(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 2 025 769 A1

(12) **EUROPEAN PATENT APPLICATION**
published in accordance with Art. 153(4) EPC

(43) Date of publication:
18.02.2009 Bulletin 2009/08

(21) Application number: **07744836.3**

(22) Date of filing: **31.05.2007**

(51) Int Cl.:
C22C 38/00 *(2006.01)* ***B21B 3/00*** *(2006.01)*
C22C 38/04 *(2006.01)* ***C22C 38/54*** *(2006.01)*

(86) International application number:
PCT/JP2007/061497

(87) International publication number:
WO 2007/139234 (06.12.2007 Gazette 2007/49)

(84) Designated Contracting States:
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HU IE IS IT LI LT LU LV MC MT NL PL PT RO SE SI SK TR
Designated Extension States:
AL BA HR MK RS

(30) Priority: **01.06.2006 JP 2006153303**

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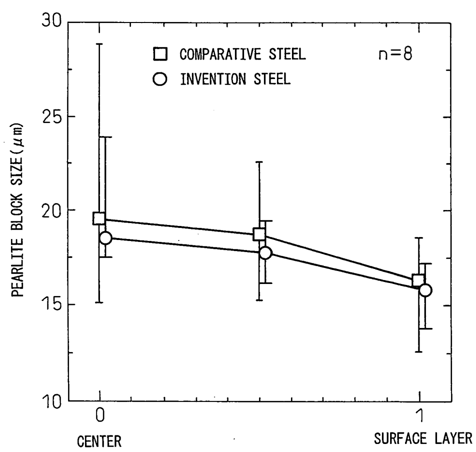
(54) HIGH-DUCTILITY HIGH-CARBON STEEL WIRE

(57) A high-carbon steel wire rod of high ductility for steel cord and the like is provided that experiences little breakage during drawing. The high-carbon steel wire rod of high ductility is a high-carbon steel wire rod fabricated by hot rolling that that has a carbon content of 0.7 mass% or greater, wherein 95% or greater of the wire rod metallographic structure is pearlite structure and the maximum pearlite block size of pearlite at the core of the hot-rolled wire rod is 65 μm or less. The high-carbon steel wire rod of high ductility has a tensile strength in a range of {248 + 980 x (C mass%)} $\pm$ 40 MPa} and a reduction of area of {72.8 - 40 x (C mass%) %} or greater. The high-carbon steel wire rod of high ductility is **characterized in that** the average pearlite block size at the core of the hot-rolled wire rod constituted by ferrite grain boundaries of an orientation difference of 9 degrees or greater as measured with an EBSP analyzer is 10 μm or greater and 30 μm or less.

Fig. 2



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Description

FIELD OF THE INVENTION

[0001] This invention relates to high-carbon steel wire rod of high post-hot-rolling ductility having a metallographic structure mainly of pearlite. Specifically, this invention relates to piano wire or high-carbon steel wire complying with JIS, more particularly to hot-rolled wire of high-carbon steel that, as the final product steel wire, is a fine wire of a diameter of around 0.1 to 2 mm usable, for example, in steel cord, saw wire, hose wire, fine rope and the like.

DESCRIPTION OF THE RELATED ART

[0002] Steel cords and other reinforcing wires used to reinforce rubber products such as tires, conveyor belts and heavy-duty hoses are manufactured from high-carbon steel wire rods. The high-carbon steel wire rods are manufactured by hot rolling, followed by descaling and then borax coating or Bonde coating to provide a carrier coating, whereafter processing to a steel wire of 0.8 to 1.2 mm is optionally conducted by use of intermediate patenting. As termed with respect to the present invention, the hot-rolled steels are called "wire rods" and the steels of smaller diameter than the hot-rolled steels fabricated by subsequent processing are called "steel wires."

[0003] When the steel wires are to be used for steel cord, the patenting is followed by brass plating and then further drawing to steel wires of 0.15 to 0.35 mm diameter, whereafter the wires are stranded into steel cord that is embedded in a rubber product for use. Research is being continued on, for example, improvement of workability in the secondary processing step and improvement of the abrasion property of the drawing dice.

[0004] Japanese Patent Publication (A) No. H3-60900, for example, teaches a wire rod whose C content is 0.59 to 0.86%, tensile strength is 87.5 x C equivalent + 27 $\pm$ 2 (kg/mm^2) (C equivalent = C + Mn/5), and area accounted for by coarse pearlite in the wire rod metallographic structure as measured under a microscope at x500 is adjusted to -60 x C equivalent + 69.5 $\pm$ 3 (%). This wire rod is directed to enabling the drawing dice to have excellent service life and increases dice service life by specifying tensile strength and controlling the volume fraction of coarse pearlite to within a certain range. Although this patent publication focuses on coarse pearlite structure with an eye to improving drawing dice service life, it teaches nothing whatsoever regarding relationship with the cause of breakage after direct drawing, which is the issue dealt with by the present invention.

[0005] Japanese Patent Publication (A) No. 2000-6810 teaches a high-carbon steel wire rod excellent in wire drawability wherein 90% or greater of the metallographic structure is pearlite structure, and the pearlite has an average lamellar spacing of 0.1 to 0.4 μm and an average colony diameter of 150 μm or less. The fact is, however, that the colony diameter obtained by ordinary hot rolling is smaller than 150 μm, and an improvement in breakage property cannot necessarily be expected because the ductility obtained when the colony diameter is controlled to 150 μm or less is inconsistent.

[0006] Japanese Patent No. 3681712 teaches a high-carbon steel wire rod excellent in drawability wherein 95% or greater of the wire rod metallographic structure is pearlite structure, the pearlite has an average nodule diameter (P) of 30 μm or less and an average lamellar spacing (S) of 100 nm or greater, and the value of F obtained by the equation

$$F = 350.3 / \sqrt{S} + 130.3 / \sqrt{P} - 51.7$$

is F > 0, where P is represented in μm and S in nm.

[0007] The invention taught by this patent publication controls the lamellar spacing and nodule size by incorporating a cooling process for isothermal holding during Stelmor cooling at the time of hot rolling. However, in ordinary Stelmor cooling the cooling is continuous, so that the range of lamellar spacing values is wide and the range of nodule size values also becomes wide. In such a case, good workability cannot be obtained no matter how small the average values are made, and what is more, a problem of attendant internal defects arises. Moreover, the patented invention is directed to obtaining a wire rod excellent in high-speed drawability by varying the cooling conditions after wire rod rolling so as to adjust the structure into the range of F defined by the foregoing equation. This is problematic, however, because bringing the structure into the range of the equation requires use of special heat treatment that is generally difficult to implement.

SUMMARY OF THE INVENTION

[0008] Owing to the importance of good economy in secondary processing, recent years have seen an increasing need for the development of wire rod that resists occurrence of internal defects during drawing and wire rod that even when processed with a relatively large amount of working during primary drawing does not experience an increase in breakage thereafter.

[0009] The present invention relates to high-carbon steel wire rod utilized as piano wire rod, hard steel wire rod and the like for use in finely drawn applications such as steel cord, belt cord, rubber hose wire, rope wire and the like, and in light of the foregoing circumstances, provides high-carbon steel wire rod of high ductility that is excellent in post-hot-rolling drawability, resists occurrence of internal defects at the time of drawing, and enables omission of intermediate patenting.

[0010] The inventors achieved the present invention based on the results of in-depth research regarding pearlite structure hot-rolled wire rod whose secondary processability is unaffected by omission of intermediate patenting. A summary of the invention follows:

1) A high-carbon steel wire rod of high ductility, which is a high-carbon steel wire rod having a carbon content of 0.7 mass% or greater, wherein 95% or greater of the wire rod metallographic structure is pearlite structure and maximum pearlite block size at a core of a cross-section perpendicular to the wire rod axis is 65 μm or less.
2) A high-carbon steel wire rod of high ductility according to 1), having a tensile strength in a range of {248 + 980 x (C mass%)} $\pm$ 40 MPa} and a reduction of area of {72.8 - 40 x (C mass%) %} or greater.
3) A high-carbon steel wire rod of high ductility according to 1) or 2), wherein an average pearlite block size at the core of the cross-section perpendicular to the wire rod axis is 10 μm or greater and 30 μm or less.
4) A high-carbon steel wire rod of high ductility according to any of 1) to 3), wherein the wire rod metallographic structure includes pro-eutectoid ferrite at a volume percentage of 2% or less.
5) A high-carbon steel wire rod of high ductility according to any of 1) to 4), wherein the wire rod comprises, in mass%, C: 0.7 to 1.1%, Si: 0.1 to 1.0%, Mn: 0.1 to 1.0%, P: 0.02% or less, S: 0.02% or less, and a balance of Fe and unavoidable impurities.
6) A high-carbon steel wire rod of high ductility according to 5), wherein the wire rod further comprises, in mass%, one or more of Cr: 0.05 to 1.0%, Mo: 0.05 to 1.0%, Cu: 0.05 to 1.0%, Ni: 0.05 to 1.0%, V: 0.001 to 0.1%, Nb: 0.001 to 0.1%, Ti: 0.005 to 0.1%, B: 0.0005 to 0.006%, O: 18 to 30 ppm, and N: 0 to 40 ppm.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011]

FIG. 1 shows correspondence between (a) cracks occurring during drawing in the case of conducting ordinary Stelmor processing and (b) pearlite block size.
FIG. 2 is shows change in pearlite block size between the surface and core of a rolled wire rod.

DETAILED DESCRIPTION OF THE INVENTION

[0012] The inventors discovered that when steel wire is drawn from wire rod to a wire diameter at which final patenting is conducted without conducting intermediate patenting, the steel wire may at first sight appear not to decline in ductility with increasing amount of working, but defects nevertheless occur internally and are promoted during the ensuing patenting and the drawing thereafter, sometimes leading to breakage.

[0013] Also in the case where severe working (i.e., working in terms of true strain equal to or exceeding 2) is conducted during primary drawing, it is necessary to ensure that the patenting and other ensuing processes are not affected by controlling the wire rod metallographic structure so as to prevent occurrence of internal defects in primary drawing to the utmost, and also to conduct primary drawing that minimizes occurrence of defects.

[0014] The inventors observed the internal defect sites after primary drawing and studied the associated conditions, which are complexly affected by numerous factors such as the mechanical properties, processing conditions and wire rod structure. As a result, they discovered that among these conditions, it is the pearlite block size of the pearlite structure at the core of the wire rod, as measured with an EBSP (Electron Back Scatter Pattern) analyzer, that characterizes the structure readily experiencing internal defects. A measurement method using an ordinary light microscope cannot accurately ascertain the pearlite block size and therefore does not enable determination of the structure that impairs workability. An EBSP analyzer must therefore be used to measure the pearlite block size.

[0015] Pearlite block size was measured with a system using a TSL (TexSEM Laboratories) EBSP analysis unit in combination with a Hitachi thermal FE-SEM (model S-4300SE). The pearlite block was measured with the EBSP analyzer as the region with the same ferrite crystal orientation, in accordance with the definition given by Takahashi et al. in The Journal of the Japan Institute of Metals, Vol. 42 (1978), p702. Since measurement using the structure observed with a light microscope or the secondary electron image obtained by SEM observation was found to be extremely difficult, the pearlite block size was determined from the ferrite crystal orientation map obtained by EBSP analysis. Differently from in the ferrite single phase of low-carbon steel, countless small angle boundaries are present in the ferrite crystal grains of pearlite steel, even after patenting.

[0016] An investigation was therefore made regarding an appropriate threshold angle above which the grain boundaries that have an orientation difference of 15 degrees or greater and can be recognized as ordinary crystal grain boundaries account for around 90% or greater of all grain boundaries. The best results were obtained when the grain boundaries were defined as those obtained using a boundary orientation difference of 9 degrees or greater. Units constituted by boundaries having orientation differences of 9 degrees or greater were therefore defined as pearlite block grains.

[0017] Through an extensive study of ways to control the pearlite block size, the inventors discovered that occurrence of coarse pearlite blocks can be prevented by control of oxygen amount along with control of post-rolling finish-rolling temperature so as to carry out Stelmor cooling with the γ grain size in a granulated state on the finish rolling exit side. When the γ grains are of mixed grain size, pearlite transformation occurs more readily at small γ grain regions, in which case the pearlite transformation nuclei are present heterogeneously, so that pearlite blocks grow easily to make the grain size large.

[0018] In order to make the γ grain size after finish rolling small, the steel is required to have an oxygen content of 18 ppm or greater, preferably 20 ppm or greater. However, increasing oxygen content increases the amount of inclusions and causes formation of large inclusions. As this degrades ductility, the upper limit of oxygen content is defined as 30 ppm.

[0019] When ordinary continuous cooling is used, the pearlite block size varies from the surface layer toward the center of the wire rod. And, as shown in FIG. 2, the pearlite block size varies at locations outward from the center also in the case where the ordinary Stelmor cooling process is conducted. In FIG. 2, each pearlite block size shown is the average of values measured at eight locations. Since the pearlite block size at the core differs greatly even when the average value is the same, the inventors studied what criteria should be used for the control in the case of continuous cooling. They learned that the pearlite lamellae are also coarse at the core region where the pearlite block size is large and that the coarse pearlite portions become starting points of breakage during drawing. Therefore, in order not to leave any defects following primary drawing, it is necessary to control the maximum value of the pearlite block size to 65 μm or less. An investigation of the relationship between the pearlite block size and the breakage index of the final drawn wire showed that making the pearlite block size at the core 65 μm or less improves drawability and enables reduction of wire breakage in the ensuing drawing process.

[0020] The reasoning behind specification of the average value of the pearlite block grains will now be explained. Owing to the use of continuous cooling, the pearlite block grains are present in a mixture of sizes. If the average pearlite block size is determined by simple averaging based on the measurement of pearlite block size made in this mixed condition, the numerous small pearlite blocks present will make the average value so small that it does not reflect the breakage property. The Johnson-Saltykov method of calculating the average diameter of particle groups of mixed particle size was therefore used to determine the average value of the obtained pearlite block size as the average of values at 8 sites in each of the wire rod surface layer, 1/4 diameter region and core region (1/2 diameter region), i.e., at a total of 24 sites. Details regarding the Johnson-Saltykov method can be found in Quantitative Microscopy, R.T. DeHoff and F.N. Rhines, Ed., McGraw Hill Publishers, New York, NY, 1968, p169.

[0021] When the obtained average value is 10 μm or less, achievement of pearlite structure of 95% or greater is difficult and the volume percentage of ferrite in the pearlite structure becomes 2% or greater. The average pearlite block size therefore needs to be made 10 μm or greater. Moreover, if the average value exceeds 30 μm, the probability of coarse blocks being included is very high in the case of continuous cooling, so that the average must be controlled to 30 μm or less.

[0022] At a tensile strength of less than {248 + 980 x (C mass%) - 40 MPa}, the lamellar spacing of the pearlite structure becomes so large as to make attainment of good workability impossible. The tensile strength must therefore be controlled to not less than {248 + 980 x (C mass%) - 40 MPa}. At a tensile strength of greater than {248 + 980 x (C mass%) + 40 MPa}, large work hardening makes post-drawing strength high so that ductility declines. The tensile strength must therefore be controlled to not greater than {248 + 980 x (C mass%) + 40 MPa}.

[0023] Reduction of area is preferably controlled to not less than {72.8 - 40 x (C mass%)}. At a reduction of area of less than 40%, internal defects occur readily during wire drawing. In order to keep the reduction of area from falling below 40%, the volume fraction of pro-eutectoid ferrite observed inside the wire rod obtained by Stelmor cooling is controlled to 2% or less. When present at a volume fraction exceeding 2%, the pro-eutectoid ferrite tends to act as starting points of internal defects during drawing and as starting points of internal defects during tensile testing. Pro-eutectoid ferrite is therefore controlled to 2% or less. Pro-eutectoid ferrite becomes a problem in the carbon content region below 0.85 mass%. In the carbon content region of 0.85 mass% and greater, pro-eutectoid ferrite is generally held to 2% or less owing to the presence of abundant carbon content.

[0024] The reasons for limiting the components of the steel of the high-carbon steel wire rod according to the present invention will now be explained. All contents are expressed in mass%.

[0025] C is an element that effectively enhances strength. For obtaining a high-strength steel wire, C content must be made 0.7% or greater. However, when C content is excessive, ductility tends to be lowered by ready precipitation of pro-eutectoid cementite. The upper limit of C content is therefore specified as 1.1%.

[0026] Si is an element required for deoxidation of the steel. Since the deoxidation effect is insufficient at too low a content, Si is added to a content of 0.1% or greater. Moreover, Si increases post-patenting strength by dissolving into the ferrite phase in the pearlite formed after heat treatment. But it also impairs heat treatability. It is therefore kept to a content of 1.0% or less.

[0027] P easily segregates and P concentrating at the segregation sites dissolves into the ferrite to lower workability. P content is therefore controlled to 0.02% or less.

[0028] S, if contained in a large amount, lowers the ductility of the steel by forming much MnS. It is therefore controlled to a content of 0.02% or less.

[0029] Mn is added to a content of 0.1% or greater in order to impart hardenability to the steel. However, heavy addition of Mn excessively prolongs transformation time during patenting. Addition is therefore limited to 1.0% or less.

[0030] Cr is added to enhance steel strength. When included, it is added to a content at which this effect is exhibited, namely to a content of 0.05% or greater, and to a content of 1.0% or less, namely to a content that does not give rise to a decrease in steel wire ductility.

[0031] Mo is added to enhance steel strength. When included, it is added to a content at which this effect is exhibited, namely to a content of 0.05% or greater, and to a content of 1.0% or less, namely to a content that does not give rise to a decrease in steel wire ductility.

[0032] Cu is added to enhance corrosion resistance and corrosion fatigue property. When included, it is added to a content at which these effects are manifested, namely to a content of 0.05% or greater. However, heavy addition tends to cause brittleness during hot rolling, so the upper limit is defined as 1.0%.

[0033] Ni has an effect of increasing steel strength. When included, it is added to a content at which the effect of addition is manifested, namely to a content of 0.05% or greater. However, since excessive addition lowers ductility, Ni content is held to 1.0% or less.

[0034] V has an effect of increasing steel strength. When included, it is added to a content at which the effect of addition is manifested, namely to a content of 0.001% or greater. However, excessive addition lowers ductility, so the upper limit is defined as 0.1%.

[0035] Nb has an effect of increasing steel strength. When included, it is added to a content at which the effect of addition is manifested, namely to a content of 0.001% or greater. However, excessive addition lowers ductility, so the upper limit is defined as 0.1%.

[0036] B has an effect of refining γ grain size during austenitization, and by this, of improving reduction and other ductility properties. Therefore, when included, B is added to a content at which its effect is manifested, namely to a content of 0.0005% or greater. However, addition to a content exceeding 0.006% makes the transformation time at the time that transformation is effected by heat treatment too long. The upper limit of B content is therefore defined as 0.006%.

[0037] As the production method for obtaining the high-carbon steel wire rod of high ductility according to the present invention, it is preferable in hot rolling a billet having the aforesaid chemical composition to conduct the hot rolling at a hot finish temperature of 800 ˚C or greater and 1050 ˚C or less, then carry out coiling at 800 to 830 ˚C within 10 seconds, and thereafter conduct Stelmor cooling or direct patenting by immersion in 500 to 570 ˚C molten salt.

EXAMPLES

[0038] The chemical compositions of specimen steels used in prototyping are shown Table 1. Steels No. 1 to No. 18 are of compositions controlled in accordance with the invention. Steels No. 19 and No. 20 are Comparative Steels. Comparative Steel 19 is lower in oxygen content than the Invention Steels and Comparative Steel 20 is higher in oxygen content than the Invention Steels.

[0039] The steels were prepared in a full-scale furnace to have the compositions shown in Table 2 and continuously cast into bloom of 500 x 300 mm cross-sectional dimensions. The bloom was thereafter reheated and rolled with a billeting mill to obtain a 122 mm-square billet. The steel was then reheated to the γ region, hot rolled to 5.5 mm-diameter wire rod, finish rolled, controlled to a coiling temperature of 850 to 900 ˚C in 10 seconds, and continuously subjected to Stelmor cooling divided into four zones. The wire rod manufacturing conditions are shown in Table 2. Table 2 also shows the mechanical properties and the maximum and average values of the measured pearlite block sizes of the wire rods obtained under the manufacturing conditions shown in the same Table.

[0040] Wire rods No. 1, No. 2 and, No. 6 to No. 21 in Table 2 were manufactured in accordance with the invention. Wire rods No. 3 to No. 5, No. 22 and No. 23 were manufactured for comparison.

[0041] In Table 2, the symbol ○ indicates that when, for the purpose of investigating primary drawability, the wire rod was drawn from the diameter of 5.5 mm to a diameter of 1.0 mm with the die approach angle at 20 degrees, neither breakage nor abnormality in the tensile tests conducted at the individual passes occurred. In addition, for the purpose of investigating secondary drawability, the wire rod was drawn from the diameter of 5.5 mm to a diameter of 1.56 mm, brass plated and further drawn from the diameter of 1.56 mm to a diameter of 0.2 mm, whereafter the 0.2 mm-diameter wire was subjected to drawing under a weight of 100 kg or greater to determine the wire breakage index. When the wire breakage index was good, it was designated by the symbol ○. In Table 2, the symbol X indicates that the result for the item concerned was unsatisfactory.

[0042] The invention wire rods No. 1, No. 2, and No. 6 to No. 21 exhibited good results for both primary drawability and secondary drawability.

[0043] Comparative wire rod No. 3, made with a comparative steel, had a maximum pearlite block size value exceeding 65 μm owing to the high finishing temperature and therefore exhibited poor results for both primary drawability and secondary drawability.

[0044] Comparative wire rod No. 4 had a maximum pearlite block size value exceeding 65 μm owing to the high coiling temperature and therefore exhibited poor results for both primary drawability and secondary drawability.

[0045] Comparative wire rod No. 5 had a tensile strength (TS) below the invention range because the air flow in Stelmor cooling was at a moderate level. In this case, too, poor results were exhibited for both primary drawability and secondary drawability.

[0046] Comparative wire rod No. 22 was made of a steel of a chemical composition whose oxygen content was below the invention range. The maximum value of the pearlite block size at the core region of the wire rod was greater than that defined by the invention.

[0047] Comparative wire rod No. 23 was made of a steel of a chemical composition whose oxygen content was below the invention range. Although the maximum value of the pearlite block size at the core region of the wire rod met the requirement of the invention, the total amount of inclusions was large owing to the high oxygen content and the secondary drawability was therefore low.

Table 1

Steel No.	C	Si	Mn	P	S	Cr	N	O	Other	Remark
1	0.72	0.19	0.49	0.010	0.009	-	21	23		Invention
2	0.82	0.18	0.51	0.010	0.007	-	21	24	-	Invention
3	0.92	0.19	0.51	0.008	0.008	-	19	23	-	Invention
4	0.92	0.19	0.31	0.009	0.009	0.21	19	24	-	Invention
5	0.96	0.19	0.31	0.008	0.009	0.22	20	22	-	Invention
6	1.02	0.19	0.31	0.009	0.009	0.19	19	23	-	Invention
7	0.92	0.90	0.32	0.009	0.008	0.19	29	21	B:0.002	Invention
8	1.02	0.90	0.60	0.009	0.009	0.1	29	23	-	Invention
9	1.02	0.90	0.32	0.009	0.009	0.1	34	23	Mg:0.05,B:0.0025	Invention
10	0.82	0.19	0.21	0.010	0.008	-	26	28	Mo:0.1	Invention
11	0.82	0.20	0.49	0.011	0.008	-	24	18	Cu:0.1	Invention
12	0.82	0.20	0.48	0.009	0.007	-	23	22	Ni:0.1	Invention
13	0.82	0.21	0.49	0.009	0.006	-	26	24	V:0.07	Invention
14	0.82	0.19	0.49	0.009	0.005	-	28	26	Nb:0.05	Invention
15	0.82	0.19	0.49	0.015	0.004	-	21	25	-	Invention
16	0.82	0.20	0.30	0.010	0.008	0.15	34	25	V:0.07,B:0.002	Invention
17	0.82	0.19	0.50	0.010	0.009	-	22	23	Ti:0.002,B:0.002	Invention
18	0.82	0.20	0.55	0.012	0.008	-	21	22	-	Invention
19	0.82	0.21	0.30	0.009	0.008	-	38	17	-	Comparative
20	0.82	0.20	0.32	0.010	0.008	-	23	45	-	Comparative

Table 2

Wire Rod No.	Steel No. (see Table 1)	Finishing temp (˚C)	Coiling temp (˚C)	Air flow (Stelmor vane opening)	TS (MPa)	RA (%)	Max pearlite block size (μm)	Average pearlite block size (μm)	Primary drawing	Secondary drawing	Remark
1	1	1048	890	All-100	1020	46	54	28	○	○	Invention
2	2	1045	880	All-100	1032	44	58	29	○	○	Invention
3	2	1120	890	All-100	1032	42	67	26	×	×	Comparative
4	2	1052	900	All-100	1101	41	67	27	×	×	Comparative
5	2	1049	890	50-50-100-100	1018	38	78	36	×	×	Comparative
6	3	1038	880	All-100	1124	39	43	23	○	○	Invention
7	4	1040	880	All-100	1132	38	54	25	○	○	Invention
8	5	1065	880	All-100	1190	36	57	28	○	○	Invention
9	6	1043	880	All-100	1220	34	58	26	○	○	Invention
10	7	1066	880	All-100	1116	38	62	25	○	○	Invention
11	8	1059	880	All-100	1215	37	61	25	○	○	Invention
12	9	1072	880	All-100	1253	36	64	26	○	○	Invention
13	10	1041	880	All-100	1063	43	56	27	○	○	Invention
14	11	1062	880	All-100	1074	44	59	28	○	○	Invention
15	12	1053	880	All-100	1076	42	58	24	○	○	Invention
16	13	1052	880	All-100	1058	41	57	25	○	○	Invention
17	14	1063	880	All-100	1062	41	62	24	○	○	Invention
18	15	1037	880	All-100	1088	45	63	27	○	○	Invention
19	16	1039	880	All-100	1087	43	61	26	○	○	Invention
20	17	1047	880	All-100	1071	44	57	26	○	○	Invention
21	18	1061	880	All-100	1066	43	54	28	○	○	Invention
22	19	1054	880	All-100	1054	41	72	31	×	×	Comparative
23	20	1067	880	All-100	1076	39	66	28	○	×	Comparative

[0048] The high-carbon steel wire rod of high ductility according to the present invention enables manufacture of excellent extra fine wire of high fatigue strength that is capable of reducing the weight and prolonging the service life of rubber products.

Claims

1. A high-carbon steel wire rod of high ductility, which is a high-carbon steel wire rod having a carbon content of 0.7 mass% or greater, wherein 95% or greater of the wire rod metallographic structure is pearlite structure and maximum pearlite block size at a core of a cross-section perpendicular to the wire rod axis is 65 μm or less.

2. A high-carbon steel wire rod of high ductility according to claim 1, having a tensile strength in a range of {248 + 980 x (C mass%)} ± 40 MPa} and a reduction of area of {72.8 - 40 x (C mass%) %} or greater.

3. A high-carbon steel wire rod of high ductility according to claim 1 or 2, wherein an average pearlite block size at the core of the cross-section perpendicular to the wire rod axis is 10 μm or greater and 30 μm or less.

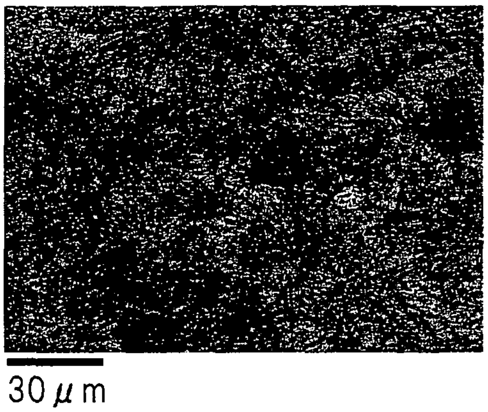
4. A high-carbon steel wire rod of high ductility according to any of claims 1 to 3, wherein the wire rod metallographic structure includes pro-eutectoid ferrite at a volume percentage of 2% or less.

5. A high-carbon steel wire rod of high ductility according to any of claims 1 to 4, wherein the wire rod comprises, in mass%, C: 0.7 to 1.1%, Si: 0.1 to 1.0%, Mn: 0.1 to 1.0%, P: 0.02% or less, S: 0.02% or less, and a balance of Fe and unavoidable impurities.

6. A high-carbon steel wire rod of high ductility according to claim 5, wherein the wire rod further comprises, in mass%, one or more of Cr: 0.05 to 1.0%, Mo: 0.05 to 1.0%, Cu: 0.05 to 1.0%, Ni: 0.05 to 1.0%, V: 0.001 to 0.1%, Nb: 0.001 to 0.1%, Ti: 0.005 to 0.1%, B: 0.0005 to 0.006%, O: 18 to 30 ppm, and N: 0 to 40 ppm.

Fig.1

(a)



(b)

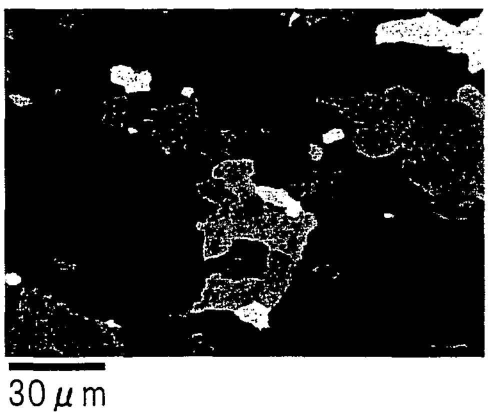
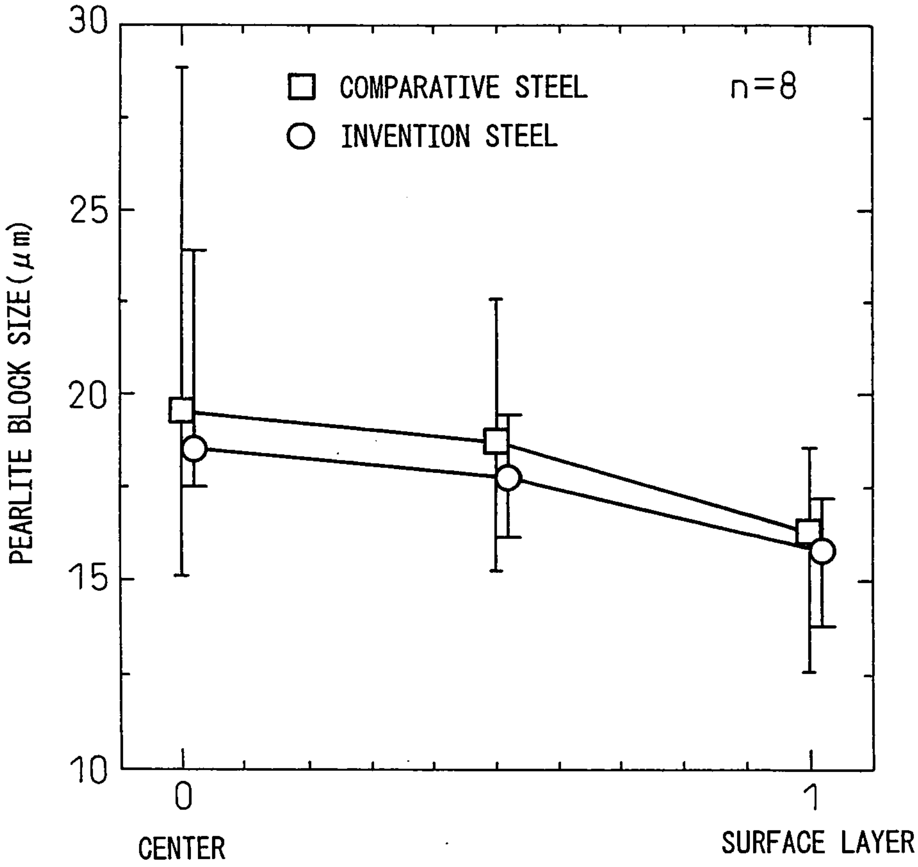


Fig. 2


30
25
20
15
10
PEARLITE BLOCK SIZE (μm)
COMPARATIVE STEEL
INVENTION STEEL
n=8
0
1
CENTER
SURFACE LAYER

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2007/061497

A. CLASSIFICATION OF SUBJECT MATTER
C22C38/00(2006.01)i, *B21B3/00*(2006.01)i, *C22C38/04*(2006.01)i, *C22C38/54*(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C22C38/00, B21B3/00, C22C38/04, C22C38/54

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2007
Kokai Jitsuyo Shinan Koho	1971-2007	Toroku Jitsuyo Shinan Koho	1994-2007

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
WPI

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	JP 2001-181790 A (Nippon Steel Corp.), 03 July, 2001 (03.07.01), Claims; Par. Nos. [0001], [0026] to [0036]; table 1 (Steel according to the present invention: 9) & WO 2001/046485 A1 & CN 1341155 A	1-4,6 5
Y	JP 2004-137597 A (Kobe Steel, Ltd.), 13 May, 2004 (13.05.04), Claims; Par. Nos. [0001] to [0006], [0085] to [0089]; tables 4, 5 (Steel Type Nos.1, 11, 12) & WO 2004/029315 A1 & CA 2500108 A & CN 1685072 A & EP 1577410 A1 & TW 228542 B & US 2006/48864 A1	5

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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- "&" document member of the same patent family

Date of the actual completion of the international search 31 July, 2007 (31.07.07)	Date of mailing of the international search report 21 August, 2007 (21.08.07)
Name and mailing address of the ISA/ Japanese Patent Office Facsimile No.	Authorized officer Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2007/061497

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2004-91912 A (Sumitomo Metal Industries, Ltd.), 25 March, 2004 (25.03.04), Full text (Family: none)	1-6
A	JP 2003-82434 A (Kobe Steel, Ltd.), 19 March, 2003 (19.03.03), Claims; Par. Nos. [0007], [0039] to [0042] & BR 202725 A & DE 60205825 T & EP 1277846 A1 & US 2003/79815 A1	1-6
A	JP 61-261436 A (Kawasaki Steel Corp.), 19 November, 1986 (19.11.86), Claims; page 3, upper left column, line 9 to page 4, upper left column, line 15 (Family: none)	1-6

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REFERENCES CITED IN THE DESCRIPTION

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- JP H360900 A **[0004]**
- JP 2000006810 A **[0005]**
- JP 3681712 B **[0006]**

Non-patent literature cited in the description

- **TAKAHASHI et al.** *The Journal of the Japan Institute of Metals,* 1978, vol. 42, 702 **[0015]**
- **JOHNSON-SALTYKOV.** Quantitative Microscopy. McGraw Hill Publishers, 1968, 169 **[0020]**