

[54] **COLD-DRAWN, STRAIGHTENED AND STRESS RELIEVED STEEL WIRE FOR PRESTRESSED CONCRETE AND METHOD FOR PRODUCTION THEREOF**

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[58] Field of Search **148/12 B, 36**

[56] **References Cited**

UNITED STATES PATENTS

3,532,560	10/1970	Tomioka et al.	148/12 B
3,844,848	10/1974	Stacey	148/12 B

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[57] **ABSTRACT**

Cold-drawn, straightened and stress relieved high carbon steel wire for prestressed concrete, and a method for the production thereof, having reduced load loss due to stress relaxation and good ductility. The steel comprises, by weight percent, from about 0.70 percent to about 0.90 percent carbon, about 0.5 percent to about 1.0 percent manganese, about 0.025 percent maximum phosphorus, about 0.035 percent maximum sulfur, about 0.15 percent to about 0.35 percent silicon, about 0.010 percent to about 0.020 percent nitrogen, about 0.010 percent to about 0.030 percent columbium, and remainder essentially iron except for incidental impurities. The cold-drawn wire has a pearlitic microstructure wherein the pearlite colony size is reduced by adding columbium to confer good ductility, and sufficient uncombined nitrogen is present to provide improved stress relaxation properties. Processing includes austenitizing a hot-reduced rod stock at about 980°C to about 1030°C and isothermal treating at about 540° to about 590°C, followed by air cooling. The stock is then cold-drawn into wire, straightened, and stress relieved.

7 Claims, No Drawings

COLD-DRAWN, STRAIGHTENED AND STRESS RELIEVED STEEL WIRE FOR PRESTRESSED CONCRETE AND METHOD FOR PRODUCTION THEREOF

BACKGROUND OF THE INVENTION

1. Field of the Invention:

This invention relates to cold-drawn, straightened and stress relieved high carbon steel wire for prestressed concrete, having reduced load loss due to stress relaxation in combination with good ductility, which is attained by addition of columbium to a high carbon steel and by heat treatment in a specific temperature range. For convenience, the term "cold-drawn" will be used hereinafter to designate wire which has been cold-drawn, straightened and stress relieved.

2. The Prior Art:

Japanese Patent Publication No. 42290/71, published Dec. 14, 1971, discloses high carbon steel wire having excellent resistance against relaxation by reason of a total nitrogen content of 0.008 to 0.05 percent by weight (the steel further containing 0.55 to 0.85 percent carbon, 0.30 to 0.90 percent manganese, 0.15 to 0.35 percent silicon and remainder iron except for impurities unavoidable in the steel-making process) wherein aluminum is restricted to a maximum of 0.015 percent by weight. Other nitride formers such as titanium, vanadium, columbium and the like, should also be kept at a low level, according to the disclosure, in order to permit the presence of at least about 0.008 percent by weight uncombined nitrogen, thereby attaining steel wire having reduced load loss due to stress relaxation. Silicon is used as a deoxidant in order to obtain a fully killed starting material.

United States Pat. No. 3,671,334, issued June 20, 1972 to J. H. Bucher et al, discloses a formed and strained steel article having a yield strength above 70 ksi, and a process for the production thereof, the steel containing 0.08 to 0.18 percent carbon, 0.3 to 1.0 percent manganese, 0.01 to 0.05 percent columbium, 0.008 to 0.014 percent nitrogen, 0.10 percent maximum silicon, less than a total of about 0.02 percent of aluminum, zirconium, vanadium and titanium, and the balance essentially iron. The steel of this reference is thus a low carbon, semi-killed steel which has a ferritic microstructure in the cold-rolled, strained and aged condition.

The patentees state that the primary effect of columbium in imparting strength to the steels is to refine the grain size of the steels. It is pointed out that "columbium is the only one of the conventionally employed grain refining elements, i.e., zirconium, vanadium and titanium, which is not also a strong nitride former; and, consequently, is the only one of these elements which can be used in conjunction with nitrogen to produce a strainaging steel."

An article by T. Gladman et al. in Journal of the Iron and Steel Institute, pages 916-930 (December 1972) discusses the influence of aluminum, titanium, vanadium and niobium (columbium) as grain refiners in steels containing 0.4 to 0.6 percent carbon, 1.4 to 1.5 percent manganese, 0.3 to 0.9 percent silicon, 0.016 to 0.021 percent nitrogen, and balance essentially iron. From experimental data reported therein, it was concluded that less than the expected dispersion strengthening was obtained when using niobium, and "may be attributed to the very restricted solubility of niobium in a high-carbon austenite." The article was concerned

with factors controlling yield and tensile strengths and impact transition temperature in high carbon ferrite-pearlite steels, and it was found that low uncombined or free nitrogen was necessary in order to obtain low impact transition temperatures. Hence, only aluminum, titanium and vanadium were considered advantageous in steels having a high total nitrogen content.

While the above-mentioned Japanese Patent Publication disclosed high carbon wire having reduced load loss due to stress relaxation, by reason of a relatively high uncombined nitrogen content, this increase in nitrogen would render the steel subject to excessive breakage during wire drawing and cold straightening if heated above about 940°C before drawing.

The problem of obtaining adequate ductility in prestressed wire of the type disclosed in this Japanese reference is not believed to be obvious to a person skilled in the art in view of the disclosures of the above-mentioned Bucher et al. patent or the Journal of the Iron and Steel Institute articles. The Japanese reference emphasizes the criticality of maintaining the elements aluminum, titanium, vanadium and columbium at a low level. More specifically, the maximum aluminum content is stated to be 0.015 percent while the minimum total nitrogen content is 0.008 percent.

The disclosure in the Bucher et al patent that columbium is not a strong nitride former would be of no benefit to a person skilled in the art if faced with the problem of obtaining good ductility in a cold drawn wire of the type disclosed in the Japanese reference. Bucher et al disclose a relatively low carbon steel having a fully ferritic microstructure in the cold rolled and strained condition. The columbium addition in such a steel controls grain size after the austenite to ferrite transformation, a mechanism which is entirely different from that of transformation of a high carbon steel to pearlite.

In ferritic steels particles such as carbides in the grain boundaries restrict the ferritic grain size. A fully pearlitic structure has grain boundaries which are not as mobile as ferrite boundaries. Hence the pearlite colony size, after transformation, is controlled completely by the grain size of the prior austenite. In contrast to this, in a ferritic structure, or in a ferritic-pearlitic structure, ferrite grain size is controlled only to a minor extent by particles in the prior austenite phase and predominantly by particles such as columbium carbides after transformation to ferrite.

Similar observations apply to the ferrite-pearlitic structures of the 0.4 to 0.6 percent carbon steels of the above-mentioned Journal article, despite the unsupported statement at page 922 thereof that pearlite colony size depends on the prior austenite grain size which in turn can be controlled by grain-refining additions. However, in the reported data the addition of 0.05 percent columbium results in no refining of the pearlite colony size, apparently due to the cooling cycle followed therein.

Moreover, in the Journal article columbium was added in an amount of 0.05 percent. This columbium level forms a carbide which is stable up to about 1370°C in a steel containing 0.8 percent carbon and a nitride which is stable up to about 1130°C in a steel containing 0.012 percent nitrogen. Accordingly, the addition of 0.05 percent columbium to a high carbon steel may result in precipitation of large carbides during or immediately after solidification of the cast ingot, and such carbides cannot be dissolved during subsequent processing since heating to a temperature up to

about 1370°C cannot be practiced without adverse effect on mechanical properties.

It is therefore evident that the prior art has not disclosed nor suggested the provision of cold-drawn, high carbon steel wire having a fully pearlitic microstructure which combines reduced load loss due to stress relaxation with good ductility.

It is a principal object of the present invention to provide such a product and a method for the production thereof.

SUMMARY

The present invention provides cold-drawn, high carbon steel wire for prestressed concrete having a fully pearlitic microstructure, reduced load loss due to stress relaxation and good ductility, consisting essentially of, by weight percent, from about 0.70 percent to about 0.90 percent carbon, about 0.5 to about 1.0 percent manganese, about 0.025 percent maximum phosphorus, about 0.035 percent maximum sulfur, about 0.15 to about 0.35 percent silicon, about 0.010 to about 0.020 percent total nitrogen, about 0.010 to about 0.030 columbium, substantially all the columbium being combined with carbon, and remainder essentially iron except for incidental impurities.

The method of the present invention comprises providing a hot reduced rod stock of the above composition, austenitizing the stock by heating in the range of about 980° to about 1030°C, transforming the stock to a fully pearlitic microstructure by isothermal heating at about 540° to about 590°C, air cooling, whereby to obtain a pearlite colony size ranging between about 15 and about 30 μ , and cold-drawing, straightening and stress relieving the rod stock into wire for prestressed concrete.

The austenitizing and isothermal heat treatments of the process of the invention are rapid (comprising a time of about 5 minutes for austenitizing and about 1 to 2 minutes for austenite to pearlite transformation, these times being subject to minor variations depending upon rod diameter), and hence the process provides an efficient and high production rate.

In the present invention the addition of from 0.010 to 0.030 percent columbium to a steel containing from about 0.70 to about 0.90 percent carbon is critical in achieving improved ductility. More specifically, the hot reduced rod stock after heat treatment will exhibit tensile reduction-in-area values ranging from about 25 to about 35 percent. By way of comparison, a steel having a similar composition without columbium addition exhibits tensile reduction-in-area of about 20 to about 22 percent when subjected to the same heat treatment.

Cold-drawn steel wire for prestressed concrete produced in accordance with the invention exhibits a load loss by the 1000 hours stress relaxation test at 20°C and 67.5 percent initial stress of not greater than about 3 percent. By comparison, cold-drawn steel wire containing no columbium and having a total nitrogen content not greater than about 0.007 percent exhibits a load loss by the same test of about 6 percent.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

While the composition of the steel has been set forth above in broad limits, optimum properties are obtained in a steel in which carbon is from about 0.80 to about 0.85 percent, manganese about 0.80 to about 0.90 percent, silicon about 0.20 to about 0.30 percent, nitrogen

from about 0.011 to about 0.016 percent, columbium from about 0.014 to about 0.020 percent, with the maximum phosphorus and sulfur contents being as set forth above, and remainder essentially iron except for incidental impurities. At least about 0.008 percent uncombined nitrogen is preferably present in the final product.

Although not critical, preferably incidental impurities other than phosphorus and sulfur are maintained within the following limits:

Copper	0.20% maximum
Chromium	0.15% maximum
Nickel	0.15% maximum
Molybdenum	0.05% maximum

The carbon, manganese, nitrogen and columbium ranges are critical, and departure therefrom results in loss of one or more of the desirable properties.

A minimum of about 0.70 percent carbon and preferably about 0.80 percent is necessary in order to provide adequate strength and to insure transformation to a fully pearlitic microstructure under the desired heat treatment conditions. More than about 0.90 percent carbon would adversely affect the cold-drawing properties of the steel. Preferably a maximum of about 0.85 percent carbon is observed for optimum properties.

A minimum of about 0.5 percent manganese, preferably about 0.80 percent, is believed to be desired for its effect in holding nitrogen in solution in the steel. However, a maximum of about 1.0 percent manganese and preferably about 0.90 percent, must be observed in order to avoid unduly long austenite to pearlite transformation time during heat treatment.

About 0.010 percent minimum nitrogen is necessary in order to achieve the marked improvement in reduced load loss due to stress relaxation which is one of the principal objects of the present invention. More than about 0.020 percent total nitrogen is undesirable because of its tendency to produce extensive strain aging and consequent brittleness. A preferred maximum of 0.016 percent is observed for this reason.

To obtain homogeneously sound steel it is necessary to add silicon as a deoxidizer during the steel making process in the range of about 0.15 percent to about 0.35 percent silicon. Preferably aluminum is not added since it ties up free nitrogen.

A columbium range of about 0.010 percent to about 0.030 percent, and preferably from about 0.014 percent to about 0.020 percent, is necessary, at the carbon levels involved, in order to produce relatively small columbium carbide particles only after solidification of the molten steel in amounts which will concentrate in the austenite grain boundaries. Columbium in excess of about 0.030 percent results in formation of relatively massive carbides which are stable up to temperatures well above the austenitizing heat treatment range of 980° to 1030°C of the present process. As indicated previously, fine columbium carbide particle size and distribution in the grain boundaries of the prior austenite grains are essential in the present invention for control of pearlite colony size and resultant improved ductility.

Heats of similar composition have been prepared with and without columbium additions, hot reduced to rod stock, austenitized at about 980°C, transferred to a lead bath at about 555°C for controlled transformation to pearlite, and air cooled. Pearlite colony size and

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ASTM grain size are compared below for two such heats together with analyses of the elements carbon, manganese, silicon, nitrogen and columbium:

Example	Composition					ASTM Prior Austenite Grain Size	Pearlite Colony Size- μ
	C	Mn	Si	N	Cb		
A	.82	.82	.24	.010	none	4 & 5	100-70
B	.85	.83	.27	.012	.014	8 & 9	25-18

Example A exhibited tensile reduction-in-area of 22 percent after transformation to pearlite and air cooling, while specimens from Example B (present invention) exhibited tensile reduction-in-area ranging between 28 and 35 percent.

Specimens were then cold-drawn, straightened, and stress relieved, and subjected to load loss testing. The load loss after the 1000 hour stress relaxation test at 20°C and 67.5 percent initial stress was about 2.8 percent for both Examples, indicating no detrimental effect of columbium on load loss characteristics. The reduced load loss and improved ductility of the columbium containing wire of the present invention are, therefore significant.

In summary, the composition of the steel, and the heat treatment in the method of the present invention are critical in achieving the combination of reduced load loss due to stress relaxation, good ductility and high strength.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. Cold-drawn, high carbon steel wire for prestressed concrete having a fully pearlitic microstructure, reduced load loss due to stress relaxation, and good ductility, said wire being cold-drawn from hot reduced rod stock having a tensile reduction-in-area value of at least about 25 percent after austenitizing and transformation to pearlite, said steel consisting essentially of, by weight percent, from about 0.70 to about 0.90 percent carbon, about 0.5 to about 1.0 percent manganese, about 0.025 percent maximum phosphorus, about 0.035 percent maximum sulfur, about 0.15 to about 0.35 percent silicon, about 0.010 to about 0.020 percent total nitrogen, about 0.010 to about 0.030 percent columbium, sub-

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stantially all the columbium being combined with carbon, and remainder essentially iron except for incidental impurities.

2. The wire claimed in claim 1, wherein carbon is from about 0.80 to about 0.85 percent, manganese is from about 0.80 to about 0.90 percent, silicon is from about 0.20 to about 0.30 percent, nitrogen is from about 0.011 to about 0.016 percent, and columbium is from about 0.014 to about 0.020 percent.

3. The wire claimed in claim 1, wherein at least about 0.008 percent uncombined nitrogen is present.

4. A method of producing cold-drawn steel wire for prestressed concrete having reduced load loss due to stress relaxation and good ductility, comprising the steps of providing a silicon killed, hot reduced rod stock consisting essentially of, by weight percent, from about 0.70 to about 0.90 percent carbon, about 0.5 to about 1.0 percent manganese, about 0.025 percent maximum phosphorus, about 0.035 maximum sulfur, about 0.15 to about 0.35 percent silicon, about 0.010 to about 0.020 percent total nitrogen, about 0.010 to about 0.030 percent columbium, and remainder iron except for incidental impurities, austenitizing said stock by heating in the range of about 980° to about 1030°C, transforming said stock to a fully pearlitic microstructure by isothermal heating to about 540° to about 590°C, and air cooling, whereby to obtain a pearlite colony size ranging between about 15 and 30 μ , and cold-drawing, straightening and stress relieving said rod stock into wire of desired final diameter.

5. The method claimed in claim 4, wherein said rod stock contains from about 0.80 to about 0.85 percent carbon, about 0.80 to about 0.90 percent manganese, about 0.20 to about 0.30 percent silicon, about 0.011 to about 0.016 percent nitrogen, and about 0.014 percent to about 0.020 percent columbium.

6. The method claimed in claim 4, wherein said prestressed wire contains at least about 0.008 percent uncombined nitrogen.

7. The method claimed in claim 4, wherein the columbium content is so selected as to result in formation of small columbium carbide particles which are distributed in the austenite grain boundaries in the hot reduced rod stock, whereby to control the austenite grain size.

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