HIGH FLEXIBILITY STEEL WIRE AND METHOD OF TREATING SAME

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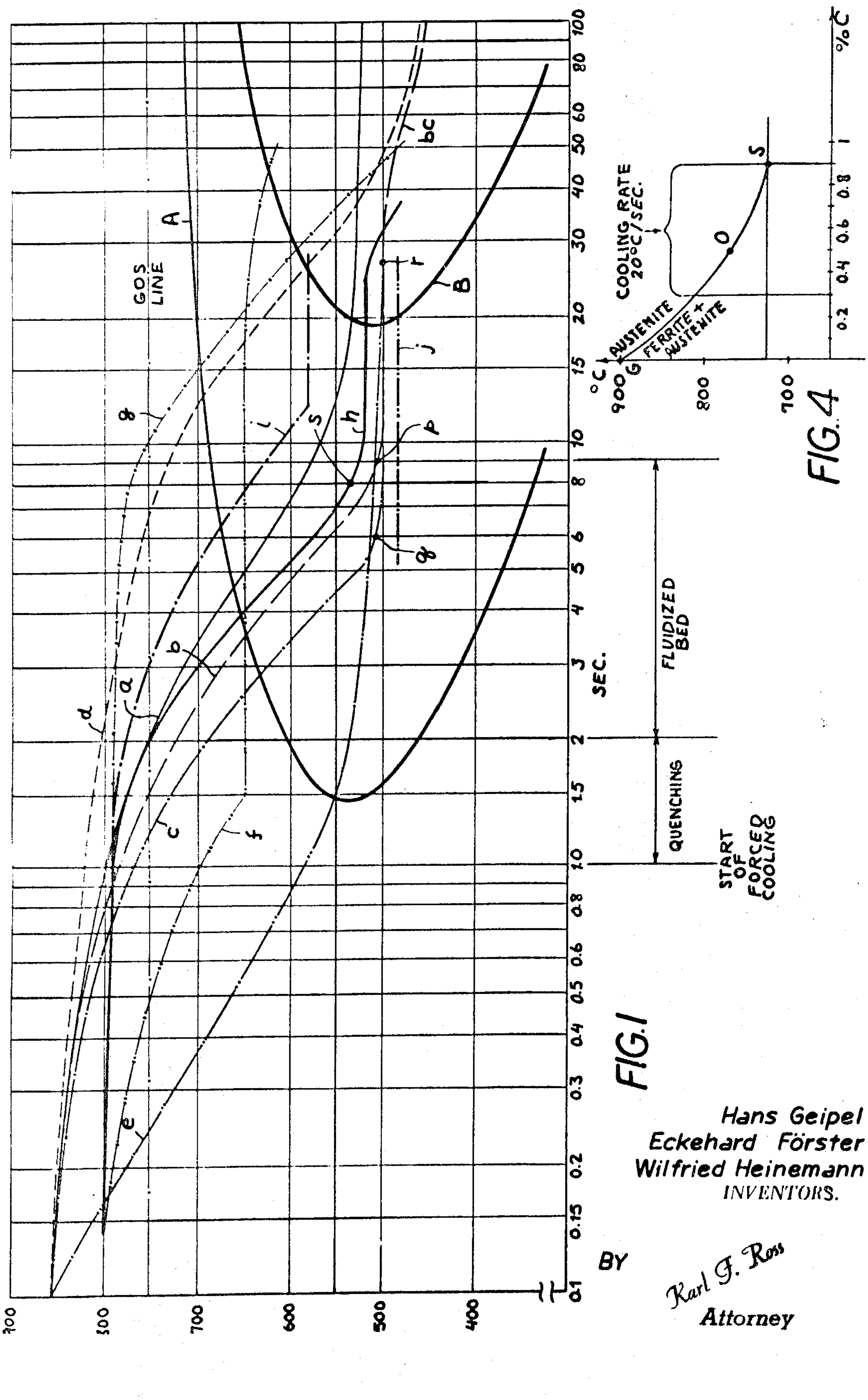

FIG. 1

FIG. 4

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HIGH FLEXIBILITY STEEL WIRE AND METHOD OF TREATING SAME

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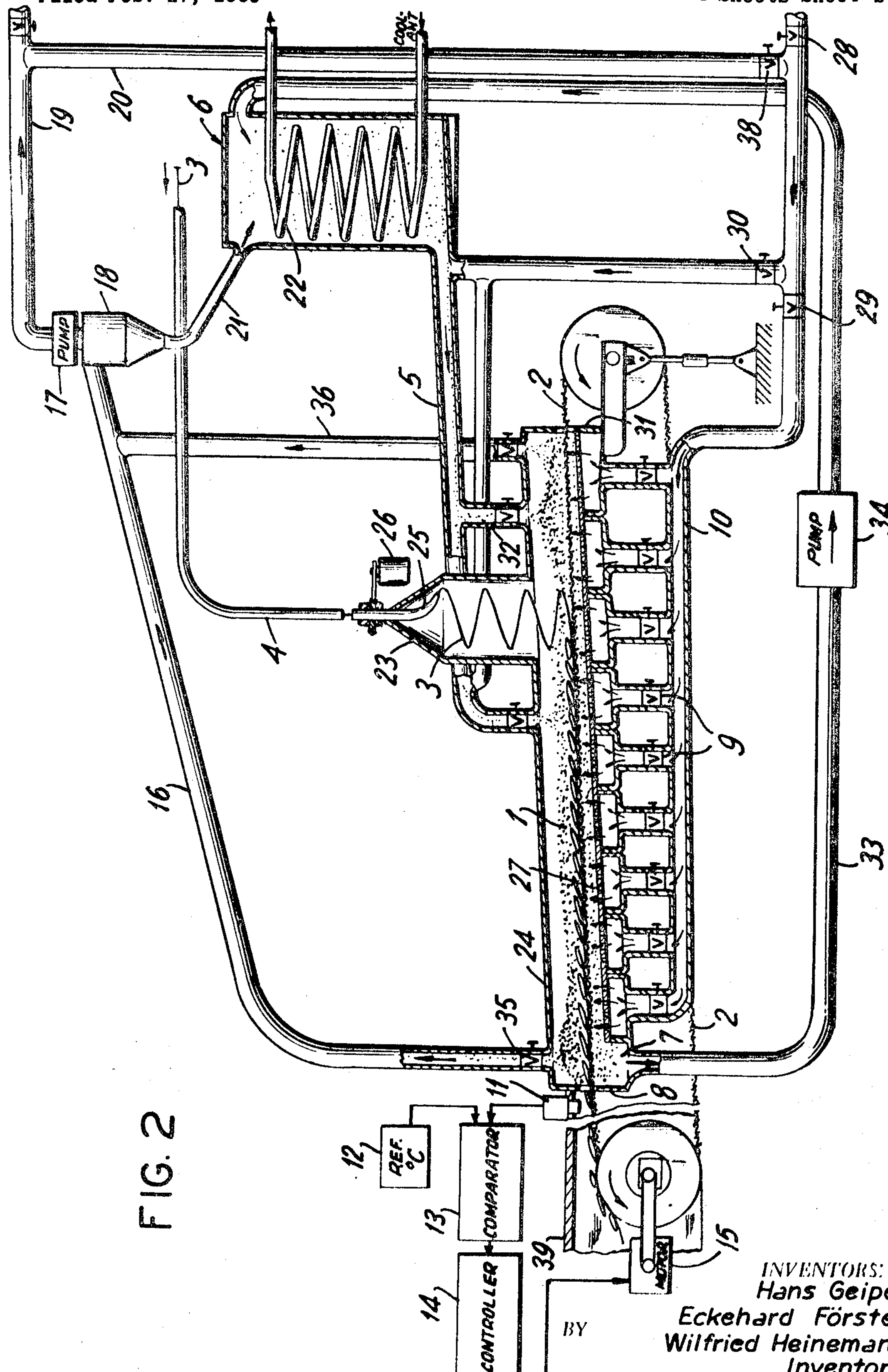

FIG. 2

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HIGH FLEXIBILITY STEEL WIRE AND METHOD OF TREATING SAME

Filed Feb. 17, 1969 4 Sheets-Sheet 3

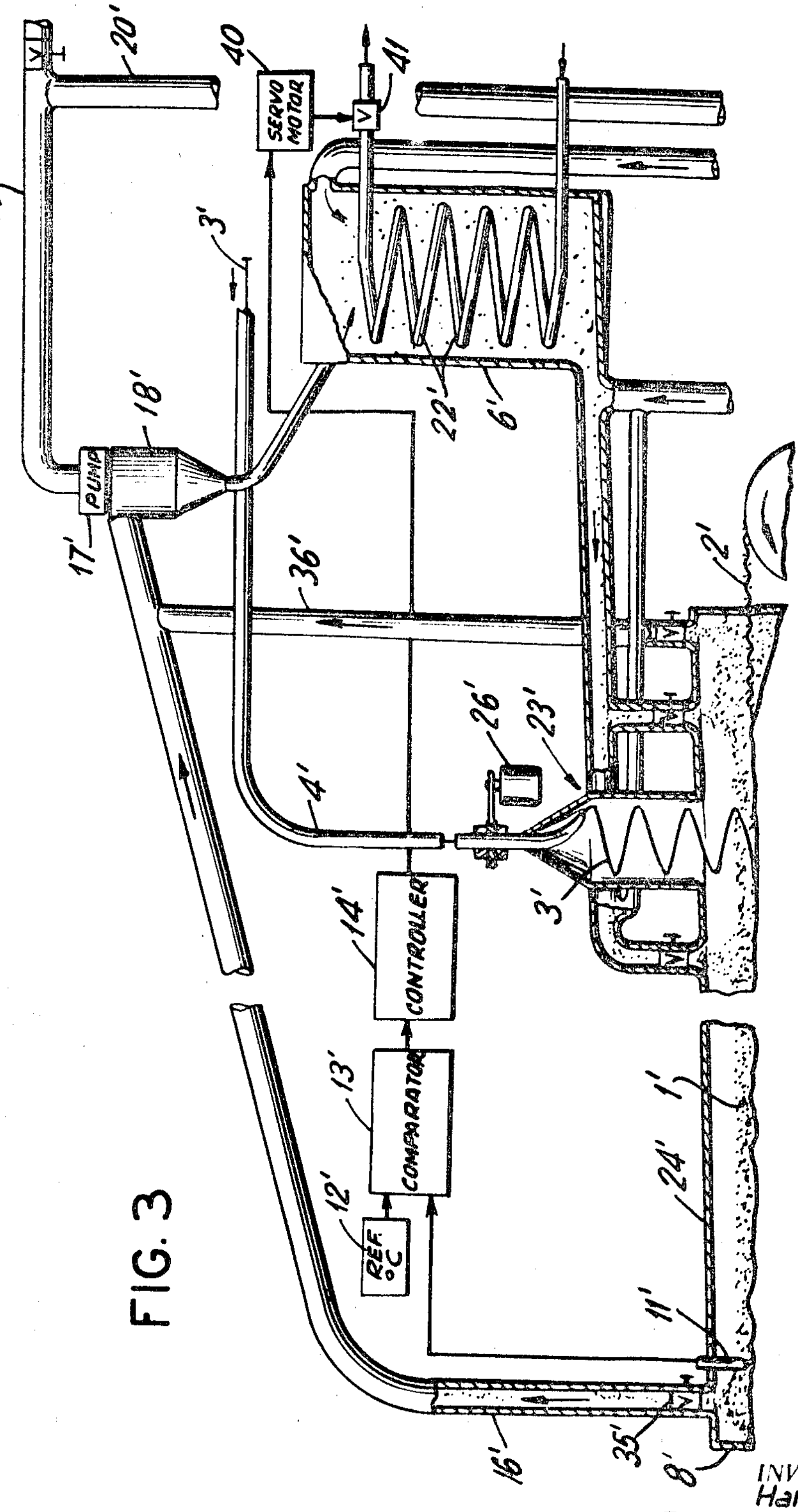

FIG. 3

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HIGH FLEXIBILITY STEEL WIRE AND METHOD OF TREATING SAME

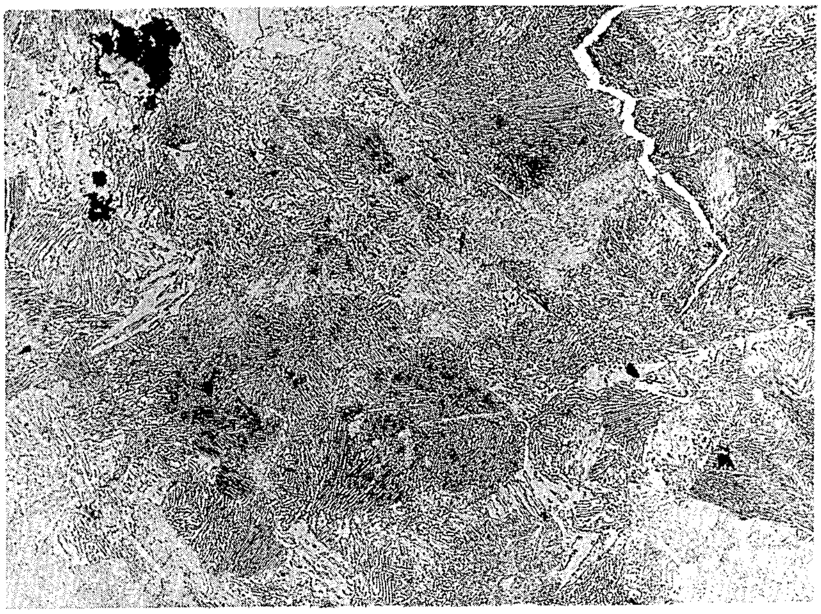

Fig. 5

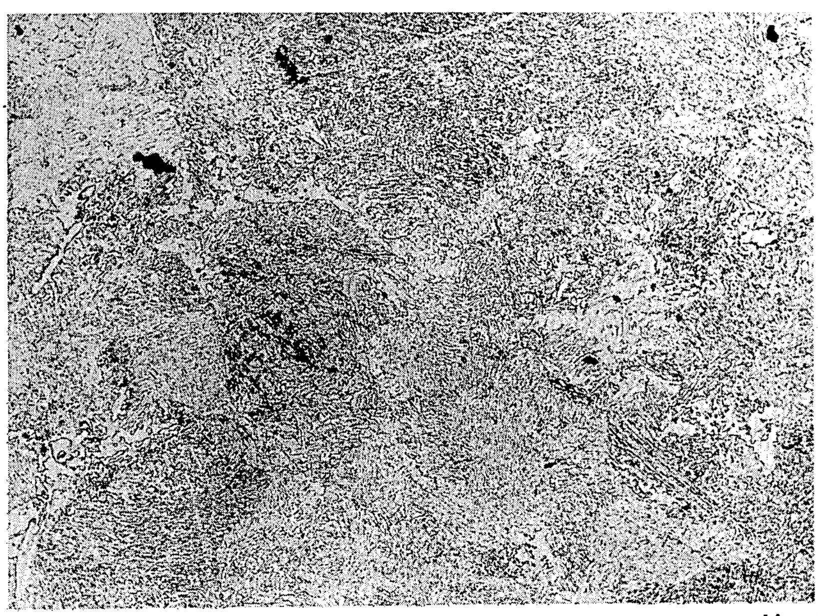

Fig. 6

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HIGH FLEXIBILITY STEEL WIRE AND METHOD OF TREATING SAME

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Continuation-in-part of applications Ser. No. 675,522, Oct. 16, 1967, and Ser. No. 750,642, Aug. 6, 1968. This application Feb. 17, 1969, Ser. No. 805,941
Claims priority, application Germany, Feb. 15, 1968, P 15 83 986.8
Int. Cl. C21d 1/62, 7/14, 9/57
U.S. Cl. 148—12 6 Claims

ABSTRACT OF THE DISCLOSURE

Steel wire coming hot from a rolling mill is rapidly cooled, preferably with the aid of a fluidized bed, to a temperature between about 500° and 550° where transformation of austenite to pearlite takes place, the final phase of this transformation taking place substantially isothermally. This wire, when drawn to a fraction of its original diameter, manifests a microcrystalline structure with distinct lamellate zones and has improved torsional and flexural capacity compared with lead-patented and air-patented wires.

This application is a continuation-in-part of our copending applications Ser. No. 675,522, now Pat. No. 3,525,507, filed Oct. 16, 1967, and Ser. No. 750,642, now Pat. No. 3,506,468, filed Aug. 6, 1968.

Our present invention relates to a method of treating steel wire to improve its tensile, flexural and torsional properties, and to a wire so treated.

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 Ac_3 (transformation of austenite to ferrite) to a range in which austentite is transformed into pearilte.

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 still 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 substantially 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 copending applications 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 between about 500 and 1000 Cal./m.²/hr./° C.). The particles may consist, for example, of magnesia and may range

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between 0.03 and 0.15 mm. in diameter, with a bulk weight of 1.5 to 5 g./cm.². 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 falls below the 500° C. mark. This method can be applied directly to wire coming hot from a rolling mill and thus represents a more economical process for obtaining the desired sorbitic structure with substantial exclusion of bainite.

The general object of our present invention is to provide a steel wire of high flexural and torsional endurance, e.g. for use in coil springs.

As more fully set forth in our aforementioned application Ser. No. 675,522, austenitic steel wire with a carbon content between about 0.3 and 0.9% (by weight) is treated 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 is accomplished by immediately cooling the hot-rolled wire at a rapid rate of at least 20° C. per second to a temperature within the austentite/pearlite transformation range, i.e. a temperature lying generally between 500° and 550° C. although its lower and upper boundaries may be around 480° 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 at a minimum temperature of about 800° C., 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: the GOS line should be penetrated during the first half of that phase, preferably within the first two seconds after discharge of the wire from the rolling mill. The final transformation phase may proceed substantially isothermally over a period of about 10 seconds.

The initial cooling phase (past the GOS line) may be 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 the afore-described 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 ferrite skeleton usually associated with air cooling.

After the wire has emerged from the fluidized bed, transformation proceeds to completion under substantially isothermic 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 value 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 air of a flow of carrier gas which may itself be recirculated.

We have now found that wire so treated, when observed under the electron microscope, exhibits a structure of distinct lamellate zones, not encountered in conventionally lead-cooled material, which account for a significant part of the cross-sectional area, the lamellae of the several zones extending in different directions while lying substantially parallel to one another within each zone. This lamellate structure may account for the surprising fact that the treated wire according to our invention has both a torsional and a flexural endurance appreciably greater than those of lead-patented wire of like composition and dimensions. Particularly good results are obtained with steels having a carbon content between about 0.5 and 0.7%, by weight, which pass the GOS line near the 750° level so that a workpiece with an initial temperature of 800° to 850° C. can be brought to that level in 1 to 3 seconds by forced cooling at a rate of 30° to 50° C. per second.

The wire so treated is cold-drawn, in a manner known per se, so as to undergo a deformation of approximately 80 to 90% in terms of reduction of cross-sectional area, corresponding to a decrease in diameter by a factor of roughly 1.5 to 3.5. The drawn wire exhibits a torsional capacity exceeding that of conventionally lead-patented drawn wire of like dimensions and composition by about 20%, its bending capacity lying by about 10% above that of the conventional wire.

A plant suitable for carrying out the aforedescribed method comprises a conveyor, preferably in the form of an apertured 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 our present process;

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;

FIG. 4 represents part of the iron-carbon-equilibrium diagram, including the GOS line; and

FIGS. 5 and 6 are two electron micrographs taken, respectively, of wire according to the invention and of conventionally lead-patented wire.

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 860° C. attained at the output stage of the rolling mill, 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 18½ 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 coming at relatively high speed from a rolling mill. Conventional air cooling (graph *d*) takes even longer and leads to incipient transformation at a temperature close to 700° C., with resulting formation of a large-grain ferrie structure in the pearlite. Other conventional methods, e.g. as disclosed in U.S. Pats. Nos. 2,944,328 and 3,320,-101, are represented by graphs *f* and *g*, respectively starting at a temperature level of 800° C.

The treatment of wire in accordance with out present invention is represented by graphs *b*, *c* and *h*. Graph *b* illustrates the cooling by ceramic granules of the aforedescribed type having a heat-transfer coefficient $\alpha=600$ Cal./m.²/hr./° C. as compared with a value $\alpha=1180$ 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 9 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 graph *b* and *c* with curbe 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. According to graph *h* forced cooling (at a rate of about 40° C. per second) is initiated 1 second after the wire emerges from the rolling mill with a temperature of 800° C., the wire leaving the fluidized bed at a point *s* 7 seconds later (thus, at the 8-second mark) after having reached the temperature range between 480° and 580° C.; it then remains at a nearly constant temperature, of about 520° C., for approximately 10 seconds before clearing the lower boundary B of the transformation range.

Curve *i* represents the limiting case of cooling at a rate of 20° C. per second down to a level of 580° C. within about 10 seconds, followed by substantially isothermal completion of transformation at that level during an interval of slightly less than 15 seconds. The other boundary of the operative region has been partly shown by a horizontal line *j* marking the 480° level.

The rapid beginning of forced cooling immediately after rolling prevents any reorientation of the stressed grains of the crystalline structure which would otherwise occur at the high workpiece temperature, thereby effectively locking in the strain imparted to the structure by the rolling process.

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, lies at a level of 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*, *c* and *h* within the first two seconds and at points where the rate of cooling, as represented by the slopes of these curves, is well over 20° C. per second. If the initial cooling is carried out by an air stream or by water, e.g. with the aid of spray nozzles, the transition to a fluidized bed may take place immediately below the GOS line, thus at a temperature of about 700° C.

Reference will now be made 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 run of an endless conveyor belt **2** which is continuously 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 insuring optimum distribution of the loops over the available conveyor surface. Belt **2**, designed as a wire screen or other apertured 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** traversed by a coolant. Conduit **5** opens into the tunnel **24** in the vicinity of the housing **23** of the dispenser arm **25**.

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** undnerlying 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 returned 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 side of the compressor 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**.

A temperature feeler **11** just beyond shutter **8** senses the temperature of the emerging wire loops 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 conventional type of loop depositor including, for example, devices of the type shown in U.S. Pats. 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 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 (all percentages by weight), balance Fe and usual impurities, is rolled to a diameter of 5.5 mm. at a temperature of 800° C. One second after leaving the last rolling stage, forced cooling of the wire is started, proceeding at an average rate of 40° C. per second to a level of 520° C., this temperature being maintained for 12 seconds while the transformation from gamma to alpha iron proceeds to completion. After pickling and rustoproofing (bonderizing), the wire is drawn without further heat treatment to a diameter of 1.8 mm., this corresponding to a deformation of about 90%.

Wire so drawn exhibited a tensile strength of 180 kg./mm.^{2} and withstood 22 consecutive cycles of flexing and straightening. A cable formed from six strands of seven such wires each was found to have a service life two to four times as long as identical cables made from conventional lead-patented wire.

EXAMPLE II

The procedure of Example I is followed, using a wire with a content of 0.65% C, 0.55% Mn, 0.24% Si, 0.012% P and 0.2% S, rolled to the same diameter of 5.5 mm. After pickling and bonderizing, the wire is drawn without further heat treatment to a diameter of 2.2 mm., this corresponding to a deformation of about 85%.

EXAMPLE III

The composition of the steel is 0.66% C, 0.76% Mn, 0.23% Si, 0.019% P and 0.029% S, balance again iron and usual impurities. The rate of cooling between the 800° starting temperature and the traverse of the GOS line, within two seconds after the discharge of the wire from the rolling mill, is 43° C. per second, this rate being substantially maintained to well below the 550° level. The further treatment is the same as in Example II.

Graph *h* of FIG. 1, being illustrative of the optimum within the preferred ranges of carbon content (0.5 to 0.7%), initial cooling rate (30° to 50° C.) and terminal transformation temperature (500° to 550° C.) substantially conforms to all the foregoing examples.

Comparative elongation, bending and twist tests performed for wires treated in accordance with our invention (specifically as per Example III) and for conventionally lead-patented and air patented wires of like composition and similar diameter yielded the following results as to tensile strength and flexibilities:

TABLE 1

[Blue wire, nominal diameter 5.5 mm.]

Lot No.	Diameter, mm.	Tensile strength	
		Kp.	Kp./mm.²
(A) Cooling immediately after rolling (Example III):			
a1	5.56	2,790	115
	5.63	2,790	112
a2	5.44	2,312	111
	5.50	2,682	113
(B) Lead patenting:			
b1	5.60	2,900	118
	5.74	3,070	119
b2	5.56	2,860	118
	5.69	3,030	119
(C) Air patenting:			
c	5.55	2,370	98

TABLE 2

[Same wire after 84% deformation, drawn to diameter of 2.2 mm.]

Lot No.	Diameter, mm.	Tensile strength		No. of bends (r=7.5 mm.)	No. of twists (L=100d)
		Kp.	Kp./mm.²		
a1	2.21	728	189	24	36
	2.21	725	189	24	37
a2	2.21	726	189	24	40
	2.21	732	190	23	37
b1	2.20	712	187	28	27
	2.20	694	183	18	30
b2	2.20	718	189	19	29
	2.20	692	182	21	25
c	2.20	626	165	18	38
	2.20	619	163	19	39

It will thus be seen that the deformed wire of Table 2, when previously treated in accordance with our invention, has a tensile strength on the order of 200 kp./mm.², a torsional endurance in terms of up to 40 consecutive cycles of reversing twist (with a length-to-diameter ratio L:d of 100), and an average flexural endurance in terms of 24 consecutive cycles of alternating bend (about a radius r=7.5 mm.). This table also shows that our improved wire, after drawing, exceeds the tensile strength of both lead-patented and air-patented wires, compares favorably with both types of conventional wires in flexural capacity, and matches the torsional capacity of the air-patented wire while greatly exceeding that of the lead-patented one. Its construction on rupture is about 50%.

The structure of the drawn wire obtained by Example III and deformed in accordance with Table 2, as observed under the electron microscope with a magnification of 4,000:1, has been illustrated in FIG. 5 whicn shows distinct lamellate zones distributed throughout the cross-sectional area of the steel sample; FIG. 6, representing a similar electron micrograph for lead-patented wire subjected to the same drawing process, exhibits only the rudiments of such lamellae at isolated locations.

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.

Strands of such wire may also be twisted into a cable of great flexibility.

We claim:

1. A method of producing wire of high torsional and flexural capacity, comprising the steps of:

rolling austenitic steel wire with a carbon content between substantially 0.3 and 0.9% by weight at a temperature above the transformation point Ac_3;

subjecting said wire, immediately after rolling, to forced cooling at a rate of at least 20° C. per second, the forced cooling being terminated within a maximum period of substantially 10 seconds in a temperature range between substantially 490° and 580° C.;

maintaining said wire at a substantially constant temperature level within said range for a minimum period of substantially 10 seconds for completion of transformation of austenite to pearlite;

and thereafter cold-drawing said wire to a fraction of its initial diameter.

2. A method as defined in claim **1** wherein said carbon content lies between substantially 0.5% and 0.7%.

3. A method as defined in claim **1** wherein the rate of forced cooling is between substantially 30° and 50° C. per second.

4. A method as defined in claim **1** wherein said temperature range lies between substantially 500° and 550° C.

5. A method as defined in claim **1** wherein said fraction lies between substantially 1/1.5 and 1/3.5.

6. A method as defined in claim **1** wherein the initial temperature of the rolled wire and the rate of cooling are chosen to bring about a traverse of the GOS line of the iron-carbon-equilibrium diagram within substantially 2 seconds from the end of rolling.

References Cited

UNITED STATES PATENTS

3,506,468 Geipel et al. ---------------- 148—12.4

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U.S. Cl. X.R.

148—143, 144, 153, 156