

March 15, 1966

F. LIHL
FERRO-CARBON ALLOYS OF IMPROVED MICROSTRUCTURE AND PROCESS
FOR THEIR MANUFACTURE
Filed March 27, 1963

3,240,639

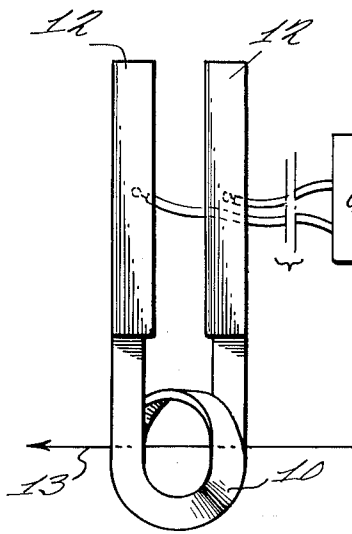


Fig. 1

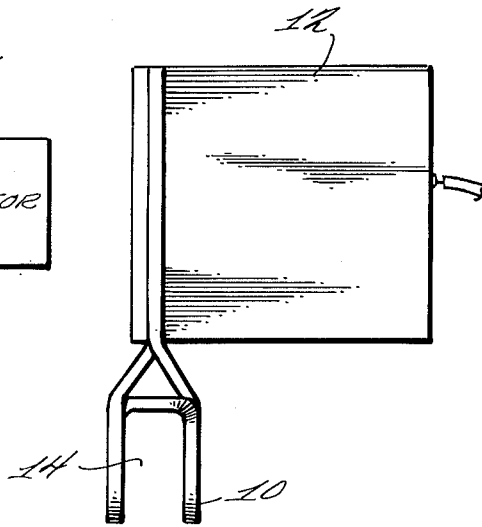


Fig. 2

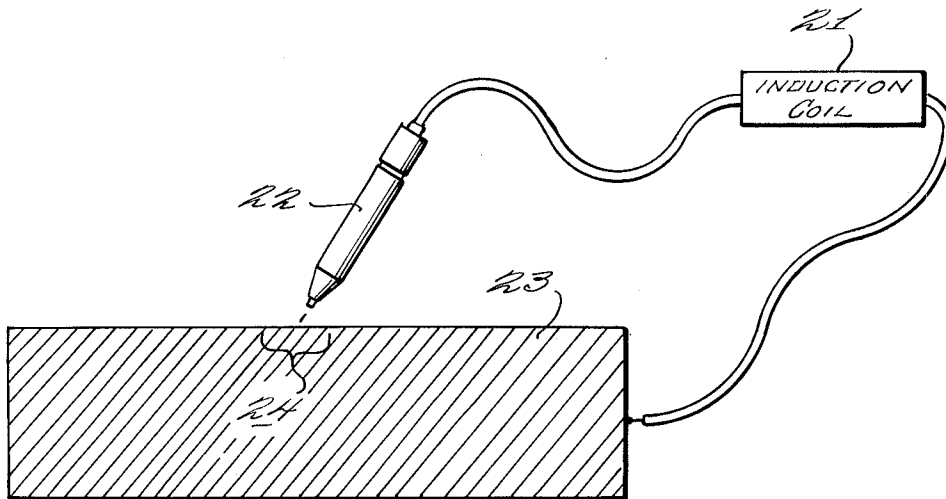


Fig. 3

INVENTOR

FRANZ LIHL

BY

Cushman, Darby & Cushman
ATTORNEYS

1

3,240,639

FERRO-CARBON ALLOYS OF IMPROVED MICRO-STRUCTURE AND PROCESS FOR THEIR MANUFACTURE

Franz Lihl, 29 Belghofergasse, Vienna, Austria

Filed Mar. 27, 1963, Ser. No. 268,269

Claims priority, application Switzerland, Jan. 12, 1957, 41,552/57

8 Claims. (Cl. 148—143)

This application is a continuation-in-part of my application Serial No. 53,053, filed August 31, 1960, now abandoned, which in turn is a continuation-in-part of my application Serial No. 707,121, filed January 6, 1958, now abandoned.

This invention relates to a novel heat treatment process for steel and ferro-carbon alloys, to an apparatus for carrying out such process, and to the new steel structure thereby produced. More particularly, the present invention relates to the production of vastly improved steels and ferro-carbon alloys having a novel microstructure and an improved and hitherto unknown hard texture.

It is well known that machine tools and parts therefor, tool steels and precision instruments must withstand the severest frictional and abrasive wear and resist the damaging effect of various types of shock and corrosion. Rotary and bearing elements, and their journals in high speed tools and machines are also subject to some of the most severe strains known in the metallurgical arts. Due to the wearing effects encountered, and due also to the desire for a long and dependable service life, such parts are normally constructed from the hardest known steel compositions.

The common hard steels and case-hardened steels are produced by first transforming the ordinary steel microstructure, with the aid of high temperatures, into austenite, which is identified by a face-centered cubic crystal structure and comprises a solid solution in which gamma iron is the solvent. The temperature at which the ferrite to austenite transformation is completed during heating varies with steel composition and is therefore usually identified as the A_{c3} point, which may be as low as about 700° C. and may be above about 900° C. and the achievement of such temperatures appears to be generally independent of heating time or rate. Following austenitic formation at the temperature of A_{c3} , the steel is subjected to a sudden quench at temperatures identified as M_s , and lying within the range of about 200 to about 500° C., to yield martensite, the hardest previously known transformation product of austenite.

This well known hardening process employs cooling speeds varying from above about 0.1 second to 4 minutes, depending on the composition of the steel used, to cool at least a surface layer from A_{c3} , the temperature of the ferrite to austenite transformation, down to about the highest temperature of the martensitic transformation M_s , which is about 500° C., to yield martensite. The martensitic formation process is commonly independent of any heating rate since martensite can only be formed by a cooling from austenitic transformation temperatures. The mass of produceable martensite is somewhat limited by cooling speed and accordingly, small objects or surface layers of martensite are easier to produce than large, solid blocks of the material.

The foregoing constitutes the essential principles of the present hard steel production process, although many variations have been developed in the several decades in which such processes have been in use.

Now it is known that at maximum hardness, martensite is too brittle for most useful purposes and accordingly, martensitic materials must be tempered prior to usage. It is an unfortunate fact, however, that martensite loses its hardness when attempts are made, as by tempering, to

2

reduce the objectionable brittleness. It is also known that the martensitic hardening provides no increase in corrosion resistance unless expensive alloying procedures are employed.

5 The greatest hardness, measured as Vickers macro-hardness, thus far observed for any hardened martensitic steel is about 926 kilograms per square millimeter. As observed above, this is unfortunately not a generally useful hardness since steels of such hardness have a micro-structure so brittle that the steel chips or fragments easily. Accordingly, to reduce brittleness to a useful degree, such hard steels are commonly tempered by re-heating to approximately one-half the hardening temperature.

Unfortunately, this tempering likewise serves to reduce 15 the hardness by approximately one-half. Thus, it is always the case that the frictional and wear resistance properties of a useful and hard martensitic steel product are considerably reduced whenever such a hardened steel is subjected to tempering.

20 Now it is also known that for resistance against wear, cavitation, corrosion and the like, the properties of hardness and toughness of a steel will increase with finer steel microstructures and will decrease in steels that retain increasing proportions of their austenitic content. The smallest grain size observed up to now is of the magnitude 25 of ASTM No. 12, i.e., grains measuring greater than about 5.5 microns on a side with an average diagonal greater than 7.8 microns or an area greater than about 30×10^{-6} square millimeters per grain. The usual content of retained austenite varies between 10 and 30% and this is best determined through optical means, whereas hardness is best determined by physical means. For example, if a typical ground and polished steel specimen is first treated with 3% alcoholic nitric acid, both the mar- 35 tensitic and austenitic structures will be visible under an optical microscope. The same may be said for the use of other strong solvents, but 3% alcoholic nitric acid is employed throughout the following discussion as a basis for comparison.

40 Relative hardness may be compared through use of the Meyer constant for hardness level a through the relationship:

$$L = ad^n$$

45 where L is the load, d the impression diameter and n is a constant denoting capacity for work hardening. In the hardness test, a diamond testing tool is impressed or used to cut into the surface of a steel structure. If the grain of the microstructure is large enough so that the indentation of the testing tool does not exceed the area of a single grain and does not bridge over to other grains, the influence of the grain boundaries will be eliminated, and the hardness figure thus measured will be higher than in cases where the indenting tool hits several grains.

50 For example, at low test loads between 10 and 30 grams, the diagonal of indentation by the testing tool measures between 4 and 8 microns and the Meyer constant of hardened tool steel with a carbon content of approximately 0.8% amounts to only 1.5. With slightly larger test loads between 60 and 100 grams, the indentation will vary from 7.5 to 10 microns and the Meyer constant will amount to 1.9. For this reason, it is only at large test loads, and those above 2.5 kilograms, that testing tool indentations of known microstructures of hardened steels reach a Meyer constant equal to 2. Thus, 65 it can be seen that the Meyer constant can be used both as an indication of grain size, as well as a standard of hardness.

70 With the foregoing in mind, it would be very desirable to produce a tough, usable steel that has both great hardness and great toughness evidenced by high Meyer constant at low loads, and accordingly a very small grain

size below ASTM No. 12 as evidenced by optical microscopic examination following treatment with a strong solvent such as 3% alcoholic nitric acid.

It is an object of the present invention to overcome the defects of prior art hard steels and provide an improved steel that will have greater hardness, toughness, corrosion resistance and resistance to wear than presently known martensitic steels.

It is another object of this invention to produce a ferro-carbon alloy having a microstructure exhibiting an average grain size of less than about 5 microns diameter.

It is a further object of this invention to produce a hard steel that will be useful without tempering.

It is still another object of this invention to provide a process for the production of an improved homogeneous steel microstructure which comprises heating a steel structure to a temperature between about 1000° C. and the liquidus point for a time period not longer than about 0.1 second, and thereafter immediately cooling said steel from that temperature down to a temperature in the range between about 600° C. and room temperature within a time period of at most about 0.01 second.

It is still a further object of this invention to provide a process for surface hardening a non-austenitic steel workpiece having a central body portion and a surface layer which comprises heating said surface layer to raise the temperature thereof to at least an austenitic-forming temperature within the range of about 1000° C. and the liquidus point for a time period of not longer than about 0.1 second, and thereafter immediately cooling said surface layer from the austenitic-forming temperature to a temperature in the range between about 600° C. and room temperature within a period of not more than about 0.01 second by transfer of heat from the surface area into the contiguous but relatively cool mass of said steel body portion to form a microstructure in said surface layer distinct from the microstructure in said body portion exhibiting homogeneity following a twenty second treatment with 3% alcoholic nitric acid, and having an average grain size lying below about 5 microns diameter and below ASTM No. 12, said surface layer having a retained austenite content lying below about 2%, a Vickers hardness exceeding 926 kilograms per square millimeter at test loads over 1000 grams, and a Vickers hardness Meyer constant independent of test load with test loads down to ten grams of about two.

It is another object of this invention to provide a non-austenitic steel body having a hardened surface layer of up to about 0.5 millimeter in thickness, said surface layer having a microstructure distinct from the microstructure of the remaining body portion, said surface layer microstructure exhibiting homogeneity after a twenty second exposure to three percent alcoholic nitric acid, and having an average grain size lying below about five microns diameter and below ASTM No. 12, a retained austenite content lying below about 2%, a Vickers hardness exceeding 926 kilograms per square millimeter at test loads over 1000 grams, and a Vickers hardness Meyer constant independent of test load with test loads down to ten grams of about two.

Other and further objects of this invention will become apparent to those skilled in the art when reference is had to the following disclosure and drawings.

The hardening process provided by this invention achieves the above objects by using, in combination, particular hardening temperatures, heating speeds and cooling speeds of a magnitude beyond anything previously conceived of or considered useful or possible. The heating temperature of this invention must lie considerably above A_{c3} , and preferably exceeds this temperature by at least one hundred centigrade degrees, and may even exceed the *solidus* point. Thus, the heating temperatures employed normally lie within the range of at least about 1000° C. and the liquidus point. As will be explained hereinafter, these temperatures must necessarily be

achieved very quickly, the present invention necessarily employing a rapid rate of heating, wherein heating must occur in not more than about 0.1 second.

As is also explained hereinafter, the present invention also employs an extremely rapid rate of cooling and the cooling from the highest heating temperature of above A_{c3} down to at least about 600° C. or below, must take place in not more than about 0.01 second, and this cooling speed is critically essential to achieve the present novel improved microstructure.

When it is desired to practice the invention and carry out cooling by employing external positive cooling media such as gases and fluids, the rapid cooling speed necessary can only be achieved if the article being treated is of very small mass in at least one dimension, as in the case of very thin metal leaves, very fine gauge wires, or very small spheres. Furthermore, an external cooling medium of extraordinarily high efficiency must be employed.

In the case where it is desired to treat materials of greater width, thickness and mass according to this invention, the necessary extreme rate of cooling can only be accomplished by means of a self-quenching or inner heat conduction process. According to the self-quenching procedure, only a thin layer of a steel article is heated rapidly, such as a surface layer, so that this layer may rapidly lose its heat to the adjacent mass, which remains unheated and at lower, cooler temperatures. The speed of self-quenching can also be facilitated by the use of external cooling media especially if such media are applied to the material adjacent the heated layer before, and even during the heating process. The present process is so rapid, and the heating rate employed is so intense, that in some cases, an external cooling media may be directed at the layer being heated even during the time of heat application.

Even when proceeding according to the self-quenching process however, the required great cooling speed can only be achieved by observing special precautions. For example, a surface layer of the article to be treated must be heated so rapidly that even the immediately adjacent layers are not appreciably heated; and the required precise cooling control places a consequent restriction on the rate of heating. Accordingly, to satisfy the proper cooling requirements of this invention, all heating must be conducted very rapidly and the heating to temperatures within the range of about 1000° C. to the liquidus point must occur within a period of time that does not exceed about 0.1 second.

To satisfy in turn this necessarily rapid heating rate, heating energy must be applied with a density or surface intensity of at least about two kilowatts per square centimeter or approximately one-half kilocalorie per square centimeter-second. The heating process can also be improved somewhat by prehardening steel and this may be accomplished by well known heat treatments.

Since the present process is most easily performed on thin materials or thin layers of larger materials, it is most suitable for surface hardening treatments. The thickness of the hardened layer thus obtained may be as much as one-half millimeter (0.5 mm.), but this thickness depends on the use of an extremely rapid rate of heating. For example, a heating period to reach temperatures above A_{c3} and within the range between about 1000° C. and the liquidus point must occur within a time that amounts to no more than 0.1 second, and can be less than 0.1 millisecond. Heating times within the range of 0.001 to 0.02 second and even as short as 0.0001 second have proved suitable. Such rates of heating are only attained by supplying the heat effect with a high surface intensity as noted above.

It has been found that surface layer thicknesses up to at most about 0.5 millimeter are suitable for present purposes, although presently unknown methods may be used to achieve even greater thicknesses. Surface layer depths within the range of 0.001 to 0.05 millimeter are commonly

5

produced by this invention, thicknesses within the range of 0.05 to 0.5 millimeter also proving suitable.

Two methods have been found useful to control the length of the heating period, check its duration and measure the temperature. According to the first method, the article to be treated is rapidly traversed across an intense source of heat, for example an intense flame or heat radiator. The second method envisions heating by means of high energy direct or alternating electric current which is switched on only for the required short period of time.

This invention will now be more fully described with reference to electric heating procedures which are more desirable in terms of intensity and control, although it is to be understood that the nature of the energy source employed for heating in the present process is immaterial for the purposes of the present invention, e.g. it is only the intensity of the best heat source which is important and thus, even nuclear or atomic energy may prove suitable at some future date.

For the purposes of this invention, the term "electric heating" is intended to be generic to any heat source employing electric current, including such devices as induction heating, electron discharges and spark discharges. Referring to induction heating, frequencies in the range of 2 to 100 megacycles per second have proven suitable, while frequencies in the range of 2 or 5 or 10 to 20 or 30 are most often used, as well as those within the range of 30 to 50 and 50 to 80. It will be understood that for a given time of exposure, the choice of frequency may be used to control the amount of heat applied and the thickness of the layer being heated.

The above noted high induction current frequencies are very suitable for the present process since they can be switched on and off with great rapidity. Short switching periods in turn can be assured by taking the current from a generator relay which is controlled by a condenser discharge. It is of advantage if the generator relay controlling impulse is triggered off automatically by the feed mechanism of the article to be treated, as by means of a photoelectric cell.

At equilibrium conditions, the temperature to which the hardened goods are heated according to this invention lies at least 100 degrees beyond A_{c3} as noted above. For example, in a heating period of 15 to 20 milliseconds, a temperature of 1300° C. has proved suitable, and in many cases it has proven advantageous to advance the heating even into the range between the liquidus and solidus line. In proceeding under the present teaching, peak heating temperatures within the range of 950 to 1100° C. and even 1100 to 1350° C. are realized. According to the prior art processes, and when using known heating rates, these temperatures were felt to produce unsuitable overheating with a consequent undesirable coarsening of the grain. Grain coarsening does not occur in the present process since the heating period is far too short for a change of grain structure, and this includes heating times as noted previously.

As in the self-quenching process above discussed, substantially the whole mass of the material contiguous with or adjacent to the thin layer being heated, remains cool. Thus, following the period of heat application, the excess heat will flow off into this cooler mass. Based on experience and thermo-dynamic calculations, the length of cooling time of the heat treated layer has proved to be extremely short, and lies, when measured from about room temperature or from about 600° C. to the range of peak temperature above about A_{c3} , in the order of 0.01 second and is preferably less. This extremely short cooling period is believed to be critically essential for obtaining the hard microstructure according to this invention and is only believed obtainable by using the novel heating process disclosed herein.

The hard microstructure achieved by this invention is quite distinct from martensite as well as all other presently known hard steel structures, and may be character-

6

ized as follows: For instance, treatment with 3% alcoholic nitric acid does not etch the new grain structure so as to exhibit dissolution under an optical microscope, even when subjected to the influence of this strong solvent for considerably longer than 20 seconds. The average grain size surprisingly lies under about five microns on a side and under about 25×10^{-6} square millimeters in area and therefore under the grain size known as ASTM No. 12, the average diagonal of the grain lying under about 7. The content of retained austenite is also surprisingly low and is less than 2%. The Vickers hardness is practically or entirely independent of the load, with loads down to 10 grams, showing a Meyer constant equal to 2, plus or minus 0.05. The hardness is also independent of load with loads over 1000 grams, as those greater than 926 kilograms per square millimeter.

It is to be understood that many other testing procedures may be employed according to the present invention but this application has been limited to those indicated above for simplicity and ease of comparison. Obviously, other testing media may be employed as various ethyl alcohol and/or water solutions of nitric, hydrochloric, sulfuric and picric acids, as well as various chloride and sulfate salt solutions that are known in the art.

The same may be said for the physical testing procedures employed.

It should also be understood that the novel steel microstructure of the present invention can be varied somewhat. For example, by lengthening the heating time it is possible to obtain any desired texture mix between martensite and the novel and improved structure of the present invention, since at heating times greater than about 0.01 second, martensite begins to appear in the hardening texture. With careful control, it is possible to obtain a mixture of the present homogeneous microstructure and martensite in the treated surface layer, while the body portion of the treated steel may contain ferrite, austenite, martensite, or mixtures of any two or all three of these materials in a steel or ferro-carbon alloy.

The present process can also be applied to virtually any known type of steel, including both alloyed and simple or unalloyed steels defined as iron containing from 0.05 to 2% by weight of carbon. Alloyed steels include those alloyed with one or more of the following elements in percentages that are well understood in the art: aluminum, chromium, cobalt, copper, manganese, molybdenum, nickel, phosphorous, silicon, sulphur, titanium, tungsten and vanadium, in the presence of and varying with known amounts of carbon.

Whatever the composition of the steel or ferrocabon alloy treated according to this process, it will be found that the extremely hard structure produced is not brittle and may be used as is. That is, the present novel microstructure offers the surprising advantage, as compared with martensite, of not being brittle as produced, but being instead both tough and durable and accordingly not requiring any tempering and weakening treatments prior to use.

Attention is now directed to the drawings which are illustrative of only a few of the many ways in which the process of the present invention may be accomplished. It is to be understood that these drawings are diagrammatic and not drawn to scale.

FIGURE 1 is an end view showing in elemental detail the construction of a suitable induction coil for use in the present invention, together with a generator;

FIGURE 2 is a side view of the structure shown in FIGURE 1, and

FIGURE 3 is a schematic diagram of a working example according to the present invention.

Turning now to FIGURE 1, there is shown an induction coil 10 which may be connected to a high frequency vacuum tube type generator of known construction indicated generally by the reference numeral 15. The cur-

rent delivered by the generator must have a frequency within the range of 2 to 100 megacycles per second and the generator must be able to deliver from two to at least ten kilowatts for a given short period of time. The induction coil 10 may consist of one and one-half turns of flat silver wire two millimeters in width and one millimeter in thickness. Coil 10 is attached by means of two joining sheets 12 and suitable wires to the electrodes of the high frequency generator.

The material to be hardened is inserted into the empty space inside the turn and one-half winding and is passed through in the direction of the feeder arrow 13. The workpiece (not shown) may be a cutting instrument such as the blade of a saw. In such case, only the tooth points need be treated according to the invention and this will be best understood by reference to FIGURE 2 where the tooth points (not shown) would pass through the opening 14 provided by the wires of coil 10.

During the brief time increment in which the saw tooth point is in opening 14 and at the mid-point of the winding, the high frequency current may be turned on by a photoelectric cell switch arrangement. During the "on" period, the current may "run" for any desired time length, for example, one-tenth second, one one-hundredth second or less, although times within the range of 0.005 to 0.02 second and times up to 0.1 second are preferred. To permit such short time durations, a time switch of known construction may be combined with the photoelectric cell arrangement, but this is not an important feature of the present invention.

However, the on and off-switching may desirably be automated and controlled by the feeder or other device controlling the movement of the workpiece being treated in order to achieve the desired short heating period. For example, the movement of each saw tooth through opening 14 may interrupt a photo-electric cell, as noted previously, which will in turn control the generator switch impulse by means of a standard selenium cell. In this manner, the present invention may be performed with extreme simplicity since the heating period will automatically be controlled by the simple movement of the workpiece, a saw tooth in this case, through the induction coil. Because this heating period is understandably short, the self-quenching process will immediately avail itself in the case of each tooth and the heated surface thereof will be very quickly cooled due to the cooler interior mass of each tooth. If desired, an external cooling media, such as a relatively inert or non-combustible gas, may be directed at the induction coil opening 14 to hasten the cooling of the workpiece.

Referring now to FIGURE 3 of the drawing, there is diagrammatically shown an apparatus for accomplishing the present treatment by means of an electric spark discharge. Induction coil 21 may be subjected for a brief period to a potential of from one thousand to three thousand volts. Spark-emitting electrode 22 is attached to one pole of the induction coil and the opposite pole of induction coil 21 is attached to workpiece 23 which serves as the other electrode. Spark propagation due to the instantaneously applied voltage will reproduce the microstructure of the invention on the work surface in small area 24. Since such a spark is of very short duration, the required shortness of heating time necessary to this invention is insured. By forward movement of spark electrode 22 over the surface of workpiece 23, suitable adjoining areas can be treated to achieve homogeneity as described in Example II hereinafter. Cooling of course, is instantaneously accomplished by self-quenching.

It will be understood that increases in the size of the area treated by the spark discharge, as well as the depth of penetration of this treatment can be controlled within certain limits by adjustment of the electrical potential. Suitable technical improvements will become obvious to those skilled in the art whereby the spark discharge process may become automated and speeded up.

There are certain factors worth observing that will increase the effectiveness of the present process. For example, if generator output can be increased, the time duration of the heating cycle will be reduced due to increasing frequency and intensity of the induction impulses. The depth of the present microstructure hardening effect can also be influenced by the choice of the induction frequency according to known principles. Since the depth of penetration d in millimeters, may be equated to the electrical conductivity ρ in ohms-square mm. per meter, the magnetic permeability μ , and the current frequency f in cycles per second, by the equation:

$$d = 503 \sqrt{\frac{\rho}{f \cdot \mu}}$$

the layer thickness will be changed in proportion to the applied frequency. The magnetic permeability μ equals one (1) in the case of austenite and ρ may be assumed to be unity (1) for the purposes of comparison and thus, equating f and d , the following values are found for current penetration:

Frequency (f), kilocycles per second	Penetration (d), millimeters	Heating Time (t), seconds
100.....	1.60	1.8
500.....	0.71	0.36
2,000.....	0.36	0.090
80,000.....	0.09	0.0050

Since the joulean heat is proportional to the square of the current, it is calculated that the heating power or wattage penetration is only about one-half as much. However, it has been found in practice that the thickness of the present hardened layer is greater than that suggested by these empirical calculations. For the above f and d values, the relative heating times are also given and it has been found by experiment that only the latter two heating times will produce the microstructure of the invention, having therefore, the appropriate thickness d by using the frequency f .

The understanding of this invention will be facilitated by reference to the following examples which are given, however, only by way of illustration.

Example I

According to one embodiment of this invention, the tops of teeth of a band saw blade 0.7 millimeter (0.28 inch) thick are fed at a speed of 17 feet per minute through an induction heater having two five millimeter (0.200 inch) thick circular coils operated at a frequency of about 27 megacycles and a power input of about four kilowatts. This saw had a composition as follows:

Component:	Percentage part by weight
Iron	98.4
Carbon	0.75

While each tooth is being fed through the coils, its heating period is automatically controlled by a photo-electric cell which switches a generator relay and permits application of the induction current for a period of 0.012 second. While the current is switched on, the top of the tooth being heated becomes brightly incandescent at a temperature above 1000° C. and as high as 1350° C. due to the skin effect of the high frequency induction current. Following this extremely brief heating period, the tooth cooled itself rapidly from about 1350° C. down to 600° C. in about 0.01 second by self-quenching to produce the grain microstructure of this invention.

Following the induction treatment, the product is a cross-sectionally non-homogeneous structure having a surface layer exhibiting a microstructure so hard, that even after treatment with 3% alcoholic nitric acid, for a period of twenty seconds, the treated surface layer ap-

appears completely homogeneous under a metallographic microscope and reveals no distinctions or larger crystals in the uniform grain structure. The depth of surface layer was about 0.1 millimeter in thickness. The average grain size was found to be below five microns diameter, that is, below or smaller than the size known as ASTM No. 12. The retained austenite content is less than two percent and even at test loads over one thousand grams, the Vickers hardness will exceed 926 kilograms per square millimeter. Independent of test load, this Vickers hardness will be perceivable down to test loads of ten grams, that is, a Vickers hardness Meyer constant equal to about two, plus or minus five hundredths.

Example II

In another mode of practice of this invention, use is made of a high velocity electron beam of the type supplied by an electron radiation apparatus of the kind employed in the trade for close mill work. The beam of electrons proceeding from the beam source is focused by a magnetic lens and directed at the area of the workpiece surface which is to be hardened. The workpiece had the following composition:

Component:	Percentage part by weight
Iron -----	98.4
Carbon -----	0.75

The surface area treated by such a beam will approximate the shape of an ellipse having diameters measuring 0.16 and 0.08 millimeter respectively, for the long and short axes. The voltage potential of the beam may vary from 10,000 to 100,000 volts, and the intensity of the electron beam may be 5 milliamperes, although under certain conditions this figure may be reduced to only one-tenth of this value. The length or time duration of the emission is measured in hundredths or thousandths of a second and may be less than one one-thousandth of a second. Whatever length of time is employed however, it is necessary that the beam apply not less than about two kilowatts power per square centimeter of workpiece surface area. In this manner, a steel structure having a hardened surface layer of about 0.2 millimeter thickness will be attained within a period of not more than about 0.1 second by heating to temperatures between about 1000° C. and the liquidus point. Following such heating, no further energy will be applied to permit the workpiece to cool from these austenite-forming temperatures to about room temperature within a period of not more than about 0.01 second by means of self-quenching as above explained.

Following such treatment of a section of the workpiece, the workpiece will be moved forward a distance equal to the length of the treated area such that similar adjoining areas may be treated according to this invention. These treated areas may be of any shape, and by successive treatments of adjoining areas, a workpiece having any shape or size surface can be treated. Obviously, due to the speed of the present heating and cooling, the operation does not have to be carried out with an incremental or intermittent motion, but may be carried out at a smooth rate by continuously applying an electron beam and by continuously moving the workpiece forward. The rate of advance may lie between two and ten millimeters per second. Conceivably, with improvements in technology and power applications, the speed of the present process can be improved and the size of the area treated can be increased for a given unit of time.

As with the induction process of Example I, the electron beam-treated surface was subjected to 3% alcoholic nitric acid and then viewed under an optical microscope. Again, complete homogeneity of grain structure was observed, the grain size lying below ASTM No. 12. The

several hardness tests exhibited the same Vickers macro-hardness and Meyer constant as in Example I.

Example III

In still another method of practicing the present invention, use was made of the apparatus of FIGURE 3. The workpiece had the following composition:

Component:	Percentage, parts by weight
Iron -----	98.4
Carbon -----	0.75

Induction coil 21 was operated at a potential of about 2500 volts and the spark discharged from electrode 22 appeared to last for a time interval measuring about 0.0005 second and effected an elliptical surface area of the workpiece measuring 0.06 and 0.05 inch along the respective axes to effect a surface layer depth of about 0.02 millimeter. Cooling was attained within a period of less than about 0.001 second, by means of self-quenching.

Even with the simplicity of this spark discharge process, this workpiece was found upon examinations like those conducted in Examples I and II above, to have approximately the exact same surface properties as found in Example I.

The processes of the foregoing examples may be modified in other apparent ways. That is, intermittent and continuous procedures may be combined together, and/or with various straight line or rotary and spiral feeding procedures to treat larger work areas, or work pieces of odd shapes such as drill or screw thread surfaces.

The extraordinary toughness of steel treated in accordance with this invention is of far-reaching technological importance. Surprisingly, a treated surface layer of 0.008 to 0.020 inch thickness on the edge of a cutting tool has been found to adhere to the untreated and martensitic body of the material even under the most stringent working conditions since the surface layer treated according to the invention has the quality of remaining inseparably attached to a base layer of martensite material, even under great stress. Long run experiments have proved that this hardened layer has no tendency either to separate or to chip off. Consequently, the new microstructure of this invention can be used directly at full hardness and without tempering.

Due to the great heating speed of the present process, it is possible to heat steel far above A_{c3} without grain growth and consequent deterioration of the microstructure. The high temperature is believed to accelerate the dissolution of the cementite. Some cautions should be observed however. For example, if after arriving at the present structure it is again heated to temperatures of several hundred degrees Centigrade, it will be transformed into martensite. Also, at somewhat lower cooling speeds the present microstructure appears to be intermingled with martensite.

The present process yields a microstructure which is clearly different from all hardened steel structures now known. The resistance against corrosion is greater than that of martensite, as may be observed from the etching of metallographic specimens. Other advantages of the present process will also become apparent as the present invention is utilized. For example, it is known that this process may be combined with known processes of heat treatment, that is, with a previous or simultaneous martensitic hardening procedure or with previous or simultaneous carburizing or nitriding procedures according to the intended use of the treated article. Accordingly, the spirit of the invention should only be limited by the scope of the following claims.

What is claimed is:

1. A surface hardening process for the production of an improved homogeneous steel microstructure which comprises heating the surface of a hardenable steel structure

to a temperature between about 1000° C. and the liquidus point within a time period not longer than about 0.1 second, and thereafter immediately cooling said steel by self-quenching from that temperature down to a temperature in the range between about 600° C. and room temperature within a time period of at most about 0.01 second.

2. A process for surface-hardening a hardenable non-austenitic steel workpiece having a central body portion and a surface layer which comprises heating said surface layer to raise the temperature thereof to at least an austenite-forming temperature within the range of about 1000° C. and the liquidus point within a time period of not longer than about 0.1 second, and thereafter immediately cooling said surface layer from the austenite-forming temperature to a temperature in the range between about 600° C. and room temperature within a period of not more than about 0.01 second by transfer of heat from the surface area into the contiguous but relatively cool mass of said steel body portion to form a microstructure in said surface layer distinct from the microstructure in said body portion, the surface layer microstructure exhibiting homogeneity following a twenty second treatment with 3% alcoholic nitric acid, and having an average grain size lying below about 5 microns diameter and below ASTM No. 12, said surface layer having a retained austenite content lying below about 2%, a Vickers hardness exceeding 926 kilograms per square millimeter at test loads over 1000 grams, and a Vickers hardness Meyer constant equal to about two, independent of test load, with test loads down to ten grams.

3. The process of claim 2 wherein the heating is effected with a power output of not less than about two kilowatts per square centimeter of surface area.

4. The process of claim 2 wherein the surface layer is heated to a depth of not more than about 0.5 millimeter in thickness.

5. A process for surface-hardening a hardenable non-austenitic steel workpiece having a central body portion and a surface layer which comprises first heating said steel by inducing an electric current in a portion of said surface layer to raise the temperature thereof to at least an austenite-forming temperature within the range of about 1000° C. and the liquidus point within a period of not longer than about 0.1 second, said induction being effected at a frequency within the range of from about two to about one hundred megacycles per second and with a power output of not less than about two kilowatts per square centimeter of surface area to heat a surface layer of up to at most about 0.5 millimeter in thickness, immediately cooling said surface layer portion from the austenite-forming temperature to a temperature in the range between about 600° C. and room temperature within a period of not more than about 0.01 second by transfer of heat from the surface layer into the contiguous but relatively cool mass of said steel body portion to form a microstructure in said surface layer distinct from the microstructure in said body portion, said surface layer microstructure exhibiting homogeneity following a twenty second treatment with 3% alcoholic nitric acid, and having an average grain size lying below about 5 microns diameter and below ASTM No. 12, said surface layer having a retained austenite content lying below about 2%, a Vickers hardness exceeding 926 kilograms per square millimeter at test loads over 1000 grams, and a Vickers hardness Meyer constant equal to about two, independent of test load, with test loads down to ten grams.

6. A process for surface-hardening a hardenable non-austenitic steel workpiece having a central body portion and a surface layer which comprises first heating said

steel by projecting a high velocity electron beam onto a portion of said surface layer to be hardened at a power output of not less than two kilowatts per square centimeter of surface area to heat a surface layer of up to at most about 0.5 millimeter thickness and to raise the temperature thereof from about room temperature to at least an austenite-forming temperature within the range of about 1000° C. and the liquidus point within a period of not more than about 0.1 second, thereafter immediately cooling said surface layer portion from the austenite-forming temperature to a temperature in the range between about 600° C. and room temperature within a period of not more than about 0.01 second by transfer of heat from the surface layer into the contiguous but relatively cool body portion of the steel, thereby forming a surface layer microstructure distinct from that of said body portion, said surface layer microstructure exhibiting homogeneity after a twenty second treatment with 3% alcoholic nitric acid and having an average grain size lying below about five microns diameter and below ASTM No. 12, said surface layer having a retained austenite content lying below about 2%, a Vickers hardness exceeding 926 kilograms per square millimeter at test loads over 1000 grams, and a Vickers hardness Meyer constant equal to about two, independent of test load, with test loads down to ten grams.

7. A process for surface-hardening a hardenable non-austenitic steel workpiece having a central body portion and a surface layer which comprises first heating a portion of said surface layer by an electric spark discharge operated at a potential within the range of about 1000 to about 3000 volts to raise the temperature of said surface layer of up to at most about 0.5 millimeter in thickness to at least an austenite-forming temperature within the range of about 1000° C. and the liquidus point within the period of the electrostatic discharge, and moving the treated surface layer portion from contact with the discharge such that the surface layer cools down from the austenite-forming temperature to a temperature in the range between about 600° C. and room temperature within a period of not more than about 0.01 second by transfer of heat from the surface layer into the contiguous but relatively cool mass of said steel body portion to form a microstructure in said surface layer distinct from the microstructure in said body portion, said surface layer microstructure exhibiting homogeneity following a twenty second treatment with 3% alcoholic nitric acid, and having an average grain size lying below about five microns diameter and below ASTM No. 12, said surface layer having a retained austenite content lying below about 2%, a Vickers hardness exceeding 926 kilograms per square millimeter at test loads over 1000 grams and a Vickers hardness Meyer constant equal to about two, independent of test load, with test loads down to ten grams.

8. A hardened steel structure obtained by the process of claim 1.

References Cited by the Examiner

UNITED STATES PATENTS

2,371,459	3/1945	Mittelman	148—150
2,424,794	7/1947	Brown	148—150
2,444,259	6/1948	Jordan	148—150

OTHER REFERENCES

Induction Heating, by H. B. Osborn, Jr., et al.; published by the A.S.U. 1946; pages 17, 18 and 102 relied on.

70 DAVID L. RECK, *Primary Examiner*.