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[54] **HOT WORKED STEEL METHOD AND PRODUCT**

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[58] **Field of Search** ...72/205, 342, 364, 286; 148/12

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[57] **ABSTRACT**

Hot worked medium carbon steel wire, strip or bar is given a high elastic limit, good workability, freedom from surface tensile stresses, good stress corrosion resistance and low creep, by heating the steel prior to hot working, to a temperature such that the temperature immediately after hot working is 350°–500° C., while simultaneously imposing tension on the heated steel in the range between 15 percent of the tensile strength and the elastic limit, for a period of time not more than 10 seconds. Preferably, the steel is tensioned between the hot working mechanism such as a hot drawing die and an immediately preceding cold deformation mechanism such as a cold drawing die, the heat being applied by electric resistance between contact points constituted by the dies.

7 Claims, No Drawings

HOT WORKED STEEL METHOD AND PRODUCT

The present invention relates to the hot working of elongated workpieces such as wire, strip or bar, of carbon steel with a ferrite-pearlite structure, more particularly to such material which has previously been subjected to cold reduction. The present invention has particular utility in the hot working of such material which will be used as reinforcement for prestressed concrete.

The reinforcement for prestressed concrete should have an elastic limit as high as possible, so as to permit the greatest prestress with the least steel. Also, it is desirable that the elastic limit be high, so that the material upon unrolling will have the least tendency toward permanent set. In this way, it is possible to use winding reels of smaller diameter than when the elastic limit is lower.

Another requirement for such steels is good workability so as to permit the necessary plastic deformation during the formation of the reinforcement structure.

A third desideratum for such steel is that the residual stresses caused by cold deformation of the material, that is, the hoop stresses in the skin of the material, should not be tensile. Such tensile stresses would promote surface cracking in the prestressed concrete.

Still another desirable characteristic of such steel is good stress corrosion resistance.

Finally, a fifth desideratum is low creep.

The steel with which the present invention is practiced is that usually used for reinforcing elements for prestressed concrete, namely, medium carbon steel having a carbon content from about 0.50 percent up to and including eutectoid, namely, about 0.89 percent. Preferably, the carbon content falls in the range about 0.65 percent to about 0.80 percent by weight. At equilibrium, such steels are constituted by admixtures of eutectoid pearlite and ferrite, and small quantities of other components such as silicon, manganese, sulfur and phosphorus are not adverse to the present invention.

The steels of the present invention are in elongated form and can be of indeterminate length such as wire or strip, or can be of determinate length such as bars and can have any cross section such as circular or other. The steel is first cold deformed, as by cold rolling or cold drawing in one or several successive stages, whereby a high elastic limit is imparted to the steel but highly detrimental stresses remain and the workability is not optimal. Moreover, the creep is undesirably high and stress corrosion resistance is undesirably low.

It is possible to reduce residual stresses and at the same time improve workability, by tempering for example at 350° C., but the other mentioned properties are not substantially improved.

Accordingly, it is an object of the present invention to provide methods of treating steel by hot working so as to improve the properties mentioned above.

Another object of the present invention is to provide hot worked steel having improved properties as described above.

Finally, it is an object of the present invention to provide such methods and products which will be relatively simple and inexpensive to practice and to produce, with existing equipment that requires little modification, and with uniformly desirable results.

Other objects and features of the present invention will become apparent from a consideration of the following more particular disclosure.

Briefly, the present invention is the discovery that the above objects can be achieved if, immediately after having undergone a last cold working operation, the workpiece is heated and the cross-sectional area is reduced by hot working with the heated portion of the workpiece under a tension in the range between 15 percent of the tensile strength and the elastic limit, the workpiece having a temperature between 350° and 500° C. immediately after hot working and the cold and hot working taking place on any given portion of the workpiece at an interval of not more than ten seconds. The purpose of the limitation of the time interval between the cold and hot deformation is to limit the opportunity for carbon migration to make permanent the crystal dislocations caused by the last cold working. Thus the present invention is preferably practiced on material of indeterminate length, by a continuous process in which the material passes immediately from the last cold deformation to the hot deformation, with heating and tension between.

The tension in the heated material may be produced in any desired way. However, when the tension is produced for example by a brake drum, then the braking energy is at least to some extent wasted. Therefore, it is preferred that the tension be produced by the braking action of the cold deformation apparatus itself. Thus, if cold reduction and hot reduction are performed, for example, between rolls, then the braking action of the cold rolls and the draft action of the hot rolls can be used to produce the tension in the heated material between them. If cold reduction and hot reduction are effected through drawing dies, then the braking action of the cold drawing die upstream of the hot drawing die, with respect to the direction of movement of the workpiece, can be used to produce the necessary tension.

The heating of the workpiece between the last cold working step and the hot working step, the workpiece entering the last cold working step at a temperature not more than about 175° C., may be effected in any number of ways, such as feeding the workpiece through an induction heating oven or through a heating bath. Preferably, however, heating is effected by electric resistance, the workpiece being placed in circuit between the cold and hot working operations by means of spaced electrical contacts that slide on the material. These contacts may be external to the hot and cold working apparatus; but a highly desirable way of effecting electric resistance heating is to pass an electric current through the hot and cold working devices themselves and through the workpiece between them. Thus, for example, in the case of cold and hot reduction through dies, the dies themselves and the workpiece between them can be placed in electrical circuit and the current characteristics regulated so as to produce by electric resistance heating sufficient to insure that the temperature of the workpiece emerging from the hot reduction die will fall in the range 350°–500° C.

To enable those having ordinary skill in this art to practice the invention, the following illustrative examples are given:

EXAMPLE I

Continuous wire rod stock having an initial diameter of 10 mm. and the following composition:

C—0.76%

Si—0.27%

Mn—0.59%
S—0.026%
P—0.015%,

balance essentially iron, is reduced in a plurality of drafts through cold drawing dies by 60 percent of its initial cross-sectional area, to a diameter of 5 mm. In a final cold drawing die, a final cold reduction of 25 percent of the cross-sectional area is imparted to the wire, which then travels 20 cm. to a hot drawing die through which the wire is reduced 5 percent of its area. A current of about 1,000 amperes and 11 volts is impressed across the last-mentioned hot and cold dies and through the wire, so that the wire leaves the hot die at a temperature of 380° C. The rate of travel of the wire between the hot and cold dies is 3.3 feet per second. The elastic limit of the wire is 10.7×10^4 p.s.i. and the tensile strength 15.7×10^4 p.s.i. The tension in the wire between the last-mentioned hot and cold dies is about 8.1×10^4 p.s.i. The electrical contact between the dies and the wire deformed thereby is found to be excellent.

EXAMPLE II

A wire of the composition of Example I is reduced by a series of cold drawing operations to 5.5 mm. diameter and then cold flat rolled to a strip 10 mm. wide and 2 mm. thick. The strip is led via a set of straightening rollers, between two laminating rollers, where it is reduced to a width of 12 mm. and a thickness of 1.5 mm. The electric resistance heating current is as in Example I but is established between the straightening rollers and the laminating rollers, the distance between the electrified straightening rollers and laminating rollers being eight inches. The strip exits from between the laminating rollers at a temperature of 375° C., the tension between the straightening rollers and the laminating rollers being about 6×10^4 p.s.i. which is about 30 percent of the tensile strength. In this case, it is the straightening rollers that perform the final cold working operation to produce the necessary dislocations as as result of cold plastic deformation of the crystal structure immediately prior to hot reduction and also to exert the necessary tension on the strip. The strip speed between the straightening rollers and the laminating rollers is about 3.3 feet per second.

The hot worked products of Examples I and II were tested as to creep, in terms of relaxation. The products were subjected to a steady tension of 13×10^4 p.s.i., which is about 70 percent of the tensile strength, for a period of 1,000 hours at room temperature. Products according to Examples I and II suffered a relaxation, which is to say a decrease in linear recovery, of only 1.5 to 2 percent, respectively 1.9 to 2.6 percent. However, when the same test was applied to a cold drawn and then to a hot drawn product to which no tension had been applied between cold drawing and hot drawing and which was otherwise the same as the products according to Example I, the relaxation was 2.5 to 3.5 percent. For further purposes of comparison, the two reduction steps were carried out according to the present invention except that no heat was applied between them. The relaxation was found to be 4.5 to 5.5 percent, and this relaxation was the same whether or not the material was in tension between the two cold working operations.

To establish the importance of prompt heating and hot deformation after the final cold deformation, as by limiting the time interval to 10 seconds, Example I was repeated except that 30 minutes were permitted to elapse between the last cold forming pass and the heating and tensioning and hot working operation. The relaxation was 2.5 to 3 percent.

Wires as produced in Example I were then torsion tested by twisting a length 50 times the diameter, through a cycle consisting of 360° twist in one direction, then 720° twist in the opposite direction, and then 360° twist in the first direction. Wires drawn according to Example I, with exit temperatures from the hot working die of 410° and 420° C., resisted 7 and 10 such torsion cycles, respectively. By contrast, wires hot drawn according to the prior art, with no heating and tension between immediately successive cold and hot drawing operations but otherwise the same as in Example I, could resist only two such torsion cycles.

The other desirable properties recited in the initial portion of the present application were also found to be at high levels.

From a consideration of the foregoing disclosure, there-fore, it will be apparent that all of the initially recited objects of the present invention have been achieved.

Although the present invention has been described in connection with preferred embodiments, it is to be understood that modifications and variations may be resorted to without departing from the spirit of the invention, as those skilled in this art will readily understand. Such modifications and variations are considered to be within the purview and scope of the present invention as defined by the appended claims.

Having described my invention, I claim:

1. A method of hot working an elongated carbon steel workpiece having a ferrite-pearlite structure and a carbon content of not more than about 0.89 percent by weight, comprising subjecting the workpiece to cold deformation, heating the workpiece, and reducing the cross-sectional area of the heated workpiece and applying to the heated workpiece between the cold deformation and hot reduction a tension in the range of 15 percent of the tensile strength up to the elastic limit of the workpiece, the workpiece being heated to a temperature such that its temperature is between 350° and 500° C. immediately after said hot reduction, said cold deformation and hot reduction being performed within an interval of not more than 10 seconds for any given portion of the workpiece.

2. A method as claimed in claim **1**, and exerting said tension by means of said cold deformation.

3. A method as claimed in claim **1**, in which said heating is effected by electric resistance through the workpiece by applying electrical contacts to two longitudinally spaced portions of the workpiece.

4. A method as claimed in claim **3**, in which the cold deformation and hot reduction apparatuses are electrified to apply said electric current to the workpiece.

5. A method as claimed in claim **1**, in which said cold deformation and hot reduction are produced by drawing through dies.

6. A method as claimed in claim **5**, in which said dies serve as electric contacts in sliding electrical contact with said workpiece thereby to apply said current to said workpiece between said dies.

7. A method as claimed in claim 1, in which said work-piece has a carbon content of 0.65 to 0.80 percent by weight.

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