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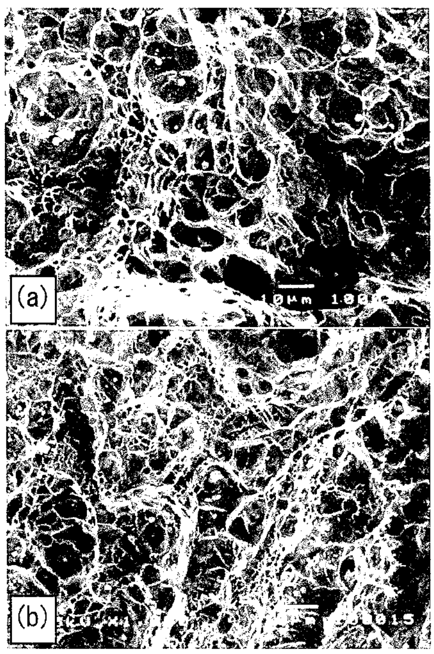
(54) FREE-CUTTING STAINLESS-STEEL MATERIAL FOR PRECISION PROCESSING AND PROCESS FOR PRODUCING SAME

(57) The present invention provides a free-cutting stainless steel material for precision machining capable of attaining all of excellent cutting accuracy, machinability, corrosion resistance, and environmental friendliness at the same time and a method for producing the same material. The free-cutting stainless steel material for precision machining of the present invention is used for forming performed by cutting of a micrometer level, and is characterized in that a free-cutting additive is h-BN particles that are distributed in a simple substance state in a steel. Also, the method for producing the free-cutting stainless steel material for precision machining of the present invention is characterized in that a free-cutting stainless steel material for precision machining in which h-BN particles precipitate is heated followed by rapid cooling to make the h-BN particles once dissolve and disappear, and subsequently is tempered, whereby the h-BN particles are dispersedly precipitated again evenly in the material.

Fig. 1



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Description

Technical Field

[0001] The present invention relates to a free-cutting stainless steel material used for forming performed by cutting of a micrometer level.

Background Art

[0002] Conventionally, as a material from which precision parts are machined, stainless steels have been used by making the most of the corrosion resistance thereof. Since the use of stainless steel in precision machining makes it difficult to perform cutting work as compared with the use of other steels, it has been desired to improve the machinability of stainless steel. As a stainless steel having an improved machinability, a free-cutting stainless steel SUS303 containing sulfur has been known widely. For the stainless steel of this type, the surface after cutting is rough, and it has been supposed that this stainless steel has a difficulty in being used for precision cutting work of a micrometer level. That is, it has conventionally been supposed that in a stainless steel, machinability and precision workability (surface roughness after cutting) are incompatible with each other.

[0003] International Patent Publication No. WO2008/016158 discloses a free-cutting stainless steel capable of attaining excellent machinability and corrosion resistance at the same time and a method for producing the same stainless steel. In this invention, the corrosion resistance is equivalent to that of the conventional stainless steel material, and the machinability has been improved by about 25%; however, the surface roughness after cutting of this material is not disclosed.

[0004] Thus, a free-cutting stainless steel material for precision machining, which is excellent in surface property after cutting and corrosion resistance, and a method for producing the same material have not been disclosed up to now.

Summary of Invention

Technical Problem

[0005] The present invention has been made in view of the above situation, and accordingly an object thereof is to provide a free-cutting stainless steel material for precision machining capable of attaining both of machinability and precision workability and a method for producing the same material.

Solution to Problem

[0006] The present invention has been made by finding a free-cutting stainless steel material for precision machining, which is excellent in surface property after cutting, in which importance is attached to dimensional accuracy, machinability, and corrosion resistance, and a method for producing the same material by effectively utilizing the properties of h-BN (hexagonal boron nitride) particles, which are excellent as a solid lubricant, are chemically stable, and are resistant to acid or alkali, and by utilizing the solid dissolution and reprecipitation of h-BN caused by specific heat treatment.

[0007] Invention 1 employs a configuration characterized by a free-cutting stainless steel material for precision machining used for forming performed by cutting of a micrometer level, characterized in that a free-cutting additive is h-BN (hexagonal boron nitride) particles that are spherical particles having a particle diameter of 200 nm to 5 μm, and are dispersedly precipitated in a simple substance state in a steel. The simple substance state means a state in which a plurality of h-BN particles are not cohesive to each other, or the h-BN particles are not cohesive to nonmetallic inclusion particles other than the h-BN particles.

[0008] Invention 2 employs a configuration characterized by the free-cutting stainless steel material for precision machining of invention 1, characterized in that the content of B is 0.003 to 0.1 mass%.

[0009] Invention 3 employs a configuration characterized by the free-cutting stainless steel material for precision machining of invention 1, characterized in that the content of N is equivalent to or higher than the content of B in mole ratio.

[0010] Invention 4 employs a configuration characterized by the free-cutting stainless steel material for precision machining described in any one of inventions 1 to 3, characterized in that the material has a lathe-turned surface property such that the 10-points average roughness (Rz) of surface roughness of the lathe-turned surface is 5 μm or smaller.

[0011] Invention 5 employs a configuration characterized by the free-cutting stainless steel material for precision machining of invention 4, characterized in that the lathe-turned surface property is obtained by turning a 8 mm-diameter round bar under the conditions of cutting speed: 16 m/min, cutting depth: 0.2 mm, tool feeding speed: 0.08 mm/rev, tool material: M30, tool shape: regular triangle, chip breaker: provided, and cutting fluid: not used.

[0012] Invention 6 employs a configuration characterized by a method for producing the free-cutting stainless steel material for precision machining described in any one of inventions 1 to 5, characterized in that B is added to molten stainless steel by the addition of ferroboron or metallic boron, and N is added to the molten stainless steel by melting in the melting atmosphere of (argon plus nitrogen) or reduced-pressure nitrogen.

[0013] Invention 7 employs a configuration characterized by a method for producing the free-cutting stainless steel material for precision machining described in any one of inventions 1 to 5, characterized in that B is added to molten stainless steel by the addition of ferroboron or metallic boron, and N is added to the molten stainless steel by the addition of a nitrogen-containing compound.

[0014] Invention 8 employs a configuration characterized by a method for producing the free-cutting stainless steel material for precision machining described in any one of inventions 1 to 5, characterized in that a stainless steel in which h-BN particles precipitate unevenly in the microstructure obtained by the method described in claim 6 or 7 is heated to a temperature of 1200°C or higher followed by rapid cooling to make the h-BN particles once dissolve and disappear, and subsequently is subjected to tempering heat treatment at a temperature of 950 to 1100°C, whereby the h-BN particles are dispersedly precipitated again.

Advantageous Effects of Invention

[0015] The present invention provides a free-cutting stainless steel material for precision machining which is excellent in machinability, cutting accuracy, and corrosion resistance, and a method for producing the same material by dispersedly precipitating h-BN particles, which are chemically stable, are resistant to acid or alkali, and are excellent as a solid lubricant, in a simple substance state. In particular, as described in Examples, the free-cutting stainless steel material for precision machining has a property that the surface roughness after cutting is equivalent to or smaller than that of the stainless steel having poor machinability, so that the material scarcely needs surface treating work after precision machining. These effects are achieved by effectively applying the h-BN particles having excellent property as a solid lubricant to the free-cutting stainless steel material for precision machining. Since environmental load substances such as Pb and Se are not used, the provision of the free-cutting stainless steel material for precision machining not only having excellent working accuracy, corrosion resistance, and free-cutting property but also attaining satisfied environmental friendliness can be realized. Also, since the working accuracy is excellent, a process for further improving the working accuracy, such as grinding or polishing, can be omitted. Also, the power for a cutting machine can be saved by the improvement in machinability, which leads to a reduction in electrical energy consumption, and high-speed cutting can be performed, which leads to the improvement in productivity.

Description of Embodiment

[0016] The present invention has features described above, and the embodiment thereof is explained hereunder. In the production method of the present invention, the free-cutting stainless steel material for precision machining is melted by using a melting furnace for melting an ordinary stainless steel, in which furnace the melting atmosphere can be controlled. In this melting, as a raw material of B (boron), ferroboron or metallic boron is used. The ferroboron having a low melting point is technically advantageous as a melting raw material, and is economical because the market price per unit weight of B (boron) is low.

[0017] For the added amount of B, the final B content in the free-cutting stainless steel material for precision machining is preferably 0.003 to 0.1 mass%B, further preferably 0.003 to 0.03 mass%B as a general criterion. Also, as a raw material for N (nitrogen), N in a melting atmosphere is absorbed in molten stainless steel, or nitrides of alloying elements for constituting a stainless steel, such as chromium nitride or ferrochromium nitride, are added.

[0018] For the content of N in the free-cutting stainless steel material for precision machining, N/B in mole ratio has only to be 1 or higher as a general criterion. If the mole ratio of N to B in the free-cutting stainless steel material for precision machining is lower than 1, the amount of solute B increases, and the precipitation amount of h-BN effective in machinability decreases. Therefore, the ratio of N/B must be made 1 or higher. For the N content, depending on the constituent element components in the free-cutting stainless steel material for precision machining, since B increases the activity of N, the equilibrium concentration of N decreases with the increase in B. In the component composition of SUS304, the N content is 0.25 mass% or less excluding the melting in the pressurized N atmosphere.

[0019] The molten stainless steel containing B and N, thus produced, is poured into a mold to form a free-cutting stainless steel ingot for precision machining.

[0020] The free-cutting stainless steel ingot for precision machining is subjected to ordinary forging and hot working such as rolling, and is formed into a bar material, wire material, plate material, or the like of the free-cutting stainless steel material for precision machining. After hot working, the free-cutting stainless steel material for precision machining is air-cooled to room temperature. In the free-cutting stainless steel material for precision machining, in the cooling process after hot working, h-BN having grown coarsely to about 20 to 30 μm is sometimes produced depending on the cooling rate in a state of being distributed unevenly in some of the material.

[0021] The h-BN precipitating in the free-cutting stainless steel material for precision machining can exist in the matrix in a state of being decomposed into B and N having solid dissolved in a relatively short time period (for example, 0.5 to 1 hour at 1250°C) by being held at a temperature of 1200°C or higher. By utilizing the solid dissolution phenomenon of this h-BN, heat treatment for solid dissolving the h-BN, which has been produced unevenly in the material or produced coarsely, again in the material is performed. Since such a treatment is impossible to do when the free-cutting stainless steel material for precision machining is melted, this heat treatment must be performed at a temperature lower than the melting temperature of the material.

[0022] By being rapidly cooled, a free-cutting stainless steel material for precision machining containing B and N in a state of supersaturated solid solution can be obtained. The rapid cooling operation may be performed by water cooling that is performed for the ordinary stainless steel, but the cooling rate in the temperature range in which h-BN precipitates, described later, must be a cooling rate at which precipitation does not occur.

[0023] When B and N in the state of supersaturated solid solution are tempered at a temperature of 800 to 1150°C, the h-BN having been solid dissolved by solid solution heat treatment precipitates again. When B and N are tempered at a temperature of about 800°C, the nucleation of h-BN takes place in preference to nucleus growth on account of two factors that the difference between equilibrium solubility and supersaturation solubility at about 800°C of B and N is large and that the diffusion rate of B and N at about 800°C is low so that the diffusion distance is short. Therefore, the even precipitation of very fine h-BN on the whole material can be seen. Inversely, if B and N are tempered at a temperature of about 1150°C, contrary to the tempering at about 800°C, the nucleus growth of h-BN takes place in preference to nucleation, so that the precipitation of h-BN having grown to a large particle diameter can be seen.

[0024] Therefore, in order to precipitate h-BN having a particle diameter and distribution state such that the machinability is excellent, the selection of tempering temperature is of importance. As the result of trials, it was revealed that the tempering temperature at which the particle diameter and distribution state such that the machinability is excellent can be obtained is preferably in the range of 950 to 1100°C. Also, in the case where hot working is performed at a temperature at which h-BN is in a solid dissolved state, a state in which B and N are in the state of supersaturated solid solution can be formed by rapid cooling after hot working. In the case of such a working temperature condition, needless to say, the heat treatment for solid dissolution of h-BN at a temperature of 1200°C or higher is unnecessary.

[0025] Further, concerning the holding time for tempering, as the temperature increases, the diffusion rate of B and N is high, so that only a short holding time is needed, and the sufficient range of holding time is 0.5 to 3 hours, preferably 1 to 2 hours. This tempering heat treatment can double as solution heat treatment, which is performed for a general stainless steel, so that cooling is performed at a cooling rate with which the solution heat treatment is performed.

[0026] The reason why the content of B is made 0.003 to 0.1 mass% is that if the B content is less than 0.003 mass%, the remarkable effect of machinability is lost, and if the B content exceeds 0.1 mass%, a tendency for a plurality of h-BN particles to be made cohesive by the precipitation of a large amount of h-BN is enhanced, and the machinability is greatly improved; however inversely, the surface roughness is adversely affected.

[0027] The reason why the N content is made such that N/B in mole ratio is 1 or higher is that if the ratio of N/B is lower than 1, the reprecipitation of h-BN at the time of heat treatment of B and N h in the state of supersaturated solid solution cannot be attained, and plastic working is difficult to do because B exists excessively.

Examples

Example 1

[0028] A commercially sold austenitic stainless steel (SUS304) round bar (weight: 2 kg) was used as a melting raw material, and was melted by using a cold crucible levitation melting furnace. The chemical composition (mass%) of melting raw material was 0.06% C, 0.28% Si, 1.33% Mn, 0.035% P, 0.025% S, 8.05% Ni, and 18.39% Cr. At the melting time, N of 0.07 MPa was filled into a vacuum induction melting furnace, and thereby the N concentration in molten steel was controlled. After melting, a predetermined amount of commercially sold ferroboron (19.2 mass%B) was added to the molten metal, and the B concentration was controlled. After the steel had melted down in a reduced-pressure N atmosphere, the molten steel was held at 1600°C for 10 minutes, and was solidified in a cold crucible, whereby an ingot was produced. The ingot was worked into a 14 mm-square rod material by being subjected to hot forging at 1200°C, and was air-cooled. After being held at 1250°C for 0.5 hour, the rod material was water-cooled, and further, after being held at 1100°C for one hour, it was subjected to water cooling.

[0029] The analysis values of development steels are given in Table 1. Also, as comparison material 1, a commercially sold SUS304 stainless steel, which was used as the melting raw material of Example 1, and as comparison material 2, a commercially sold free-cutting SUS303 stainless steel containing sulfur were cut out of a 55 mm-diameter round bar, and were used as specimens for a surface roughness test. The analysis values (unit: mass%) of B, N and S of the material are given in Table 1.

Table 1

Analysis values of B and N in specimens (unit: mass%) (mark - indicates not analyzed)			
Specimen name	B content	N content	S content
Development steel 1	0. 0031	0. 23	0. 025
Development steel 2	0. 0070	0. 22	0. 025
Development steel 3	0. 0140	0. 22	0. 025
Comparison material 1	-	0. 058	0. 025
Comparison material 2	-	-	0. 29

[0030] As the evaluation test for surface roughness, for each of the round bar material specimens cut out of the specimens, surface roughness (10-points average roughness Rz) was measured by using a scanning laser microscope. Each of the specimens was lathe-turned to 7.6 mm in diameter under the same turning conditions (cutting speed, cutting depth, tool feeding speed). The final cutting conditions were cutting speed: 16 m/min, cutting depth: 0.2 mm, tool feeding speed: 0.08 mm/rev, tool material: M30, tool shape: regular triangle, chip breaker: provided, and cutting fluid: not used. The measurement results of surface roughness are given in Table 2.

Table 2

Measurement values of surface roughness Rz	
Specimen name	**R** z μ m
Development steel 1	3. 33
Development steel 2	3. 22
Development steel 3	4. 67
Comparison material 1 (SUS304)	4. 85
Comparison material 2 (SUS303)	12. 04

[0031] Table 2 reveals that the surface roughness of the respective developed free-cutting stainless steel materials for precision machining was smaller than that of comparison material 1 (SUS304), and reduced to one-third as compared with the free-cutting stainless steel SUS303 of comparison material 2 and was far smaller than that of comparison material 2. The reason for this is that in the development steels, fine h-BN particles are distributed in a simple substance state, and in contrast, in comparison material 2, a microstructure in which MnS particles, which are a free-cutting additive, are coarse and extend in a needle form is formed. Figure 1 shows a SEM micrograph of a fracture surface of a specimen cut out of development steel 2. Figure 1(a) is a micrograph of a specimen subjected to heat treatment in which the specimen was water-cooled after being held at 1250°C for 0.5 hour, and further was water-cooled after being held at 1100°C for one hour. Figure 1(b) is a micrograph of a specimen subjected to heat treatment in which the specimen was water-cooled after being held at 1250°C for 0.5 hour, and further was water-cooled after being held at 850°C for two hours. It was recognized by EDS analysis that all of the white spherical particles in the figures are h-BN particles. It was recognized that on the observation surface in Figure 1(a), h-BN particles of 3 μm or smaller are distributed in a simple substance state, and further it was observed that there is a tendency that if h-BN particles are precipitated in the state in which the reprecipitation temperature is low, the diameters of the h-BN particles become smaller.

[0032] Figure 2 shows a SEM micrograph of a fracture surface of a specimen of comparison material 2 (SUS303). It was confirmed by EDS analysis that the portions indicated by arrow marks are MnS particles existing in a fiber form in the steel, in which the particles are extended so that the diameter is several micrometers and the length is several tens micrometers. When cutting work is performed, the extended MnS particles come out onto the worked surface and fall. The surface roughness corresponding to the shape of MnS having fallen is also shown in Table 2

[0033] Needless to say, the present invention is not limited to the above examples, and the details thereof can be modified variously.

Industrial Applicability

[0034] As described above in detail, by the present invention, a free-cutting stainless steel material for precision machining excellent in cutting accuracy and machinability and also excellent in corrosion resistance and environmental friendliness can be provided, and excellent usability can be brought about in various work fields using a stainless steel.

Brief Description of Drawings

[0035]

Figures 1(a) and 1(b) are SEM micrographs of fracture surfaces of development steel specimens, Figure 1(a) being a micrograph of a specimen subjected to heat treatment in which the specimen was water-cooled after being held at 1250°C for 0.5 hour, and further was water-cooled after being held at 1100°C for one hour, and Figure 1(b) being a micrograph of a specimen subjected to heat treatment in which the specimen was water-cooled after being held at 1250°C for 0.5 hour, and further was water-cooled after being held at 850°C for two hours.
Figure 2 is a SEM micrograph of a fracture surface of a specimen of comparison material 2.

Citation List

Patent Literature

[0036]

Patent Literature 1: Japanese Patent Laid-Open No. 2002-38238
Patent Literature 2: Japanese Patent Laid-Open No. 2001-234298
Patent Literature 3: International Patent Publication No. WO2008/016158

Claims

1. A free-cutting stainless steel material for precision machining which is cut to a surface roughness of a micrometer level, **characterized in that** spherical h-BN particles having a particle diameter of 200 nm to 5 μm are distributed in a simple substance state as a free-cutting additive.

2. The free-cutting stainless steel material for precision machining according to claim 1, **characterized in that** the content of B is 0.003 to 0.1 mass%.

3. The free-cutting stainless steel material for precision machining according to claim 1, **characterized in that** the content of N is equivalent to or higher than the content of B in mole ratio.

4. The free-cutting stainless steel material for precision machining according to any one of claims 1 to 3, **characterized in that** the material has a lathe-turned surface property such that the 10-points average roughness (Rz) of surface roughness of the lathe-turned surface is 5 μm or smaller.

5. The free-cutting stainless steel material for precision machining according to claim 4, **characterized in that** the lathe-turned surface property is obtained by turning a 8 mm-diameter round bar under the conditions of cutting speed: 16 m/min, cutting depth: 0.2 mm, tool feeding speed: 0.08 mm/rev, tool material: M30, tool shape: regular triangle, chip breaker: provided, and cutting fluid: not used.

6. A method for producing the free-cutting stainless steel material for precision machining described in any one of claims 1 to 5, **characterized in that** B is added by the addition of ferroboron or metallic boron, and N is added by making the melting atmosphere of a raw material stainless steel inert gas plus nitrogen or reduced-pressure nitrogen.

7. A method for producing the free-cutting stainless steel material for precision machining described in any one of claims 1 to 5, **characterized in that** B and N are added to molten stainless steel in such a manner that for B used as a raw material of BN added to the molten stainless steel, ferroboron or metallic boron is added, and for N, a nitrogen-containing compound is added.

8. A method for producing the free-cutting stainless steel material for precision machining described in any one of claims 1 to 5, **characterized in that** a stainless steel in which h-BN particles precipitate unevenly in the microstructure obtained by the method described in claim 6 or 7 is heated to a temperature of 1200°C or higher followed by rapid cooling to make the h-BN particles once dissolve and disappear, and subsequently is subjected to tempering heat treatment at a temperature of 950 to 1100°C, whereby the h-BN particles are dispersedly precipitated again.

Fig. 1

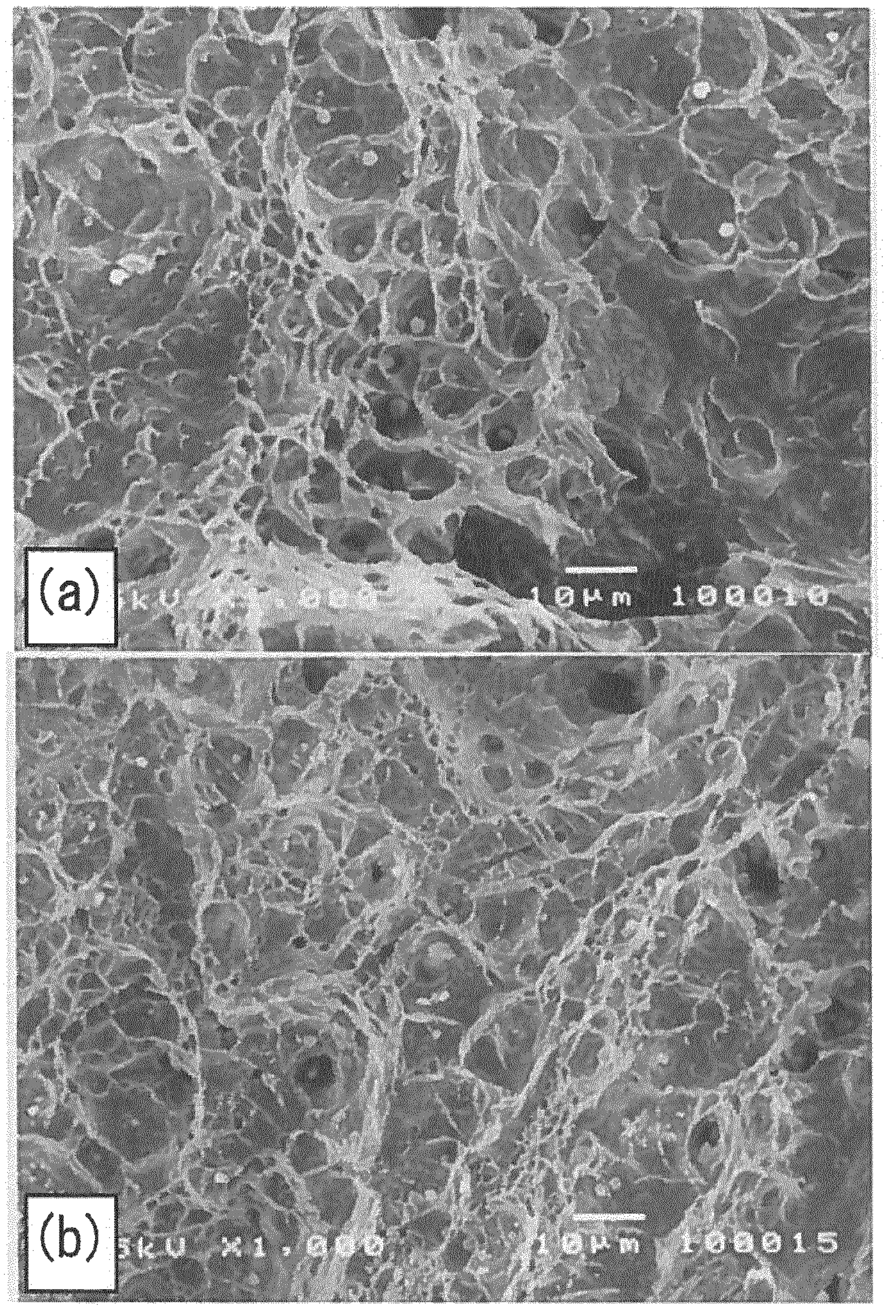
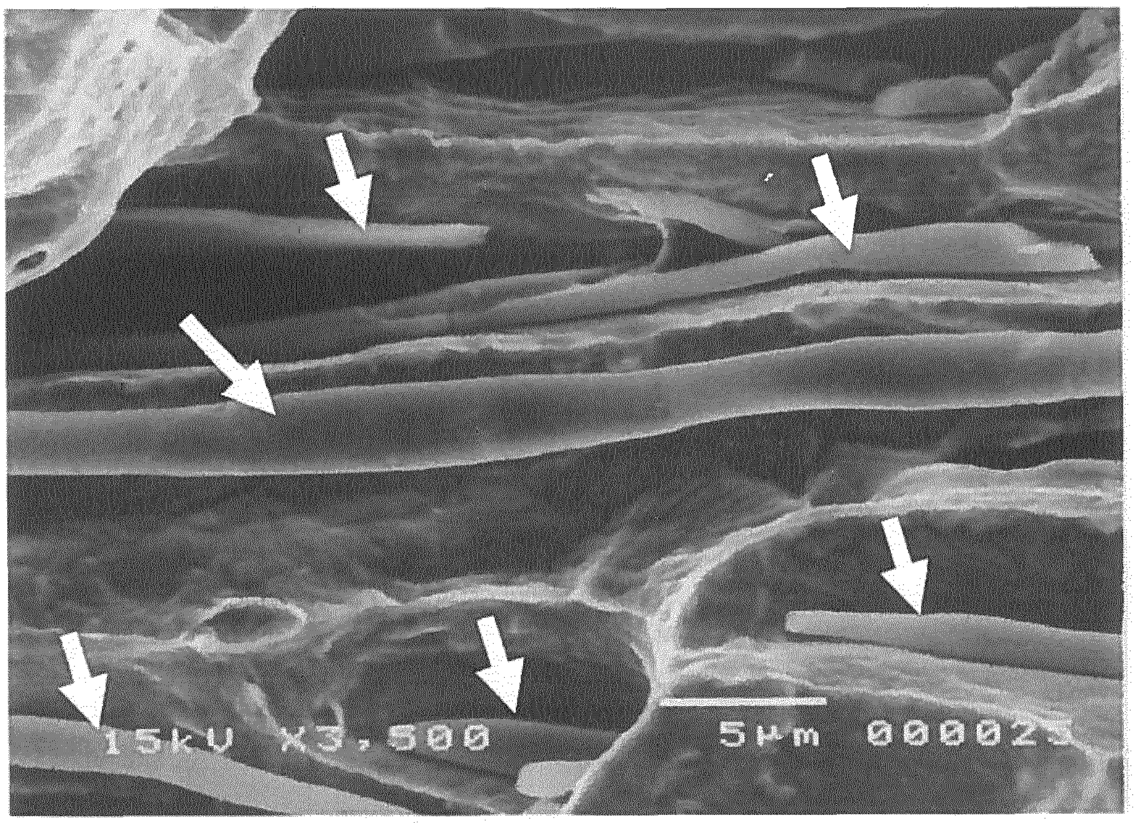


Fig. 2



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2011/053330

A. CLASSIFICATION OF SUBJECT MATTER
C22C38/00(2006.01)i, *C21C7/00*(2006.01)i, *C21C7/04*(2006.01)i, *C21C7/072*(2006.01)i, *C21C7/10*(2006.01)i, *C21D6/00*(2006.01)i, *C22C38/54*(2006.01)n

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, C21C7/00-C21C7/10, C21D6/00

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	1996-2011
Kokai Jitsuyo Shinan Koho	1971-2011	Toroku Jitsuyo Shinan Koho	1994-2011

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.
X	WO 2008/016158 A1 (Independent Administrative Institution National Institute for Materials Science), 07 February 2008 (07.02.2008), claims; description, page 7, line 8 to page 12, line 13 & EP 2048257 A1	1-8
A	JP 2006-291296 A (Nisshin Steel Co., Ltd.), 26 October 2006 (26.10.2006), claims; examples 1, 2 (Family: none)	1-8

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

* Special categories of cited documents:
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Date of the actual completion of the international search	Date of mailing of the international search report
11 May, 2011 (11.05.11)	24 May, 2011 (24.05.11)

Name and mailing address of the ISA/	Authorized officer
Japanese Patent Office	
Facsimile No.	Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2011/053330

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 2004-332021 A (Sanyo Special Steel Co., Ltd.), 25 November 2004 (25.11.2004), claims; examples (Family: none)	1-8

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

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- WO 2008016158 A **[0003] [0036]**
- JP 2002038238 A **[0036]**
- JP 2001234298 A **[0036]**