Patented May 21, 1946 2,400,866

UNITED STATES PATENT OFFICE

2,400,866

METHOD OF DRAWING METAL STOCK

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No Drawing. Application November 8, 1941, Serial No. 418,415

5 Claims. (Cl. 205—21)

This invention relates to wire drawing, and more particularly to drawing wires composed of certain alloy steels. The invention has for its principal object the provision of an improved method for drawing alloy steel wires rapidly and with minimum development of work strains. This application is a continuation-in-part of my copending application Serial No. 370,494, filed December 17, 1940.

The term "wire," as used herein, is not limited to wires of circular cross section, but instead is employed in its generic sense to include long relatively slender articles of all cross-sectional configurations, such, for example, as rounds, flats, ovals, squares, polygons in general, and the various other cross-sectional shapes which wires may possess.

The invention is of particular value in conjunction with drawing wires composed of alloy steels such as carbon tool steels and high speed steels which are sensitive to hardening when subjected to cold deformation, and which harden appreciably when rapidly cooled even slightly from a temperature closely approaching or above the lower critical (Ac_1) point. Wires of this character, such, for example, as wires composed of high speed steel or of carbon tool steel, heretofore have been cold-drawn, that is, they have been drawn at temperatures not very much above ordinary room temperatures. For example, in drawing a wire composed of high speed steel of conventional composition, a procedure somewhat as follows has been customarily employed:

A hot-rolled rod or bar, say about $\frac{9}{32}$ inch in diameter, is drawn successively through a series of progressively smaller dies at temperatures not very much above room temperature. With each pass through a die, a reduction in cross-sectional area of about 10% to 15%, more or less, is effected. After each pass, or at best after each two or three passes, the rod or wire becomes work-hardened to such an extent that it must be annealed before further drawing can be effected. After annealing, the wire is pickled in acid in order to remove the scale formed and after pickling it has been customary to bake the wire in lime in order to form a smooth surface for further drawing. A typical mill schedule for thus cold-drawing wire composed of a high speed steel is given in Table No. 1:

Table No. 1

	Inch		*Per cent*
Original bar diameter	.281	Cross section area	100
After 1st pass	.261	Cross section area	85
After 2nd pass	.241	Cross section area	74
After 3rd pass	.221	Cross section area	62
After 4th pass	.200	Cross section area	51
After 5th pass	.185	Cross section area	43
After 6th pass	.170	Cross section area	37
After 7th pass	.165	Cross section area	33
After 8th pass	.150	Cross section area	29
After 9th pass	.135	Cross section area	23
After 10th pass	.120	Cross section area	18
After 11th pass	.110	Cross section area	15
After 12th pass	.100	Cross section area	13
After 13th pass	.090	Cross section area	10
After 14th pass	.080	Cross section area	8
After 15th pass	.070	Cross section area	6
After 16th pass	.065	Cross section area	5

In consequence of these many operations and because of the large number of draws and anneals required, the production of small wires of high speed steel and carbon tool steel is costly and requires a long period of time.

A further disadvantage to the heretofore customary method of cold-drawing wires of high speed steels and other similar alloy steels is that, due to the severe distortion of the crystalline structure of the metal during cold-working, the wire becomes hardened and exceedingly strained. Although the wire is annealed between passes it is virtually impossible completely to eliminate the effect of the cold-work distortion. The finished wire is therefore non-uniform in quality. It has been observed, for example, that cold-worked material varies greatly as to general hardenability, grain size, uniformity of grain, carbide size and carbide distribution, etc. Investigations have also shown that the strength of the material is decreased in proportion to the amount of cold-working employed, even though the cold-worked wire has been thoroughly annealed before it is used. This non-uniformity and decrease in strength of the steel is particularly objectionable if the cold-drawn wire is used for making small precision tools such as drills and reamers. In the case of steels for tools of this character, it is of the utmost importance that all the variable metallurgical factors be controlled within narrow limits.

The above-described difficulties involved in drawing tool steel wires also are encountered in drawing wires of other non-austenitic alloy steels such as low and medium carbon steels, nickel steels, chromium steels, molybdenum steels, etc.

I have discovered that alloy steels of the character which are sensitive to hardening when subjected to cold working, and which harden appreciably upon being rapidly cooled even slightly from a temperature closely approaching or above the lower critical point, may be drawn with relatively large reductions in cross-sectional area per pass, and without significant hardening or appreciable development of work-strains, and hence without the need for intermediate or final anneals, if the drawing is conducted with the wire heated to a temperature above about 900° F. but appreciably below the lower critical temperature. By drawing a steel of the character described at a temperature within the range stated, there is little or no work-hardening of the steel, and little or no hardening resulting from unavoidable cooling of the wire between passes from the drawing temperature to some lower temperature which may be as low as room temperature. If the drawing is conducted at a temperature substantially lower than 900° F., steels of the character described work-harden to such an extent that only a small cross-sectional reduction is possible before annealing is required. On the other hand, if the drawing is conducted at a temperature closely approaching or above the lower critical point of the steel, then the steel becomes hardened to a very considerable extent upon rapid cooling even very slightly (even by as little as 100° F. or 200° F.). Rapid cooling between passes is unavoidable in practice, as it is not feasible to maintain the wire continuously at the high drawing temperature from the initial drawing operation to the production of the finished wire. The hardening resulting from unavoidable rapid cooling from a temperature close to or above the lower critical point of such steels, even though such cooling be slight, is so great that annealing is necessary before any further substantial reduction in cross section by drawing is possible.

Based on this discovery, the present invention provides an improved method for the manufacture of wire composed of alloy steels which harden appreciably upon rapid cooling, even to a slight extent, from a temperature closely approaching or above their lower critical (Ac_1) point. The improved method of the invention comprises heating a rod or wire composed of such a steel to an elevated temperature well above room temperature but always appreciably below (for example 50° F. to 100° F. below) the lower critical temperature, drawing the rod or wire at such temperature through a series of fixed dies of such size as to effect relatively large reductions of cross-sectional area, and maintaining the rod or wire at the elevated temperature by heating it between certain of the passes through dies to offset losses of heat while being passed through the dies, but with no heating between passes incident to an annealing operation, the latter being made unnecessary by drawing the alloy steel through the dies while in the heated condition though observing care not to heat the stock to a temperature approaching the lower critical temperature of the alloy. In drawing wires of carbon tool steel or high speed steel, best results are obtained if the drawing operation is conducted with the wire heated to a temperature within the range from 1000° F. to 1100° F. Reductions of cross-sectional area of the order of 40% per pass are possible in accordance with this method.

The new method is such that wires composed of high speed and carbon tool steels and similarly hardenable steel alloys may be drawn to a given diameter much more quickly than has heretofore been possible, and without the development of work strains of significant magnitude or the need for intermediate or final anneals. The method may be applied with the attainment of these advantages, for example, to the drawing of wire from a bar or rod of an alloy tool steel such as a carbon tool steel containing 0.9% to 2.5% carbon, upwards of 0.5% chromium, and upwards of 0.25% vanadium, or a high speed or semi-high speed tool steel containing about 0.6% to 1.5% carbon, together with about 4% to 16% molybdenum or 4% to 24% tungsten. The method may also be employed in drawing wires composed of medium carbon steels containing up to 0.9% carbon, nickel steels containing 0.5% to 5% nickel, chromium steels containing 0.5% to 1.5% chromium, molybdenum steels containing 0.1% to 0.5% molybdenum, vanadium steels containing 0.1% to 0.5% vanadium, non-austenitic rust-resistant steels of the so-called "stainless" type, and the like. The method of the invention may also be applied to the drawing of wires composed of steels containing upwards of 7% cobalt or upwards of 3% vanadium. Heretofore no commercially successful method for drawing wires of steel containing such large proportions of cobalt or vanadium have been known. These steels all are characterized by hardening appreciably when rapidly cooled from a temperature closely approaching or above their lower critical temperature (about 1300° F. to 1400° F.). Moreover, they are all non-austenitic steels.

By way of example, the invention is described in greater detail below with particular reference to the drawing of a small circular wire of carbon tool steel or high speed steel. It is understood, however, that the invention is not limited to drawing wires of the particular size, shape or composition, or to the particular and specific embodiment of the new type of drawing operation, described below by way of example for a better understanding of the invention.

The wire is drawn from the usual hot-rolled bar or rod. Typical (but not limiting) analyses of carbon tool steels and high speed steels which may be drawn by the method of the invention are given in the following table:

Table No. 2

	Carbon tool steels			High speed steels		
	#1	#2	#3	#4	#5	#6
Carbon	1.35	1.40	2.50	.75	.80	.80
Tungsten		4.0		18.0		18.0
Chromium	.50	.50	12.0	4.0	4.0	4.0
Vanadium	.50	.25	.25	1.0	2.0	2.0
Molybdenum					9.0	
Cobalt						9.0

In addition to the foregoing, these steels may contain the small percentages of manganese, silicon, sulphur, and phosphorus commonly found in steels. These steels are characterized by being hardenable by rapidly cooling (even to a small extent) from a temperature very close to or above their lower critical (or transformation) point (about 1300° F. to 1400° F.). Mechanical working of these steels at ordinary temperatures up to about 800° F. or 900° F. causes them to become work-hardened to a considerable extent, the precise extent being dependent on the severity of

the mechanical working. These steels are, however, quite readily drawn in accordance with the invention without appreciable hardening at temperatures within the range from about 900° F. to appreciably (50° to 100° F. more or less) below the lower critical point.

In drawing the hot rolled rod to wire, the rod is pointed to permit insertion into the die and is coated with graphite to lubricate its passage through the die. In place of graphite, other lubricants capable of withstanding the high drawing temperatures may be employed. The rod is conveniently coated with graphite (if graphite is used as the lubricant) by passing it through a stream of a suspension of graphite in distilled water. The water acts as a vehicle for the graphite and is, of course, evaporated when the wire is heated preparatory to drawing.

A convenient practical arrangement for coating the rod with graphite comprises a spout from which the graphite-water suspension is continuously discharged into a tank. A pump, having its intake connected to the tank, may be employed to deliver the suspension to the spout. The rod on its way to the die is passed through the stream of graphite suspension discharging from the spout and thereby is coated with graphite.

The graphite-coated rod is next heated to the working temperature. Heating is effectively accomplished and readily controlled by passing the rod through a small induction heating coil. The current supply to the induction heating coil is correlated with the speed of the rod passing therethrough so as to heat the rod to the desired temperature by the time it has passed through the coil. Alternatively the rod may be heated by passing it through a small gas-fired or electrically heated furnace, or by other heating means.

As indicated above, the temperature to which the steel rod is heated preparatory to drawing is in the range from about 900° F. to appreciably (say 50° F. to 100° F.) below the lower critical point of the steel. In the case of the common carbon tool steels and high speed steels, this temperature range is from 900° F. to about 1300° F.

At temperatures below about 900° F., the rod is too cold to permit the relatively large reduction per pass which constitutes one of the major advantages of the new method. Drawing below this temperature causes the rod to become severely work-hardened after only a small percentage reduction in cross-sectional area. Hence a large number of passes through dies and frequent anneals between passes are required in order to effect any very substantial reduction in area if drawing is conducted below about 900° F.

If the rod (or wire) is heated to a temperature closely approaching or exceeding its lower critical point, it hardens very substantially upon being rapidly cooled, even though such cooling may be by no more than 100° F. or 200° F. This property makes it impractical to draw wires from rods of such steels at temperatures approaching or exceeding the lower critical point, because cooling sufficiently to effect substantial hardening is unavoidable. For example, the wire in passing from one die to the next is exposed to the air at about room temperature, and it must be coated with lubricant between passes through dies. The application of a lubricant such as graphite suspended in water actually brings about quenching of a heated wire. Once the steel has been hardened by such treatment, it retains its hardness even upon reheating to or above the temperature from which it was cooled, and it must be subjected to a long annealing treatment in order to soften it. Hardening by heat-treatment of the character described is so great that continued drawing without annealing is impossible.

The discovery that steels of the character described do not work-harden to any substantial extent when drawn into wires at elevated temperatures, appreciably above about 900° F., and do not become hardened by cooling from elevated temperatures, appreciably above about 900° F. but always appreciably below the lower critical point, is the basis of the present invention. It is characteristic of the method of the invention, therefore, that the drawing is conducted with the wire heated to an elevated temperature but one which is appreciably below the lower critical temperature. In the case of many steels of the character to which the invention is applicable, and especially in the case of carbon tool steels, high speed steels, and semi-high speed steels, it is advantageous to draw the rod or wire while it is heated to a temperature in the relatively narrow range of 1000° F. to 1100° F., a temperature of about 1050° F. being optimum for steels of this character. Such temperatures are high enough so that large reductions may be made with each pass through a die without work-hardening or setting up work-strains of appreciable magnitude within the drawn wire, and at the same time it is safely below the critical temperature so that any extra heating of the wire due to friction as it passes through the die, followed by cooling, will not cause hardening of the rod or wire. If properly drawn within the temperature range stated, the finished wire will have substantially the same hardness as the original hot-rolled bar or rod.

For carrying out the new method, a die of conventional construction is mounted close to the induction heating coil or other heating unit at the end from which the rod emerges. The die, of course, is of smaller diameter than the rod, and as the rod is drawn therethrough its cross-sectional area is reduced.

The actual extent of the reduction effected is dependent on the size of the rod being drawn and on other operating factors. Generally speaking, however, the method of the invention permits much larger reductions in cross-sectional area to be made with each pass through a die than has been possible by heretofore commonly employed drawing techniques. Reductions in cross-sectional area of the order of 40% per pass may be achieved quite easily when employing the method of the invention. For example, in an operation involving the drawing of high speed steel wire, a total reduction in cross-sectional area of 95% has been consistently achieved in five or six passes through fixed dies without any intermediate annealiing. This represents a marked improvement, both in the reduced number of passes required and in the greater ease with which the operation is carried out, over the previous known methods for drawing wires of this character. In addition, the new method permits the drawing speed (in feet per minute of wire through the die) to be substantially increased.

To illustrate the greater speed of the method of the invention, the following table gives a typical hot-drawing schedule for high speed steel, which is directly comparable with the schedule given above in Table No. 1 for cold-drawing substantially the same material:

Table No. 3

	Inch		Per cent
Diameter, original bar	.281	Cross section area	100
Diameter, after 1st pass	.230	Cross section area	67
Diameter, after 2nd pass	.178	Cross section area	40
Diameter, after 3rd pass	.140	Cross section area	25
Diameter, after 4th pass	.109	Cross section area	15
Diameter, after 5th pass	.087	Cross section area	10
Diameter, after 6th pass	.065	Cross section area	5

It is to be noted that wire hot-drawn according to the schedule given in Table No. 3 did not require and did not receive any intermediate or final anneals, pickling, or bakings in lime, whereas substantially the same wire cold-drawn under the lengthier schedule of Table No. 1 required and received many intermediate anneals and bakings in lime, and a final anneal of the finished wire. In consequence of the large reductions which may be made with each draw in accordance with the method of the invention, and in consequence of the elimination of the need for intermediate anneals and treatment of the wire to form a satisfactory surface for further drawings, the method hereindescribed makes it possible to produce wires of very small size much more rapidly and economicaly than has heretofore been possible. It is of course understod that any number of passes through dies may be employed in accordance with the method of the invention. The number of passes required to produce a wire depends upon the size of the of the original rod and the desired size of the finished wire. The number of passes necessary to produce a given size wire from a rod of given size is, however, much smaller than is required by wire drawing methods heretofore commonly employed.

A further important advantage attained by the hot-drawing method of the invention is that the drawn wire is substantially free of work-strains and is considerably stronger than a corresponding cold-drawn wire produced by heretofore known drawing methods. The following tables present a comparison of the strength of cold-drawn wires produced by methods heretofore commonly employed with the strength of corresponding wires hot-drawn by the method of the invention. In Table No. 4 a comparison is made between the torsional strengths of duplicate hardened wires identically made of high speed steel of substantially the same composition produced by the two methods, and in Table No. 5 a comparison is made of the bending strengths of duplicate hardened wires identically made of high speed steel of substantially the same composition produced by the two methods. The figures in each table give, in degrees, the arc through which the hardened wires were deformed at the point of fracture.

Table No. 4

Diameter of wire	Cold-drawn	Hot-drawn
	Degrees	*Degrees*
1/8 inch	60.0	61.9
3/32 inch	87.5	92.6
1/16 inch	95.7	142.5

Table No. 5

Diameter of wire	Cold-drawn	Hot-drawn
	Degrees	*Degrees*
1/8 inch	15.3	19.2
3/32 inch	25.9	30.1
1/16 inch	28.9	34.6

A still further important advantage of the method of the invention is that it makes it possible to draw wires composed of certain steel alloys which cannot be drawn successfully by any heretofore known procedure. Thus the drawing of wires of cobalt steel containing more than 7% cobalt, and the drawing of wires composed of vanadium steels containing in excess of 3% vanadium, has not heretofore been successful because of the very great extent to which these steels are work-handened at ordinary temperatures. However, such steels have been successfully reduced from hot-rolled bars to fine wires by hot drawing in accordance with the hereindescribed method at temperatures within the range stated above, and especially in the neighborhood of 1050° F.

Wire drawn in accordance with the invention employing graphite as the lubricant possesses a smooth, shiny, black surface which is slightly greasy to the touch. The blackness and slightly greasy feel are due to the residual graphite lubricant but the actual metallic surface of the drawn wire is smooth and free of cracks, tears or slivers. The amount of graphite remaining adherent to a properly coated wire after it has been passed through one die is sufficient so that the wire may be drawn through the next one or two smaller dies without recoating with graphite. If desired, however, a new graphite coating may be applied preparatory to each pass through a die. The graphite which remains adhering to the wire after drawing is not objectionable, for it has the effect of protecting the drawn wire from rust.

I claim:

1. The manufacture of a wire composed of an alloy steel containing not more than about 1.5% carbon and which hardens appreciably upon being rapidly cooled from a temperature above its lower critical point, the improvement which comprises heating a rod or wire of such alloy steel to a temperature above about 900° F. but appreciably below its lower critical point, and drawing the rod or wire at such temperature through a fixed die of such size as to effect a relatively large reduction of cross-sectional area.

2. In the manufacture of a wire composed of wire from steel alloy stocks composed of high speed steel, carbon tool steel, steel containing cobalt in amount greater than about 7%, and steel containing vanadium greater than about 3% which hardens appreciably upon being rapidly cooled from a temperature above their lower critical points, the improvement which comprises heating a rod or wire of such steel to a temperature aboye about 900° F. but appreciably below its lower critical point, and drawing the rod or wire at such temperature through a fixed die of such size as to effect a relatively large reduction of cross-sectional area.

3. In the manufacture of wire from alloy steel stocks composed of alloy steel, carbon tool steel, and high speed steel, which harden appreciably upon being rapidly cooled from a temperature above their lower critical points, the improvement which comprises heating a rod or wire of such steel to a temperature of about 1000° F. to 1100° F., and drawing the rod or wire at such temperature through a fixed die of such size as to effect a relatively large reduction of cross-sectional area.

4. In the manufacture of a wire composed of an alloy steel containing not more than about 1.5% carbon and which hardens appreciably upon being rapidly cooled from a temperature above its lower critical point, the improvement which comprises applying a coating of graphite to a rod or

wire of such steel, heating the coated rod or wire to a temperature above about 900° F. but appreciably below its lower critical temperature, and drawing the coated rod or wire at such temperature through a fixed die of such size as to effect a relatively large reduction of cross-sectional area.

5. The method of hot-drawing non-austenitic alloy steel wire containing not more than about 1.5% carbon and which hardens appreciably upon being rapidly cooled from a temperature above its lower critical point, the essential steps of which consist of heating the allow steel stock for the wire to a temperature elevated well above room temperature and above about 900° F. but to a maximum temperature which is appreciably below the lower critical point of the alloy, drawing the stock through dies of progressively decreasing size in passes through the several dies successively, each draw effecting a relatively large reduction in the cross-sectional area of the stock, and maintaining the stock throughout the period of passage through the several dies at said temperature, any heating of the stock during intervals between passes being insufficient to raise it above said maximum temperature.

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