

May 16, 1967

D. W. McLEAN ETAL

3,320,101

HOT ROLLED STEEL ROD

Filed May 24, 1963

6 Sheets-Sheet 1

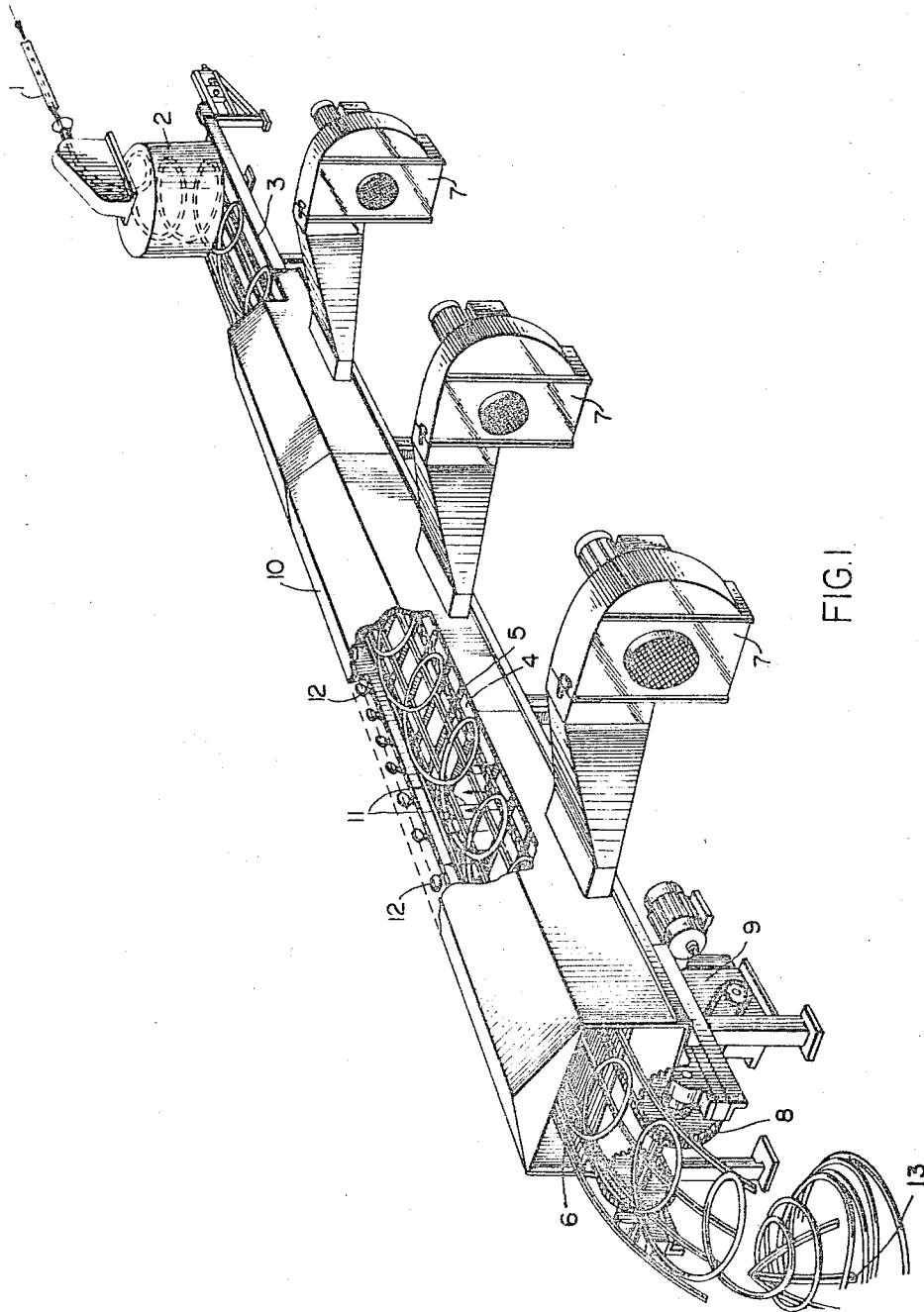


FIG. 1

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CHARLES G. EASTER
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Russell, Chittick, & Pfund
ATTORNEYS

May 16, 1967

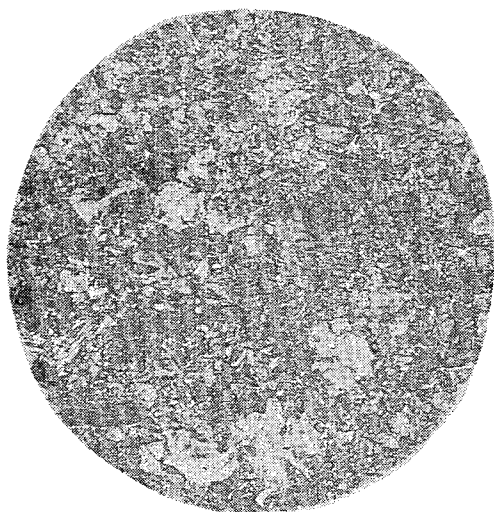
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HOT ROLLED STEEL ROD

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6 Sheets-Sheet 2



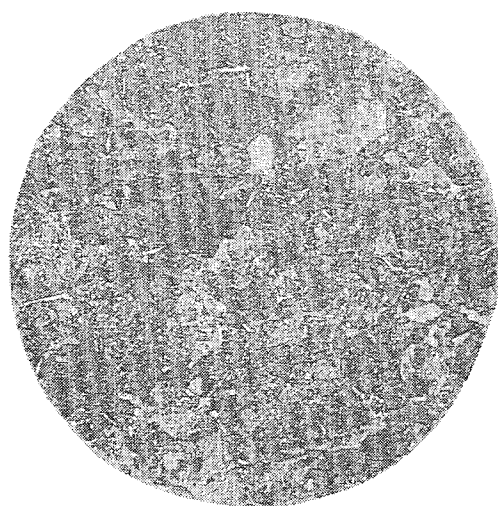
A

REPRESENTATIVE STRUCTURE OF
CONTROLLED COOLED ROD SHOWING A
FINE PEARLITIC STRUCTURE WITH LESS
THAN 10% RESOLVABLE LAMELLAE.



B

REPRESENTATIVE STRUCTURE OF
REGULAR COOLED ROD SHOWING FINE
PEARLITE AND 25% RESOLVABLE
LAMELLAR PEARLITE.



C

REPRESENTATIVE STRUCTURE OF AIR
PATENTED ROD SHOWING ABOUT 20%
RESOLVABLE PEARLITE LAMELLAE.

FIG. 2

MICROPHOTOGRAPHS OF A HIGH CARBON STEEL
(500X)

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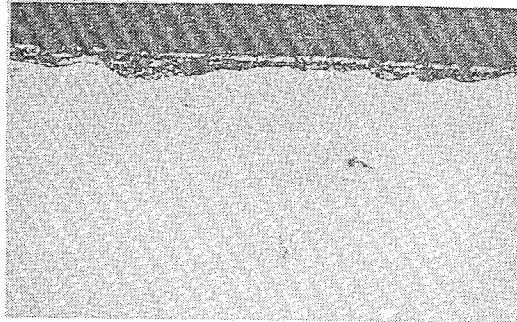
D. W. McLEAN ET AL

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HOT ROLLED STEEL ROD

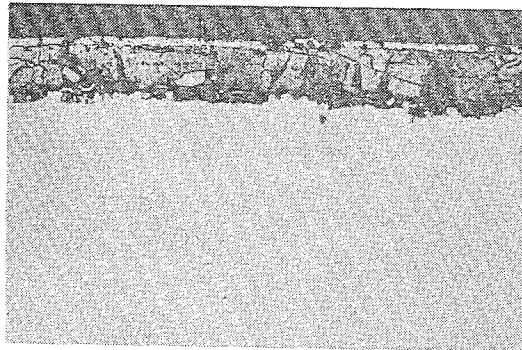
Filed May 24, 1963

6 Sheets-Sheet 3



D

REPRESENTATIVE SCALE COATING STRUCTURE ON CONTROLLED COOLED ROD SHOWING FIRM BONDING OF SCALE TO THE BASE METAL.



E

REPRESENTATIVE SCALE COATING OF AIR PATENTED ROD SHOWING THE HEAVY FeO LAYER AND THE DISINTEGRATION OF THE SCALE AT THE SCALE-BASE METAL INTERFACE.

FIG. 3

MICROPHOTOGRAPHS OF HIGH CARBON STEEL .
ILLUSTRATING DIFFERENCES IN SCALE STRUCTURE

(500X)

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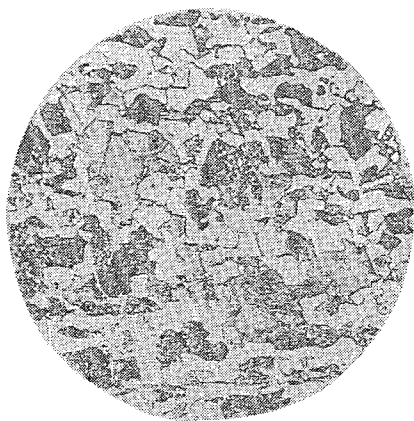
D. W. McLEAN ET AL

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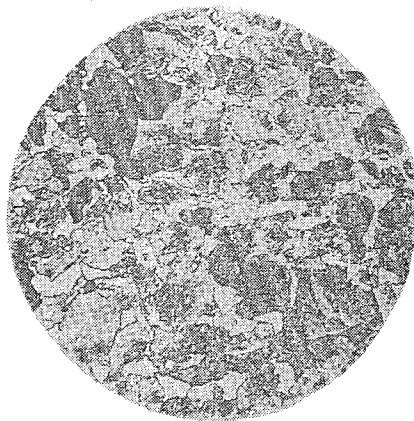
HOT ROLLED STEEL ROD

Filed May 24, 1963

6 Sheets-Sheet 4



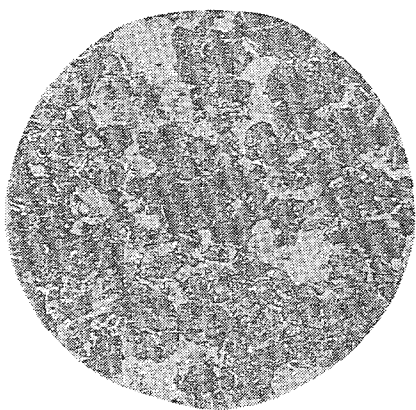
A



B

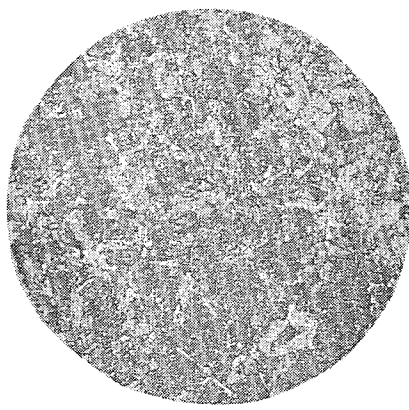
TYPICAL MICRO-STRUCTURES FROM INNER AND OUTER STRANDS RESPECTIVELY
OF A NORMALLY COOLED COIL.

INNER STRANDS - TENSILE STRENGTH 106,000 psi. - REDUCTION OF AREA 42 %
OUTER STRANDS - TENSILE STRENGTH 133,000 psi. - REDUCTION OF AREA 48 %



C

REPRESENTATIVE AIR PATENTED STRUCTURE.
TENSILE STRENGTH - 136,500 psi.
REDUCTION OF AREA 52 %



D

REPRESENTATIVE STRUCTURE
THROUGHOUT ENTIRE COIL.
OF A ROD OF THIS INVENTION
TENSILE STRENGTH - 140,000 psi.
REDUCTION OF AREA 53 %

FIG.4
(500X)

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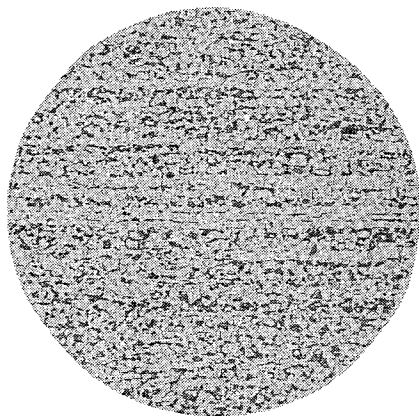
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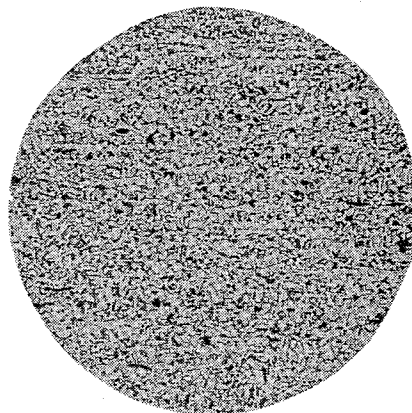
6 Sheets-Sheet 5



A

REPRESENTATIVE CORE STRUCTURE OF
REGULARLY COOLED ROD SHOWING
BANDED FERRITE WITH INTERGRANULAR
PEARLITE.

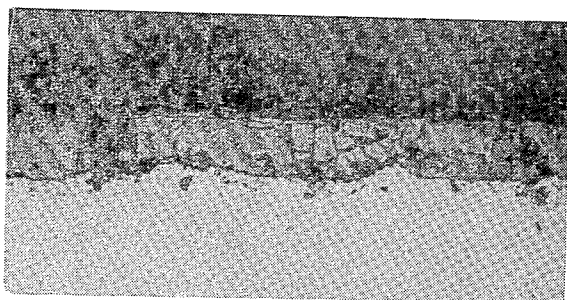
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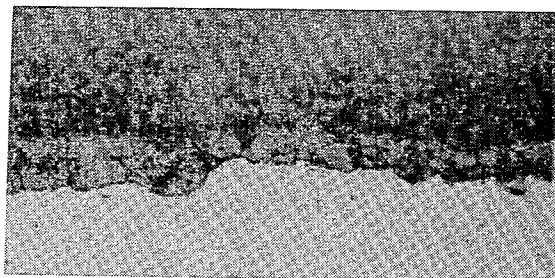
B

REPRESENTATIVE CORE STRUCTURE OF
CONTROLLED COOLED ROD SHOWING
FINE, LIGHTLY BANDED, SLIGHTLY
ACICULAR FERRITE WITH INTERGRANULAR
PEARLITE.

(100X)



REPRESENTATIVE SCALE COATING STRUCTURE
OF REGULAR COOLED ROD SHOWING A HEAVY
FeO LAYER. (500X)



REPRESENTATIVE SCALE COATING STRUCTURE
OF CONTROLLED COOLED ROD
(500X)

FIG. 5

MICROPHOTOGRAPHS OF A
GRADE C 1020 RIMMED STEEL

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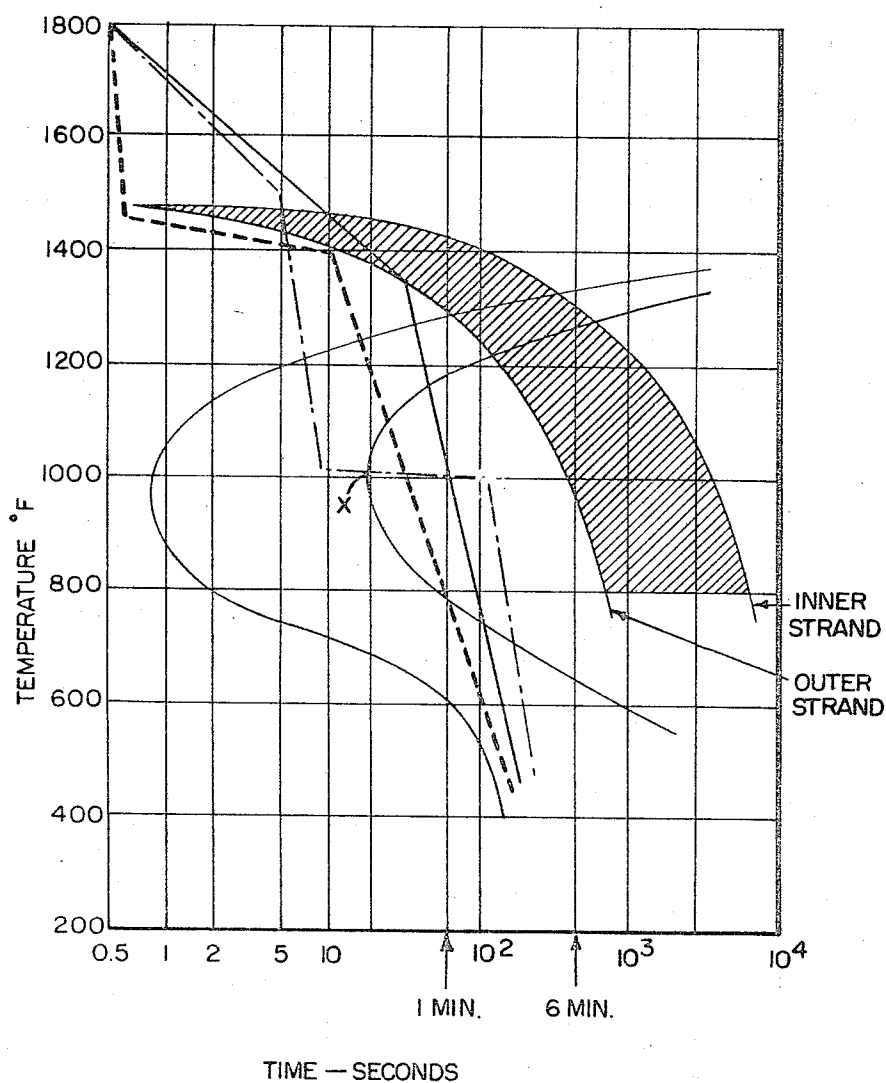
3,320,101

HOT ROLLED STEEL ROD

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FIG. 6
TYPICAL COOLING CURVES



- CONTROLLED COOLING
- AIR PATENTING
- ▨ NORMAL COOLING IN COILS
- · - LEAD PATENTING

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3,320,101

HOT ROLLED STEEL ROD

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Filed May 24, 1963, Ser. No. 282,939

4 Claims. (Cl. 148—36)

This application is a continuation-in-part of Ser. No. 219,220, entitled, "Apparatus and Process for the Controlled Cooling of Rods," filed Aug. 24, 1962, by the present inventors, now abandoned.

This invention is an improved hot rolled steel rod suitable for wire and bar products. More particularly, this invention is concerned with a rolled steel rod having distinctive physical properties and microstructure that is capable of being greatly reduced in area in its as-rolled state without intervening heat treatment.

The above application is concerned with a method and apparatus for the controlled cooling of hot rolled rod in direct sequence with the rod mill to obtain a product amenable to being directly drawn into wire without intervening heat treatment. This method is characterized by the depositing of the rod issuing from the rod mill in the form of non-concentric rings on a conveyor and force cooling the non-concentric rings with a cooling medium, e.g., air, selectively applied to achieve uniform cooling throughout the length of the rod and at a rate to secure substantially complete transformation of the austenite before the temperature of the rod has dropped below that temperature represented by the knee of the inner curve of the isothermal transformation diagram for that particular grade of steel.

It was originally thought that this controlled cooling of the steel rod in the form of non-concentric rings would produce direct from the rod mill a rod having properties about equal to those obtained by air patenting. It has been surprisingly found, however, that the microstructure and physical properties obtained are unique and that the controlled cooled rods have materially improved properties and a character essentially different from rods produced by air or lead patenting, i.e., controlled cooling produces a new distinctive type of hot rolled rod that is particularly amenable to being drawn into wire.

The controlled cooled rod of this invention is characterized by the following features:

Higher average tensile strength with high ductility.

Uniformity of properties along its length.

Distinct microstructure.

Light, friable scale.

The first three features contribute to the improved drawability of the rod and the last results in materially less loss to scale and shorter acid cleaning times.

Patenting of a hot rolled steel rod makes the physical properties of a rolled rod uniform throughout its length so that during drawing into wire there are no structural irregularities that would lead to breaking or poor drawability. The controlled cooled rod of this invention has a uniformity throughout its length equal to or better than that of rods properly patented by conventional air patenting methods. The tensile strength spread throughout a coil of a controlled cooled rod is less than 10,000 p.s.i. The tensile strengths of the controlled cooled rods, however, are consistently and significantly higher than the tensile strengths of conventional rods used for wire drawing.

The average tensile strengths of the controlled cooled rods run about 3 to 5 percent higher than the average tensile strengths of air patented rods of the same heat of steel, as determined by the common wire mill tensile test (ASTM method). Because of this higher average

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tensile strength, one skilled in the art would believe that the controlled cooled rods could not have as great a reduction of area as air patented rods. It is quite surprising that the reverse is true.

The reason why a controlled cooled rod with a greater average tensile strength will draw better than an air patented rod cannot be explained with certainty at this time. The microstructure of a controlled cooled rod is distinct, however, and this may in part account for its improved drawability.

The microstructure of a controlled cooled rod consists of uniformly dispersed fine grains. Grains of fine pearlite with only minute traces of grain boundary ferrite predominate in steels having a carbon content greater than about 0.40 weight percent, and at lower carbon levels grains of ferrite and carbon occur, the relative amounts of each depending on the chemical constituents of the steel. The microstructure is substantially free from bainite. The ferritic grain structure is always finer than the grain structure of a properly air patented rod or of a conventionally cooled rod from the same heat of steel, and does not fall under a number 5 grain size.

Because of the rapid cooling of the controlled cooled rods in the manner of this invention, the scale loss is only $\frac{1}{2}$ to $\frac{1}{3}$ of that of air patented rods and the scale is fine and friable. The cooling rate is such that the degradation of wustite to magnetite and iron is at a minimum. The magnetite layer that forms is characteristically crazed because of the different thermal coefficients of expansion of the constituent layers of the scale and the base metal. This crazing and the thinness of the scale greatly facilitate acid cleaning. Cleaning of the controlled cooled rods can usually be accomplished in half the time required for normally cooled rods. This advantage becomes more marked as the carbon content of the steel falls below 0.40 weight percent. Acid cleaning times using accepted procedures are well under 30 minutes. The amount of scale is less than 1.0 weight percent at carbon levels under 0.40 weight percent, and generally less than 0.6 weight percent for higher carbon contents (average values for several coils from the same heat). This reduced amount of scale greatly reduces acid consumption during cleanin. Considering the total scale loss that occurs in preparing air patented rods, i.e., the scale on the as-rolled rods and the scale formed during air patenting, the light scale given by controlled cooling is a significant advantage of this process. For example, on a trial of 260 tons of rod of various grades the average scale loss was 0.44 weight percent as compared to a scale loss of 0.88 weight percent for normally cooled as-rolled rods. An additional scale loss would occur, of course, when the normally cooled rods were air patented.

The following article will help to make clear the significant advantages of the type of scale on the controlled cooled rods of this invention: "The Cleaning of Carbon Steel Wire as Affected By the Metallurgical Nature of the Scale," A. Dove, Wire and Wire Products, November 1960, p. 1547. The same article also appears in "Regional Technical Meetings," American Iron and Steel Institute, Sept. 29, 1960, pp. 29-57.

The nature of the scale given by controlled cooling results in another advantage. Since it is relatively loose and easily removed, pitting of the surface of the rod during acid cleaning does not occur, i.e., deep etching to remove exceptionally adherent pieces of scale is not required. The surface of the cleaned rod is therefore smoother and more uniform and free from pits that could lead to breaking or surfacing imperfections during drawing. While acid cleaning has been particularly referred to, controlled cooled rods are particularly amenable to

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mechanical descaling by being flexed. The ease by which the scale can be removed by simple bending is surprising.

Preliminary data indicate that with respect to scale loss the controlled cooled rods of this invention give an additional benefit when the product is given a secondary heat treatment during wire drawing. It has been observed that when wire drawn from controlled cooled rods is lead patented considerably less scale forms than in the case of wire drawn from lead patented rods. This could be the result of the inherently finer and smoother surface structure of the controlled cooled rods.

The improved ductility of the controlled cooled rod of this invention is observed by stretching a sample of the rod and a comparative normally cooled sample from the same heat to fracture in a tensile test. It will be found that the rods of this invention will have at least 6% and usually a 10% higher reduction of area than the comparative sample, based on 95% of a sufficient number of samples to give a statistical distribution.

The uniformity of the controlled cooled rod over its length is given by its small tensile strength spread and the small variation in the reduction of areas. The tensile strength spread over the length of the rod is less than 10,000 p.s.i., and usually less than 8,000 p.s.i., based on 95% of a sufficient number of samples to give a statistical distribution. The remaining 5% of the samples normally will exceed these values because of variations in the customary tensile test. The variation in the reduction of area in the ASTM tensile test is less than $\pm 10\%$ about the means of the values obtained from several specimens taken from the length of rod.

In brief compass, this invention is an improved "as-rolled" steel rod 0.10 to 0.50 inch in diameter and at least 400 feet long. The rod consists of a steel having a carbon content in the range of 0.01 to 0.90 weight percent, e.g., AISI numbers C1006-C1085 inclusive and other AISI grades. The microstructure of the steel consists of fine uniformly dispersed grains and is substantially free from bainite. The rods from any grade of carbon steel have a tensile strength spread of under 10,000 p.s.i. and an average tensile strength at least 3% higher than an air patented rod from the same heat. The rod will have on the average at least a 6% higher ASTM reduction of area than the air patented rod.

The rod is produced from a rod mill billet that has been heated prior to being introduced into the rod mill. The rod does not subsequently receive a heat treatment prior to cold reduction.

The nature of this invention will become clear from the following description and examples made with reference to the drawings attached to and forming a part of this specification.

In the drawings:

FIGURE I schematically illustrates the process used to manufacture the controlled cooled rods of this invention;

FIGURES II and III present comparative microphotographs of sections of steel rods of the same grade of steel showing the microstructure and scale of a controlled cooled rod in comparison to the structures of "as-rolled" rods normally cooled in coil form and air patented rods ready for wire drawing;

FIGURE IV consists of microphotographs of another grade of steel and illustrates the uniformity of the structure of controlled cooled rods across the coils;

FIGURE V presents microphotographs that clearly show the distinctive difference in scale on a controlled rod and a normally cooled unpatented rod formed from a low carbon steel; and

FIGURE VI is an illustrative isothermal transformation diagram for the purpose of showing the cooling rates of rods handled in different manners as they issue from a rod mill, i.e., normally cooled, air or lead patented, and controlled cooled.

The microphotographs of the microstructures were in all cases prepared by etching the specimens with Nital,

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and the microphotographs of the scales were prepared with a 50 percent muriatic acid etch.

The process of controlled cooling of rolled steel rods as they issue from the rod mill to produce the unique rod of this invention may be understood by reference to FIGURE I.

Each length of rod is produced from a single billet. Each billet usually weighs at least 400 pounds and may weigh as much as 1500 pounds or more. The length of the rod is dependent upon the size of the billets and is usually at least 400 feet long and may be as long as 9000 feet or more.

The rolled rod issuing from the rod mill at a temperature of about 1750° to 1950° F. is directed through a cooling and guide pipe 1 to a laying reel or cone 2. Water is introduced into the cooling pipe guide to quench the rod to about 1350° F. for descaling quality low carbon grades and 1450° F. for higher carbon grades. The exact temperature depends on the end product requirements but is usually greater than 1300° F. Laying cone 2 is positioned to deposit the rod on a conveyor indicated generally by the number 3. The conveyor consists of a conveyor bed 4 upon which guide bars 6 rest. The conveyor bed is slotted at 5 to permit passage of cooling gas blasts supplied by blowers 7. Dampers 12 are used to adjust the flow of the coolant through these slots. A conveyor chain 8 driven by drive 9 is used to drag the rod over guide bars 6. A hood 10 covers the conveyor and helps to direct the flow of the cooling gas.

The rod is deposited on the conveyor bed in the form of a succession of non-concentric, circular convolutions, the spacing of which as illustrated by exaggerated for purposes of clarity. The deposited rod cools by radiant cooling in an equalizing zone and then enters the hood area where it is rapidly and uniformly cooled by the cooling gas. The spacing of the circular rings allows the gas to uniformly contact all portions of the rod. The mass flow rate of the rods along the conveyor is greater at the outside edges than in the middle. A larger proportion of the coolant is therefore supplied to the outer edges of the conveyor, as illustrated by arrows 11, so that heat extraction from the rod is uniform across the coils, i.e., the mass flow rate of coolant across the width of the conveyor is proportional to the mass flow rate of the deposited rods across the width. The amount of coolant supplied along the length of the conveyor is sufficient to cool the rod rapidly enough to achieve substantially complete transformation of the austenite before the temperature has dropped to below that of the knee of the inner curve of the isothermal transformation diagram for that particular grade of steel.

The rod is discharged at a temperature of 1100° F. or less and is collected in coil chamber 13. After descaling, it can be directly drawn into wire without further heat treatment.

Example I

A typical microstructure of a controlled cooled rod of this invention is shown in FIGURE II along with comparative specimens. FIGURE III illustrates the scale structure on the rods.

All of the specimens were prepared from the same heat of Ordinary Spring Steel (0.63 weight percent carbon, 1.00 weight percent manganese and 0.17 weight percent silicon). The billets weighed approximately 400 pounds and were rolled to 0.263 (nominal) inches diameter on the same mill. The rod from which Samples A and D were obtained was coiled on the previously described conveyor at about 1440-1470° F., in the form of 48-inch diameter non-concentric coils, with the spacing between the leading edges of the coils being about 1.5 inches. The total number of coils was 129 and the conveyor speed was 60 feet per minute. Controlled cooling by air blasts commenced within 15 seconds from the time the rod temperature reached approximately 1440° F. and the rod

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cooled uniformly thereafter from about 1375° F. at a rate of 800° F. per minute and was discharged from the conveyor and coiled at 480° F.

The rod from which Sample B was prepared was coiled at about 1450° F. in a conventional manner as it issued from the mill, with the coil being allowed to cool in still air.

Samples C and E were taken from the rod from which Sample B was obtained after the rod had been air patented.

The following table gives the inspections that were obtained.

Coil No.	Ultimate, p.s.i.	Percent Red. of Area	Micro- structure, Percent Lamellar Pearlite	Scale Thickness-Inches			
				FeO	Fe ₃ O ₄	Fe ₂ O ₃	Total
Reg. Cool:							
1	132,080	46.3	1 25	.0002	.0002	.0001	.0005
2	135,840	45.8	25	.0005	.0002	.0001	.0008
3	128,590	38.2	25	.0003	.0001	.0001	.0005
4	133,160	47.4	25	.00025	.0002	.00005	.0003
5	130,210	44.2	25	.0004	.0002	.0001	.0007
6	131,530	48.7	25	.0004	.0001	.00005	.00055
Control Cool:							
1	154,120	58.9	2 10-15	.00025	.00011	.00005	3 .00045
2	152,670	55.4	10-15	.00025	.00015	.00005	.00045
3	147,230	55.4	10-15	.00035	.00015	.00005	.00045
4	152,670	58.9	10	.0001	.00015	.00005	.00030
5	152,240	55.7	10	.00025	.0001	.00005	.00040
6	150,860	55.4	10	.00035	.0001	.00005	.00050
Air Patent:							
1	144,300	55.4	4 15-20	.00125	.00025	.0001	5 .00160
2	145,020	52.0	10-20	.00124	.00025	.0001	.00150
3	143,240	53.0	10-20	.00130	.0002	.00005	.00155
4	146,480	51.1	10-20	.00125	.00025	.00005	.00155
5	143,240	56.7	10-20	.0010	.00025	.00005	.00130
6	141,800	54.7	10-20	.00125	.00025	.00005	.00155

¹ Photograph B.

² Photograph A.

³ Photograph D.

⁴ Photograph C.

⁵ Photograph E.

It can be seen that as compared to the air patented rod the rod of this invention has a finer grain structure of ferrite and fine pearlite and is substantially free of bainite. One reason, of course, for this finer grain size is the rapid cooling of the rod in addition to the fact that the rod has been heated only once at the rod mill billet stage and not thereafter. Conventional air patenting involves reheating of the rolled rods and this encourages crystal growth. The controlled cooled rods of this invention are characterized therefore by the fact that they are not heat treated subsequent to being rolled. This lack of subsequent heating reflects itself in crystal size as compared to conventional rod mill product suitable for wire drawing which always in the past had to be heat treated in some manner subsequent to the rolling mill operation and thus had a coarser grain size. Alloy constituents do, of course, affect the grain size as does the history of the billet, but for any given grade of carbon steel the micro-structure of the controlled cooled rods of this invention is always finer and more uniform. This finer structure is readily observable when compared to a specimen from the same rod mill billet or from the same heat of steel that has been conventionally coiled and normally cooled and subsequently properly air patented.

Comparison of microphotographs D and E in FIGURE III clearly show that the scale on rods cooled according to this invention is less in total amount, and crazed. Photograph D shows a single phase (wustite) bonding of the scale to the base metal whereas in photograph E there is a partial conversion of the wustite to iron and undesirable magnetite at the scale base metal interface. (The white areas of the photographs are the steel base.) The wustite layer is keyed to the steel base by the iron and magnetite. The acid insoluble magnetite area in photograph E is almost twice as thick as in photograph D.

Samples for determining the improvement secured by controlled cooling can be prepared by selecting two identical rod mill billets from the same heat of steel and reduc-

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ing them in the same rod mill to the same size, e.g., Number 5 rod. The rod from one billet is formed into non-concentric rings and cooled in the manner of this invention and the other is coiled and cooled in a conventional manner and subsequently air patented. Air patenting of the sample is carried out by passing the rod through a reheating furnace to raise its temperature to above 1800° F. followed by cooling in still air, after which it is coiled.

Example II

Approximately 20 tons of steel from the same heat were processed in the manner of this invention into 101 coils of

Number 5 rod. The average coil weight was 408 pounds. The coils were then processed into 4 types of wires, as follows:

- 18,000 pounds—0.1055 M.B. spring wire
- 10,000 pounds—0.076 H.S. spring wire
- 8,000 pounds—0.095 breakdown for patenting to make 0.036 drawn galvanized spring wire
- 2,000 pounds—0.052 breakdown for patenting to make 0.0207 M.S. spring wire.

The ladle analysis of the heat was (weight percent):

	Percent
Carbon	0.63
Manganese	0.99
Phosphorus	0.006
Sulfur	0.032
Silicon	0.17

The Number 5 rods were produced from rod mill billets 2 $\frac{1}{16}$ inches square using a continuous 3-strand mill with 6 primary roughing stages, 4 intermediate roughing stages, 4 stranding stages and 6 finishing stands. The rods issued from the mill at a temperature of about 1875° F. and were immediately cooled to 1460°–1490° F. by the application of water. The rod at this temperature was deposited in the form of non-concentric approximately 48 inch O.D. rings on a conveyor using a laying head. The conveyor had an overall length of 75 feet and moved at a rate of about 60 feet per minute. The spacing between the forward edges of the non-concentric coils was about 1.5 inches. The conveyor had suitable slots in it over a length of about 38 feet to permit application of blasts of cooling air to the coils. No cooling air was applied in the first 15 feet then the air was applied to cool the rods within the time given by the isothermal transformation diagram for that grade of steel. Heat was extracted from all parts of the non-concentric rings at substantially the same rate. The rods were coiled at about 400° F.

Microstructures of these as-rolled controlled cooled rods were equivalent in quality to a good air patented structure; approximately 80 percent fine pearlite, 20 percent medium coarse pearlite and only a minute trace of grain ferrite (at 750× magnification).

The tensile strengths of samples taken from the coils were as follows:

Front Ends, Number of Samples	Pounds	Back Ends, Number of Samples
1	6,200-6,249	1
1	6,150-6,199	-----
2	6,100-6,149	2
12	6,050-6,099	12
13	6,000-6,049	17
8	5,950-5,999	9
22	5,900-5,949	22
14	5,850-5,899	10
12	5,800-5,849	14
10	5,750-5,799	8
2	5,700-5,749	7
4	5,650-5,699	3
2	5,600-5,649	1
1	5,550-5,599	-----

Avg. Breaking load, 5,912 lbs. Avg. Breaking load, 5,923 lbs.
Avg. U.T.S., 150,800 p.s.i. Avg. U.T.S., 151,000 p.s.i.
Range, 142,100 to 158,700 p.s.i. Range, 143,400 to 158,500 p.s.i.

The above values are based on a nominal rod diameter of .2235". The distribution and uniformity of the tensile values are considered good. The average tensile strengths of this particular lot is approximately 10,000 p.s.i. higher than a conventional air patented .218" rod of this analysis.

Rod measurements were as follows (as determined from 12 random coils):

	Front Ends	Middle	Back Ends
Low Side.....	.214 to .221"	.210 to .221"	.212 to .224"
High Side.....	.227 to .239"	.225 to .234"	.223 to .234"
Average.....	.216×.231"	.216×.231"	.217×.231"
Nominal Round.....	.2235"	.2235"	.224"

The following tests were also taken on the as-rolled rod:

	Average	Minimum	Maximum
Percent Elongation in 10" (bench marks):			
Front Ends.....	6.3	4.37	8.75
Back Ends.....	6.7	4.37	8.75
Percent Reduction in Area (Tensile Neckdown):			
Front Ends.....	53.4	46.8	59.2
Back Ends.....	54.4	45.0	62.0

Chemical analysis (20 random samples).—C, .62/.64; MN, .99/1.05; P, .009/.012; S, .028/.031; Si, .171/.188; Cu, .11/.12.

Percent scale on rod surface (lab. check, 20 random samples).—Average, .50%; minimum, .27%; maximum, 72%.

Seams (20 random samples).—Coil #10 1 seam .004"; coil #11 1 seam .002".

All others examined were seam-free.

Laps (20 random samples).—Coil #9 1 lap .003".

All others examined showed no laps.

Grain size (20 random samples).—As-rolled rod, 6 to 3; McQuaid Ehn, 6.

Surface—Partial Decarb (20 random samples, X.001)—Samples:

10	-----	None
3	-----	0 to 1
6	-----	0 to 2
1	-----	0 to 3

The coils were cleaned by a batch dip in diluted sulphuric acid. Seven coils were used per yoke. The temperature of the batch was about 145±15° F. and the cleaning time was about 10–15 minutes per yoke. Seventy-

seven coils were limed and 24 were coated with borax. Four random loads of the borax coated rods were weighed before and after cleaning and coating. With two loads no change in weight was observed, with one load the weight loss was 0.32 percent and with the remaining one it was 0.36 percent. One skilled in the art will appreciate that this small loss of weight due to scale removal is startling.

The M.B. spring wire was drawn from the limed rod using 6 holes at 700 feet per minute and a dry lubricant. The total reduction was 76%. The die line-up was: .190; .166; .146; .128; .112; .1055.

In this case, as in all the following, the wire drawing operation was accomplished without difficulty. No breaks were encountered and die life was good. The finished wires showed no brittle tendency. The .1055 M.B. spring wire passed the 1X wrap test and had the following tensile strength (50 coils approximately 360 pounds each).

	Average	Minimum	Maximum
Front Ends, p.s.i.....	234,700	226,000	247,000
Back Ends, p.s.i.....	229,300	219,000	248,000
Required, p.s.i.....	-----	216,000	248,000

The 0.076" high tensile H.S. spring wire was drawn from the limed rods using 8 holes at 700 feet per minute and a dry lubricant. The total reduction was 88.4%. The die line-up was: .175; .151; .133; .116; .102; .089; .081; .076.

The following inspections were obtained:

MECHANICAL TESTS ON 7 CARRIERS, APPROXIMATELY 1800 LBS. EACH

	Average	Minimum	Maximum
U.T.S.:			
Front Ends, p.s.i.....	267,200	259,000	278,000
Back Ends, p.s.i.....	274,000	271,000	278,000
Required, p.s.i.....	-----	248,000	282,000
Torsions in 8":*			
Front Ends.....	40.8	39	43
Back Ends.....	41.3	37	44
90° Bends over .45" Radius:*			
Front Ends.....	78.1	68	87
Back Ends.....	82.0	73	95
Ductility.....	All samples passed a 1X wrap test		

*Torsion and bend tests are not a requirement on this grade of spring wire. The tests were conducted in line with Improved Plow Rope Wire testing procedure merely as a matter of general interest. All samples tested passed the torsion and bend specifications for Improved Plow Rope Wire.

The 0.095" breakdown stock was drawn from the boraxed rod using 7 holes at 1000 feet per minute and a dry lubricant. The total reduction was 82%. The die line-up was: .186; .163; .143; .125; .110; .101; .095.

The following inspections were obtained:

MECHANICAL TESTS ON 35 COILS, APPROXIMATELY 370 LBS. EACH

	Average	Minimum	Maximum
U.T.S.:			
Front Ends, p.s.i.....	233,800	220,000	243,000
Back Ends, p.s.i.....	232,000	227,000	241,000
Torsions in 8":*			
Front Ends.....	37	31	44
Back Ends.....	38.4	32	44
90° Bends over .57" Radius:*			
Front Ends.....	104.4	66	116
Back Ends.....	106.6	97	123
Ductility.....	All samples passed a 1X wrap test		

*Torsion and bend tests are not usually made on this type of wire. The tests were conducted in line with Improved Plow Rope Wire testing procedure as a matter of general interest. All samples tested passed the torsion and bend specifications for Improved Plow Rope Wire.

The 0.052" breakdown stock was drawn through 10 holes at 1000 feet per minute using a dry lubricant. The total reduction was 94.6%. The die line-up was: .165; .133; .116; .102; .089; .078; .069; .060; .055; .052.

The following inspections were obtained:

MECHANICAL TESTS ON 7 COILS, APPROXIMATELY 300 LBS. EACH

	Average	Minimum	Maximum
U.T.S.:			
Front Ends, p.s.i.	324,000	319,000	334,000
Back Ends, p.s.i.	331,000	326,000	336,000
90° Bends over .27" Radius:*			
Front Ends	59.3	51	69
Back Ends	60.0	52	69
Ductility	All samples passed a 1X wrap test		

*Drawing this type of steel to .052 from a number 5 gauge rod is considered a rather severe wire drawing practice.

Example III

The microphotographs of FIGURE IV were all obtained from the same heat of .57 carbon steel. Samples A and B were obtained from a coil weighing approximately 400 pounds that was coiled in a conventional manner as the rod issued from the rod mill. Air patented Sample C and controlled cooled Sample D were obtained from coils prepared as described in conjunction with Example II. The same rod mill was used as in Example II and the rod size was 5 gauge.

The variation in microstructure with corresponding lower mechanical properties and lower ductility on conventionally cooled rod are shown in photographs A and B and illustrate the effect of slower cooling rates and variation in transformation behavior. The outer strand, which cooled the fastest, is closest to an air-patented product while the inner strand has more blocky ferrite and pearlitic matrix which lacks the toughness for wire drawing.

A typical air patented structure of the same steel is shown in specimen C. It's largely sorbio-pearlitic matrix with a minimum of ferrite precipitation. This type of structure can be very successfully drawn into the wire. Specimen D is representative of the entire length of the controlled cooled rod of this invention and it can be said that it compares favorably with the air patented structure. The microstructure shows minimum ferrite formation and a fine sorbito-pearlitic matrix.

Example IV

A Number 5 rod was rolled from a spring steel as described in Example II. The coil weight was approximately 400 pounds. The steel contained 0.66 weight percent carbon, 0.83 weight percent manganese and 0.17 weight percent silicon. Test specimens were taken approximately every 10 rings alternately between the side and center locations on the controlled cooling conveyor. The following table shows the uniformity of the rod throughout its length.

Test Number	Side of Conveyor, Ultimate p.s.i.	Center of Conveyor, Ultimate p.s.i.
1	142,320	
2	145,220	
3		140,480
4	141,420	
5	144,100	
6		143,350
7	139,960	
8	144,690	
9		144,290
10	143,000	
11	144,690	
12		142,280
13	143,860	
14	146,830	
15		145,330
16	144,150	
17	144,690	
18		144,510
19	144,150	
20	145,400	
21		140,880
22	143,620	
23	142,320	
24		144,690
25	142,000	
26	142,850	
27		141,210
28	146,020	
29	143,620	

Example V

Billets from the same heat of Grade C 1020 Rimmed Steel were rolled to .391-inch diameter and one lot was controlled cooled in the manner of this invention and another was coiled while hot and cooled in a conventional manner. Photographs A and C of FIGURE V illustrate the microstructure and scale obtained with the conventionally cooled rod and photographs B and D illustrate the microstructure and scale obtained by controlled cooling.

The conventionally cooled rod had an ultimate tensile strength of 59,070 p.s.i. and a reduction of area of 65.1 percent. The controlled cooled rod inspections were 63,680 p.s.i. and 65.9 percent respectively.

It can be seen from the photographs that the conventionally cooled rod had a structure of banded ferrite with intergranular pearlite. The structure of the controlled cooled specimens in comparison thereto was finer and more lightly banded with slightly acicular ferrite and intergranular pearlite. The scale on the conventionally cooled rod was considerably heavier and more firmly adherent.

FIGURE VI sets out typical cooling curves that result from different treatments or handling of rolled rods. It can be seen that the controlled cooling of this invention does not duplicate the curve given by lead patenting, which is rather idealized, but it does nevertheless result in substantially complete transformation of the austenite before the temperature of the rod has dropped below that of the knee of the inner curve of the diagram (point X). The spread shown for the curve given by normal cooling results because the rod is placed in the coil form while at a temperature of above about 1400° F. and the mass of the coil causes the inner strands to cool at a slower rate. This results in an intolerable variation in properties. These variations must be removed or cancelled by air or lead patenting to make the rod acceptable for wire drawing.

Having described this invention, what is sought to be protected by Letters Patent is succinctly set forth in the following claims.

We claim:

1. A steel product comprising a substantial length of medium to high carbon steel rod, the microstructure of said steel throughout the length of said rod being substantially uniformly dispersed predominantly fine pearlite grains with a minimum of grain boundary ferrite and substantially free of bainite, said grains being the transformation product of austenite grains which have been hot worked and sequentially cooled prior to transformation rapidly enough to give a resulting grain size which is substantially smaller than that which results from reheating the same rod, after it has once cooled through transformation, to about 1800° F. and thereafter cooling the same in still air; the scale on the surface of said rod being uniform and relatively free from iron and magnetite in the wustite area, said scale amounting to less than 1 weight percent of said rod.

2. The steel product of claim 1 wherein said rod is suitable for wire drawing without heat treatment, and said rod has a tensile strength spread over its length of less than 10,000 p.s.i. and a variation over its length in reduction of area by the ASTM tensile test of less than ±10 percent about the means.

3. The steel product of claim 1 wherein said rod has a carbon content in the range of 0.4 to 0.9 weight percent and wherein said scale amounts to less than 0.6 weight percent thereof and is friable.

4. The steel product of claim 1 wherein said rod is a hot rolled rod which has been sequentially water quenched to a temperature above, but near, transformation temperature immediately after said rod issued from the final finishing stand of the rod mill, immediately fol-

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lowing which the said rod has been air cooled through transformation to produce said microstructure.

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