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HEAT TREATMENT OF FERROUS BASE ALLOYS

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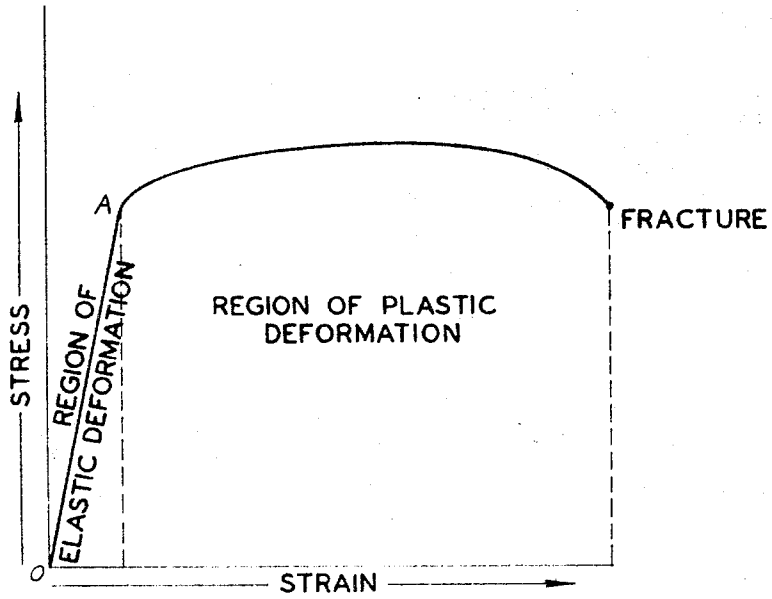


Fig. 1

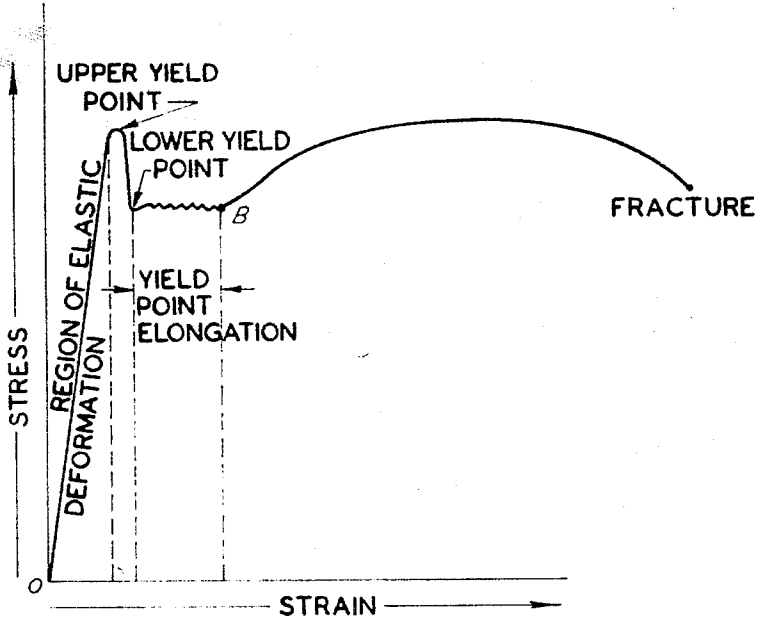


Fig. 2

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HEAT TREATMENT OF FERROUS BASE ALLOYS
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8 Claims

ABSTRACT OF THE DISCLOSURE

A method is disclosed for eliminating the upper yield point in ferrous base alloys which display this phenomenon. In a preferred embodiment low-carbon steel is heated with electromagnetic radiation to a temperature above 320° C. but below the lower critical temperature of the material and immediately quenched in water. The upper yield point is thus eliminated and the material may be drawn or otherwise deformed without the formation of stretcher strains.

This invention relates to the cold working of ferrous alloys and more particularly to a method of eliminating the upper yield point in suitable ferrous alloys to enhance their formability. As used herein, cold working is intended to refer to drawing, stamping, rolling, and other similar processes which are used to plastically deform a metal below its recrystallization temperature.

A better appreciation of what my invention accomplishes will be obtained by referring to the drawings. Both figures are tension stress-strain curves illustrating the manner in which different ductile metals deform under an applied tensile stress.

FIGURE 1 depicts the tension stress-strain curve for a ductile metal such as aluminum or copper in which a suitably designed specimen is subjected to an increasing axial load until it fractures. The curve of FIGURE 1 will be readily recognized by those skilled in the art. The straight line portion from O to A represents the elastic region of deformation. The curved portion from A to the termination of the curve represents the manner in which the specimen deforms plastically under an increasing load until it eventually fractures. From the standpoint of my invention, it is significant to note that in FIGURE 1 the transition from the elastic region to the plastic region of deformation is smooth and continuous.

It is also known that there are metals and metal alloys, a very important example of which is low-carbon steel, which do not deform under tension as illustrated in FIGURE 1. When suitably prepared specimens of these materials are subjected to an increasing axial load, the nature of the deformation is more accurately depicted as shown in FIGURE 2. In general, as the tensile stress on these materials is increased beyond the elastic limit there is no smooth and continuous deformation into the plastic region. On the contrary, as soon as a particular point is reached, which is called the upper yield point (identified in FIGURE 2), there is a sudden reduction in force per unit area because there is an abrupt plastic yielding of the metal. Further strain then occurs at a lower but fairly constant stress. After a period of deformation at fairly constant stress a point is reached (B in FIGURE 2) at which the deformation becomes more analogous to that of the plastic region of FIGURE 1. At this stage the stress must be increased for continued deformation until the specimen fractures. In the type of deformation represented by FIGURE 2 the strain under relatively constant stress is known as the yield point elongation and is so indicated. The value of the relatively constant stress is termed the lower yield point.

The observation of the upper yield point in metals such as low-carbon steel is of more than academic interest. For example when a sheet of low-carbon steel, which has not been specially treated to eliminate the upper yield point, is drawn to form a body panel of an automobile all areas in which the deformation is less than about 6% are scarred by Lüders lines or stretcher strains. Lüders lines or stretcher strains are depressions in the metal surface which cannot be masked by paint. They are directly attributed to the presence of an upper yield point on stress-strain curve, i.e. to the heterogeneous transition from elastic to plastic deformation illustrated in FIGURE 2. At the upper yield point highly stressed portions of the sheet will preferentially yield. The deformation is not relatively uniform throughout the whole area. It occurs in specific regions and manifests itself as depressions in the surface of the material, the metal therein having been strained to point B in FIGURE 2. The remainder of the metal in the steel sheet has probably received essentially zero strain. If a deformation of the entire sheet is not continued until it has been uniformly strained beyond the point B, the depressions will remain in the surface of the drawn article as unsightly defects.

Attempts have been made in the prior art to eliminate the formation of stretcher strains or Lüders bands when low-carbon steel is drawn. They will be described in more detail below. However, these prior art techniques while at least temporarily eliminating stretched strains have at the same time resulted either in a loss of ductility of the low-carbon steel or have led to a substantially weaker material.

Therefore, it is an object of my invention to provide a method of treating sheet steel and the like without decreasing the ductility of the material or its strength, such that it subsequently may be cold worked without introducing surface defects therein, as for example Lüders bands.

It is a more specific object of my invention to provide a method of treating suitable ferrous alloys to eliminate the heterogeneous transition from elastic to plastic deformation which produces an upper yield point in the tensile stress-strain curve of the alloy as shown in FIGURE 2.

It is a still more specific object of my invention to provide a method of eliminating, for a period of time, the upper yield point in those ferrous alloys which display this phenomenon, when they are plastically deformed without decreasing the ductility of the alloy or detracting from its strength.

It is also an object of my invention to provide ferrous alloy stock which has been treated to eliminate its upper yield point, but which treatment has not reduced the strength or ductility of the stock.

Iron alloys which may advantageously be treated by my method are those which contain relatively small amounts of solute atoms such as nitrogen and carbon which may adversely affect the deformation of such an alloy. In accordance with my invention, the above specified objects and others may be accomplished by heating a suitable iron alloy member with alternating electromagnetic radiation to a temperature above approximately 320° C. but below the lower critical temperature of the alloy and immediately quenching the member in water at room temperature.

In another embodiment of my invention the iron alloy may be heated by any means such as by combustion of gas or by electric furnace and the like to a temperature in the range from approximately 320° C. to the lower critical temperature of the alloy and then subjected to alternating electromagnetic radiation, preferably of frequency from about 1 kilocycle to about 500 kilocycles per second for a brief period, usually from 1 to 5 seconds.

The iron alloy member is then immediately cooled at a rate sufficient to prevent the return of the upper yield point. The member may then be plastically deformed without forming Lüders bands.

To better understand how the above-stated objects are accomplished in accordance with my method, a general discussion of the characteristics of metal in the solid state is required. It is well known that in general, the atoms comprising the metal arrange themselves in relatively orderly geometric configurations in crystals. Moreover, metallic materials, which are normally subjected to forming processes, are polycrystalline, that is, they are comprised of a large number of crystals. However, the arrangement of atoms in these crystals is not completely orderly in a geometric sense, but rather there are defects in the configurations which are called dislocations. These dislocations are characterized by the fact that, unless obstructed, they have mobility and may be shifted throughout a crystal in response to an applied force. It is the mobility of these defects or dislocations which permits a metal to be deformed at stresses much lower than would be required to overcome the attractive forces between the atoms themselves. Moreover, it is the mobility of these dislocations which apparently permits the plastic deformation of a metal in the first place. Were it not for the presence of dislocations the metallic solid under stress would be elastically deformed until the interatomic attraction forces were overcome, at which point the metal would fracture having undergone little, if any, plastic deformation. Therefore, it may be seen that the presence and mobility of dislocations in the crystals comprising a metallic member are of extreme importance in the workability of the metal.

In general, the relatively free movement of dislocations in metals such as aluminum and copper account for the smooth and continuous transition from the elastic to plastic region of deformation which is depicted in FIGURE 1. Accordingly, it is the lack of mobility of such dislocations which accounts for the heterogeneous transformation from the elastic to plastic region of deformation typified in FIGURE 2. In the case of low-carbon steel sheet, for example, relatively small amounts of carbon and nitrogen solute atoms are present. Low-carbon steels are usually considered to be those containing less than about 0.4% carbon. In general, sheet steel contains less than about 0.1% carbon and even less nitrogen by weight. Normally the solute atoms are not uniformly dispersed throughout the iron matrix but tend to congregate about dislocations. They form an "atmosphere" which retards the mobility of the dislocations. Since the metal may not be plastically deformed until the dislocations can move, it is apparent that sufficient stress must be applied to tear the dislocations away from the atmosphere of solute atoms. Once this is accomplished the dislocations may move relatively freely and at a lower stress level until the metal undergoes strain hardening and increased stress is required for further deformation. Thus, this accounts for the phenomenon illustrated in FIGURE 2. The upper yield point is the stress which is required to tear the dislocations away from the solute atoms and commence plastic deformation. Once the dislocations have "escaped" deformation continues at a fairly constant stress level (the yield point elongation) until the well known strain hardening process occurs.

While this upper yield point phenomenon has been observed in many metals and alloys such as polycrystalline molybdenum, titanium, and in aluminum alloys, and in single crystals of iron, cadmium, zinc, alpha and beta brass and aluminum, an extremely important commercial example of this problem is in low-carbon sheet steel. In low-carbon sheet steel it is generally concluded that nitrogen is the most critical solute element, with regard to the upper yield point phenomenon, because of its relatively high diffusion rate in iron. It has been estimated that the presence of 0.001% nitrogen is sufficient

in low-carbon steel to effect the upper yield point phenomenon.

In the prior art at least two different methods have been used to eliminate the upper yield point in low-carbon steel sheet. One technique involves adding elements such as aluminum, vanadium, titanium, columbium, or boron for the purposes of taking carbon and nitrogen out of solid solution in the form of stable carbides or nitrides. Steels to which such elements have been added are called "killed" steels. The technique has two disadvantages: The cost of the steel is significantly increased by the addition of the alloying elements. At the same time the strength of the steel is reduced because carbon and nitrogen are removed from solution.

A second industrial solution to the problem has been to temper roll the steel. This involves reducing the sheet in cross section about 1/2 to 4%. The cold rolling improves the surface of sheet metal and at the same time creates large numbers of new mobile dislocations which render the deformation characteristics of the steel more like the curve of FIGURE 1. However, such a treatment is not permanent because nitrogen and carbon diffuse to the newly created dislocations and form an atmosphere about them retarding their mobility. This diffusion occurs in a metal from a few hours to a few days. Moreover, the amount of cold rolling that is needed to create sufficient new dislocations reduces the ductility and thus the formability of the sheet steel. An object of my invention is to readily eliminate the upper yield point in low-carbon steel without incurring the disadvantages of alloying or temper rolling.

I have discovered that by subjecting low-carbon steel to high frequency electromagnetic radiation at a temperature above about 320° C. but below the lower critical temperature of the alloy for a very brief period of time and immediately quenching the material in water, the upper yield point is eliminated for a period of some several hours to several days if stored at room temperature or several weeks if stored at sufficiently low temperature. During this time the steel sheet so treated may be deformed without forming Lüders bands or stretcher strains. Heating the low-carbon steel to temperatures in this range by means other than induction heating does not eliminate the upper yield point. The mechanism of the effect of the electromagnetic radiation is not fully understood. It has been suggested, however, that the concentration of solute atoms, such as those of nitrogen and carbon, in the vicinity of dislocations increases the electrical resistance of the iron alloy in these areas. When the metal is placed in a high frequency electromagnetic field a current is induced therein. Because of the greater resistance in the neighborhood of the dislocation it is believed that these areas may be preferentially heated to temperatures higher than the surroundings. Assuming this to be true, it could explain why the atmosphere of solute atoms about the dislocations is dispersed by my process but is not affected by normal heating means.

In accordance with my invention, the upper yield point in low-carbon steel may be eliminated by subjecting the metal to alternating electromagnetic radiation preferably of a frequency between about 1 kilocycle and 500 kilocycles per second. Some beneficial results may be obtained by utilizing alternating electromagnetic radiation outside this preferred frequency range. However, at frequencies below about 1 kilocycle per second the efficiency and uniformity of induction heating is lower, particularly in steel members of thin cross section such as sheet steel. This is known in the art of induction heating as is indicated at pages 186 and 187 of the "Metals Handbook," 8th Edition, volume 2. Moreover, at frequencies above about 500 kilocycles per second it becomes more difficult to uniformly through heat steel members of any substantial thickness. However, it is noted that in these cases the limitations are inherent in the art of induction heating rather than in the characteristics of my method.

In my method electromagnetic radiation may be used to heat low-carbon steel to a temperature above about 320° C. but below the critical temperature of the alloy. In this case the yield point is generally eliminated by simply attaining a temperature in that range and immediately water quenching the workpiece. However, as I have pointed out above, the alloy may be furnace heated to the temperature range in question and then briefly subjected to electromagnetic radiation. I have found that an exposure of 1 to 5 seconds in the specified temperature range is usually sufficient. Of course, this could vary depending upon size and geometry of the workpiece and in some cases it may be necessary to determine preferred time experimentally.

It is important that the iron alloy which has been treated in accordance with my invention be rapidly cooled, preferably to about room temperature, so that the solute atoms do not recombine with the dislocations. It has been my experience that the piece must be quenched with water or other suitable liquid of similar viscosity. Quenching in oils such as are normally used in the heat treating art is not sufficient to generate the benefits of my process.

Since the concentration of solute atoms such as nitrogen and carbon in the region of the dislocations appears to be the preferred thermodynamic configuration, it appears that no heat treatment or cold working could permanently eliminate the upper yield point. Only a chemical change such as the addition of the alloying elements which are used to kill steel could accomplish this. However, it is expected that my process could be carried out conveniently and readily prior to the expected forming operations. Depending on the application of the steel and the manner in which it is to be deformed, the benefits of my process remain for a period of some several hours to several days if stored at room temperature or several weeks if stored at sufficiently low temperature.

This process may be successfully and advantageously applied to any ferrous alloy exhibiting the upper yield point phenomenon. As a practical consideration, however, it will preferably be conducted in connection with low-carbon steels, which are the ferrous-based alloys most economically formed by cold working. Moreover, it is expected that the most preferred application of this invention will be in connection with the forming of low-carbon steel sheets and strip. These materials are used primarily in consumer goods, an application requiring materials that are serviceable under a wide variety of conditions, adaptable to low cost techniques of mass production and that present an attractive surface to enhance sales appeal in the finished article. To attain these characteristics under the most economical conditions for production, the bulk of the flat rolled steel is of low-carbon content—0.15% maximum. In producing sheets, rimmed steel is ordinarily used. In general, typical ladle analysis are approximately by weight, 0.05–0.10% carbon, 0.25–0.50% manganese, 0.04% phosphorus maximum, and 0.05% sulfur maximum. These alloys also contain small amounts of nitrogen, for example, 0.001–0.003% by weight, which is sufficient to effect the yield point phenomenon.

The following examples will better serve to illustrate the practice of my invention.

Example I

A large number of $\frac{3}{4}$ " x 2" specimens were sheared from a sheet of annealed, rimmed, 18 gauge (0.48") sheet steel. The existence of a pronounced upper yield point in such material was demonstrated by the development of flutes or kinks when the steel specimen was bent around a rubber stopper of about 1" radius.

A Lepel high frequency (460 kilocycles) induction heater and six turns of a copper coil about a 3" diameter were adapted to heat the central 1" portion of the 2" long steel specimen. The preliminary heat treatments were done in air. It was determined that the specimen was at approximately 350° C. by using "Tempilsticks," at which

temperature it developed a characteristic silvery blue color. The induction heater was operated at a power level which heated the specimen to 350° C. in about 5 seconds.

At first specimens were removed from the coil and allowed to cool in air until they could be handled. These specimens showed the normal amount of fluting. In order to determine the effect of rapidly cooling a specimen from 350° C. subsequent specimens were quenched in water immediately after being removed from the coil. They could then be bent around the rubber stopper with perfectly uniform deformation and no fluting. Further experimentation demonstrated that the deformation was also uniform when a specimen was heated to temperatures as high as 900° C. and water quenched. Above that temperature the steel transformed to austenite.

Example II

A simple modification of the above treatment was also tried. Instead of performing all of the heating in an induction coil, the specimens were preheated to about 350° C. in an ordinary electric furnace. It was then found that a preheated specimen needed to be in the induction coil only about a second to prevent fluting.

Having demonstrated that the upper yield point can be readily eliminated in simple bending, the effectiveness of the heat treatment for biaxial stretch during a drawing operation remained to be shown.

Example III

A coil was prepared to heat a narrow zone across an 11" wide sheet of steel with a Tocotron 15 kilowatt, 460 kilocycle induction unit. With a two-turn coil a sheet 12" x 11" of 20 gauge steel could be processed in about 40 seconds. A sheet was passed downward through the coil the rate of passage being controlled by hand to effect the silvery blue oxide layer characteristic of 350° C. As the sheet left the coil, it passed into a water quenching bath located immediately below.

A die assembly and punch was then selected for drawing large flat bottom cups. Ten-and-three-quarter-inch diameter circular blanks were cut from the 20 gauge sheet. The blanks were precisely clamped by a bolted hold down pad. The press was then operated in a consistent manner, cups being drawn from (1) annealed, rimmed steel (2) heat treated annealed, rimmed steel in accordance with my process, and (3) annealed, killed steel. The bottom of the cups drawn from annealed, rimmed steel showed pronounced stretcher strains. Furthermore, noticeable buckling occurred just below the flange of the cups. In contrast, the bottom of the cups drawn from material from the same large sheet but heat treated in accordance with my process, as described above, showed no stretcher strains and the buckles just below the flange were markedly reduced. As would be expected, the cups drawn from killed steel were also free of stretcher strains and buckles.

In accordance with my process, automobile body components such as fenders, tulip panels and the like have also been drawn. These parts were characterized by the complete absence of Lüders bands or stretcher strains despite the fact that the sheet material had not been killed.

As stated above, it is believed that my process will be extremely useful in the drawing of automobile body parts and the like from low-carbon sheet steel. Preferably such material would be annealed and given a minimum temper roll at the steel mill sufficient only to leave a fine, smooth surface thereon. The extent of deformation during the temper roll will not be as great as at present as the purpose therefor will not be to eliminate stretcher strains but simply to improve the surface. There will be no problem in having to use the material within a short period of time after it has been temper rolled as my process can be applied immediately before it is formed. By treating the steel in accordance with my process, there is no reduction in ductility as occurs after temper rolling. In fact, it has been observed that my process actually in-

creases ductility. Also, the hardness of treated, formed and aged parts will be greater than the hardness of similar members formed using killed steel. This could, of course, permit reduction of weight in many articles of commerce. There will certainly be many other applications for my invention. For example, bumpers can be more readily formed without having stretcher strains therein which are difficult to cover by plating.

Thus, while my invention has been described in terms of certain specific embodiments, it is appreciated that other forms could be adopted by those skilled in the art and my invention should be considered limited only by the scope of the following claims.

I claim:

1. A method of treating a ferrous base alloy of composition having a lower critical temperature above 320° C. and such that solute atoms interact with dislocations in the alloy to produce an upper yield point, said method comprising subjecting said ferrous base alloy to electromagnetic radiation having a frequency of about one kilocycle to five hundred kilocycles per second at a temperature in the range from about 320° C. to said lower critical temperature of said alloy for a time sufficient to dissociate said solute atoms from said dislocations and immediately cooling said alloy at a rate sufficient to prevent the recombination of said solute atoms with said dislocations whereby said upper yield point is temporarily eliminated.

2. A method as in claim 1 wherein said ferrous base alloy is cooled at said rate by quenching in a liquid.

3. A method as in claim 2 wherein said liquid is water.

4. A method of eliminating the upper yield point in a low carbon steel alloy comprising heating said alloy to a temperature in the range from about 320° C. to the lower critical temperature of the material, subjecting said low carbon steel alloy for at least about one second to electromagnetic radiation having a frequency of about one kilocycle to five hundred kilocycles per second to eliminate said upper yield point and then quenching said alloy in water.

5. A method of eliminating the upper yield point in a low carbon steel alloy comprising induction heating said alloy with electromagnetic radiation having a frequency of about one kilocycle to five hundred kilocycles per second to a temperature in the range from about 320° C. to the lower critical temperature of the material and immediately quenching said low carbon steel alloy in water.

6. An upper yield point free ferrous base alloy when prepared in accordance with the method of claim 1.

7. In a method of deforming a ferrous base alloy member of composition having a lower critical temperature above 320° C. and such that solute atoms interact with dislocations in the alloy to produce an upper yield point, the improvement of subjecting said ferrous base alloy member to electromagnetic radiation having a frequency of about one kilocycle to five hundred kilocycles per second at a temperature in the range from about 320° C. to said lower critical temperature of said alloy for a time sufficient to dissociate said solute atoms from said dislocations, immediately cooling said alloy at a rate sufficient to prevent the recombination of said solute atoms with said dislocations whereby said upper yield point is eliminated, and then deforming said alloy.

8. In a method of deforming a low carbon steel alloy member having an upper yield point, the improvement of subjecting said low carbon steel alloy member to electromagnetic radiation having a frequency of about one kilocycle to five hundred kilocycles per second at a temperature in the range from about 320° C. to the lower critical temperature of said alloy for a time sufficient to eliminate said upper yield point, immediately quenching said alloy in water and subsequently deforming said steel alloy.

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