Nov. 5, 1974 R. J. HENRY 3,846,183

METHOD OF TREATING STEEL RAIL

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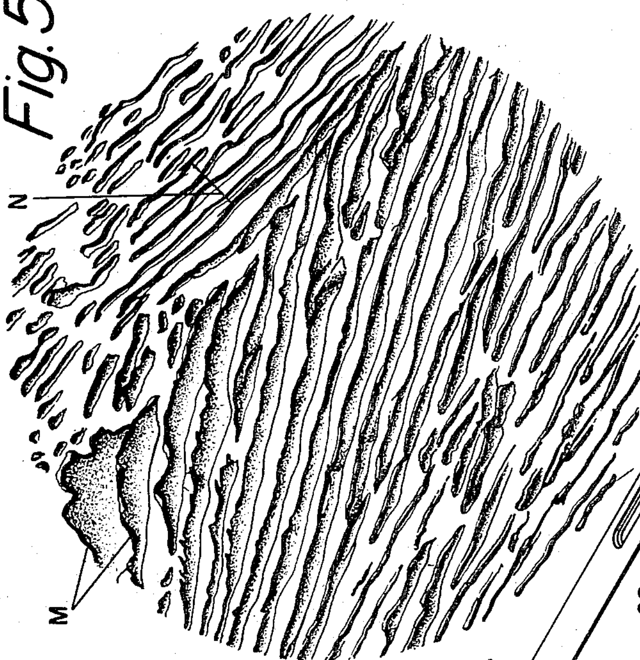
Fig. 5



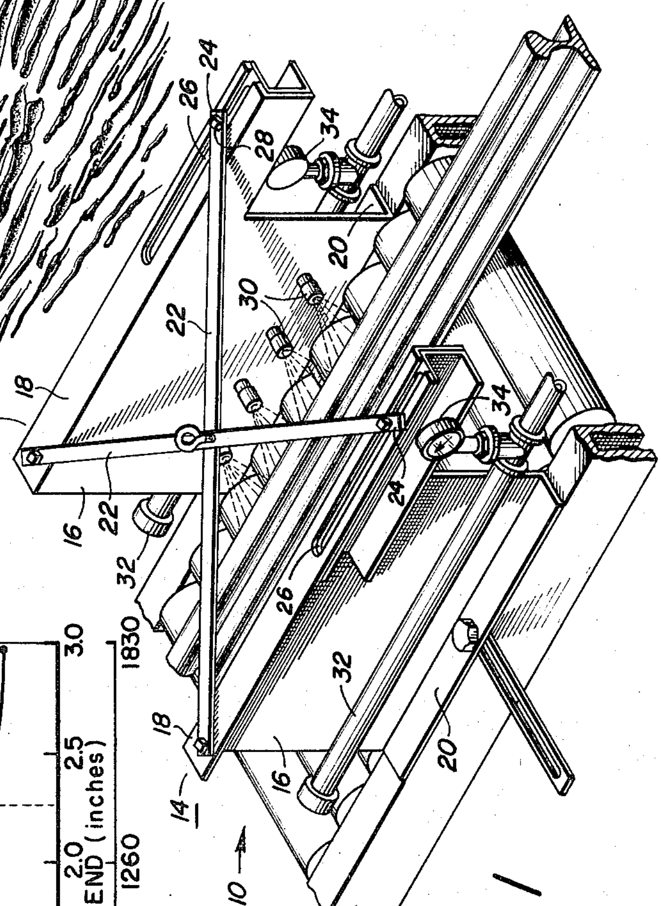


Fig. 1

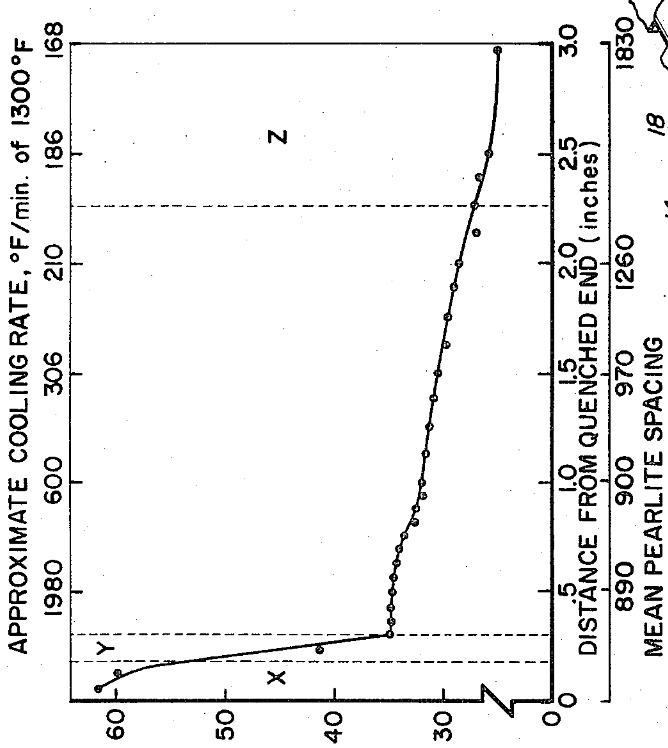


Fig. 4

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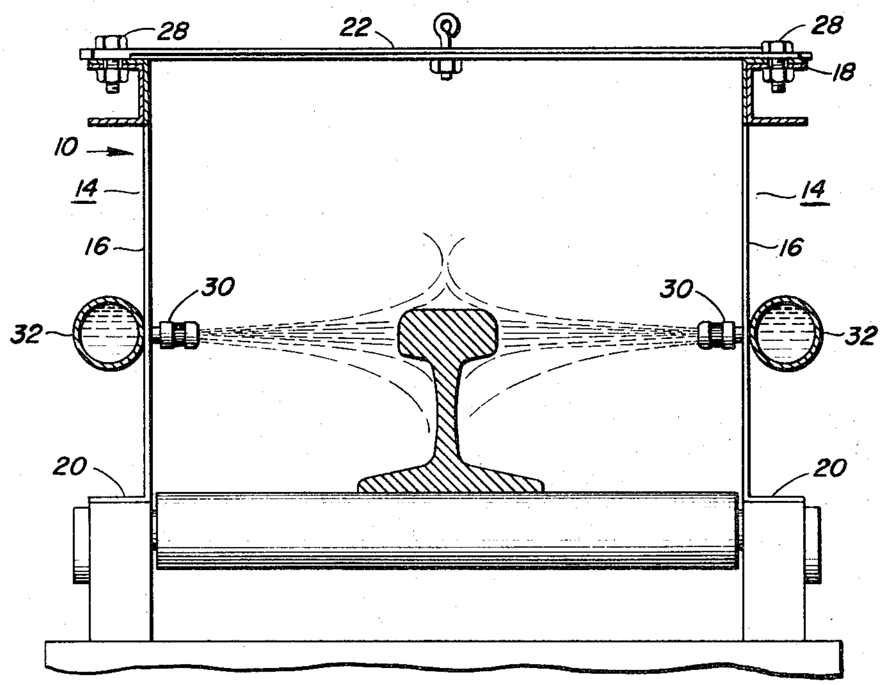
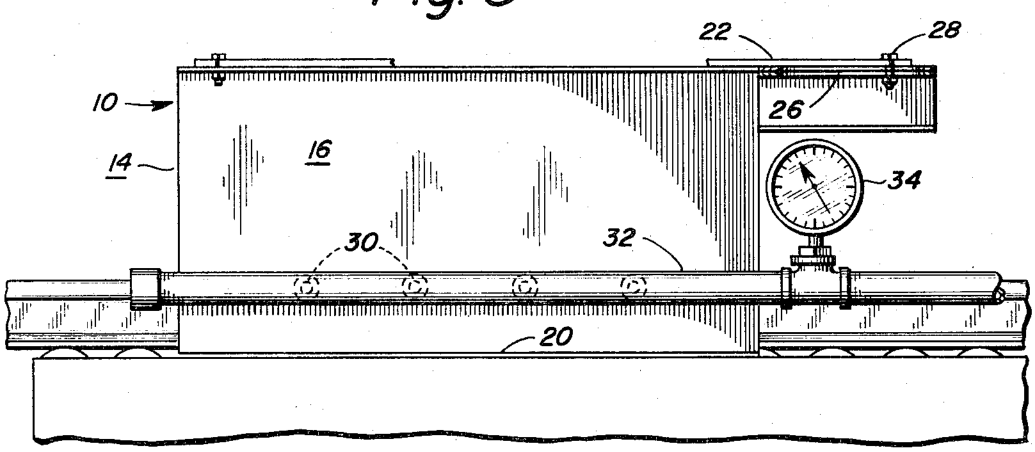


Fig. 2

Fig. 3



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3,846,183
METHOD OF TREATING STEEL RAIL
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U.S. Cl. 148—12 9 Claims

ABSTRACT OF THE DISCLOSURE

This invention is directed to a method of treating a formed railroad steel rail to improve its deformation and shelling resistance. More particularly, said method includes hot forming a rail whose chemistry falls within the ranges, by weight, 0.64 to 0.82% carbon, up to about 1.50% manganese, up to about 0.04% phosphorus, up to about 0.05% sulfur, up to about 1.25% silicon, up to about 2.5% chromium, balance essentially iron, and rapidly cooling from a temperature above about 1800° F. to about 700° F. The rate of cooling is such as to produce a fully pearlitic microstructure and a mean interlamellar spacing of pearlite no greater than about 1500 A., preferably no greater than about 1100 A., as determined by a plurality of measurements at random locations on a polished and etched surface.

BACKGROUND OF THE INVENTION

The invention herein is concerned with the production of formed steel rail having a high rolling contact fatigue life, or resistance to deformation and shelling. By way of background, shelling as defined in the Proceedings of A.R.E.A., vol. 61, 1960, p. 832 is a phenomenon observed on the surface of steel rails in use, where small pieces, on the order of up to several inches by ½ inch, of the rail head fall off. Typically these failures are noted on inside corners.

Accepting the premise that microstructural features play a role in controlling the mechanical properties of a steel, the prior art introduced heat treatments to the conventional hot rolled and air cooled rails which were characterized by a coarse pearlitic microstructure and a hardness ranging between about R_c 25 to 30. Through heat treatment it was possible to refine the pearlitic microstructure, raise the hardness to a level between about R_c 35 to 40, with the result that the resistance to deformation and shelling improved. As a consequence of said additional treatment, costs increased resulting in a premium rail.

Actually, there are two generally accepted practices employed in heat treating rails, namely, a fully heat treated rail and a partially heat treated rail. The former is produced by reaustenitizing a batch of rails at about 1550° F., oil quenching, followed by tempering. The partially heat treated rails have an induction or flame treated head portion only so that the microstructure of the rail is heterogeneous. That is, as a result of the localized heat treatment, a portion of the head is characterized by a fine pearlite, with the remainder of the head, the web, and base a coarse pearlite. As in the case of the fully heat treated rail, said portion of the head of the rail must be reaustenitized before refinement of the microstructure takes place.

As should be evident in these situations, with the additional post-forming operations, costs increased significantly due to the particular treatment and supplementary equipment needed to insure a straight and usable rail. Much of the prior art is devoted to this latter aspect of treating rails. U.S. Pat. Re. 27,221 to Dewez, Jr. et al. is exemplary of a prior art process for partially heat treating a rail by a procedure which includes bending and holding the rail

prior to heating and quenching thereof, and releasing the rail to permit it to resume its normal straight condition.

A different approach to the specification of steel rails is taught in British patent specification No. 1,131,662. In the practice of this development, the rail, while still hot on leaving the rolling mill, is immersed in a cooling medium consisting of a fluidized bed of refractory powder maintained at a constant temperature. The cooling rate resulting therefrom is relatively slow. As a consequence, the pearlite which forms is relatively coarse with a mean interlamellar spacing of pearlite exceeding about 2000 A. Accordingly, a steel rail produced thereby does not have the rolling contact fatigue life and resistance to deformation of the steel rail produced according to the method described and claimed herein.

SUMMARY OF THE INVENTION

The invention herein resides in the recognition that the deformation and shelling resistance, or rolling contact fatigue life, of a rail steel can be improved by controlling or minimizing the interlamellar spacing of pearlite. The invention further resides in the discovery that control of such a microstructure can be achieved directly off the forming or rolling mill without the need of costly post treatments and supplementary equipment.

Briefly, the rail steels to which this invention relates are those whose chemistry fall within the following ranges; by weight: carbon 0.64 to 0.82%, manganese up to about 1.50%, phosphorus up to about 0.04%, sulfur up to about 0.05%, silicon up to about 1.25%, chromium up to about 2.5%, balance essentially iron. The steel is melted, cast and finally rolled in a conventional manner at a temperature between about 2100° to 2350° F. While still hot and at a temperature above about 1800° F., the formed steel rail is rapidly cooled to a temperature between about 1000° to 700° F., followed by controlled cooling to prevent hydrogen flaking. Under such conditions, upon examination, the microstructure will be characterized as fully pearlitic, having a mean interlamellar spacing of pearlite no greater than about 1500 A., and preferably no greater than about 1100 A.

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 is a perspective view of apparatus capable of carrying out the method of this invention.

FIG. 2 is a sectional view of the apparatus of FIG. 1 taken along a plane perpendicular to the axis of the rail being treated according to this invention.

FIG. 3 is a plan view of the apparatus described above.

FIG. 4 is a graph showing approximate cooling rates and mean pearlite spacing of a rail steel of this invention subjected to a Jominy bar test.

FIG. 5 is a reproduction of a fine grain pearlitic microstructure at approximately 20,700×, showing the interlamellar spacing of the cementite lamellar.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENT

This invention is directed in particular to the treatment of railroad rails to increase their shelling resistance or rolling contact fatigue life. While present day rails are rolled in various sizes ranging from 81 lb./yd. up to 155 lb./yd. one of the common rails in main line use is the 140 lb./yd. rail. According to the standards established by the American Railway Engineering Association, a representative chemical composition for such a rail is one falling within the following ranges, by weight:

Carbon	0.69–0.82%.
Manganese	0.70–1.00%.
Phosphorus	0.04% max.
Sulfur	0.05% max.
Silicon	0.25% max.
Iron	Balance.

While the further description shall be directed to a 140 lb./yd. rail, it should not be read as a limitation on the invention; for, the process herein is applicable to different shapes or weights of rails, and to chemistry variations therefor. For example, variations in manganese and silicon, as noted previously, are contemplated. Further, chromium may be present up to about 2.5%, preferably between about 1.0 to 2.0%. Accordingly, the only limitations to be imposed herein are those set forth in the claims appended to these specifications.

Referring now to further details of this invention, a ferrous alloy, having a rail steel chemistry as noted above, is suitably melted and cast into ingots. By procedures well known in the rail making arts, the ingots are processed hot by rolling into blooms and/or directly to shaped rails by such methods as the tongue-and-groove or diagonal method. In each case, the rail is formed hot at a temperature of about 2100° to 2350° F. The temperature at finishing is typically above about 1800° F. At this juncture the method of this invention is employed to secure optimum rail steel properties.

In the practice of this invention, the rail, while still hot from the forming operation, is rapidly cooled to a temperature above about 700° F. so as to produce a fully pearlitic microstructure having a mean interlamellar spacing of pearlite no greater than about 1500 A., preferably no greater than about 1100 A. Although a rapid cooling is used, it can not be so rapid as will result in martensite, or a mixed phase of martensite-pearlite. The apparatus of FIGS. 1–3 illustrate equipment capable of achieving the proper cooling rate needed to optimize properties.

FIG. 1 is a perspective view of a preferred cooling system **10** which can be used in conjunction with a conventional roll out table. FIGS. 2 and 3 are different views of the said cooling system.

While the rail is still at a temperature above about 1800° F., it is caused to traverse the roll out table **12** passing through the cooling system **10**. Since the sides **14** and their respective attachments of the system are substantially the same, the description of one said side should suffice to describe the system.

Each said side is characterized by an upstanding wall **16** and top and bottom flanges, **18** and **20** respectively. The top flange **18** of each side **14** is joined to the other by cross members **22**. As seen in FIG. 1, one end **24** of the cross member **22** is adapted to slide along slot **26** and be firmly secured by fastener **28** at any point therealong. By this arrangement, the sides **14**, while maintaining a parallel relationship, may be moved relative to each other.

Through the wall **16**, a plurality of nozzles **30**, connected to a common manifold **32** or pipe, are secured and directed toward the rail to be cooled. The rate or pressure of the cooling medium, such as steam, may be monitored by gages **34** and may be modified as conditions and steel chemistry may dictate. A broad range of cooling rates can be attained by this system using a combination of different cooling medium, rates and distance from nozzle to rail.

As may be evident from the description thus far, the method of this invention is directed to a procedure that will produce a relatively small mean interlamellar spacing of pearlite. It is therefore difficult to select a specific cooling rate, or range thereof, as the rate will vary with the alloy used. However, by the simple expedient of a standard Jominy bar test, one can readily determine that rate or rates of cooling which will yield the microstructure desired. FIG. 4 is a Jominy bar test of an alloy whose chemistry, by weight, is 0.73% carbon, 0.84% manganese, 0.019% phosphorus, 0.022% sulfur, 0.25% silicon, balance iron. A cooling rate within vertical zones X and Y is too severe and will result in a microstructure containing martensite. At the other extreme, a cooling rate falling within zone Z, would result in a fully pearlite microstructure, but one whose mean interlamellar pearlite spacing is too great. It will be appreciated that if alloying additions are made to the steel which shift the pearlite nose of the isothermal T.T.T. curve further to the right, zones X and Y will be broadened. For such an alloyed steel rail, slower cooling rates may be used. But in any case, the Jominy bar test represents a convenient method for preselecting a suitable cooling rate for the chemistry of the rail.

After determining the range of cooling rates needed to produce the desired pearlite spacing, and processing in the manner taught herein, a microstructure for the steel will develop similar to that shown in FIG. 5. Actually, the microstructure is a graphic reproduction of a 0.69%, by weight, carbon steel, magnified about 20,700×.

By way of background, the cementite lamellae, which are generally pancake shaped, form in colonies within the prior austenite grains. The colonies, containing a plurality of generally parallel lamellae, are randomly oriented within the prior austenite grain and hence throughout the steel. Thus, upon viewing any polished surface of a steel treated according to this invention, some sets of lamellae will appear thin and in close proximity to each other, while an adjacent set might appear flattened with broad spacings between lamellae.

The interlamellar pearlite spacing is generally about the same throughout, so the differences are due to the angle the lamellae assume with the polished surface. In FIG. 5, the lamellae illustrated at M are at an oblique angle to the polished surface. In contrast to this, the lamellae illustrated at N approach an angle normal to the polished surface. The spacings $N_1 \ldots N_4$ are clearly more representative of the actual interlamellar spacing of pearlite.

Since it is often times difficult to select the minimum value or actual pearlite spacing, a system, as reported in the *Transactions of the A.S.M.*, December 1942, at pp. 1049–1084 by G. E. Pellissier et al. was developed. Very briefly, this system is a mathematical-analytical method. By making a sufficiently large number of measurements at random locations on a polished and etched surface, a statistical average or mean pearlite spacing can be determined. Other authorities have attempted to extend the results to project an actual spacing. They have determined that the mean spacing is approximately 1.65× the minimum or actual pearlite spacing. While the mean pearlite spacing has been used thus far in this description, it is obvious that the latter approach may be made to determine a theoretical or minimum interlamellar spacing.

In order to demonstrate the effectiveness of this invention over the conventional treatments noted above, steel rail sections of 140 lb./yd. rails were subjected to one of the following schedules:

A—hot rolled, air cooled

B—hot rolled, rapidly cooled with steam
 steam pressure, 100 p.s.i.
 steam flow, 2080 lbs./hr.

C—hot rolled, rapidly cooled with steam
 steam pressure, 60 p.s.i.
 steam flow, 1040 lbs./hr.

D—hot rolled, air cooled, reheated to 1550° F., oil quenched, tempered at 750° F.

The ladle chemistry, by weight, for said steel is listed in Table I.

TABLE I

	Percent
Carbon	0.74
Manganese	0.88
Phosphorus	0.015
Sulfur	0.040
Silicon	0.20
Nickel	0.07
Chromium	0.09
Molybdenum	0.024
Iron	Balance

The steam cooling in Schedules B and C was performed using a system such as illustrated in FIGS. 1–3. For convenience, reference shall be made to the reference characters applied above.

At each side **14**, five nozzles **30** spaced at 8 inch intervals were used. The respective steam cones emitting therefrom were about 12 inches in height and cooled separate but adjacent areas. That is, the cones did not overlap. While continuous cooling is contemplated, these particular rail sections during cooling were stationary. The mechanical and metallographic results of the latter treatments, along with said results from Schedules A and D, are listed in Table II.

TABLE II

Schedule	Finish temp., ° F.	Mean pearlite spacing A.	Hardness, R_c
A1	2,040	2,000	24–27
A2	2,050	2,100	24–27
B	2,040	1,000	36–38.5
C	2,050	1,080	35–37
D1	2,040	913	35–39
D2	2,050	987	35–38.5

The pearlite spacings weer measured on a polished and etched surface cut $\frac{5}{16}$ inch below the rail head surface and the hardness range from the center to the surface of the rail head. More specifically, the mean pearlite spacing (M.P.S.) was measured by counting the number of carbide lamellae that intersect a diameter on the screen of a transmission electron miscroscope. Thirty-five fields were counted so that a mean spacing might be determined. The spacing in angstroms was obtained using the equation:

$$\text{M.P.S.} = \frac{977 \times 10^6}{\text{Intersections} \times \text{Magnification}},$$

where Intersections was the average number of intersections, in the 35 fields and the Magnification was usually 10,000×.

From Table II, it will be seen that the rails treated according to Schedules B, C and D had about the same mean pearlite spacing, which were about half as fine as the M.P.S. of Schedule A. With respect to hardnesses, the rails of Schedules B, C and D were significantly higher than in Schedule A. Preliminary data indicate deformation and shelling, prior to full runout, in the material treated according to Schedule A. Tests are continuing on the remaining material. However, mid test observations suggest that the treatment of this invention results in a product having equivalent or superior rolling contact fatigue life to the heat treated material of Schedule D. By way of brief background regarding these tests, the rolling contact fatigue test consists of rolling a test roller with a crowned shape to simulate the rail head shape against a cylindrical case hardened drive roller. The number of cycles to produce a spall or shelling is measured by a counting device and is called the rolling contact life of the test roller. A runout for the purpose of this test is 50,000,000 cycles without spalling or shelling.

Thus, the simple expedient herein of rapidly cooling off the rolling mill results in a rail having properties superior to that of the air cooled, and properties at least comparable to those of the costly heat treated rails.

To this point, the term "rapid cooling" has been defined functionally as a rate sufficient to produce a fine pearlite having a mean interlamellar spacing of pearlite no greater than about 1500 A., preferably no greater than about 1100 A. It is obvious that the cooling rate used is not so severe as to produce martensite, or a mixed martensite-pearlite. However, to further demonstrate the criticality of and to categorize the "rapid cooling" herein, a series of tests were conducted comparing the present invention to a rail isothermally transformed using a fluidized bed for cooling purposes.

For this series of tests, rail head sections of 140 lb./yd. composition were subjected to air cooling and "rapid cooling" from an austenitizing temperature of 2050° F. To treat specimens in the fluidized bed, samples 2" x 2" x 3", having a 140 lb./yd. rail composition, were austenitized at 2050° F. before immersing in the fluidized bed. By measuring the slope of the cooling curve at two different temperatures, it was possible to assign an approximate cooling rate to the specimen being treated. After treatment, a reading of the mean pearlite spacing was made. The results thereof are reported in Table III.

TABLE III

Cooling treatment	Cooling rate, ° F./min. at— 1,400° F.	1,200° F.	Mean pearlite spacing, A.
Air cooled	50	43	2,100
Fluidized bed (1,140° F.*)	50.4	15.2	3,900
Fluidized bed (1,090° F.*)	54.5	24	2,440
Fluidized bed (780° F.*)	110	96	2,220
Fluidized bed (720° F.*)	148	160	2,150
Fluidized bed (R.T.*)	212	160	1,920
Rapid cooling	306	252	1,000

*Fluidized bed temperature.

As an incident to taking the pearlite spacing readings it was noted that as the mean spacing increased, the standard deviation increased about sixfold from the lowest to the highest mean spacing. Thus, not only does the invention herein result in smaller pearlite spacings, there is found a greater uniformity in pearlite spacing.

Up to this point, only brief mention has been made regarding the fact that the rapid cooling is stopped at a temperature above about 700° F., typically between about 700° to 1000° F. When the rail reaches this temperature, controlled cooling must start to prevent hydrogen flaking. Since this phenomenon is known and is practiced in the manufacture of rails (A.R.E.A. Rail Specification for steel rail as written in ASTM Standard A1 on controlled cooling) no attempt is made, nor is believed needed, to further explain it. However, a variation is offered to the extent that controlled cooling could be eliminated by vacuum degassing the steel before hot rolling.

What is claimed is:

1. A method of treating a rolled steel railroad rail to improve its shelling resistance, comprising the steps of forming the said rail from a steel whose composition, by weight, comprises carbon between about 0.64 to 0.82%, manganese up to about 1.50%, phosphorus up to about 0.04%, sulfur up to about 0.05%, silicon up to about 1.25%, chromium up to about 2.5%, balance essentially iron, at a temperature above about 2000° F. and rapidly cooling said rail from a temperature above 1800° F. to at least a temperature between about 700 to 1000° F. at a rate sufficient to produce a fully pearlitic microstructure and an average pearlite spacing of less than about 1500 A.

2. The method according to Claim **1** wherein the rapid cooling is at such a rate as to produce a maximum average pearlite spacing of about 1100 A.

3. The method according to Claim **2** wherein the average pearlite spacing is between about 900 to 1100 A.

4. The method according to Claim **1** including the step of slowly cooling the rail from a temperature between 700 to 1000° F. to ambient temperature to prevent hydrogen flaking.

5. The method according to Claim **1** wherein said rail is cooled immediately after the termination of the forming thereof at a rate between about 200 to 600° F./min., and after reaching a temperature between 700 to 1000° F., control cooled to prevent hydrogen flaking.

6. The method according to Claim **4** wherein the rapid cooling rate falls within the range between about 250 to 400° F./min.

7. The method according to Claim **1** wherein the carbon is present in an amount of at least 0.69%.

8. The method according to Claim **7** wherein the manganese is present in an amount between about 0.70 to 1.00%, and the maximum silicon is about 0.25%.

9. The method according to Claim 1 wherein the chromium is present in an amount between about 1.0 to 2.0%.

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