent	R.A.	Hardness, B.H.N.	Normal Hardness Equivalent to Achieved Physicals
HR 0% S_r	105,400	70,600	18	40.9	200	
6% S_r 400° C.D	136,200	127,800	5.5	36.4	200	279
6% S_r 400° C.D 600°	146,100	134,200	7.0	32.7	204	294
HR 8% S_r 600° F	120,300	115,600	16.0	42.8	183	231

The second test piece was first stressed 6 percent, then stress relieved at 400 degrees F. and finally cold drawn. By comparison, the same procedure was followed with the third test piece with the addition of a final stress relieve at 600 degrees F. The additional stress relieving operation markedly improved the tensile and yield strengths. The increase in physical properties in specimen number 3 was achieved with substantially no increase in hardness over the reference specimen or the stress relieved and cold drawn specimen.

The foregoing tabular data can be visually summarized from the typical stress-strain curves of FIGURES 2 and 3.

In FIGURE 2 a C1018 type steel having the following approximate analysis is illustrated:

C	.18
Mn	.74
P	.012
S	.030

Curve H represents a hot rolled, cold drawn specimen. Curve J represents a hot rolled, 6 percent stressed, 400 degrees F. stress relieved, cold drawn, and 600 degrees F. stress relieved specimen. Specimen K was first stressed 6 percent in its hot rolled condition, stress relieved at 400 degrees F. and cold drawn. The stressing and stress relieving operations preceding the cold drawing step in each of the specimens J and K materially improved the strength characteristics. The hardness of the various specimens stayed constant within the limit of experimental error.

In FIGURE 3 a 4140 type steel having the following approximate analysis is illustrated:

C	.40
Mn	.84
P	.015
S	.025
Si	.25
Cr	.93
Mo	.20

In this figure, as in FIGURE 2, the improved physical properties resulting from my method are compared to the physical properties achieved by a specimen which has been hot rolled, cold drawn and stress relieved at 600 degrees F., the hot rolling, cold drawing and stress relieving operations being carried out in a conventional manner. The hot rolled, cold drawn, and stress relieved specimen is represented by curve L. The hot rolled specimen represented by curve M was first stressed 6 percent and then stress relieved at 400 degrees F. From a comparison of the curve, specimen M showed markedly higher strength properties while the hardness was maintained substantially equal to the specimen represented by curve L.

A typical method of treating ferrous material in accordance with my invention is outlined below.

Steel bar stock in either a hot rolled, normalized, quenched and tempered, or annealed condition will be used as an exemplary material. My method is applicable to bar stock in all conditions.

The steel bar stock, in its condition as delivered from the mill, is first subjected to tensile stress in the plastic deformation range.

Either concurrently with or after the stressing operation the steel is stressed relieved. The stress relieving temperature and the time at which the steel is subjected to the temperature will vary on many factors including, among others, the size of the workpiece, the analysis of the steel, the grain structure, and the amount of final residual stresses desired. With 1 1/16" hot rolled round type C1018 bar stock I have subjected 3' specimens to temperatures in the range of from about 200 degrees F. to 800 degrees F. for approximately an hour.

The type of heat employed is not especially important. If a bar is stress relieved simultaneously with the stressing, electric heat can be used. Gas heating could just as well be utilized however.

After stressing and stress relieving, the steel bar stock may be subjected to a further sizing operation. I have applied my method particularly to cold drawing operations. The cold drawing steps indicated in the figures and preceding tables represent cold drawing operations in which the reduction in diameter of the bar stock was approximately 1/16". I wish to make clear, however, that the cold drawing operation may be used merely as a sizing operation.

The cold drawing operation is most advantageously carried out at room temperature and I define the term "cold drawing" as used in this specification and claims to describe a drawing operation in which the dies are exposed to ambient temperatures. The dies may, of course, pick up heat during the drawing operation but the addition of heat is not necessary to the practice of my invention and, in fact, I prefer that the dies be unheated.

The bar stock after stressing, stress relieving and cold drawing may then be used in its cold drawn condition. The stock will, however, contain stresses, particularly surface stresses, as a result of the drawing operation. In order to minimize, and perhaps eliminate these stresses, a second optional, stress relieving operation can be performed. The manner of performing the second stress relieving operation can be identical to the first stress relieving operation. Temperatures in the range of from about 200 degrees F. to 1000 degrees F. have been employed to advantage.

Alternately, the improvement in physical properties may be achieved by the use of ultrasonics in conjunction with the stressing operation. Briefly, a workpiece is subjected to ultrasonic sound waves as it is stressed. To the best of my knowledge, the method of applying the ultrasonic sound is not critical. I have utilized both

the transmission method, in which a crystal is placed at both ends of a bar to provide a through emission of sound waves, and the reflection method, in which one crystal is placed adjacent the bar and the waves bounce off the crystal and back to the oscillator. The results of both methods of ultrasonics in conjunction with the application of stress are tabulated in Table V. All specimens were hot rolled 11/16" round 4140 stock.

Table V

	T.S.	Y.S.	EL. 2" percent	R.A. percent	Hardness, R_c	Normal Hardness Equivalent to Achieved Physicals
BAR #1						
HR 6%	154,100	152,000	10	47.3	30/32	33
HR 6% 400°	168,000	161,800	7	41.2	31/32	36
HR 6% 400°	174,200	168,100	7	41.2	34/35	37.5
HR 6% C.D., 650°	176,100	172,500	8.5	43.8		38
BAR #2						
HR 6%	163,500	163,000	5.5	41.2	29/30	34.5
HR 6% 400° F	176,100	171,100	5.5	42.8	34/35	38

The transmission method was used with specimens 2 through 4 and the reflection method with specimens 5 and 6. In both methods a frequency of 2½ megacycles was used during the time the specimens were subjected to stress. In specimens 3 and 6 the hardness increased slightly over the hardness of specimen 1. The amount of hardness increase was, however, considerably less than the hardness that would have been required to reach the achieved physicals.

Experimentation has also indicated that the length of time that a stress is held on the specimen is not especially important. The following table shows the physical properties produced in chemically identical specimens subjected to a holding stress of varying duration. Each specimen was a 3 foot piece of 4140, 11/16" round bar stock. Each was first stressed 6 percent, and the stress maintained for the times set forth in the table.

Table VI

	Holding Time, Sec.	T.S.	EL. 2"	R.A.	Hardness, R_c
6%	0	154,100			30
6%	30	144,200	10.0	50.0	28/29
6%	60	144,200	10.0	50.0	28/30
6%	120	142,800	10.0	53.0	28/29.5

As can be seen, the achieved physical properties are within the range of experimental error from specimen to specimen. This is an important economic consideration since a commercial operation need not be slowed down to provide stress dwell times.

I have also observed that the achieved physical properties do not vary significantly with differences in the rate of application of the stress. This factor is likewise an important commercial consideration because production of bar stock in large quantities need not be slowed due to a limiting rate of application of stress.

One great advantage of my method is that the conventional scale removal step generally employed by bar stock fabricators can be eliminated. Hot rolled or annealed bar stock as it comes from the mill has gone through the last phase of the rolling mill at around 1600 degrees F. and has merely air cooled thereafter. Air cooling causes scale to form on the surface of the stock. The scale must be removed, generally by acid pickling or shot-blasting, before the stock is drawn because the surface of the stock can be deformed or the drawings dies will be worn before their economic life has run. In my method the stressing of the stock causes the scale to actually pop off. At the end of the stressing operation the stock is as clean as if it had been subjected to a conventional scale removal operation.

The improvement in tensile and yield strength properties in ferrous materials will vary widely with the type of material, and particularly the carbon. In some types of steel the improvement may be less marked than in those discussed herein. It may still be extremely desirable, however, to employ my method on such a steel because the machinability may be increased. For example, in many applications, such as sucker rod connectors, machinability is the limiting service factor of the steel. A sucker rod connector is essentially a sleeve type coupling which connects two adjacent lengths of pipe used in oil well drilling. Generally, the connector is machined in its heat-treated condition because heat treating a machined piece would tend to distort the threads. In order to be machinable the steel is limited to about 32 Rockwell C which in turn limits the inherent strength of the stock. By utilizing my method it is possible to obtain improved machinability with steels having a higher strength than a limit of 32 Rockwell C would dictate.

My method will also be useful in treating structural steels. It is desirable to increase the physical properties of structural steels while reducing the mass for obvious reasons. At the present time it is generally not possible to increase the physical properties of structural steels by heat treatment because most heat treating furnaces cannot handle structural steel sizes. Even if they could, the heating and quenching operations required would create distortion, and it is extremely difficult to compensate for distortion in structural shapes. Since my method imparts little or no distortion it is possible to achieve the benefits of heat treatment without the adverse side effects.

It should also be noted that in some cases my method will actually reduce the hardness of the steel as contrasted to the hardness of the starting stock while improving the physical properties.

To the best of my knowledge, the type of stress imparted to the ferrous material is not especially critical. Generally, I contemplate that it will be more expedient to impart a tensile stress than a compressive stress.

The foregoing description is intended to be illustrative only as other applications of my invention will at once be apparent to those skilled in the art. Those applications are, of course, within the scope of my invention. It is my intention that the scope of my invention be limited only by the scope of the following claims.

I claim:

1. In the method of imparting increased physical properties to carbon bearing steel stock which responds to strain or precipitation hardening, the steps comprising

providing said stock having a cross sectional area greater than a final, desired cross sectional area,

reducing the cross sectional area by applying a pure tensile stress to the entire cross sectional area of the stock until a permanent set is imparted to it,

subjecting the stressed stock to a temperature below the recrystallization temperature of the stock in its

unstressed condition to yield a structure having increased physical properties, and

cold sizing the stock to the final desired size.

2. The method of claim 1 further characterized in that the temperature to which the stressed stock is subjected is in the range of from about 200° F. to about 1000° F.

3. The method of claim 2 further characterized in that the temperature to which the stressed stock is subjected is in the range of from about 400° F. to about 600° F.

4. The method of claim 1 further characterized in that the stressed stock is subjected to the aforesaid temperature until the strain or precipitation hardening becomes effective.

5. The method of claim 1 further characterized in that the increase in length imparted to the stock is in the range of from about 2% to about 8% of the original length of the stock.

6. The method of claim 5 further characterized in that the stock is stressed about 6%.

7. The method of claim 1 further including the steps of

cold drawing the stock until a change in cross section configuration is achieved subsequent to subjection of the stock to the aforesaid temperature, and

again subjecting the stock to a temperature below the recrystallization temperature of the stock in its unstressed condition,

said preceding two steps being carried out immediately prior to the final cold sizing operation.

References Cited by the Examiner

UNITED STATES PATENTS

1,373,589	4/1921	Blood	148—12.9
1,692,521	11/1928	Sturcke	148—12
1,978,219	10/1934	Otte	148—12
2,235,026	3/1941	Kruse	148—12.9
2,813,049	11/1957	MacCutcheon	148—12
2,848,775	8/1958	Ettenreich	148—12.9
2,924,543	2/1960	Nachtman	148—12
3,053,703	9/1962	Breyer	148—12

FOREIGN PATENTS

295,390	1/1929	Great Britain.
373,453	5/1932	Great Britain.
400,395	10/1933	Great Britain.

DAVID L. RECK, *Primary Examiner.*

RAY K. WINDHAM, *Examiner.*