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584,659, Oct. 6, 1966, now abandoned.

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[54] HIGH-STRENGTH STEEL WIRE

5 Claims, 1 Drawing Fig.

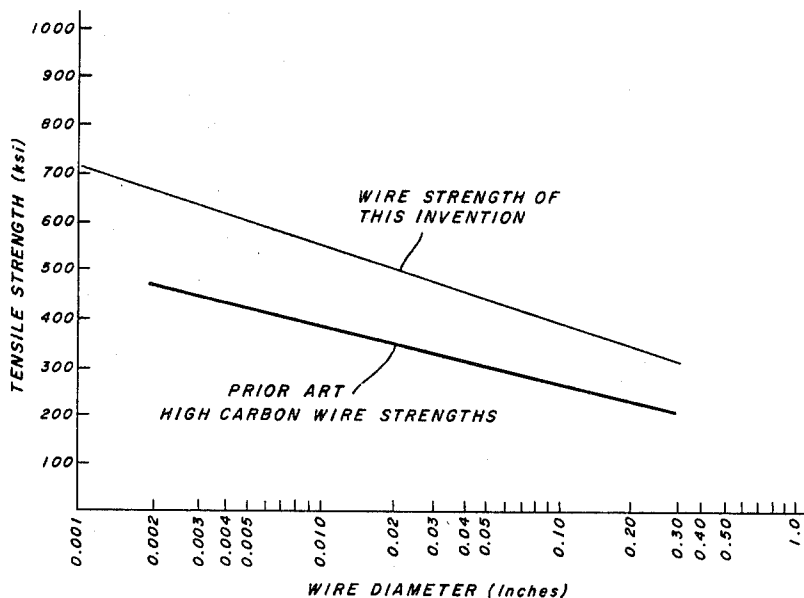
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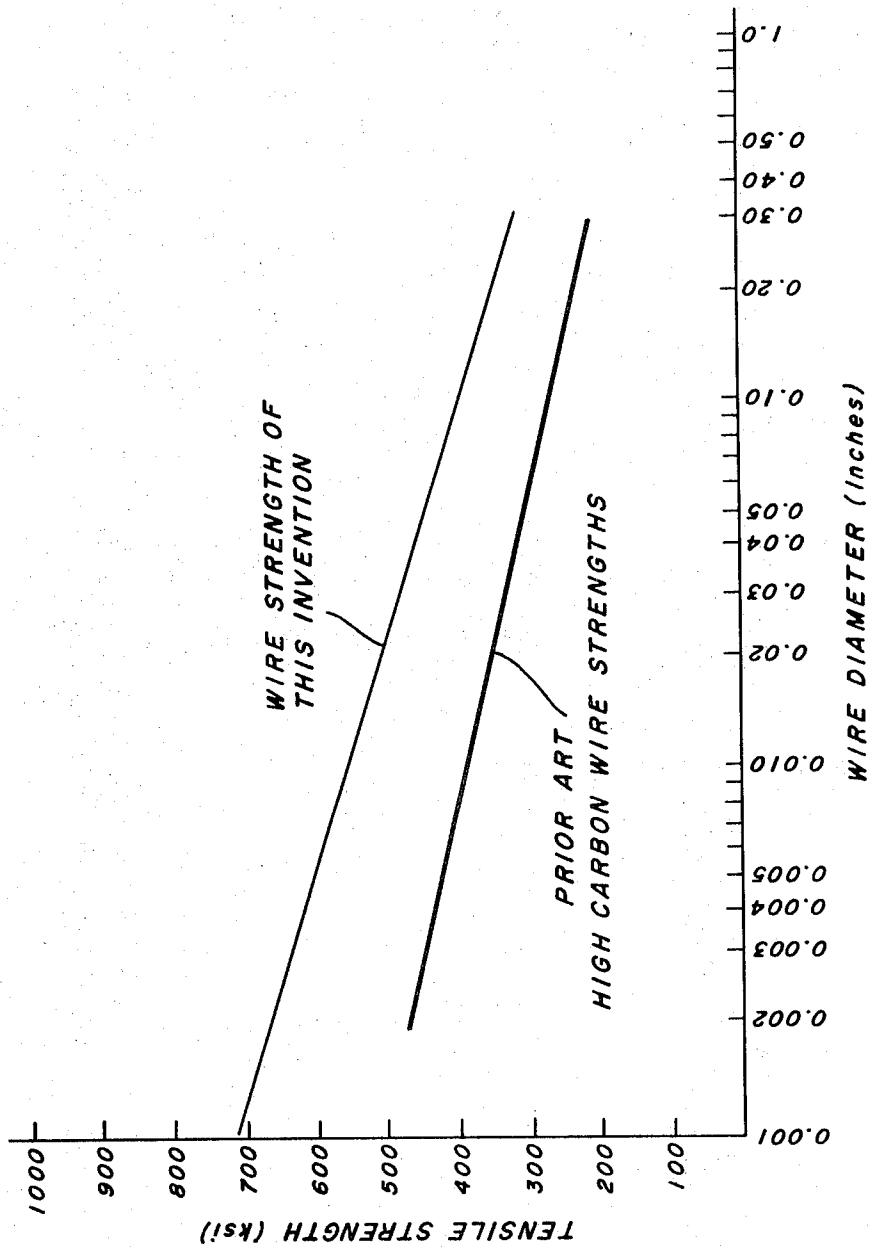
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ABSTRACT: A steel wire consisting essentially of 0.9 to 1.10% carbon, 0.3 to 0.6% manganese, not more than 0.01% sulfur, not more than 0.005% phosphorus, not more than 0.1% silicon, and not more than 0.002% nitrogen, cold drawn to a diameter of from 0.25 to 0.001 inch to provide a high tensile strength within the range 350 to 700 K.s.i. and yet exhibiting sufficient ductility as to be characterized by a ductile mode fracture.





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HIGH-STRENGTH STEEL WIRE

BACKGROUND OF THE INVENTION

This application is a continuation-in-part of our copending application Ser. No. 584,659, filed Oct. 6, 1966, now abandoned.

This invention relates generally to ultra-high-strength steel wires, and more particularly to a wire having a unique composition allowing a high capacity for cold working to ultra high strengths without complete loss of ductility.

Ultra-high-strength steel wires such as music spring wire, piano wire and the like are presently made from near-eutectoid steels of closely controlled chemical compositions. The American Iron and Steel Institute describes composition ranges for music spring wire as follows:

0.70-1.00%	C
0.20-0.60%	Mn
0.025% maximum	P
0.035% maximum	S
0.12-0.30%	Si

However, since the steel is to be severely cold worked in the manufacture of such fine wire, it is customary for producers to furnish steels therefor to still-closer tolerances so that high strength and cold workability are more readily assured. For example, sulfur is known to decrease the cold workability of steel, and hence even lower sulfur limits are customary, e.g. 0.025 percent. In a like manner, carbon and phosphorus also decrease workability. Yet, carbon and phosphorus are primarily responsible for the work hardening effect in the steel which makes possible the ultra high strength. Therefore, customary practices have been to control carbon and phosphorus within narrower, more preferred ranges, to assure cold workability without sacrificing strength. Normal practice, therefore, has been to furnish steel wire within the following specified range:

0.82-0.92%	C
0.30-0.60%	Mn
0.015% maximum	P
0.025% maximum	S
0.15-0.30%	Si

Although the nitrogen content is not usually specified, these steels generally contain conventional residual levels of about 0.005 to 0.007 percent nitrogen. In addition, the phosphorus, although specifying only a maximum tolerable limit, is not regarded as an impurity as such a specification might imply to one not familiar with the wire art. On the contrary, small amounts of phosphorus within the conventional residual range, but no more than about 0.015 percent, is deemed essential in achieving ultra-high strengths due to its work-hardening effect in combination with the carbon.

With careful processing, steels within the above-described composition ranges can be drawn into fine wires having tensile strengths in the 200 to 500 Ks.i. range. With still greater care in processing, the strength can be increased above 500 Ks.i., but such wires typically possess sporadic embrittlement as a result of the extreme cold reduction required.

SUMMARY OF THE INVENTION

This invention is predicated upon our discovery that substantially higher tensile strengths can be achieved, and without complete loss of ductility, if even closer carbon limits are imposed, and if residual impurities and phosphorus are reduced to exceptional low levels. In direct conflict with prior art beliefs, therefore, we have learned that a phosphorus content reduced below conventional residual levels, will not reduce the attainable tensile strength as has been heretofore believed, but rather will enhance attainable strength substantially by permitting more severe drawing, and in addition, will provide a considerable degree of ductility at the elevated strength levels.

It is, therefore, an object of this invention to provide a new and improved cold drawn steel wire having tensile strengths substantially in excess of levels heretofore attainable, and yet retaining a substantial degree of ductility.

It is another object of this invention to provide a new and unique low phosphorus, low nitrogen composition for steel wire which has a high capacity for cold working and may be drawn into wire of fine gauge and ultra high strengths without complete loss of ductility.

It is a further object of this invention to provide an ultra high strength steel wire exhibiting tensile strengths in excess of 500 Ks.i. and characterized by a ductile mode fracture when stressed to fracture.

BRIEF DESCRIPTION OF THE DRAWING

The attached drawing is a logarithmic graph illustrating typical tensile strengths attainable in cold drawn wire as a function of wire diameter. The heavy lower line represents the typical tensile strengths of prior art ultra high strength wires, while the finer upper line represents typical tensile strengths of a wire according to this invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Steel wire in accordance with this invention consists essentially of 0.9 to 1.10 percent, preferably 0.93 to 0.98 percent carbon, 0.3 to 0.6 percent manganese, preferably 0.35 to 0.45 percent manganese, not more than 0.010 percent sulfur, preferably not more than 0.005 percent sulfur, not more than 0.005 percent phosphorus, not more than 0.10 percent silicon, not more than 0.002 percent nitrogen, and the balance substantially iron. Normal impurities and other elements (e.g. aluminum) may be present or added to perform their known functions. The above required levels for phosphorus, sulfur and nitrogen, are, of course, below the normal residual levels readily attainable by convention steel making procedures. However, these low levels can easily be achieved by procedures which are known to the steel industry. For example, the more advanced refining techniques such as electric furnaces and basic oxygen furnaces should be used in preference to open hearth furnaces. The essential low sulfur and phosphorus contents can then be achieved by careful selection of raw materials used in making such a heat of steel. That is, the operator must carefully select ore and blast furnace coke having total sulfur and phosphorus contents below the specified content. As an alternative, there are several known procedures for desulfurizing and dephosphorizing steel. For examples thereof see U.S. Pat. No. 1,472,006 and 2,015,692. Insofar as nitrogen is concerned, it is well accepted that conventional vacuum degassing equipment available in most steel producing plants can be used to reduce nitrogen contents to 0.002 percent or less.

In contrast to prior art steel wire the above described steel wire composition not only has a higher capacity for cold reduction without embrittlement, as might be anticipated due to the lower phosphorus content, but such wire will also exhibit substantially greater ductility at comparable degrees of cold reduction.

It is obvious, therefore, that the composition of this invention not only provides an enhanced strength as contrasted to prior art wires of comparable diameter (i.e. comparable cold reduction), but can be drawn more extensively to produce still higher strength levels in finer wire diameters. As shown in the drawing, prior art high-carbon, ultra-high-strength wires typically exhibit tensile strengths which vary proportionally from about 250 to about 500 Ks.i. when cold drawn to wire diameters of from 0.25 to 0.002 inch. Over the same range of cold drawing, the wire of this invention exhibits tensile strengths ranging proportionally from about 350 to over 650 Ks.i. This represents a tensile strength increase of over 30 percent. In addition, wires according to this invention can be drawn to 0.001 inch which exhibits a tensile strength of about 700 Ks.i. and will still retain some degree of ductility.

Within the more common wire diameter range, i.e. 0.25 to 0.010 inch, most prior art high-strength wires will have some substantial degree of ductility. However, at diameters finer than about 0.010 inch, or at cold reductions in excess of about 80 percent prior art wires typically possess sporadic embrittlement as a result of the extreme cold reduction required. As noted above, the wire of this invention has a high capacity for cold reduction, and therefore embrittlement problems are not encountered as soon as with the prior art steels. Accordingly, the wire of this invention has a particularly useful combination of properties in that tensile strengths exceeding 500 Ks.i. are readily achieved without complete loss of ductility. Even at tensile strengths of about 600 Ks.i., representative of about 0.005-inch wire, wire will exhibit ductile mode fracture when stressed to fracture. The term "ductile mode fracture" as used herein refers to the type of fracture typical of ductile steels wherein the fracture area is characterized by a necked-down cup and cone region even when tested in 100 foot increments of wire. A ductile mode fracture would represent at least about a 40 to 45 percent reduction in area.

To further illustrate the advantages of this invention, the detailed characteristics of this wire are below contrasted to a control composition having normal levels of sulfur, nitrogen, phosphorus and silicon but which had virtually the same high carbon and manganese content. The chemical compositions of the two steels in the subsequent example were as follows:

	Control Steel	New Steel
%C	0.95	0.94
%Mn	0.41	0.043
%P	0.012	0.003
%S	0.026	0.004
%Si	0.20	0.065
%N	0.004	0.002
%Al	0.022	0.036

The response of the steels to the cold work were comparable; however, the steel in accordance with the invention demonstrated the ability to accept cold work to a remarkable degree, before experiencing embrittlement. A comparison of the two steels in drawing to wires in the coarser range of sizes is given in table I.

TABLE I

Starting Size	Maximum Reduction Possible		Added True Strain Possible New vs Conventional Steel
	Conventional Steel	New Steel	
11/32-inch rod	83%	94%	56%
0.220-inch wire	89%	96%	45%
0.102-inch wire	92%	98%	52%

Because the new steel will accept a greater strain, as shown in table I, this steel can obviously be drawn to higher strengths as shown in table II below.

TABLE II

Maximum Useful tensile Strengths (Ks.i.)

Wire Size	Conventional Steel	New Steel	Percent Increase
0.190	240	320	33
0.100	275	375	36
0.060	300	425	41
0.037	320	455	42
0.020	350	500	43

The onset of embrittlement is manifested by the appearance of brittle mode fractures upon conventional tensile testing. The brittle mode fracture, in contrast to ductile mode fracture, is an appearance typical of brittle material and, in such cases, the fracture area is not necked down and the fracture itself does not possess the typical cup and cone characteristic of ductile materials.

Steels of the above compositions were drawn into ultra-high-strength 5 mil diameter wires, and the incidence of brittle mode fractures in 100-foot tensile test specimens were determined. This is an extremely sensitive measurement of strength and ductility. The results are shown in table III.

TABLE III

Percent of Specimens Showing
Ductile Mode Fracture (30 to 40 Specimens)

Strength Level	Conventional Steel	New Steel
510 Ks.i.		100% ductile
520 Ks.i.	92% ductile	
540 Ks.i.	87% 102 ductile	
550 Ks.i.		96% ductile
570 Ks.i.	0% ductile	
580 Ks.i.		92% ductile

As can be seen above, ultra-high-strength steel wire in accordance with the invention can be cold worked to a remarkable degree in drawing intermediate size wires. Our steel may accept up to 50 percent greater reduction than an open hearth steel before becoming brittle.

It is apparent from the above that various changes may be made without departing from the invention.

We claim:

1. A high-strength steel wire consisting essentially of 0.9 to 1.10 percent carbon, 0.3 to 0.6 percent manganese, not more than 0.010 percent sulfur, not more than 0.005 percent phosphorus, not more than 0.1 percent silicon, not more than 0.002 percent nitrogen, and the balance substantially iron.

2. A steel wire according to claim 1 having a diameter of from 0.25 to 0.001 inch and an inversely proportional tensile strength of from about 350 to about 650 Ks.i.

3. A steel wire according to claim 1 containing 0.93 to 0.98 percent carbon, 0.35 to 0.45 percent manganese, and not more than 0.005 percent sulfur.

4. A steel wire according to claim 1 having a diameter of from 0.25 to 0.005 inch, an inversely proportional tensile strength of from about 350 to about 600 Ks.i., and sufficient ductility to display a ductile mode fracture.

5. A steel wire according to claim 1 having a diameter of about 0.005 inch, a tensile strength in excess of 500 Ks.i., and sufficient ductility to display a ductile mode fracture.

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