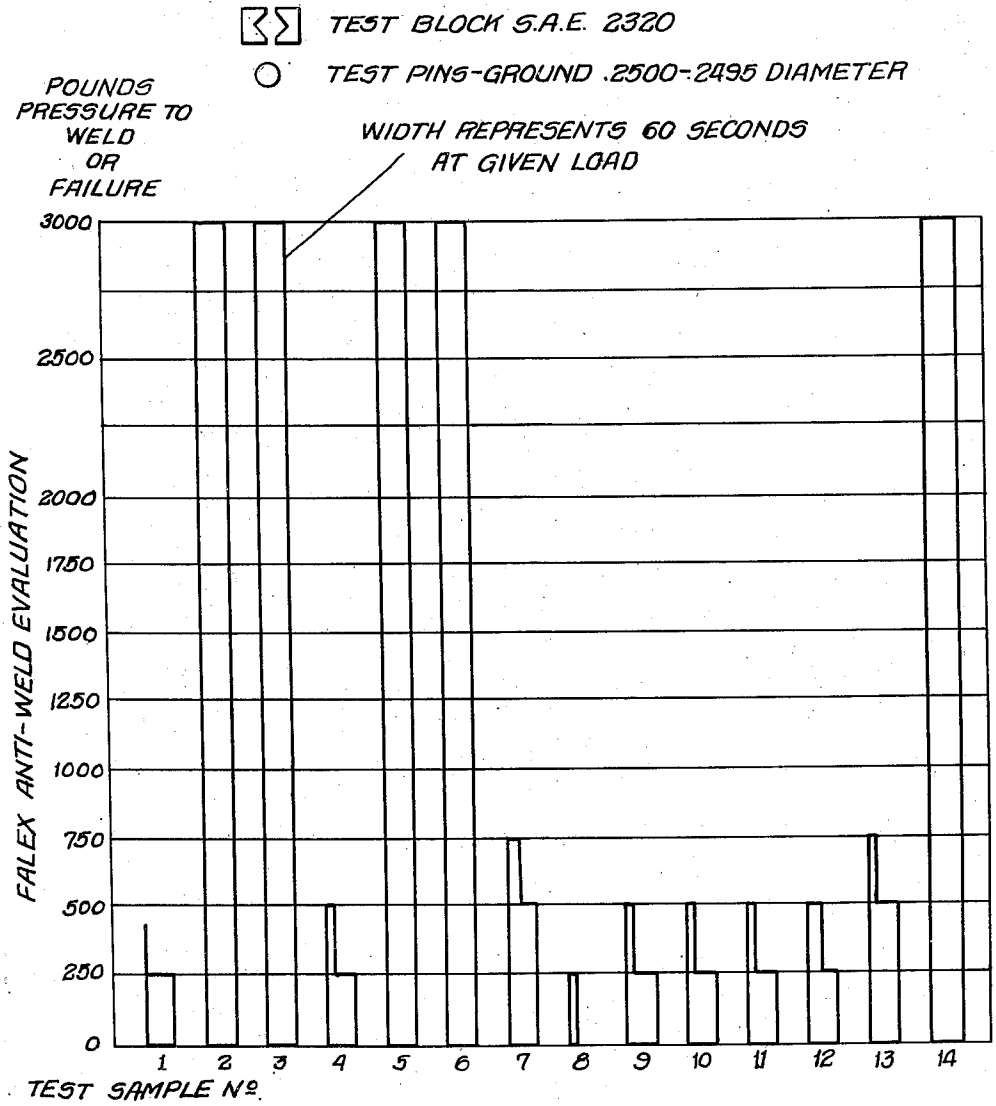
May 25, 1943. H. N. LANDIS. 2,320,040

STEEL PRODUCT AND METHOD FOR THE MANUFACTURE THEREOF

Filed April 11, 1940 2 Sheets-Sheet 1

Fig. 1.



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STEEL PRODUCT AND METHOD FOR THE MANUFACTURE THEREOF

Filed April 11, 1940 2 Sheets-Sheet 2

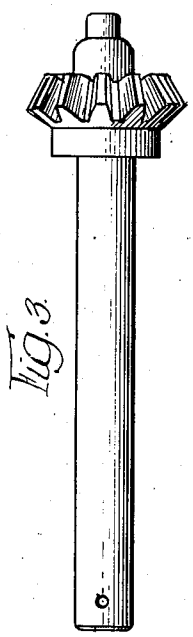


Fig. 3

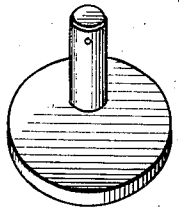


Fig. 2

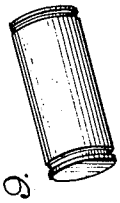


Fig. 9

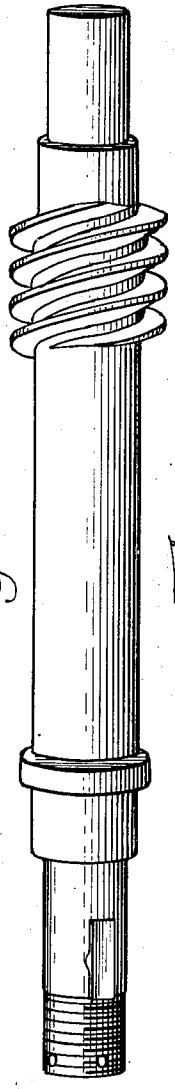


Fig. 4



Fig. 5

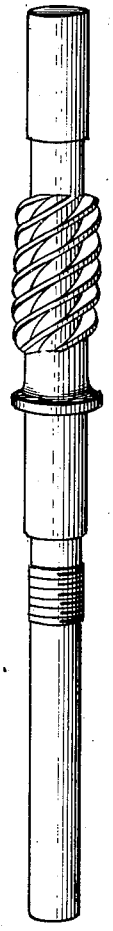


Fig. 6

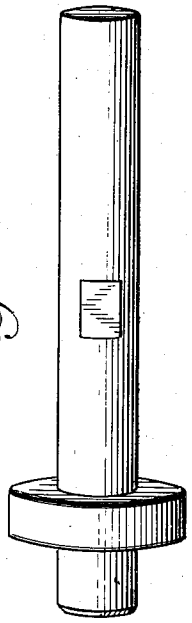


Fig. 8

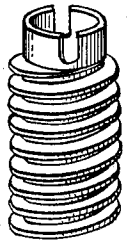


Fig. 7

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Patented May 25, 1943 2,320,040

UNITED STATES PATENT OFFICE

2,320,040

STEEL PRODUCT AND METHOD FOR THE MANUFACTURE THEREOF

Henry Neuman Landis, Chicago, Ill., assignor to La Salle Steel Company, Chicago, Ill., a corporation of Delaware

Application April 11, 1940, Serial No. 329,011

16 Claims. (Cl. 148—12)

This invention relates to new and improved steel products and a new and improved method for the manufacture thereof.

The invention more particularly relates to a method of metallurgical treatment whereby to produce a steel of the cold worked type with hitherto unachieved combinations of physical properties, such as, for example, combinations of two or more of the following properties, namely, high tensile strength, extremely satisfactory ductility, true elastic stress-strain curves, a minimum of warpage and distortion, exceptional machinability and wearability.

The present application is a continuation-in-part of my co-pending application, Serial No. 112,707, filed November 25, 1936, which in turn is a continuation-in-part of my application Serial No. 42,883, filed September 30, 1935.

One of the objects of this invention is to provide a method of producing steel of the cold worked type having highly satisfactory physical characteristics.

Another object of the invention is to provide a method for producing a cold worked steel which has combined physical properties of high tensile strength and satisfactory ductility.

Still a further and very important object of the invention is to provide a new and improved method for manufacturing steel whereby the resultant product is characterized by excellent wear characteristics.

Another object of this invention is to produce a steel of high tensile strength and satisfactory ductility which has a smooth and satisfactory surface finish without the necessity for subsequent grinding, turning or re-drawing.

Another object of the invention is to provide a method for producing a steel of high tensile strength and satisfactory ductility in a more efficient and economical manner.

It is another object of this invention to produce a cold worked steel having highly improved qualities of machinability.

It is still a further object of this invention to produce new and improved steel products of the cold worked type having a combination of one or more of the properties mentioned above.

An additional and very important object of the invention is to produce new and improved steel products of the cold worked type having the combination of properties of strength, wear resistance, a minimum of warpage or distortion together with excellent machinability.

It is a further object of the invention to provide new and improved sliding frictional members made from the new and improved steel products having the combination of properties of strength, wear resistance, a minimum of warpage and machinability.

Numerous other objects and advantages of the invention will more fully appear during the course and progress of the following specification.

At the present time large tonnages of bar steels are cold worked, that is to say, the cold bars of steel are shaped through rolls or dies and thereby subjected to a pressure which reduces the cross-sectional area of the bar. Steels may be cold worked by various methods such as cold rolling, cold drawing and cold swedging, and such cold working operations may be applied to the steel either in single or multiple passes. In the case of a single pass type of operation the entire reduction in cross-sectional area is achieved in one operation, whereas in the case of multiple pass types of operations the reduction in cross-sectional area is achieved by several successive smaller reductions in cross-sectional area.

When bar steels are cold worked crystallographic changes take place in the steel which result in an increase in strength and hardness and a reduction in ductility, area and impact strength. It further results in an increase in the apparent elastic limit, but the stress-strain curve is sloping and the yield point is indefinite. A further difficulty which is encountered with cold worked steel is lack of stability. It has been found that most steels of this character harden with age and have a tendency to warp or distort in machining. This has the disadvantage that when cold worked steels are machined into machine parts the resultant parts may, during machining, or even later become warped or distorted. Very often this warpage or distortion is made evident by a growing or increase in size of the part or portions thereof. Hence, in the production of bar steels which are subsequently to be machined or otherwise fabricated into various types of steel products, the art has generally avoided the use of excessive drafts.

It has furthermore been found that the relative increase in strength and decrease in ductility vary with the amount of reduction in area to which the steel is subjected in cold working. Where steels are subjected to relatively low drafts with an attendant relatively small reduction in cross-sectional area, it is said that the steel is subjected to a "light draft," whereas, if the steel is subjected to a relatively high draft with an attendant relatively large reduction in cross-sectional area, it is said that the steel is subjected to a "heavy draft." Since the loss of ductility is proportional to the "draft," in modern commercial practice the draft is kept at an absolute minimum where ductility is at all important in the metal being processed.

For uses where wear resistance is an essential requirement of steel it has heretofore been customary to use what is known as a "heat treated steel," or a "carburized and heat treated steel." Heat treated steel, as the term is employed in the sense just mentioned, means a steel which has been heated above the critical temperature, quenched in a medium such as oil or water, and re-heated to a particular temperature in order to obtain a desired hardness. The heat treated steels which are employed for wear resistance are usually obtained by the heat treatment of high carbon steels containing about .88% to about 1.25% of carbon or low carbon steels with a case of high carbon usually about .88% to 1.25% carbon. Occasionally satisfactory service has resulted from the heat treatment of carbon alloy steels containing about .40% to about .50% carbon. Lower carbon steels even when heat treated fail to give anything approaching satisfactory results in wear service.

Cold working alone has not heretofore been known to contribute materially toward wear resistance, although it is customary to cold finish "heat treated steels" at ordinary drafts of, say, around 7% or perhaps slightly higher. As a matter of fact, excessive cold working has been avoided heretofore for numerous reasons which have already been stated in connection with the discussion of the effect of cold working generally. Thus, to repeat, it is known that when bar steels are cold worked changes take place in the steel which result in an increase in strength and hardness and a reduction in ductility and impact strength. There is also an increase in the apparent elastic limit, but the stress-strain curve is sloping and the yield point is indefinite. Cold worked steels are unstable and there is a tendency for such steels to grow, shrink or become distorted. Likewise, they harden with age. Hence, in the production of bar steels which are subsequently to be machined or otherwise fabricated into various types of steel products or machine parts, the art has generally avoided the use of excessive drafts.

The heat treated steels, usually about .40% to about .50% carbon, which are commonly sold to the trade for wear resistance uses, leave much to be desired because they are not sufficiently wear resistant and in the more strenuous types of wear applications, for example, those involving "sliding frictional steel members," that is to say, steel members or parts of an apparatus which operate in sliding frictional contact with other members or parts, it is usually customary to resort to case hardening or case carburizing in order to obtain suitable resistance to wear. Such a procedure is costly and very undesirable as compared to any method by which a sliding frictional part or member can be machined directly from a steel to its desired form without a carburizing or case hardening step.

The present invention is based upon the discovery that new and improved steel products can be obtained by a new and improved method of treating steel comprising, first, cold working a steel, for example, a bar steel, abnormally or with excessive drafts and thereafter subjecting the cold worked steel to re-heating to a temperature beyond the precipitation hardening range but below the temperature at which substantial recrystallization begins to occur. It has been found that this treatment imparts new and improved properties to steels of many different chemical analyses. Among these properties are strength with satisfactory ductility, high impact values, a minimum of warpage, growth, shrinkage or distortion and machinability. Steels produced in accordance with the invention also have satisfactory elastic stress-strain curves and satisfactory tortional and fatigue values. Furthermore, when this method of treatment is applied to certain types of steels the steel products obtained have unusual wearability in conjunction with strength, a minimum of distortion and excellent machinability. These products, therefore, are especially valuable for manufacturing numerous machine elements or parts, more particularly sliding frictional elements where wear is an essential property or characteristic. One of the important results of the invention is the fulfillment of a demand for steel products of a type having machinability, strength, wear resistance and a minimum of distortion and which have substantially better wear characteristics than the so-called heat treated steels, and at the same time are less expensive than case carburized or case hardened steels. In other words, the steel products of the class just mentioned made in accordance with this invention occupy a sphere somewhere in between the heat treated steels and the case hardened or case carburized steels. They supply a demand for machine parts such as sliding frictional elements where a heat treated steel is not satisfactory and a case carburized or case hardened steel is too expensive.

The steels preferably employed as starting materials in accordance with this invention are non-austenitic and have a pearlitic and ferritic grain structure. The bar steels employed as starting materials are preferably hot rolled. The term "hot rolled" is applied to bars which have been rolled hot from billets and then air cooled or allowed to cool normally. The products produced in accordance with the invention are characterized by the fact that they retain a pearlitic and ferritic grain structure which may possibly be somewhat elongated due to cold working at abnormally heavy drafts.

The expression "abnormally heavy drafts" is employed herein to describe the cold working of steel under greater compressive pressures to cause a greater reduction in cross-sectional area than in normal practice. The amount of cold working necessary to effect an abnormally heavy draft will vary depending upon the size of the bar to be worked. Generally speaking, the larger the bar the larger is the draft necessary to effect an abnormally heavy draft. For example, in cold working steel bars standard practice on one inch and two inch bars usually involves about a one-sixteenth inch draft. Thus, to produce a one inch round cold drawn bar it is customary to start with a one and one-sixteenth inch di-

ameter bar and subject it to a one-sixteenth inch draft. The reduction in area of the cross-section of the bar is, therefore, about 11–12%. With a two inch bar the reduction in area of the cross-section would be about 6%. In accordance with the present invention, however, the abnormally heavy draft used in making bars varying in size all the way from one-fourth inch to two inches should preferably be such as to reduce the cross-sectional area of the bar about 20% or more. It will be understood that the invention is also applicable to the treatment of steel in the form of bars of larger size, but where the bar is greater than a two inch size it becomes increasingly difficult to subject it to an abnormally heavy draft. Furthermore, in the preparation of steel products for wear usages it has been found in accordance with this invention that even with bars having a maximum thickness of greater than two inches, the amount of cold working must be such as to reduce the cross-sectional area more than about 13%, otherwise suitable wear resistance will not be obtained regardless of the chemical analysis of the steel.

Even when treating steel bars and rods in the larger sizes it is preferable that the abnormally heavy draft be sufficient to cause an 18–20% reduction in cross-sectional area or more. For practically all purposes where wear resistance is desired, and particularly in making sliding frictional elements, it has been found that the cold working of the steel should preferably be sufficient to reduce the cross-sectional area at least 20%.

The temperature of re-heating after cold working may vary but should be at least sufficient to carry the steel through what is called the "precipitation hardening range." The "precipitation hardening range" is well known in the steel art and the term "precipitation hardening" is used to describe an effect which is invisible and cannot be observed microscopically but which causes certain changes in the physical properties of the steel, namely, an increase in strength, a decrease in impact or Izod, a lowering of ductility and an increase in hardness or Brinell. This phenomenon in cold worked steels is sometimes called "age hardening." The temperature of re-heating required to carry a steel through the precipitation hardening range will naturally vary depending upon the chemical composition of the steel as well as other factors, but in most instances with steels cold drawn or cold worked at excessive drafts this temperature will be at least 550° F. The temperature at which recrystallization begins to occur will depend upon the alloying elements present, being higher with some alloying elements than with others.

For the purpose of the present invention the temperature of re-heating is preferably within the range of about 550° F. to 1000° F. The invention is especially applicable to the treatment of steel in the form of bars, rods, tubes and the like. The particular size and shape is immaterial, for example, a bar may be round, square, rectangular, hexagonal or octagonal in cross-section. The period of re-heating may vary widely depending upon the size of the furnace and the amount of steel being re-heated in a given furnace, the size of the bars being heated and other factors. In general, the time of heating should be sufficient to permit thorough penetration of the heat throughout the steel which will usually require from about one to about four hours.

In carrying out the invention there are four preferred methods of procedure, depending upon the properties desired in the product, as follows:

1. Subjecting a steel to an abnormally heavy draft preferably sufficient to cause a cross-sectional reduction in area in excess of about 20% followed by re-heating to a temperature within the range of 590° F. to 600° F. and thereafter allowing to cool normally;

2. Subjecting a steel to an abnormally heavy draft sufficient to cause a cross-sectional reduction in area greater than about 20% followed by re-heating to a temperature within the range of about 890° F. to about 920° F. and then allowing to cool normally;

3. Subjecting a steel to an abnormally heavy draft sufficient to cause a reduction in cross-sectional area in excess of about 20% followed by re-heating to a temperature from around 980° F. to about 1000° F. and then allowing to cool normally;

4. Subjecting a steel to an abnormally heavy draft sufficient to cause a reduction in cross-sectional area in excess of about 20% followed by re-heating to a temperature of about 800° F. and then allowing to cool normally.

These four procedures will be referred to as treatment No. 1, treatment No. 2, treatment No. 3 and treatment No. 4.

The invention also has certain outstanding and preferred features as regards the chemical analysis of the steel. It has been found that in order to obtain steel having the combination of properties of strength, wear resistance, a minimum of warpage or distortion and free machinability the best results are obtained by employing steel containing a substantially greater amount of sulphur than ordinary low sulphur plain carbon steels. To this end the steel employed should preferably contain in excess of about .075% sulphur. For the purpose of this invention a steel containing .075% to about .15% sulphur may be referred to as a medium sulphur steel. A steel containing greater amounts of sulphur may be referred to as a high sulphur steel. In the practice of this invention it has been found that the high sulphur steels, and particularly those steels containing in excess of about .175% sulphur and preferably from about .2% to about .4% sulphur, give excellent results.

It has also been found that in order to obtain wearability in accordance with tests hereinafter described the amount of carbon in the steel should preferably be at least .3%. The maximum amount of carbon will ordinarily be about .55% because steels having a higher content of carbon cannot be subjected to the abnormally heavy drafts required by the practice of the invention. Steels having a lower content of carbon than about .3% are useful for some applications but apparently do not have wear resistance even when treated in accordance with this invention, even though they are medium sulphur or high sulphur steels. It is also preferable, in accordance with this invention, that the steel contain in excess of about 1% manganese. The best results have been obtained with the so-called manganese-sulphur steels. The term "manganese-sulphur steels" is used herein to describe steels having a manganese content in excess of about 1.00% and with a medium sulphur content or high sulphur content.

The following tables will serve to illustrate the drafts which may be taken in order to subject

a steel to abnormal cold working in accordance with any one of the preferred procedures previously mentioned:

Table I

TREATMENT #1

Initial size	Cold drawn size	Draft	
		Inches	Per cent
3/8	1/4	1/8	56
1/2	3/8	1/8	43
5/8	1/2	1/8	36
3/4	5/8	1/8	31
7/8	3/4	1/8	27
1	7/8	1/8	23
1 3/16	1	3/16	29
1 1/4	1 1/16	3/16	28
1 5/16	1 1/8	3/16	27
1 7/16	1 1/4	3/16	24
1 9/16	1 3/8	3/16	23
1 11/16	1 1/2	3/16	22
1 13/16	1 5/8	3/16	20
2	1 3/4	1/4	23
2 1/16	1 13/16	1/4	23
2 1/8	1 7/8	1/4	22
2 1/4	2	1/4	21

Table II

TREATMENT #2

Initial size	Cold drawn size	Draft	
		Inches	Per cent
3/8	1/4	1/8	56
1/2	3/8	1/8	43
5/8	1/2	1/8	36
3/4	5/8	1/8	31
7/8	3/4	1/8	27
1	7/8	1/8	23
1 1/8	1	1/8	21
1 1/4	1 1/16	3/16	28
1 5/16	1 1/8	3/16	27
1 7/16	1 1/4	3/16	24
1 9/16	1 3/8	3/16	23
1 11/16	1 1/2	3/16	22
1 13/16	1 5/8	3/16	20
1 15/16	1 3/4	3/16	18
2 1/16	1 13/16	1/4	23
2 1/8	1 7/8	1/4	22
2 1/4	2	1/4	21

Table III

TREATMENT #3

Initial size	Cold drawn size	Draft	
		Inches	Per cent
3/8	1/4	1/8	56
1/2	3/8	1/8	43
5/8	1/2	1/8	36
3/4	5/8	1/8	31
7/8	3/4	1/8	27
1	7/8	1/8	23
1 1/8	1	1/8	21
1 1/4	1 1/16	3/16	28
1 5/16	1 1/8	3/16	27
1 7/16	1 1/4	3/16	24
1 9/16	1 3/8	3/16	23
1 11/16	1 1/2	3/16	22
1 13/16	1 5/8	3/16	20
1 15/16	1 3/4	3/16	18
2	1 13/16	3/16	18
2 1/16	1 7/8	3/16	17
2 3/16	2	3/16	17
2 1/4	2 1/16	3/16	17
2 5/16	2 1/8	3/16	16
2 7/16	2 1/4	3/16	15
2 9/16	2 3/8	3/16	15
2 11/16	2 1/2	3/16	14

The drafts for the fourth procedure may be the same as those for either the first or second procedure. It will be understood that the drafts given in the tables are merely typical. They are based upon sizes of steel bars now available. However, the invention is not limited to the reduction of bars having any specific initial size.

The invention will be further illustrated but is not limited by the following examples:

Example I

A steel, which was prepared by the usual hot roll method, by casting, rolling around 1900° to 2000° F. and then allowing to cool normally so that it contained the normalized pearlitic and ferritic structure, had the following analysis:

Per cent carbon	Per cent manganese	Per cent phosphorus	Per cent sulphur
0.37	1.51	0.017	0.110

This might be termed a manganese and sulphur alloy steel.

A number of six-foot bars of this steel 1 1/16 inches round were reduced in one pass by cold drawing them through a die to 1 1/8 of an inch, which corresponds to about 40.5% area reduction. These bars were then heated at various temperatures and allowed to cool normally. The tensile strength, yield point, elongation in 2 inches, reduction in area when elongated 2 inches, Izod (toughness) and Brinell (hardness) properties were observed as illustrated in the following table:

Condition	Tensile strength	Yield point	Per cent elong. in 2"	Per cent reduced area	Izod	Brinell
Before cold drawing	98,750	61,500	27.9	56.0	52	207
Cold drawn	142,500	129,500	10.9	45.5	38	255
400° F.	146,750	134,500	13.5	44.6	25	-----
500° F.	151,350	146,250	11.7	42.5	21	-----
600° F.	159,700	140,500	13.0	44.9	18	269
700° F.	142,700	127,650	15.1	15.5	33	-----
900° F.	126,750	110,650	19.5	50.6	45	241

It will be observed in connection with the elongation of the steel that the cold drawn steel before being heated had an elongation of 10.9% in 2 inches. On being heated, the elongation increased at 400° F. and decreased again at 500° F., and finally began to move steadily upward at around 600° F., which was also the point of maximum hardness. At 900° F. a steel of excellent properties was obtained, having not only a high tensile strength, a high yield point and extensive elongation properties, but also excellent toughness and hardness. Microscopic examination of the grain structure showed that the steel still retained its pearlitic and ferritic structure. This steel also had the property of wear resistance as tested in the manner hereinafter described.

Example II

A manganese alloy steel, prepared by the usual hot roll method, analyzed as follows:

Per cent carbon	Per cent manganese	Per cent phosphorus	Per cent sulphur
0.34	1.75	0.018	0.024

A number of bars of this steel $1\frac{1}{16}$ inches round were cold drawn through a die to $\frac{13}{16}$ of an inch, which corresponds to an area reduction of about 40.5%. These were then heated at various temperatures and the properties after cooling observed as described in Example I:

Condition	Tensile strength	Yield point	Per cent elong. in 2"	Per cent reduced area	Izod	Brinell
Cold drawn	146,000	137,000	12.6	53.8	42	269
Reheat:						
12 hrs. @ 600° F	147,750	141,850	16.0	53.0	30	302
3 hrs. @ 900° F	129,500	116,250	19.4	54.1	50	255
3 hrs. @ 1050° F	112,000	98,650	23.0	57.0	76	229

In the foregoing table, it will be noted that at 600° F. the steel has excellent properties with approximately the highest degree of hardness. At 900° F., the tensile strength and yield point were still very high and the elongation higher than at 600° F. The effect of reheating to 1050° F. is given to illustrate what happens when recrystallization begins to occur. It is to be noted particularly that the Izod is climbing very rapidly at this point. This steel has a relatively high impact value.

Example III

A chromium-molybdenum alloy steel, prepared by the usual hot roll method, had the following analysis:

Per cent carbon	Per cent manganese	Per cent phosphorus	Per cent sulphur	Per cent chromium	Per cent molybdenum
0.40	0.67	0.024	0.020	0.97	0.20

A number of bars of this steel $1\frac{1}{16}$ inches round were cold drawn through a die to $\frac{7}{32}$ of an inch, corresponding to an area reduction of about 37%.

The properties were determined in a manner similar to that described in Example I, as illustrated in the following table:

Condition	Tensile strength	Yield point	Per cent elong. in 2"	Per cent reduced area	Izod	Brinell
Before cold drawing	130,500	98,000	17.5	52.8	22	255
Cold drawn	169,600	------	9.0	38.5	11	311
700° F	160,500	141,250	12.6	38.2	10	321
800° F	159,750	148,500	13.5	37.6	11	------
900° F	154,600	124,500	15.2	38.8	10	331
1050° F	146,250	133,250	16.0	41.9	13	------

It will be observed that in the case of this steel, a temperature of 1050° F. did not substantially change the crystal structure and it is possible to go to higher temperatures before substantial recrystallization occurs.

When the same type of steel was cold drawn from $1\frac{1}{16}$ inches to $\frac{13}{16}$ of an inch, an area reduction of about 22%, the following results were obtained:

Condition	Tensile strength	Yield point	Per cent elong. in 2"	Per cent reduced area	Izod	Brinell
Cold drawn	152,500	135,000	10.0	43.4	11	302
700° F	150,500	142,500	13.5	44.3	11	321
900° F	147,750	132,750	15.2	43.1	11	321
1050° F	140,025	114,000	16.2	41.0	14	285

Example IV

A copper-nickel alloy steel, prepared by the usual hot roll method, had the following analysis:

Per cent carbon	Per cent manganese	Per cent phosphorus	Per cent sulphur	Per cent copper	Per cent nickel
0.11	0.60	0.028	0.020	1.30	0.58

A number of bars of this steel $1\frac{1}{16}$ inches round were cold drawn through a die to $\frac{13}{16}$ of an inch round, corresponding to an area reduction of 40.5%. They were then heated to various temperatures and the properties observed as illustrated in the following table:

Condition	Tensile strength	Yield point	Per cent elong. in 2"	Per cent reduced area	Izod	Brinell
Cold drawn	116,500	110,000	10.0	47.2	27	217
500° F	123,000	115,000	13.1	47.2	10	255
700° F	121,550	118,250	16.0	46.3	19	262
900° F	109,000	102,000	19.8	48.4	37	235
1050 F	97,950	92,900	22.1	61.6	66	207

Here again it will be noted that around 1050° F. recrystallization had begun and the Izod was rising rapidly.

Example V

A plain carbon steel prepared by the hot roll method and containing the usual pearlitic and ferritic grain structure analyzed as follows:

Per cent carbon	Per cent manganese	Per cent phosphorus	Per cent sulphur
0.36	0.70	0.016	0.027

Bars of this steel $1\frac{1}{32}$ inches round were reduced in area by drawing them through a die to $\frac{25}{32}$ of an inch round, corresponding to an area reduction of 42.6%.

The properties of the steel in its original state after being cold drawn and after re-heating at various temperatures were noted as follows:

Condition	Tensile strength	Yield point	Per cent elong. in 2"	Per cent reduced area	Izod	Brinell
Before cold drawing	86,750	59,500	31.3	58.8	70	163
Cold drawn	136,600	112,000	9.4	36.6	26	241
400° F	137,500	121,500	12.0	35.7	14	------
500° F	140,500	134,250	9.5	34.7	19	------
600° F	149,350	134,350	12.0	36.6	14	229
700° F	134,600	118,750	13.8	35.0	16	------
900° F	119,200	106,000	19.2	44.9	33	229

In this case the most desirable combination of properties occurred when the steel was heated to approximately 900° F.

Other features and advantages of the invention will be apparent by reference to the following description and the accompanying drawings, in which:

Figure 1 represents graphically the results of tests made to evaluate and to compare steels of the present invention with known types of steels as to wearability;

Figure 2 illustrates a cam which is one form of sliding frictional element made with wear resistant steels of the type herein described;

Figure 3 illustrates a gear made with a wear resistant steel of the type herein described;

Figure 4 illustrates a stoker helical gear shaft, another type of sliding frictional element which may be made with a steel of the type herein described;

Figure 5 illustrates a precision spindle, still another type of sliding frictional element made with a wear resistant steel of the type herein described;

Figure 6 illustrates a worm shaft which is another type of sliding frictional element made with a wear resistant steel of the character herein described;

Figure 7 illustrates a stoker worm gear made with a wear resistant steel of the character herein described;

Figure 8 illustrates an automobile king pin which is another type of sliding frictional element made with a wear resistant steel of the character herein described;

Figure 9 illustrates a jack handle pin which is still another type of sliding frictional element made with a wear resistant steel of the character herein described.

The graphical results illustrated in Figure 1 were obtained from tests which were made to evaluate the steels of the present invention and to determine their wear resistance properties. At the present time there is no standard test for determining and evaluating wear resistance in steels and since it is practically impossible in a limited period of time to evaluate and compare various types of steels in actual usage, it was necessary to devise a method of testing which would offer a basis for evaluation and comparison. The tests which were conducted and which afforded an excellent comparison of wear resistance in various types of steels with the wear resistance of steels prepared in accordance with the present invention were carried out on a Falex extreme pressure (EP) lubricant tester manufactured by the Faville-Le Valley Corporation, Chicago, Illinois.

The Falex tester is ordinarily used for testing lubricants. The basic principle of the equipment is the rotation of a standardized pin having a diameter of about 0.250 inch between two standardized 90° V blocks at a constant speed (293 R. P. M.) in an oil bath. By means of suitable gauges the pressure applied on the pins by the blocks and the torque developed due to the friction between the pin and the blocks are measured. The oil bath temperature can be controlled and/or measured. The loads may be applied either automatically or by hand. When used as a lubricant tester, standardized steel blocks and pins are employed in this apparatus and the test conditions are in accordance with a paper entitled "The Evaluation of Extreme Pressure Lubricants," bulletin 101–1, American Transit Association Report, October 1938. When testing lubricants an evaluation is made of the pressures at which weld-seizure of standardized pins results due to the failure of the different lubricants.

In testing steels for evaluation in accordance with the present invention, this procedure was reversed. A standard black transmission oil (S. A. E. 90) having no extreme pressure lubricant value and steel pins of the various types of steel having a diameter of about 0.25 inch were used. The main function of the lubricant was to equalize the temperatures developed and to some extent dissipate the heat generated at the contact surfaces. Film failure of this lubricant was known to occur at 250 lbs. indicated pressure and from this point on resistance to seizure or welding depended entirely upon the test pieces. Since resistance to seizure is a measure of wear resistance it was possible to carry out comparative tests with a number of different types of steels and to evaluate the wear resistance characteristic of these steels.

The steels used in the tests were all machined from the mid radius of bars approximately 1 inch in diameter. All pins were 0.250–0.2495 inch in diameter and ground in the same grinding machine except the case carburized pins. These were ground to an equivalent finish and to the same size by use of a more applicable grinding wheel.

The following table, Table IV, represents the analyses of the fourteen (14) samples of steel in the order given in the drawings:

Table IV

Sample No.	Final hardness, Rockwell	Analysis percentage								
		C	Mn	P	S	Si	Cr	Mo	Ni	Pb
1	Rc28	.44	1.50	0–.05	.275	.15–.30	-----	-----	-----	-----
2	28	.44	1.50	0–.05	.275	.15–.30	-----	-----	-----	-----
3	25	.44	1.50	0–.05	.275	.15–.30	-----	-----	-----	-----
4	18	.41	1.45	.019	.135	.15–.30	-----	-----	-----	-----
5	18	.35–.40	1.35–1.65	0–.05	.075–.15	.15–.30	-----	-----	-----	-----
6	25	.41	1.45	.019	.135	.15–.30	-----	-----	-----	0.25
7	24	.40–.45	.60–.90	0–.05	0–.05	.15–.30	-----	-----	-----	0.25
8	26	.44	.78	.017	.029	.15–.30	-----	-----	-----	-----
9	19	.44	.78	.017	.029	.15–.30	-----	-----	-----	0.25
10	25	.41	.72	.015	.019	.15–.30	1.00	.18	-----	-----
11	Rb84	.39	.76	.016	.019	.15–.30	.72	-----	1.34	-----
12	Rc9–10	.10–.20	1.30–1.60	0–.05	.10–.15	.15–.30	-----	-----	-----	-----
13	14–15	.10–.20	1.30–1.60	0–.05	.20–.30	.15–.30	-----	-----	-----	-----
14	Rb62	.15	.85	.020	.026	.15–.30	-----	-----	-----	-----

The steels of the above analyses were prepared according to the methods of treatment given in the following table:

Table V

Sample No.	Steel in original bar	Size of round bar diameter	Draft	Reduction of area	Reheat below crystallization temperature after cold work
		Inches	*Inches*	*Per cent*	
1	Hot rolled normalized.	1 3/16	3/16	29	None.
2	do	1 1/4	1/4	37	Reheated to 550° F. for about 1 1/2 hours.
3	do	1 3/16	3/16	29	Reheated to 800° F. for about 1 1/2 hours.
4	do	1 1/16	1/16	11-12	None.
5	do	1 3/16	3/16	29	Reheated to 890°-920° F. for 1 1/2 hours.
6	Hot rolled	1 3/16	3/16	29	Reheated to 800° F. for about 1 1/2 hours.
7	do	1 3/16	3/16	29	Reheated to 890°-920° F. for 1 1/2 hours.
8	Hot rolled normalized.	1 1/4	1/4	37	Reheated to 800° F. for about 1 1/2 hours.
9	do	1 1/16	1/16	11-12	None.
10	Heat treated by heating above critical temperature, quenching in oil, reheating to 1000° F. and cold finishing.			7	Do.
11	Hot rolled normalized.	1 1/16	1/16	11-12	Do.
12	Hot rolled	1 3/16	3/16	29	Reheated to 890°-920° F. for 1 1/2 hours.
13	do	1 3/16	3/16	29	Reheated to 890°-920° F. for 1 1/2 hours.
14	Case carburized, heated to 1700° F. for 6 hours and quenched.				None.

In making anti-weld determinations by the Falex procedure previously mentioned, load was applied automatically to 250 lbs. and the machine was allowed to operate at this pressure for 2 minutes to run in the test parts. After this 2 minute period, load was applied automatically to the test parts in 250 lb. increments with a 1 minute period at each increment until seizure or welding resulted or a pressure of 3000 lbs. was obtained. At each 250 lb. increment the temperature of the oil and the torque developed were recorded. Tests were repeated to determine the maximum pressure before weld seizure obtainable on each grade in order to obtain an average result. In this test the test blocks were standard soft "V" blocks as indicated in the drawings.

The results obtained speak for themselves and are given in the following table:

Table VI

Sample No.	Maximum pressure (lbs. gauge) before weld seizure	Time at maximum pressure in seconds	Type of failure
1	400	0	Weld.
2	3000	60	Slight wear.
3	3000	60	Do.
4	500	10	Weld.
5	3000	60	Some wear.
6	3000	60	Do.
7	750	30	Weld.
8	250	3	Do.
9	500	15	Do.
10	500	10	Do.
11	500	5	Do.
12	500	30	Do.
13	750	15	Do.
14	3000	60	Wear on block.

These results were used in plotting or representing graphically the results shown in Figure 1. The time at which each test pin ran at a given load where failure occurred is indicated by the width of each graph representing a given sample. For instance, in considering the graph in the drawing it will at once be apparent that samples 2, 3, 5, 6 and 14 ran the full test without failure.

Sample No. 1 failed while the pressure was being raised from 250 lbs. to 500 lbs. Sample No. 4 ran the full 60 seconds at 250 lbs. but as shown on the graph, only ran a part of the 60 second period at 500 lbs. Sample No. 9 only ran a part of the 60 second period at 250 lbs. and in the same way the wearability of the other samples can be determined by inspection of the drawings.

In tests 1 to 3 the steel employed was a high sulphur manganese-sulphur steel. Test 1 shows that merely subjecting such a steel to an abnormally heavy draft does not produce wearability. On the other hand, as shown by tests 2 and 3, when the steel is subjected to an abnormally heavy draft and then re-heated to a temperature beyond the precipitation hardening range but below the temperature at which recrystallization begins to occur, the resultant product has excellent wearibility properties.

Test No. 4 shows that a medium sulphur manganese-sulphur steel when subjected to cold working but without re-heating does not have substantial wear resistance properties. As shown in test No. 5, the same steel when subjected to abnormal cold working followed by re-heating to a temperature beyond the precipitation hardening range but below the temperature at which recrystallization begins to occur, exhibits very pronounced wearability. Likewise, the same steel containing a small amount of lead has excellent wearability properties, as shown by test No. 6.

It might be added that in actual wear uses the steels referred to in tests 2 and 3 are superior to the steels referred to in tests 5 and 6.

Tests 7 and 8 illustrate the result obtained with a plain carbon steel with or without lead which has been subjected to abnormal cold working followed by re-heating to a temperature beyond the precipitation hardening range but below the temperature at which recrystallization begins to occur. It will be observed that this steel exhibited no substantial wearability.

Test 9 illustrates the result obtained with a leaded plain carbon steel without re-heating to a temperature beyond the precipitation hardening range but below the crystallization temperature. As shown, this steel has little wear value.

Test 10 illustrates the result obtained with a heat treated steel such as is now used for many wear applications. It will be observed that the products illustrated by tests 2, 3, 5 and 6 are far superior to the heat treated steel.

Test 11 illustrates that a cold worked steel containing added chromium and nickel has little wear value when tested as herein described.

Test 12 illustrates the importance of having the carbon content above about .30%. The steel of test 12 has lower carbon content and although it is substantially the same in other respects as the steels of tests 5 and 6 and has been given substantially the same treatment, it does not have the wear value.

Test 13 should similarly be compared with tests 2 and 3. The steel of test 13 is a high sulphur manganese-sulphur steel and has been given substantially the same treatment as the steels of tests 2 and 3, the only difference being that it has a lower carbon content. This difference, how-

ever, apparently has a very substantial effect on the wear value because the steel illustrated in test 13 does not compare with the steels of tests 2 and 3 in wear resistance.

The steel of test 14 is a case hardened or case carburized steel. Within the limits of the test its wear value is as good as the wear value of test samples 2, 3, 5 and 6 but it represents an entirely different type of steel and is much more expensive. Thus, it will be seen that the present invention has provided steel products which have a much better wear value than the heat treated steel of test 10 and are much less expensive than the case carburized steel of test 14.

The tests represented by the graph of Figure 1 clearly illustrate that the abnormal cold working in itself is not the cause of the increase in wear resistance but rather the increased wear value with a steel of proper chemical analysis is obtained by coupling the abnormal cold working with re-heating to a temperature beyond the precipitation hardening range but below the temperature at which crystallization begins to occur.

Practical tests in which various types of parts or members have been machined from the new steel and substituted for case carburized steel parts have brought out the results demonstrated in the Falex anti-weld test. For example, piston pins made from this steel have operated satisfactorily in an automobile for over 27,000 miles without showing signs of wear.

While the invention is not limited to any theory as regards the application of the process to the production of wear resistant steels it appears from the results obtained that the presence of sulphur in amounts greater that found in ordinary plain carbon steels coupled with the two stage treatment of abnormal working followed by heating, contributes to the wear value. The presence of manganese in greater than normal amounts also contributes to the wear value. Apparently this is true regardless of whether or not the steel is a medium sulphur or a high sulphur steel, for in one instance it was found that a high manganese, low sulphur steel of the following composition, normalized, had substantial wear resistance when subjected to the two stage treatment herein described: carbon .35%, manganese 1.55%, phosphorus .027%, sulphur .030%, silicon .285%, the remainder being substantially iron. It will be understood that in all of the analyses given in the tables the remainder of the product is substantially iron.

The steel which is being treated preferably has a substantial initial hardness. This hardness should be such that the finished product when treated by the two stage process herein described has a hardness of at least 20 Rockwell C, or about 229 Brinell. For most purposes the initial hardness of the steel is preferably at least 200 Brinell.

It will be understood that the invention in its broader aspects is not limited to the specific steels described. The steels may contain other alloying elements, as for example, copper in excess of 0.35% (e. g., up to 1.25%), chromium in excess of 0.25% (e. g., up to 1%), molybdenum in excess of .05% (e. g., up to .35%), beryllium (e. g., up to 1.00%), vanadium in excess of .05% (e. g., up to .30%), nickel (e. g., up to 2.00%) and lead (e. g., up to .50%). The process may have varying effects upon the product depending upon the chemical analysis of the steel originally employed. As previously stated, in not all cases will a steel when treated by this two stage process have wear value but other valuable properties can be imparted to the steel, such as hardness, impact value and other desirable combinations of physical properties.

In Figures 2 to 9, inclusive, illustrations have been given of various applications of the new wear resistant steels in sliding frictional elements. Preferred steels for this purpose have the following analysis:

	Per cent
Sulphur	.175–.400
Manganese	1.00–2.25
Phosphorus	0.00–0.10
Carbon	0.30–0.55
Silicon	0.10–0.40

(Balance substantially all iron.)

A steel having this analysis may be subjected to the two stage treatment according to any one of the four procedures previously mentioned. If it is given treatment No. 1, then it is preferably subjected to an abnormal cold working sufficient to cause a reduction in the cross-sectional area within the range of about 20% to about 45% or higher, followed by re-heating to above 550° F., preferably from 590° F. to 600° F. The resultant product ordinarily has a minimum yield point of 125,000 lbs. per square inch with an elongation in 2 inches of at least 7%, usually around 7% to 11%, and a reduction in area of cross-section upon elongation of at least 26%, usually around 26% to 35%.

If the steel is processed according to procedure No. 2 the temperature of re-heating is somewhat higher, the minimum yield point is usually 100,000 lbs. per square inch, the elongation in 2 inches is usually at least 9%, preferably within the range of 9% to 14%, and the reduction in area upon elongation is usually at least 27%, preferably within the range of about 27% to 37%.

Procedure No. 3 is normally employed with the larger size bars and rods and the minimum yield point of the product is normally at least 80,000 lbs. per square inch, the tensile strength around 100,000 lbs. per square inch, the ductility at least 15% in 2 inches with an elongation of around 35%.

If procedure No. 4 is followed the yield point is normally at least 115,000 lbs. per square inch.

As previously indicated, the steel initially employed is preferably a hot rolled or normalized steel which may be produced, for example, by casting and rolling a steel bar at normal rolling practice, e. g., from about 1900° F. to 2200° F. and then allowing the bar to cool normally in the air so that it contains the normalized pearlitic and ferritic structure.

To summarize, it will be observed that depending upon the particular procedure employed, the minimum yield point of the resultant product may vary all the way from 80,000 lbs. per square inch to 125,000 lbs. per square inch, and the elongation in 2 inches from about 7% to about 17%. The hardness of the finished product for wear uses should preferably be at least 20 Rockwell C, or about 229 Brinell.

Among the uses for wear resistant steel made in accordance with this invention are the manufacture of armature shafts, centrifugal pump shafts, compressor shafts, cams, thrust discs, deep well rotary pump shafts, fence puller pins, washing machine ringer gears, oil burner pump gears, scale gears, power lawn mower gears, hammermill main shafts, high speed saw shafts, king pins for trucks, tractors and automobiles, main pins, oil pump drive shafts, oil pump dowel pins, oil pump gear shafts, oil burner fuel pumps, shafts,

gears and pins, piston rods, sliding rails for printing presses, grinder spindles, speed reducer worm gears and many other types of wear resistance usages, particularly those involving sliding frictional wear.

The wear resistant steels described herein are particularly desirable for wear resistant usages because they will give longer life and better service than the heat treated steels of the type heretofore used. Furthermore, they can be used to replace parts formerly made of case hardened or carburized steel and thereby greatly reduce the cost of manufacturing a given apparatus or machine. One of the features of these steels in addition to their wear resistant properties is to be found in their non-warping properties and their ready machinability. By "non-warping" is meant the ability to remain dormant without expansion or contraction during or after the machining operation. Cold worked steels as a rule tend to grow or shrink due to the fact that they do not have a true yield point. Certain properties of the steels such as hardness may vary rather widely without substantially affecting their wearability. These steels, as well as other steels made by the two stage method of this invention, because of their high yield point and tensile strength can also be used in strength applications, for example, in bolts, girders, jacks and other types of apparatus where strength rather than wear is an essential requirement.

From the standpoint of machinability, the wear resistant steels of this invention possess excellent machining characteristics and are what is known as "free" machining steels. This term is used to describe steels which are machinable in an automatic screw machine. In certain specific applications, cutting speeds have been increased 50% and tool life 50% as compared with steels previously used. Use of these new steels for machine parts also eliminates heat treatment of parts after machining as well as subsequent costly cleaning, straightening and grinding.

In making bar steels in accordance with the present invention it is preferable to employ a uni-directional straightening treatment, as described in my co-pending application Serial No. 256,686, filed February 16, 1939. This may be accomplished, for example, by the following combination of steps involving (1) cold working, (2) uni-directional, and (3) reheating. In some instances the reheating step may be followed by a further step also involving uni-directional straightening. The expression "uni-directional straightening" is employed to describe a straightening operation in which the steel is bent or straightened backward and forward in one direction only, as distinguished from the ordinary methods of straightening such as employed in the Medart, Sutton, Schuster or Brightman Flyer straighteners, in which the steel is subjected to stress and strain in all directions. The uni-directional straightening is particularly suited to bar steels where the cold working involves an excessive draft, say, in excess of about 20% area reduction, followed by heating beyond the precipitation hardening range but below the temperature at which recrystallization begins to occur, as, for example, 550° F. to 900° F. The treatment may be applied in any of the previously described examples for making bar steels.

Having thus described the invention, what I claim as new and desire to secure by Letters Patent of the United States is:

1. A method of producing an improved bar steel which comprises cold working a non-austenitic bar steel containing a normal pearlitic and ferritic structure at abnormally heavy drafts of the character described in this specification and then re-heating the bar to a temperature beyond the precipitation hardening range but below the temperature at which substantial recrystallization begins to occur.

2. A method of producing an improved bar steel which comprises cold working a non-austenitic bar steel containing a normal pearlitic and ferritic structure at drafts sufficient to cause an area reduction in excess of about 20% of the normal cross-sectional area of the bar, then subjecting the bar to a temperature above the point where maximum precipitation hardness is obtainable and over 550° F. but not higher than the temperature at which substantial recrystallization begins to occur.

3. A method of producing a wear resistant bar steel which comprises cold working a non-austenitic bar steel containing in excess of 1% manganese and from 0.3% to 0.55% carbon at abnormally heavy drafts sufficient to cause an area reduction in the cross-sectional area of the bar in excess of approximately 20% of the normal cross-sectional area, then subjecting the bar to a temperature above the point where maximum precipitation hardness is obtainable and over 550° F. but below the temperature at which substantial recrystallization begins to occur and then allowing the bar to cool normally.

4. A method of producing a wear resistant machinable bar steel which comprises cold working a non-austenitic medium sulphur manganese-sulphur alloy bar steel containing in excess of 1% manganese, in excess of .075% sulphur and carbon within the range of 0.3% to 0.55% at heavy drafts sufficient to cause an area reduction in the cross-section of the bar in excess of approximately 20% of the normal cross-sectional area, then subjecting the bar to a temperature within the range of about 550° F. to about 1000° F., maintaining said temperature for a period of time sufficiently long to allow penetration of the heat and thereafter allowing the metal to cool normally.

5. A method of producing a wear resistant machinable bar steel which comprises cold working a non-austenitic high sulphur manganese-sulphur alloy 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, and an initial hardness greater than about 200 Brinell at abnormally heavy drafts sufficient to cause an area reduction in the cross-sectional area of finished bars from ¼ inch to 2 inch sizes in excess of approximately 20% of the normal cross-sectional area, then subjecting the metal to a temperature within the range from about 550° F. to about 1000° F., said temperature being beyond the precipitation hardening range but below the temperature at which substantial recrystallization begins to occur, maintaining said temperature for a period of time sufficiently long to allow penetration of the heat and thereafter allowing the metal to cool normally.

6. A method of treating a steel which comprises cold working a non-austenitic steel containing a normal pearlitic and ferritic structure at drafts sufficient to cause an area reduction within the range of about 20% to about 45%, then subjecting the metal to a temperature within the range of

about 550° F. to about 920° F. for a period of time sufficiently long to allow penetration of the heat, and then allowing the metal to cool normally.

7. A steel having a substantially pearlitic and ferritic structure, a yield point in excess of about 80,000 lbs. per square inch combined with a tensile strength in excess of about 100,000 lbs. per square inch, said steel being produced by cold working a steel having a normal pearlitic and ferritic structure at abnormally heavy drafts to cause a cross-sectional reduction in area greater than 13%, subsequently heating said cold worked steel to a temperature above the precipitation hardening range but below the temperature at which substantial recrystallization begins to occur and then cooling said steel to retain its pearlitic and ferritic structure.

8. An improved bar steel which is the product obtainable by cold working a non-austenitic bar steel containing a normal pearlitic and ferritic structure at abnormally heavy drafts sufficient to cause an area reduction in excess of about 20% and then subjecting the steel to a temperature above the point where maximum hardness is obtainable and over 550° F. but below the temperature at which substantial recrystallization begins to occur.

9. A wear resistant, freely machinable, medium sulphur, manganese-sulphur alloy bar steel having a substantially pearlitic and ferritic structure, a yield point in excess of about 80,000 lbs. per square inch coupled with a tensile strength in excess of about 100,000 lbs. per square inch, said steel being produced by cold working a medium sulphur, manganese-sulphur alloy bar steel having a normal pearlitic and ferritic structure and containing in excess of 1% manganese, in excess of .075% sulphur and from 0.3% to 0.55% carbon at abnormally heavy drafts sufficient to cause an area reduction in excess of approximately 20% of the normal cross-sectional area of the bar, subsequently heating the bar to a temperature above the point where maximum hardness is obtainable and over 550° F. but below the temperature at which substantial recrystallization begins to occur, maintaining said heat until it has penetrated the bar and then allowing the steel to cool normally.

10. A machinable wear resistant, high sulphur, manganese-sulphur alloy bar steel having a substantially pearlitic and ferritic structure, said steel being produced by cold working a non-austenitic, high sulphur, manganese-sulphur, alloy 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, and an initial hardness greater than about 200 Brinell at abnormally heavy drafts sufficient to cause a cross-sectional area reduction in excess of approximately 20% and then subjecting the metal to a temperature about 550° F. but below the temperature at which substantial recrystallization begins to occur.

11. A sliding frictional element made from a wear resistant non-austenitic steel produced by cold working at abnormally heavy drafts of the character described in this specification to cause a cross-sectional reduction in area greater than 13% followed by heating the steel to a temperature beyond the precipitation hardening range but below the temperature at which substantial recrystallization begins to occur, said steel having a carbon content from 0.3% to 0.55%, and a manganese content in excess of 1%.

12. A sliding frictional element made from a wear resistant machinable steel produced by cold working a non-austenitic, high sulphur, manganese-sulphur alloy 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, and an initial hardness greater than about 200 Brinell at abnormally heavy drafts sufficient to cause a cross-sectional area reduction in excess of approximately 20% followed by heating the cold worked metal to a temperature within the range from 590° F. to 920° F.

13. The method of treating steel bars and rods which comprises subjecting the metal to heavy drafts without destroying the normal crystal structure sufficient to cause an area reduction in excess of about 20% of the normal cross-sectional area of the metal, then subjecting the resultant metal to a uni-directional straightening treatment and thereafter heating it to a temperature beyond the precipitation hardening range but below the temperature at which recrystallization begins to occur.

14. A method of producing an improved bar steel which comprises subjecting a bar steel to heavy drafts sufficient to cause an area reduction in excess of about 20% of the normal cross-sectional area of the metal, then subjecting the bar to a uni-directional straightening treatment and thereafter heating the metal to a temperature within the range of about 550° F. to about 900° F. but no higher than the temperature at which substantial recrystallization begins to take place.

15. A method of producing improved bar steel which comprises subjecting a bar steel having a normalized pearlitic and ferritic grain structure to cold working sufficient to cause an area reduction in excess of about 20% of the normal cross-sectional area of the metal, then subjecting said bar to a uni-directional straightening treatment, thereafter reheating the bar to a temperature within the range of about 550° F. to about 900° F., said temperature being beyond the precipitation hardening stage but below the temperature at which substantial recrystallization takes place, allowing the metal to cool normally and subjecting it to a second uni-directional straightening treatment.

16. As a new article of manufacture, a non-austenitic alloy steel having a pearlitic-ferritic metallographic structure and having improved characteristics of strength, wear-resistance and machinability together with satisfactory ductility and minimum tendency to warp in machining, said alloy steel having been produced by cold working an alloy steel of non-austenitic pearlitic-ferritic structure to effect a reduction in cross-sectional area greater than 13%, heating the same to a temperature above the point where maximum hardness is obtainable upon reheating, and below the point where substantial recrystallization takes place.

HENRY NEUMAN LANDIS.

CERTIFICATE OF CORRECTION.

Patent No. 2,320,040. May 25, 1943.

HENRY NEUMAN LANDIS.

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows: Page 8, first column, line 36, for "that" read --than--; page 10, first column, line 63, claim 10, for "about" read --above--; and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 6th day of July, A. D. 1943.

Henry Van Arsdale,
Acting Commissioner of Patents.

(Seal)