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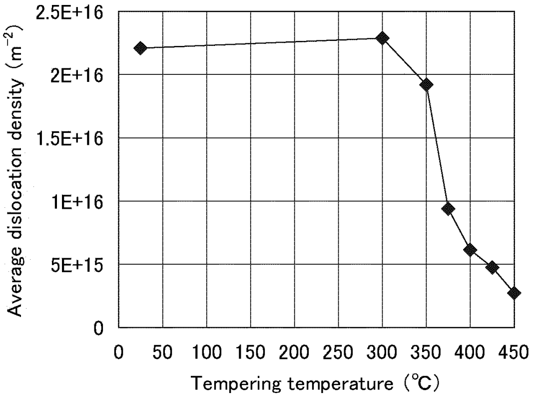
(54) STRENGTH MEMBER AND MANUFACTURING METHOD THEREFOR

(57) A strength member and a manufacturing method thereof in which settling resistance and yield strength can be substantially improved without reducing cost advantages or adding substantial process changes, is provided. A strength member comprises, by mass %, 0.5 to 0.7 % of C, 1.0 to 2.0 % of Si, 0.1 to 1.0 % of Mn, 0.1 to 1.0 % of Cr, 0.035 % or less of P, 0.035 % or less of S, and the balance of Fe and inevitable impurities, wherein an area ratio of bainite is 65 % or more, and an average dislocation density of a freely selected cross section is 2.0×10^{16} m^{-2} or less.

Fig. 2



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Description

BACKGROUND OF THE INVENTION

Technical Field

[0001] The present invention relates to a strength member and to a manufacturing method therefor having superior settling resistance and yield strength.

Background Art

[0002] For example, as a material for a strength member such as a valve spring for an automobile engine, in general, a Si-Cr steel oil tempered wire having a tempered martensite structure is widely used from a viewpoint of fatigue resistance or settling resistance. In contrast, Patent Document 1 discloses a technique in which larger plastic strain than that of the tempered martensite structure is applied without decreasing the fatigue resistance by forming fine bainite having superior ductility as a main structure after coiling. In this technique, the settling resistance is improved by reducing dislocation density, which has a negative effect on settling resistance, and by effectively fixing the dislocation using strain aging. Additionally, since the large plastic strain is applied by setting, large compressive residual stress is applied to the inside of the wire, and as a result, fatigue resistance can also be improved in addition to the settling resistance. Furthermore, the above technique also has an advantage in that manufacturing cost can be decreased, because inexpensive material can be used.

[0003] Patent Document 1 is Japanese Unexamined Patent Application Publication No. 2012-111992.

DISCLOSURE OF THE INVENTION

PROBLEMS SOLVED BY THE INVENTION

[0004] However, recently lower resource utilization of automobiles is required, and moreover, higher settling resistance or yield strength is also required in the strength members such as a spring, a bolt, etc.

[0005] Therefore, the present invention was completed in view of the above-described circumstances, and an object of the present invention is to provide a strength member and a manufacturing method therefor in which settling resistance and yield strength can be substantially improved without reducing cost advantages or adding substantial process changes.

MEANS FOR SOLVING THE PROBLEMS

[0006] The inventors have conducted various research in order to solve the above problems, and consequently, they have found that the martensite generated by water-cooling in the austempering treatment is decomposed into ferrite and cementite by tempering, the dislocation is decreased, and whereby the settling resistance is drastically improved. Additionally, in general, the structure is rapidly softened with the decrease of the dislocation in the martensite, and as a result, the fatigue strength is reduced. However, they have also found that the lowering of the fatigue strength due to the decrease of the hardness is not generated by using fine bainite as a main structure. Furthermore, since in the present invention the settling resistance is improved with increase of the yield strength, the present invention can be applied to screw members such as a bolt, tie rods, or the like, in which high yield strength is required.

[0007] The strength member according to the present invention was completed based on the above knowledge, and it comprises, by mass %, 0.5 to 0.7 % of C, 1.0 to 2.0 % of Si, 0.1 to 1.0 % of Mn, 0.1 to 1.0 % of Cr, 0.035 % or less of P, 0.035 % or less of S, and the balance of Fe and inevitable impurities, wherein an area ratio of bainite is 65 % or more, and an average dislocation density of a freely selected cross section is 2.0×10^{16} m^{-2} or less.

[0008] The manufacturing method of the strength member according to the present invention contains a forming process which forms a wire material in a product shape, a heat treatment process which austenizes at a temperature from an Ac3 point to (Ac3 point + 250 degrees C), cools at a cooling rate of 20 degrees C/second or more, maintains a temperature from (Ms point - 20 degrees C) to (Ms point + 60 degrees C) for 400 seconds or more, and cools to room temperature, and a tempering process in which the product after the heat treatment is maintained at a temperature from 350 to 450 degrees C, wherein the wire material comprises, by mass %, 0.5 to 0.7 % of C, 1.0 to 2.0 % of Si, 0.1 to 1.0 % of Mn, 0.1 to 1.0 % of Cr, 0.035 % or less of P, 0.035 % or less of S, and the balance of Fe and inevitable impurities. Here, the Ac3 point is a boundary temperature in which the material shifts from two-phase area of ferrite and austenite to single-phase area of austenite during heating, and the Ms point is a temperature at which martensite starts to be generated during cooling. When the strength member is a spring, it is desirable that the manufacturing method include a shot peening process in which shot is impinged on a product.

[0009] The present invention is not limited to a spring, and it can be applied to screw members such as a bolt or various strength members such as a tie rod which requires such strength.

[0010] According to the present invention, settling resistance and yield strength can be substantially improved without reducing cost advantages or adding substantial process changes, by reducing an average dislocation density on a freely selected cross section.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011]

Fig. 1 is a schematic view showing each process in a manufacturing method of the present invention.

Fig. 2 is a graph showing the relationship between a tempering temperature and an average dislocation density in Examples of the present invention.

Fig. 3 is a graph showing the relationship between a tempering temperature and a residual shearing strain in Examples of the present invention.

Fig. 4 is a graph showing the relationship between a tempering temperature and an inner strength of a spring wire in Examples of the present invention.

MODE FOR CARRYING OUT THE INVENTION

[0012] First, grounds of numerical limitation of chemical compositions of steels used in the present invention will be explained. In the following, terms "%" mean "mass %".

C: 0.5 to 0.7 %

[0013] C is an important element which ensures a desired strength, and it is necessary to contain 0.5 % or more in order to obtain such an effect. However, when C is excessively contained, it is difficult to obtain the desired strength since the content of retained austenite which is a soft phase is increased. Therefore, the C content is set to be 0.7 % or less.

Si: 1.0 to 2.0%

[0014] Si is an element which contributes to solid solution strengthening, and it is necessary to contain 1.0 % or more in order to obtain a desired strength. However, when Si is excessively contained, the strength is reversely decreased since the content of soft retained austenite is increased. Therefore, the Si content is set to be 2.0 % or less.

Mn: 0.1 to 1.0 %

[0015] Mn is a deoxidizing element added during refining and is also an element in which the strength can be easily improved by increasing hardenability of steel material, and it is necessary to contain 0.1 % or more in order to obtain a desired strength. In contrast, when Mn is excessively contained, workability is easily decreased by generating segregation. Therefore, the Mn content is set to be 1.0 % or less.

Cr: 0.1 to 1.0 %

[0016] Cr is an element in which the strength can be easily improved by increasing hardenability of a steel material. In addition, it also has a function in which pearlite transformation is delayed, and it is necessary to contain 0.1 % or more, since a bainitic structure can be stably obtained (a pearlite structure is suppressed) in cooling after austenitizing heating. However, when Cr is excessively contained, iron carbide is easily produced. Therefore, Cr content is set to be 1.0 % or less.

P, S: 0.035 % or less

[0017] P and S are elements in which intergranular fracture is promoted by grain boundary segregation. Thus, it is desirable that content thereof be as low as possible; however, they are inevitable impurities, and it is necessary to incur additional smelting cost in order to reduce the contents. Therefore, the upper limit is set to be 0.035 %. It is preferable that the contents of P and S be 0.01 % or less.

[0018] Next, grounds of numerical limitation of area ratio of bainite in total structures will be explained.

Bainite: 65 % or more

[0019] The bainite is generally a metallic structure in which austenitized steel material is isothermal-transformed at a temperature range from martensitic transformation start temperature to about 550 degrees C, and it is made of bainitic ferrite and iron carbide. The strength can be increased by bainite structure, even if the hardness is decreased by reducing dislocation in martensite, since the bainitic ferrite in matrix has high dislocation density and the iron carbide has a precipitation strengthening effect.

[0020] According to the manufacturing method of the present invention, austenitized steel material is isothermal-held at a temperature close to an Ms point, and as a result, the bainite structure has a structure in which iron carbide is finely deposited in fine bainitic ferrite matrix, lowering of the grain boundary strength is small, and lowering of toughness and ductility is small, even if the strength is high. Therefore, the dislocation density can be decreased without generating defects such as cracks which have a negative effect on fatigue resistance, even if large plastic strain is applied. As described above, the bainite is an essential structure for obtaining high intensity and high ductility, it is desirable that area ratio thereof be higher, and it is necessary that it be 65 % or more in order to obtain high toughness and high ductility.

[0021] In addition, non-transformed austenite in isothermal holding changes to martensite or retained austenite by cooling to room temperature. The area ratio of bainite of not more than 65 % means that isothermal holding time is too short, and the area ratio of martensite is increased by cooling, since the degree of concentration of C in non-transformed austenite in this condition is low. Therefore, when the area ratio of bainite is not more than 65 %, the strength is increased by increasing the area ratio of martensite; however, since notch sensitivity is remarkably increased, the large plastic strain cannot be applied, and the settling resistance is not improved.

[0022] Here, shear strain generated by processing easily remains since the retained austenite is soft. Therefore, an amount of the retained austenite is an index which relates to an amount of the residual shearing strain, and the settling resistance is decreased when the amount of the retained austenite is excessive. It is desirable that the area ratio of the retained austenite be set to be 6.5 % or less from this point of view.

[0023] In addition, it is desirable that Vickers hardness at the center of a freely selected cross section of a product be 450 HV or more in order to ensure strength that can withstand a load required of the product. In contrast, when the hardness is excessively high, an amount of stretch is reduced and the notch sensitivity of steel material is increased, and large plastic strain cannot be applied. Therefore, it is desirable that the Vickers hardness be 650 HV or less.

[0024] Next, a manufacturing method of the strength member of the present invention will be explained with reference to a spring as an example. Fig. 1A is a schematic view showing a manufacturing method of an embodiment of the present invention, and Fig. 1B is a schematic view showing a conventional manufacturing method. The steel material having the above chemical composition is subjected to, for example, a coiling process, and a seat surface grinding process in which both end surfaces of the spring are ground, as necessary, and it is austenitized at a temperature range from an Ac3 point to (Ac3 point + 250 degrees C). Then, it is subjected to a heat treatment process which cools at a rate of 20 degrees C/second, is maintained in a temperature range from (Ms point □ 20 degrees C) to (Ms point + 60 degrees C) for 400 seconds or more, and cools to room temperature at a cooling rate of 20 degrees C/second. Next, it is tempered at 350 to 450 degrees C, and it is subjected to a shot peening process, and a setting process, as necessary, and thereby, a spring is produced. A structure of the steel material before heating at an Ac3 point or more is not limited. For example, hot-forged bar steel material or wire-drawn bar steel material can be used. In the following, each process will be explained, and grounds of numerical limitation thereof will be described as necessary.

Coiling Process

[0025] The coiling process is a process which cold forms in a desired coil shape. A forming method may use a method using a spring forming machine (a coiling machine), a method using core metal, or the like. Here, optional springs such as a leaf spring, a torsion bar, a stabilizer, etc., can be applied in addition to the coil spring.

Seat Surface Grinding Process

[0026] This process is carried out as necessary, and it is a process which grinds both end surfaces of the spring so as to form a perpendicular surface to an axial core of the spring.

Heat Treatment Process

[0027] The coiled spring is austenitized, is isothermal-held, and then, is cooled, and therefore, the heat treatment process is completed. A structure of the steel material before austenizing is not limited. For example, hot-forged bar steel material or wire-drawn bar steel material can be used. It is necessary that an austenizing temperature be in a range from an Ac3 point to (Ac3 point + 250 degrees C). When the austenizing temperature is at an Ac3 point or less, a structure of the material is not changed to austenite. In contrast, when it exceeds (Ac3 point + 250 degrees C), there is a problem in that prior austenite grains are easily coarsened and the ductility is lowered.

[0028] The higher the cooling rate to an isothermal holding temperature after austeniting, the better the structure of the material, and it is necessary that the cooling rate be 20 degrees C/second or more, and it is preferable that it be 50 degrees C/second or more. When the cooling rate is not more than 20 degrees C/second, pearlite is generated during cooling, and as a result, bainite having an area ratio of 65 % or more cannot be obtained. It is necessary that the isothermal holding temperature be in a range from (Ms point □ 20 degrees C) from (Ms point + 60 degrees C), and the temperature is a very important controlling element in a manufacturing method for realizing spring steel material and springs of the present invention. When the isothermal holding temperature is not more than (Ms point □ 20 degrees C), since an amount of martensite generated in a transformation initial stage is large, improvement in the ductility is inhibited, and moreover, bainite having area ratio of 65 % or more cannot be obtained. In contrast, the isothermal holding temperature exceeds (Ms point + 60 degrees C), since the bainite is coarsened, the tensile strength is lowered, and the strength which withstands load as a spring cannot be obtained. Furthermore, fine bainite can be deposited by isothermal holding at a temperature close to the Ms point as described above. By depositing the fine bainite, fine spaces are retained in the austenite, and fine retained austenite grains are formed.

[0029] The bainite is deposited in the austenite by isothermal-holding. It is necessary that the isothermal holding time be 400 seconds or more, and this time is also a very important controlling element in the manufacturing method of the present invention. When the isothermal holding time is not more than 400 seconds, the bainitic transformation is not sufficiently progressed, and as a result, the area ratio of bainite is small and is not more than 65 %. Here, an amount of generated bainite is saturated, even if the isothermal holding time is excessively long, and as a result, production cost is increased. Therefore, it is desirable that the isothermal holding time be set to be 3 hours or less.

[0030] The higher the cooling rate after isothermal-holding, the more uniform the structure. It is preferable that the cooling rate be 20 degrees C/second or more, and it is more preferable that it be 50 degrees C/second or more. Specifically, oil cooling or water-cooling is preferably used.

Tempering Process

[0031] The tempering process which retains the spring at 350 to 450 degrees C is carried out after the heat treatment process. When the tempering temperature is not more than 350 degrees C, the martensite is not sufficiently decomposed, and the dislocation is insufficiently decreased. In contrast, when the tempering temperature exceeds 450 degrees C, the inner hardness of the spring is remarkably decreased, and the strength and fatigue strength are reduced. It is desirable that the tempering temperature be 400 degrees C or less in order to prevent the inner hardness of the spring from extremely decreasing. It is desirable that the tempering time be 25 to 60 minutes. When the tempering time is not more than 25 minutes, the tempering is insufficient, and in contrast, when the tempering time exceeds 60 minutes, the tempering is uneconomical.

Shot Peening Process

[0032] Shot peening is a method in which compressive residual stress is applied to a surface of a spring by striking with shot made of metal, sand, etc., and whereby the fatigue resistance of the spring is remarkably improved. In the present invention, higher and deeper compressive residual stress is formed by strain induced martensitic transformation of retained austenite, in addition to the compressive residual stress obtained by usual shot peening. As a shot used in the shot peening, cut wire, steel balls, high hardness particles made of FeCrB based material, etc., and the like, can be used. In addition, the compressive residual stress can be adjusted by efficacy, average sphere equivalent diameter, shooting rate, shooting time, and multistep shooting system of the shot.

Setting Process

[0033] The setting is optionally carried out by applying the plastic strain in order to remarkably improve elastic limit and reduce a settling amount (permanent deforming amount) in using. In this case, the settling resistance can be further improved by carrying out the setting (hot setting) at 200 to 300 degrees C. Furthermore, the retained austenite is strain-induced-transformed by setting, and it is expected to form martensite having higher strength. Therefore, the fatigue resistance can be further improved by applying high compressive residual stress due to volume expansion with the transformation.

EXAMPLES

First Example

[0034] A Si-Cr steel oil tempered wire (diameter: 4.1 mm) made of representative chemical composition described in Table 1 was cold-coiled in a fixed shape by a coiling machine, and then, it was subjected to a heat treatment (an austemper treatment). In the heat treatment, a spring was austenitized by retaining at 830 degrees C in a heating furnace for 12 minutes and was water-cooled, and then, it was retained in a salt bath maintained at 300 degrees C for 40 minutes and was cooled.

Table 1

C	Si	Mn	P	S	Cr
0.57	1.47	0.67	0.01	0.007	0.68

[0035] Next, the spring was subjected to tempering at a temperature shown in Table 2. The tempering was carried out for 60 minutes. In addition, in a shot-peening, steel shot having a sphere-equivalent diameter of 0.1 to 1.0 mm were used. Furthermore, the spring was heated at 200 to 300 degrees C, and was subjected to setting. With respect to the obtained spring, the following characteristics were researched in manners described below.

Table 2

No.	Tempering temperature (°C)	Inner hardness (HV)	Average dislocation density (m^{-2})	Residual shearing strain (10^{-4})	Area ratio of bainite (%)	Area ratio of retained austenite (%)	
1	None	587	2.21E+16	9.17	83.5	7.3	Comparative Example
2	300	584	2.29E+16	6.82	83.5	6.6	Comparative Example
3	350	571	1.92E+16	6.55	83.5	6.5	Example
4	375	568	9.39E+15	6.00	83.5	5.9	Example
5	400	555	6.13E+15	5.24	83.5	5.1	Example
6	425	509	4.75E+15	5.72	83.5	3.9	Example
7	450	469	2.72E+15	6.34	83.5	0	Example

Distinguishing of Phases

[0036] The phases were distinguished in the following manner using structures in samples soaked in 3% nital solution for several seconds. First, bainite is seen as black or gray in an optical microscope photograph since it is easily corroded by the nital solution, and in contrast, retained austenite is seen as white in an optical microscope photograph since it has high corrosion resistance to the nital solution. Using these characteristics, total area ratio of the bainite (black and gray portions) and the retained austenite (white portion) was calculated by image processing of the optical microscope photograph. The area ratio of the retained austenite of buffing finished samples was obtained using an X-ray diffraction method. Here, in Table 2, residual structure of the bainite and the retained austenite is martensite in Nos. 1 and 2, and it is ferrite and cementite in Nos. 3 to 7.

Vickers Hardness at Center

[0037] The Vickers hardness was measured at 5 points at the center portion of a cross section of the samples, and an average value thereof was calculated.

Average Dislocation Density

[0038] The average dislocation density ρ was calculated by the following Equation 1 using strain ε referring to document

("Evaluation Method of dislocation density using X-ray diffraction" in Material and Process: Iron and Steel Inst. of Japan lecture proceedings 17 (3), pages 396-399).

Equation 1

$$\rho = 14.4\ \varepsilon^2 / b^2$$

[0039] Here, b is a Burgers vector (= 2.5×10^{-10} m). Diffraction peaks of (110), (211) and (220) of ferrite were measured at the center portion of a cross section of the samples, by X-ray diffraction equipment (trade name: D8 DISCOVER produced by Bruker Corporation) using 0.3 mm collimeter, and then, using half width β of each peak, $\beta\cos\theta / \lambda$ and $\sin\theta / \lambda$ of each diffraction peak was plotted on a vertical axis and a horizontal axis of a graph, according to the following Equation 2, and inclination 2ε of an approximate curve thereof was obtained, and therefore, the strain ε was calculated.

Equation 2

$$\beta\cos\theta / \lambda = 0.9 / D + 2\varepsilon\sin\theta / \lambda$$

[0040] Here, θ is a half value of X-ray diffraction peak position 2θ, λ is a wavelength of $K\alpha_1$ wave of the tubular bulb which is used as an X-ray emission source, and D is a size of crystallite.

Residual Shearing Strain

[0041] The residual shearing strain is an index which shows settling resistance of a spring. The lower the residual shearing strain, the better the settling resistance. In a settling test of the spring, the sample was compressed and fixed by adding load so that the maximum shear stress was 1,050 MPa, and it was soaked in silicone oil at 165 degrees C. The sample was taken out from the silicone oil after soaking for 24 hours, and the load was released after cooling to room temperature. The load when the spring was compressed to a given height was measured before and after the above settling test, the load reduction amount ΔP was substituted to the following Equation 3, and therefore, the settling amount was obtained.

Equation 3

$$\gamma = \{8D / (\pi d^3 G)\} \times \Delta P$$

[0042] Here, D is an average coil diameter, d is a wire diameter, and G is a modulus of transverse elasticity (= 78,500 MPa).

[0043] The results measured as described above are shown in Table 2, and the relationships between measured values and tempering temperature are shown in Figs. 2 to 4. As shown in Fig. 2, it was confirmed that the average dislocation density rapidly decreased so as to be 2.0×10^{16} m^{-2} or less, when the tempering temperature was 350 degrees C or more. Accordingly, as shown in Fig. 3, it was confirmed that the residual shearing strain also rapidly decreased so as to be 6.7×10^{-4} or less, when the tempering temperature was 350 degrees C or more. The smaller the residual shearing strain, the higher the settling resistance, since the residual shearing strain is an index of the settling resistance. Furthermore, as shown in Fig. 4, it was confirmed that the inner hardness of the spring rapidly decreased, when the tempering temperature exceeded 400 degrees C.

[0044] As described above, it was confirmed that settling resistance could be improved by reducing the residual shearing strain to be 6.7×10^{-4} or less, when the average dislocation density was decreased to be 2.0×10^{16} m^{-2} or less.

Second Example

[0045] A Si-Cr steel hard-drawn wire rod (diameter: 6.0 mm), made of a representative chemical composition in Table 1, was cut off to a predetermined size, and it was subjected to head forging and thread rolling to form a bolt, and it was subjected to heat treatment (austempering treatment). In the heat treatment, the bolt was austenitized by retaining in a heating furnace at 830 degrees C for 12 minutes and was water-cooled, and then, it was retained in a salt bath maintained at 300 degrees C for 40 minutes, and was cooled.

[0046] Next, the bolt was subject to tempering at a temperature shown in Table 3. The tempering was carried out for

60 minutes. With respect to the obtained bolt, inner hardness, average dislocation density and area ratio of bainite were tested in the same manner as those of Example 1, and tensile strength and 0.2% yield strength were measured by a tension tester. These results are shown in Table 3.

Table 3

No.	Tempering temperature (°C)	Inner hardness (HV)	Average dislocation density (m^{-2})	Area ratio of bainite (%)	Area ratio of retained austenite (%)	Tensile strength (MPa)	0.2% yield strength (MPa)	Yield ratio (0.2% yield strength / tensile strength)	
1	None	585	2.25E+16	82.0	8.1	1806	1377	0.76	Comparative Example
2	300	586	2.13E+16	82.0	7.0	1799	1398	0.77	Comparative Example
3	350	570	1.86E+16	82.0	6.4	1749	1711	0.98	Example
4	375	563	9.15E+15	82.0	6.1	1736	1700	0.98	Example
5	400	557	5.87E+15	82.0	5.2	1698	1652	0.97	Example
6	425	504	4.50E+15	82.0	4.1	1577	1515	0.96	Example
7	450	459	2.38E+15	82.0	0	1499	1410	0.97	Example

[0047] As shown in Table 3, in the bolt according to the Example of the present invention, it was confirmed that the high yield ratio could be obtained by decreasing the average dislocation density to be 2.0×10^{16} m^{-2} or less.

[0048] The present invention can be applied to springs such as a coiled spring, a leaf spring, a torsion bar, and a stabilizer; screw members such as a bolt; or strength members such as a tie rod in which strength is required.

Claims

1. A strength member comprising, by mass %, 0.5 to 0.7 % of C, 1.0 to 2.0 % of Si, 0.1 to 1.0 % of Mn, 0.1 to 1.0 % of Cr, 0.035 % or less of P, 0.035 % or less of S, and the balance of Fe and inevitable impurities,
   wherein an area ratio of bainite is 65 % or more, and an average dislocation density of a freely selected cross section is 2.0×10^{16} m^{-2} or less.

2. The strength member according to claim 1, wherein Vickers hardness at the center of a freely selected cross section of a product is 450 to 650 HV.

3. A manufacturing method of a strength member, comprising:

   a forming process which forms wire material in a product shape,
   a heat treatment process which austenizes at a temperature from an Ac3 point to (Ac3 point + 250 degrees C), cools at a cooling rate of 20 degrees C/second or more, maintains a temperature from (Ms point - 20 degrees C) to (Ms point + 60 degrees C) for 400 seconds or more, and cools to room temperature, and
   a tempering process in which the product after the heat treatment is maintained at a temperature from 350 to 450 degrees C,
   wherein the wire material comprises, by mass %, 0.5 to 0.7 % of C, 1.0 to 2.0 % of Si, 0.1 to 1.0 % of Mn, 0.1 to 1.0 % of Cr, 0.035 % or less of P, 0.035 % or less of S, and the balance of Fe and inevitable impurities.

4. The manufacturing method of a strength member according to claim 3, further comprising a shot peening process in which shot is impinged on a product, after the tempering process.

5. The manufacturing method of a strength member according to claim 3 or 4, wherein a cooling rate in cooling to room temperature is 20 degrees C/second or more.

6. The manufacturing method of a strength member according to claim 4, further comprising a setting process which applies permanent strain to the product, after the shot peening process.

Fig. 1A

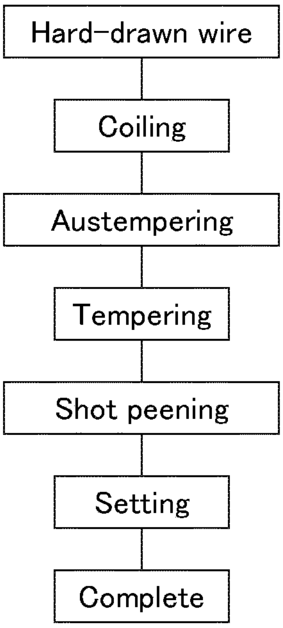


Fig. 1B

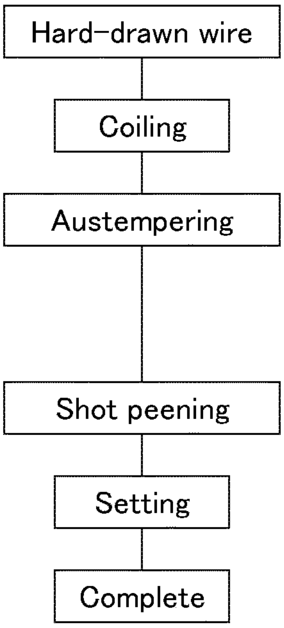


Fig. 2

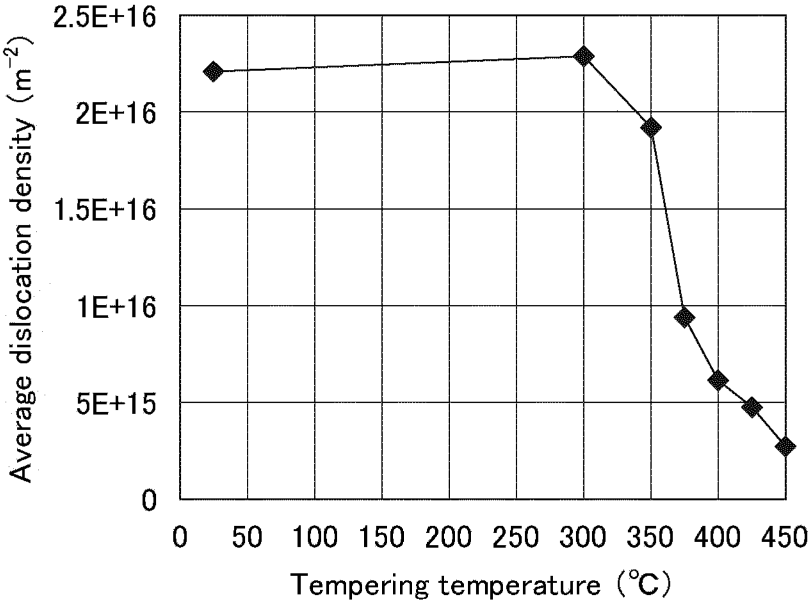


Fig. 3

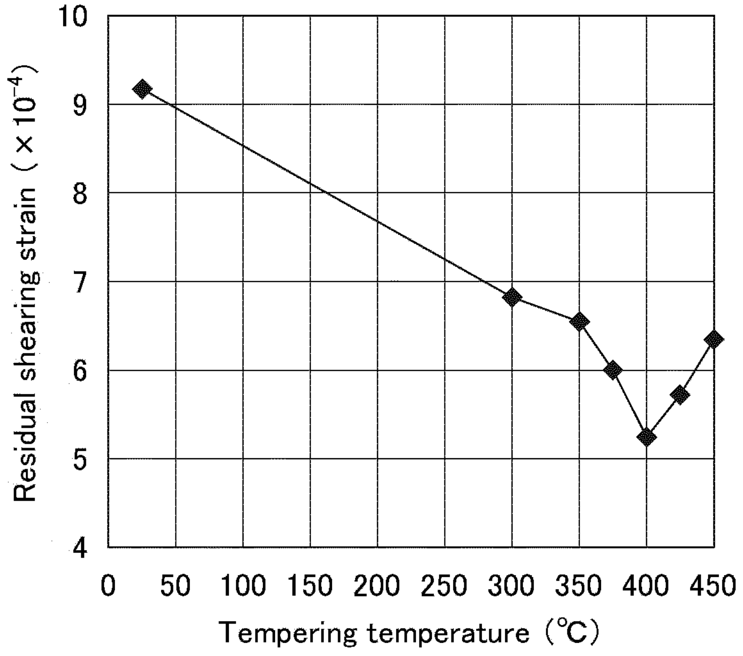
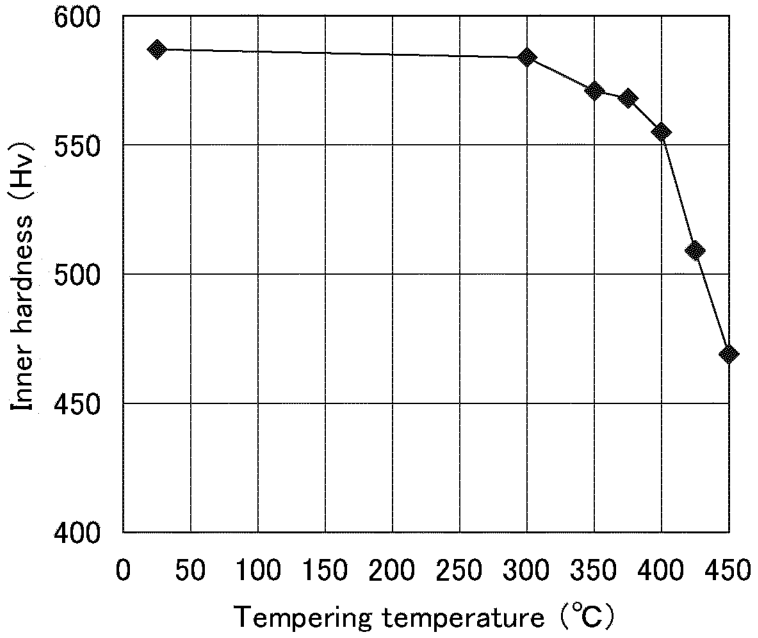

10
9
8
7
6
5
4
Residual shearing strain (×10⁻⁴)
0
50
100
150
200
250
300
350
400
450
Tempering temperature (℃)

Fig. 4


600
550
500
450
400
Inner hardness (Hv)
0
50
100
150
200
250
300
350
400
450
Tempering temperature (℃)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2014/056057

A. CLASSIFICATION OF SUBJECT MATTER
C22C38/00(2006.01)i, *C21D7/06*(2006.01)i, *C21D7/10*(2006.01)i, *C21D9/02*(2006.01)i, *C22C38/34*(2006.01)i, *F16F1/02*(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)
C22C38/00-38/60, C21D7/06, C21D7/10, C21D9/02, F16F1/02

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	1996-2014
Kokai Jitsuyo Shinan Koho	1971-2014	Toroku Jitsuyo Shinan Koho	1994-2014

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2012-111992 A (NHK Spring Co., Ltd.), 14 June 2012 (14.06.2012), entire text & WO 2012/018144 A1 & US 2013/0118655 A1 & EP 2602350 A1 & CN 103025904 A & KR 10-2013-0137137 A	1-6
A	JP 60-5820 A (Nisshin Steel Co., Ltd.), 12 January 1985 (12.01.1985), claims; examples (Family: none)	1-6
A	JP 2012-214859 A (NHK Spring Co., Ltd.), 08 November 2012 (08.11.2012), claims & WO 2012/133885 A1	1-6

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search 28 May, 2014 (28.05.14)	Date of mailing of the international search report 10 June, 2014 (10.06.14)
Name and mailing address of the ISA/ Japanese Patent Office Facsimile No.	Authorized officer Telephone No.

Form PCT/ISA/210 (second sheet) (July 2009)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2014/056057

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 7-292442 A (Nippon Steel Corp.), 07 November 1995 (07.11.1995), claims (Family: none)	1-6

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- JP 2012111992 A **[0003]**

Non-patent literature cited in the description

- Evaluation Method of dislocation density using X-ray diffraction. *Material and Process: Iron and Steel Inst. of Japan lecture proceedings,* vol. 17 (3), 396-399 **[0038]**