METHOD OF PATENTING STEEL WIRE

FIG. 4

FIG. 1

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ABSTRACT OF THE DISCLOSURE

Austenitic steel wire with a carbon content between about 0.3% and 0.9% rolled at a temperature above the transformation point \( A_c \), is cooled at a rate of at least 20°C per second immediately after coming from the last stage of a hot-rolling mill, the first phase of the cooling past the GS line being carried out by quenching while the final cooling, down to a level between 480°C and 580°C, takes place in a fluidized bed.

This application is a continuation-in-part of our pending application Ser. No. 675,522 filed Oct. 16, 1967.

Our present invention relates to a method of treating steel wire, to increase its tensile, flexural and torsional strength.

In making wire of this type, e.g. as required for producing steel cables or coil springs, the conventional practice is to wind the hot wire from the last rolling station into a coil, allowing the coil to cool and thereafter heat-treating the wire in a fused bath, such as molten lead. This type of heat treatment is generally referred to as "patenting," a term which may also be used more broadly for the cooling of wire in any medium at a controlled rate from a level above the critical point \( A_c \) (transformation of ferrite to austenite) to a range in which austenite is transformed into pearlite.

In order to satisfy the usual requirements of ductility, flexibility and tensile as well as torsional strength, the wire so treated should have a predominantly sorbitic crystal structure. Sorbite is a fine-grained variant of pearlite and comes into existence upon transformation of austenitic steel at a temperature of approximately 550°C. If the transformation occurs at a lower level, generally below 500°C, the pearlite crystals are smaller and form a structure known as bainite. This structure is considerably harder than the sorbite and unsuitable for drawing. If, on the other hand, transformation is allowed to occur at temperatures above the level of subcriticality 550°C, the pearlite becomes progressively coarser as its crystals are surrounded by a ferrite skeleton; such a wire, typically obtained by patenting in air, has good ductility and torsional strength but does not withstand flexure as well as does wire transformed in a range of about 500 to 550°C.

In our above-identified pending application we have disclosed a method of patenting such a wire in a cooling medium of the fluidized-base type, i.e. a stream of carrier gas with entrained solid particles such as ceramic granules of elevated heat-transfer coefficient (preferably about 500 and 1000 cal./cm²-hr.°C.). The particles may consist, for example, of magnesia and may range between 0.03 and 0.15 mm in diameter, with a bulk weight of 1.5 to 5 g/cm³. Hydrogen, carbon monoxide or other relatively inert gases conventionally used in metallurgical processes may serve as the carrier fluid. Though the temperature of the cooling medium (solid particles and carrier gas) may be well below the bainite-formation level of about 500°C, transformation is completed above that level because the wire is led out of the fluidized bed in a state of incipient transformation before its temperature fall below the 500°C mark. This method can be applied directly to wire coming hot from a rolling mill and represents a more economical process for obtaining the desired sorbitic structure with substantial exclusion of bainite.

Our present invention, to the extent that it is goes beyond the disclosure of our prior application Ser. No. 675,522, represents a further development of that method particularly designed for austenitic steel wire with a carbon content between about 0.3 and 0.9% (by weight). Its object is to provide a method of treating such wire in a manner resulting, independently of the type of cooling medium employed, in a structure having the desired ductility and strength for the purposes specified above.

This object is realized, in accordance with our present invention, by immediately cooling the hot-rolled wire at a rapid rate of at least 20°C per second to a temperature within the austenite/pearlite transformation range, i.e. a temperature lying generally between 500°C and 550°C although its lower and upper boundaries may be around 480°C and 580°C, respectively. The forced-cooling process, which should start not later than about one second after the wire has left the last rolling stage, should lower the temperature of the wire to a level below the GOS line of the iron-carbon equilibrium diagram within a few seconds and should be terminated after not more than about 10 seconds from the time of its inception.

According to a more specific aspect of our invention, the initial cooling phase (past the GOS line) is carried out by quenching in water while the subsequent cooling is performed in a fluidized bed as described above.

A wire so treated has surprisingly high stress resistance along with the necessary ductility allowing it to be drawn to the desired final diameter. Without wishing to commit ourselves to any definite theories in explaining these phenomena, we ascribe them to a freezing of the molecular structure produced by rolling which may be characterized by a high density of dislocations.

We have found that the treatment of wire by our present method results in a sorbitic structure comparable to that realizable, albeit at substantially lower production rates, with a bath of molten lead. Moreover, the treatment according to our invention is faster than patenting in air and tends to suppress the formation of the ferritic skeleton usually associated with air cooling.

After the wire has emerged from the fluidized bed, transformation proceeds to completion under substantially isothermal conditions, i.e. without the use of a cooling medium other than the surrounding atmosphere. To retard the cooling at this stage it is, however, desirable to shield the emerging wire by sheet-metal plates or the like reflecting its thermal radiation. The final cooling, subsequent to transformation, may also take place in air.

In order to stabilize the temperature of the emerging wire within the desired range of approximately 500 to 550°C, we prefer to measure that temperature and to compare it with a predetermined rate to compensate for deviations therefrom by a corrective adjustment of the bed temperature and/or of the residence time of the wire in the fluidized bed. To control the temperature of the cooling medium, we prefer to remove particles continuously from the bed and to let them pass through a cooling chamber before returning them to the bed; this recirculation of the particles is best accomplished with...
the aid of a flow of carrier gas which may itself be re-
circulated. A plant suitable for carrying out the aforesaid method comprises a conveyor, preferably in the form of an aperture belt, passing through a channel together with the stream of carrier gas and entrained solid particles; the discharge end of the channel is provided with a gate through which the cooled wire may emerge while the particles are retained and form a nearly stationary accumulation around the exiting wire. The hot incoming wire may be deposited on the conveyor in a succession of loops, advantageously with the aid of a transversely oscillating dispenser as disclosed and claimed in our commonly owned application Ser. No. 675,405, filed Oct. 16, 1967.

The invention will now be described in greater detail with reference to the accompanying drawing in which:

FIG. 1 is a transformation diagram showing the conversion of austenitic steel to sorbite by conventional means and by the process of our invention; FIG. 2 is a somewhat diagrammatic side-elevational view of a plant for carrying out the process; FIG. 3 is a fragmentary view similar to FIG. 2, showing a modification; and FIG. 4 represents part of the iron-carbon-equilibrium diagram indicating the GOS line.

In FIG. 1 we have shown at A and B the boundaries of the austenite/pearlite transformation range for a typical steel wire of 5.5 mm. diameter, made from unalloyed steel with a carbon content of 0.5%. Graph e represents an idealized process whereby the wire is rapidly cooled, from a starting temperature of 360°C, to a level of 550°C, which it reaches after 1½ seconds and where the graph intersects the boundary curve A of the transformation range. After a further interval of about 1½ seconds, with gradual cooling to a point at or above 500°C, the transformation to sorbite would be completed without the formation of appreciable quantities of bainite. Such an idealized cooling process, e.g., with quenching in water, would be difficult to realize because of the problems of temperature control and appears to be impractical for any but the thinnest wires.

It is widely assumed, even if not established by incontrovertible proof, that the qualities of steel wire especially in regard to flexure are improved by an approximation of the conditions represented by graph e. This may be accomplished, to a certain extent, by the use of a bath of molten lead (graph a) which, in order to avoid the formation of bainite, should be maintained at a temperature of about 500°C so that the curve approaches this level asymptotically; this type of treatment, completed after 20 seconds, does not lend itself to the processing of hot wire combining at relatively high speed from a rolling mill. Conventional air cooling (graph d) takes even longer and leads to incepted transformation at a temperature close to 700°C, with resulting formation of a large-grain ferrite structure in the pearlite.

The treatment of wire in accordance with our present invention is represented by graphs b and c. Graph b illustrates the cooling by ceramic granules of the aforesaid type having a heat-transfer coefficient $\alpha=600$ cal./m.²-hr.°C, as compared with a value $\alpha=1100$ for the lead bath of graph a. Graph c applies to ceramic particles with $\alpha=850$. The particle temperature is maintained well below 500°C, yet contact between the particle stream and the wire is terminated at a point p or q, thus after 8 or 6 seconds, respectively, when the wire temperature drops to a level of 520°C. The treatment then continues substantially isothermally for a further period of approximately 20 seconds, to a point r well beyond the intersection of graphs b and c with curve B, whereupon final cooling proceeds in the open air (without any thermal shielding) as indicated by the joint portions b, c of the two graphs.

From the diagram of FIG. 4 it will be noted that the boundary between austenite and the ferrite/austenite mixture, represented by the line GOS, is approximately 750°C for steel having a carbon content of about 0.6%. In FIG. 1 the GOS line has been indicated at that level and is shown to intersect the curves b and c at points where the rate of cooling, as represented by the slopes of these curves, is well over 20°C per second.

Reference to FIG. 2 for a description of a plant in which the process described in connection with FIG. 1 can be performed. The plant comprises a fluidized bed 1 confined within a tunnel 24, forming an elongated flow channel, to the vicinity of the upper boundary of the GOS line and driven by a motor 15 so that a hot wire 3, deposited thereon after leaving the last stage of a hot-rolling mill and preferably after preliminary quenching as indicated in FIG. 1, is transported on a downwardly sloping path from right to left. Wire 3 passes through a guide tube 4 and a continuously rotating dispenser arm 25, driven by a motor 26, whose rotation forms the wire into a succession of loops deposited on the conveyor 2; the dispenser arm 25 may be subject to continuous transverse oscillations at a frequency related to the loop-deposition rate, as described in our copending application Ser. No. 675,405, for the purpose of inducing the optimum distribution of the loops over the available conveyor surface. Belt 2, designed as a wire screen or other aperture member, transports the loops through a gate 8 at the discharge end of the channel, this gate being here shown as a simple shutter having a slot for the passage of the wire loops; a more elaborate gate, designed to prevent the loss of solid particles through the exit slot, has been disclosed in our commonly owned application Ser. No. 675,426 filed Oct. 16, 1967. A perforated base 27 within tunnel 24 forms the lower boundary of bed 1 and is connected to outlets of a manifold 10 through which a carrier gas, as indicated by the arrows, is passed at longitudinally spaced locations by way of the interstices of belt 2 into the space thereabove. The branch conduits of manifold 10 contain respective valves 9 for controlling the amount of gas thus introduced. A further valve 28 controls the input from a compressor or other high-pressure source, not shown, whereas two other valves 29, 30 determine the proportion in which a portion of the gas is branched off into a conduit 5 into which opens an outlet of a cooling chamber 6, the latter containing a coil 22 transversed by a coolant. Conduit 5 opens into the tunnel 24 in the vicinity of the band 8.

Solid particles entrained by the gas stream accumulate in a pile just ahead of the shutter 8 where the tunnel 24 is formed with a discharge port 7 for these particles. A similar accumulation is formed at the entrance end of the tunnel by means of a stationary plate 31 underlying the upper run of conveyor belt 2 beneath an inlet branch 32 of conduit 5. Port 7 communicates with a further conduit 33 which leads to the top of cooling chamber 6 and which may include means, such as a pump 34, to promote the return of solid particles from the discharge end of tunnel 24 to the cooler. Another conduit 16, provided with a control valve 35, serves as a suction line to exhaust particles from the vicinity of shutter 8 to a separator 18 whence they are return to cooler 6 via a pipe 21; the spent carrier gas drawn off by line 16, and by a branch 36 thereof extending from the entrance end of the channel, is removed by a pump 17 into a conduit 19 whence it may be discharged by way of a valve 37 to the atmosphere or to the low-pressure line 38 for delivering fresh gas to valve 28. A bypass 20, controlled by a valve 38, enables the recirculation of some or all of the gas to manifold 10.

In accordance with an important feature of our invention, a temperature felt 11 just beyond shutter 8 senses the temperature of the emerging wire and feeds this information to a comparator 13 receiving a
reference signal from a storage device 12 adjusted to the desired exit temperature (e.g. 520° C.). Comparator 13 sets a controller 14 which, if necessary, adjusts the speed of motor 15 to vary the residence time of the wire in the fluidized bed 1 in a manner compensating for any deviations of its exit temperature from the preset reference value.

Dispensing arm 25 is, of course, representative of any convenient type of loop depositor including, for example, devices of the type shown in U.S. Patents Nos. 3,056,433 and Re. 26,052.

The wire 3 exiting from gate 8, thermally shielded against excessive radiant-heat losses by a tube 39 forming an extension of tunnel 24, continues on conveyor 2 in the ambient atmosphere until its transformation has been completed (point r in FIG. 1). Thereafter, it may be air-cooled more rapidly outside the tube 39, by the same or another conveyor or without any conveyor at all, to room temperature.

In FIG. 3, where elements corresponding to those of FIG. 2 have been designated by the same reference numerals with an addition of a prime mark, we have shown the temperature sensor 11' disposed ahead of shutter 8'. Sensor 11' ascertains the exit temperature of the wire in terms of the temperature of the fluidized bed 1' at the discharge end of tunnel 24' and, as before, communicates this information to a controller 14'; the output of this controller, in contradistinction to the previous embodiment, sets a servomotor 40 which adjusts a valve 41 to regulate the amount of cooling fluid passing through coil 22' of chamber 6'. The system operates otherwise in the same manner as the arrangement of FIG. 2. Naturally, the control systems 11, 11' shown in FIGS. 2 and 3 could also be combined in a single plant.

EXAMPLE I

Steel wire containing 0.58% C, 0.38% Mn, 0.24% Si, 0.01% P and 0.02% S, rolled to the same diameter of 5.5 mm. After pickling and bonderezizing, the wire is drawn without further heat treatment to a diameter of 2.2 mm., corresponding to a deformation of about 85%.

Wire so drawn exhibited a tensile strength of 200 kg./mm.², a torsional strength in terms of 40 consecutive cycles of reversing twist and a 50% constriction on rupture. Coil springs of 85 mm. diameter, 110 mm. length and four turns, formed from this wire, showed an axial compression of only 7% after 10,000 alternate cycles of compression and relaxation, compared with a 20% for shortening in the case of identical springs of conventionally lead-patented wire. An appreciable loss of stability occurred only after 60,000 compression cycles, as compared with approximately 40,000 cycles for the conventional spring.

We claim:

1. A method of treating austenitic steel wire with a carbon content between substantially 0.3 and 0.9%, rolled at a temperature above the transformation point A_{c1} which comprises the step of subjecting said wire, immediately after rolling, to forced cooling at a rate of at least 20° C. per second, the forced cooling being terminated in a temperature range between substantially 480° and 590° C.

2. A method as defined in claim 1 wherein the wire is quenched with water in an initial phase of the forced-cooling step, said initial phase including a traverse of the GOS line of the iron-carbon-equilibrium diagram.

3. A method as defined in claim 1 wherein the forced cooling is carried out in a fluidized bed at least from a level below the GOS line of the iron-carbon-equilibrium diagram.

4. A method as defined in claim 1 wherein the forced-cooling step starts within one second after rolling and terminates within substantially 10 seconds thereafter.

5. A method as defined in claim 1 wherein the wire, after cooling, is subjected to drawing without further heat treatment.

6. A method as defined in claim 5 wherein a multiplicity of wires so drawn are twisted into a cable.

7. A method as defined in claim 5 wherein the wire so drawn is coiled into a spring.

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