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(54) **IRON POWDER FOR POWDER METALLURGY**

(57) An iron powder for powder metallurgy according to an embodiment of the present invention comprises: C: less than or equal to 0.005% by mass; Si: less than or equal to 0.030% by mass; P: less than or equal to 0.020% by mass; S: less than or equal to 0.020% by mass; O: less than or equal to 0.15% by mass; Mn, Ni, Mo, and

Cr: less than or equal to 3.0% by mass in total; and a balance being Fe and inevitable impurities, wherein a tap density of the iron powder for powder metallurgy is greater than or equal to 3.90 g/cm³ and less than or equal to 4.20 g/cm³.

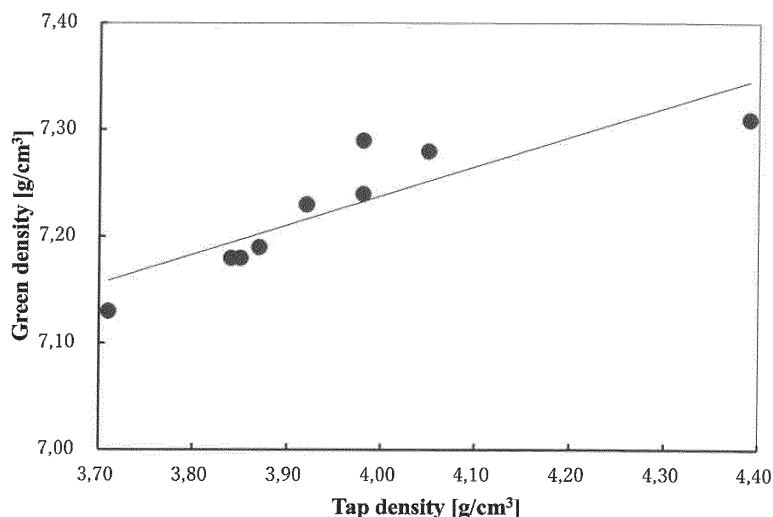


FIG.1

Description

[TECHNICAL FIELD]

5 **[0001]** The present invention relates to an iron powder for powder metallurgy.

[BACKGROUND ART]

10 **[0002]** Powder metallurgy, in which a metal powder is compacted and then sintered to form a metal part, has become widely employed. In general powder metallurgy, increasing a green density, i.e., reducing a green porosity, enables a resultant metal sintered body to have higher mechanical strength. Furthermore, in the powder metallurgy, an increase in green strength enables dimensional accuracy of the metal sintered body to be improved and yield to be increased.

15 **[0003]** According to Japanese Unexamined Patent Application Publication No. H04-173901 (Patent Document 1), by relatively increasing an apparent density of an iron powder for powder metallurgy, i.e. a bulk specific gravity of the iron powder in a stationary state, a green density can be increased. However, Patent Document 1 also discloses that when the apparent density is increased to a certain degree or more, green strength becomes insufficient. However, as a result of verification, the present inventors have found that in a limit region in which a decrease in green strength begins to become problematic, a magnitude relation between apparent densities of iron powders for powder metallurgy having an identical composition often becomes an inversion of a magnitude relation between green densities.

20 **[0004]** When a forming pressure at a time of compacting is increased, the green density and the green strength increase. However, the increase in the forming pressure leads to disadvantages of a shorter lifetime of a die, and the like, degrading production efficiency of metal parts.

[PRIOR ART DOCUMENTS]

25

[PATENT DOCUMENTS]

[0005] Patent Document 1: Japanese Unexamined Patent Application Publication No. H04-173901

30 [SUMMARY OF THE INVENTION]

[PROBLEMS TO BE SOLVED BY THE INVENTION]

35 **[0006]** In view of the foregoing disadvantages, it is an object of the present invention to provide an iron powder for powder metallurgy from which a sintered body with high strength can be obtained.

[MEANS FOR SOLVING THE PROBLEMS]

40 **[0007]** An iron powder for powder metallurgy according to an embodiment of the present invention made to solve the aforementioned problems comprises: C: less than or equal to 0.005% by mass; Si: less than or equal to 0.030% by mass; P: less than or equal to 0.020% by mass; S: less than or equal to 0.020% by mass; O: less than or equal to 0.15% by mass; Mn, Ni, Mo, and Cr: less than or equal to 3.0% by mass in total; and a balance being Fe and inevitable impurities, wherein a tap density of the iron powder for powder metallurgy is greater than or equal to 3.90 g/cm³ and less than or equal to 4.20 g/cm³.

45 **[0008]** Due to the tap density of the iron powder for powder metallurgy falling within the above range, iron powder particles can be easily rearranged in a close-packed state; therefore, the iron powder for powder metallurgy has superior compressibility at a time of compacting, and strength of a sintered body finally obtained is high.

50 **[0009]** In the iron powder for powder metallurgy, a content of particles which pass through a plain-woven wire mesh with an average opening size of 45 μm is preferably greater than or equal to 10% by mass and less than or equal to 20% by mass. This enables both a compact of the iron powder for powder metallurgy and a sintered body thereof to have sufficient strength.

[0010] "Tap density" as referred to herein means a value measured in accordance with JIS-Z2512 (2012).

[EFFECTS OF THE INVENTION]

55

[0011] As set forth above, the iron powder for powder metallurgy according to an embodiment of the present invention enables a compact with a high density, and a sintered body with high strength to be obtained.

[BRIEF DESCRIPTION OF THE DRAWINGS]

[0012]

Fig. 1 is a graph showing a relation between tap densities and green densities of iron powders for powder metallurgy. Fig. 2 is a graph showing a relation between the tap densities of the iron powders for powder metallurgy and rattler values of compacts thereof.

[DESCRIPTION OF EMBODIMENTS]

[0013] Hereinafter, embodiments of the present invention will be described in detail with reference to the drawings as appropriate.

Iron Powder for Powder Metallurgy

[0014] The iron powder for powder metallurgy according to an embodiment of the present invention comprises: C: less than or equal to 0.005% by mass; Si: less than or equal to 0.030% by mass; P: less than or equal to 0.020% by mass; S: less than or equal to 0.020% by mass; O: less than or equal to 0.15% by mass; Mn, Ni, Mo, and Cr: less than or equal to 3.0% by mass in total; and a balance being Fe and inevitable impurities, wherein a tap density of the iron powder for powder metallurgy is greater than or equal to 3.90 g/cm³ and less than or equal to 4.20 g/cm³.

Carbon (C)

[0015] Carbon (C) is an element that hardens particles of the iron powder for powder metallurgy (iron powder particles). Furthermore, C also hardens the iron powder particles by being coupled with another impurity to form a fine carbide. When the iron powder particles harden, deformation is less likely to occur in compacting, which degrades formability and reduces a green density. Hence, the upper limit of a content of C in the iron powder for powder metallurgy is 0.005% by mass, preferably 0.003% by mass, and more preferably 0.002% by mass.

Silicon (Si)

[0016] Silicon (Si) is an element that is likely to be coupled with oxygen and forms an oxide film on a particle surface of the iron powder for powder metallurgy. The oxide film of Si is difficult to reduce, thereby decreasing strength of a sintered body to be obtained. Furthermore, Si has an effect of hardening the iron powder particles, thereby degrading compressibility (the green density and green strength) of the iron powder for powder metallurgy. Hence, the upper limit of a content of Si is 0.030% by mass, preferably 0.020% by mass, and more preferably 0.015% by mass.

Phosphorus (P)

[0017] Phosphorus (P) is an element that hardens the iron powder particles and degrades the compressibility. Hence, the upper limit of a content of P is 0.020% by mass, preferably 0.017% by mass, and more preferably 0.015% by mass.

Sulfur (S)

[0018] Sulfur (S) is an element that hardens the iron powder particles and degrades the compressibility. Hence, the upper limit of a content of S is 0.020% by mass, preferably 0.015% by mass, and more preferably 0.010% by mass.

Oxygen (O)

[0019] Oxygen (O) is an element that hardens the iron powder particles and degrades the compressibility. Hence, the upper limit of a content of O is 0.15% by mass, preferably 0.12% by mass, and more preferably 0.10% by mass.

Manganese (Mn), Nickel (Ni), Molybdenum (Mo), and Chromium (Cr)

[0020] Manganese (Mn), nickel (Ni), molybdenum (Mo), and chromium (Cr) are elements that are added to increase the strength of the sintered body to be obtained by compacting and sintering the iron powder for powder metallurgy. It is to be noted that when contents of these elements are too high, the iron powder particles may become too hard for sufficient compressibility to be obtained. Hence, the upper limit of a total content of Mn, Ni, Mo, and Cr is 3.0% by mass,

preferably 2.5% by mass, and more preferably 2.0% by mass.

Tap Density

5 **[0021]** The tap density is an indicator of the ease of rearrangement of the iron powder particles. Assuming that an absolute specific gravity is constant, a larger value of the tap density allows the iron powder particles to be easily rearranged more tightly in a packed state with lower porosity. Accordingly, a higher tap density grants higher compressibility, facilitates compacting, and enables a compact with a higher density (green density) to be obtained with relatively low pressure. Meanwhile, when the tap density is too high, adhesiveness between the iron powder particles may be insufficient, and the strength of the compact (green strength) obtained may be insufficient. Hence, the lower limit of the tap density of the iron powder for powder metallurgy is 3.90 g/cm³, preferably 3.95 g/cm³, and more preferably 3.97 g/cm³. Meanwhile, the upper limit of the tap density of the iron powder for powder metallurgy is 4.20 g/cm³, preferably 4.15 g/cm³, and more preferably 4.10 g/cm³.

15 Particle Diameter Distribution

[0022] In the iron powder for powder metallurgy, the lower limit of a content of particles which pass through a plain-woven wire mesh with an average opening size of 45 μm is preferably 10% by mass, and more preferably 12% by mass. Meanwhile, in the iron powder for powder metallurgy, the upper limit of the content of the particles which pass through the plain-woven wire mesh with an average opening size of 45 μm is preferably 20% by mass, and more preferably 18% by mass. In a case in which in the iron powder for powder metallurgy, the content of the particles which pass through the plain-woven wire mesh with an average opening size of 45 μm is less than the lower limit, the strength of the sintered body of the iron powder for powder metallurgy may be insufficient. Conversely, in a case in which in the iron powder for powder metallurgy, the content of the particles which pass through the plain-woven wire mesh with an average opening size of 45 μm is greater than the upper limit, strength of a compact (green strength) finally obtained may be insufficient.

Green Density

30 **[0023]** The lower limit of a density of a compact (green density) obtained by adding 0.75% by mass zinc stearate to the iron powder for powder metallurgy and forming at a forming pressure of 7 tf/cm² is preferably 7.20 g/cm³, and more preferably 7.22 g/cm³. In a case in which the green density is less than the lower limit, strength of a sintered body finally obtained may be insufficient.

Green Strength

35 **[0024]** The upper limit of a rattler value, which is an indicator of the strength of the compact (green strength), obtained by adding 0.75% by mass zinc stearate to the iron powder for powder metallurgy and forming at a forming pressure of 7 tf/cm² is preferably 0.75%, and more preferably 0.70%. In a case in which the rattler value of the compact is greater than the upper limit, the green strength may be insufficient, and dimensional accuracy and/or yield of the sintered body may be insufficient. It is to be noted that "rattler value" as referred to herein means a value measured in accordance with JSPM Standard 4-69.

Production Method

45 **[0025]** The iron powder for powder metallurgy can be produced by a method comprising: atomizing molten iron by spraying water, the molten iron having been prepared to have the above composition (a water-atomizing step); reducing a powder obtained in the water-atomizing step by heating in a reducing gas atmosphere (a reducing step); and pulverizing an iron powder solidified in the reducing step (a pulverizing step).

50 Water-Atomizing Step

[0026] In the water-atomizing step, a fine iron powder is obtained by spraying water onto the molten iron flowing from a furnace. In the water-atomizing step, by controlling a water pressure of the water sprayed, the tap density of the iron powder for powder metallurgy to be obtained is controlled so as to fall within the above range. Specifically, the higher the water pressure is, the lower the tap density of the iron powder for powder metallurgy to be obtained.

Reducing Step

[0027] In the reducing step, the iron powder oxidized in the water-atomizing step is reduced by heating in a reducing gas environment.

[0028] As the reducing gas, for example, a hydrogen gas, an ammonia gas, or a butane gas may be used.

Pulverizing Step

[0029] In the pulverizing step, the iron powder solidified into a cake shape by a reducing treatment described above is pulverized using a mill. By sufficiently pulverizing the iron powder, a particle diameter distribution of the iron powder for powder metallurgy to be obtained is made to conform with a particle diameter distribution of the iron powder obtained in the water-atomizing step, ensuring a desired tap density.

[0030] As the mill used in the pulverizing step, for example, a hammer mill, a feather mill, or the like may be used.

[0031] Furthermore, in the pulverizing step, it is preferable that the iron powder after the pulverizing is sorted through a wire mesh, and large particles are put into the mill again.

Advantages

[0032] Due to the tap density of the iron powder for powder metallurgy falling within the above range, the iron powder particles can be easily rearranged to result in a high apparent density; thus, the iron powder for powder metallurgy is superior in compressibility at a time of compacting, and a compact with sufficient strength (green strength) can be obtained. Accordingly, by using the iron powder for powder metallurgy, a sintered body with high strength can be efficiently produced.

Other Embodiments

[0033] The above-described embodiment does not limit the configuration of the present invention. Therefore, in the above-described embodiment, the components of each part of the above-described embodiment can be omitted, replaced, or added based on the description in the present specification and general technical knowledge, and such omission, replacement, or addition should be construed as falling within the scope of the present invention.

[EXAMPLES]

[0034] Hereinafter, the present invention will be described in detail by way of Examples; the present invention should not be construed as being limited to description in the Examples.

[0035] Molten iron was prepared using an electric furnace, and the molten iron allowed to flow from the electric furnace was atomized by a water atomization method in which water was sprayed onto the molten iron. At this time, a pressure of the water sprayed was selected from within three types of ranges: a low pressure of 30 kgf/cm² to 60 kgf/cm², a middle pressure of 60 kgf/cm² to 90 kgf/cm², and a high pressure of 90 kgf/cm² to 120 kgf/cm². Next, an iron powder obtained was dehydrated and dried, a coarse powder was removed using a wire mesh with an opening size of 425 μ m, and then a reducing treatment was performed in a decomposed ammonia gas atmosphere within a temperature range of 880 °C to 980 °C for 30 min to 60 min. Then, the iron powder solidified into a cake shape by the reducing treatment was pulverized using a hammer mill and a feather mill, and sieving was performed using wire meshes with respective opening sizes of 425 μ m, 250 μ m, and 180 μ m; thus, samples No. 1 to No. 9 of iron powders for powder metallurgy were obtained.

[0036] Compositions of the samples No. 1 to No. 9 of the iron powders for powder metallurgy thus obtained were analyzed. Contents of C and S were measured with "CS-244", a carbon/sulfur analyzer available from LECO. A content of O was measured with "TC-400", an oxygen/nitrogen analyzer available from LECO. Contents of elements other than C, S, and O were measured with "ICPV-5500", an ICP emission spectrometer available from SHIMADZU CORPORATION. Analysis results of the compositions of the samples No. 1 to No. 9 are shown in Table 1.

Table 1

Sample No.	Composition (% by mass)								
	C	Si	P	S	Mn	Ni	Mo	Cr	O
1	0.001	0.007	0.014	0.006	0.19	0.03	0.01	0.04	0.13
2	0.001	0.009	0.017	0.006	0.18	0.02	0.01	0.03	0.13

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(continued)

Sample No.	Composition (% by mass)								
	C	Si	P	S	Mn	Ni	Mo	Cr	O
3	0.001	0.013	0.006	0.004	0.08	0.01	0.01	0.03	0.07
4	0.001	0.007	0.007	0.005	0.09	0.02	0.01	0.03	0.05
5	0.002	0.014	0.007	0.007	0.10	0.01	0.01	0.02	0.05
6	0.001	0.014	0.010	0.004	0.17	0.58	0.64	0.04	0.09
7	0.001	0.010	0.009	0.004	0.19	0.58	0.60	0.04	0.08
8	0.001	0.008	0.016	0.006	0.17	0.56	1.08	0.03	0.07
9	0.001	0.011	0.015	0.005	0.12	0.54	1.04	0.03	0.07

[0037] In addition, particle diameter distributions and tap densities of the samples No. 1 to No. 9 of the iron powders for powder metallurgy were measured. It is to be noted that the particle diameter distributions were measured by a sieving test in accordance with JIS-Z8815 (1994). The tap densities were measured in accordance with JIS-Z2512 (2012).

[0038] Powders obtained by adding and mixing as a lubricant 0.75% by mass zinc stearate to each of the samples No. 1 to No. 9 of the iron powders for powder metallurgy were compacted at a forming pressure of 7 tf/cm², whereby compacts each having a cylindrical shape with a diameter of 11.28 mm and a height of 10 mm were formed. Green densities and rattler values of the compacts obtained were measured. The green densities were measured in accordance with JIS-Z2501 (2000). Furthermore, the rattler values of the compacts were measured in accordance with JSPM Standard 4-69.

[0039] The particle diameter distributions and the tap densities of the samples No. 1 to No. 9 of the iron powders for powder metallurgy as well as the green densities and the rattler values of the compacts of the samples No. 1 to No. 9 of the iron powders for powder metallurgy are shown together in Table 2.

Table 2

Sample No.	Water pressure	Particle size distribution (% by mass)								Tap density (g/cm ³)	Green density (g/cm ³)	Rattler value (%)
		+250 μm	+180 μm	+150 μm	+106 μm	+75 μm	+63 μm	+45 μm	-45 μm			
1	High	1.9	6.0	4.2	12.8	16.0	12.2	17.4	29.5	3.71	7.13	0.44
2	High	0.0	0.0	2.7	15.0	23.2	12.7	20.6	25.8	3.85	7.18	0.56
3	Middle	0.0	0.0	2.6	19.8	27.3	15.6	18.3	16.4	3.98	7.29	0.74
4	Middle	0.0	4.4	8.6	18.4	22.7	11.3	16.8	17.8	4.05	7.28	0.68
5	Low	17.1	21.8	11.2	21.1	14.8	4.6	5.5	3.9	4.39	7.31	1.13
6	High	0.0	0.0	3.7	17.9	20.4	12.7	18.0	27.3	3.84	7.18	0.51
7	Middle	0.0	5.2	6.7	21.4	22.2	11.7	16.0	16.8	3.92	7.23	0.58
8	High	0.0	5.5	5.8	18.5	21.0	10.7	17.1	21.4	3.87	7.19	0.51
9	Middle	0.0	6.2	8.8	24.3	21.9	10.9	13.9	14.0	3.98	7.24	0.65

[0040] In addition, Fig. 1 shows a relation between the tap densities and green densities of the samples No. 1 to No. 9 of the iron powders for powder metallurgy, and Fig. 2 shows a relation between the tap densities of the samples No. 1 to No. 9 of the iron powders for powder metallurgy and the rattler values of the compacts thereof.

[0041] As shown in the drawings, it was confirmed that both the density and the rattler value of the compact were substantially proportional to the tap density. More specifically, it was able to be confirmed that in order to set the green density to be greater than or equal to 7.20 g/cm³, at which sufficient strength could be obtained after sintering, and to set the rattler value of the compact to be less than or equal to 0.75%, at which a degree of a crack and/or a chip fell within a permissible range, the tap density of the iron powder for powder metallurgy should be set to be greater than or equal to 3.90 g/cm³ and less than or equal to 4.20 g/cm³.

[INDUSTRIAL APPLICABILITY]

[0042] The iron powder for powder metallurgy according to an embodiment of the present invention can be suitably used, for example, for production of mechanical parts such as a gear and the like.

Claims

1. An iron powder for powder metallurgy comprising:

C: less than or equal to 0.005% by mass;
 Si: less than or equal to 0.030% by mass;
 P: less than or equal to 0.020% by mass;
 S: less than or equal to 0.020% by mass;
 O: less than or equal to 0.15% by mass;
 Mn, Ni, Mo, and Cr: less than or equal to 3.0% by mass in total; and
 a balance being Fe and inevitable impurities,
 wherein a tap density of the iron powder for powder metallurgy is greater than or equal to 3.90 g/cm³ and less than or equal to 4.20 g/cm³.

2. The iron powder for powder metallurgy according to claim 1, wherein a content of particles which pass through a plain-woven wire mesh with an average opening size of 45 μm is greater than or equal to 10% by mass and less than or equal to 20% by mass.

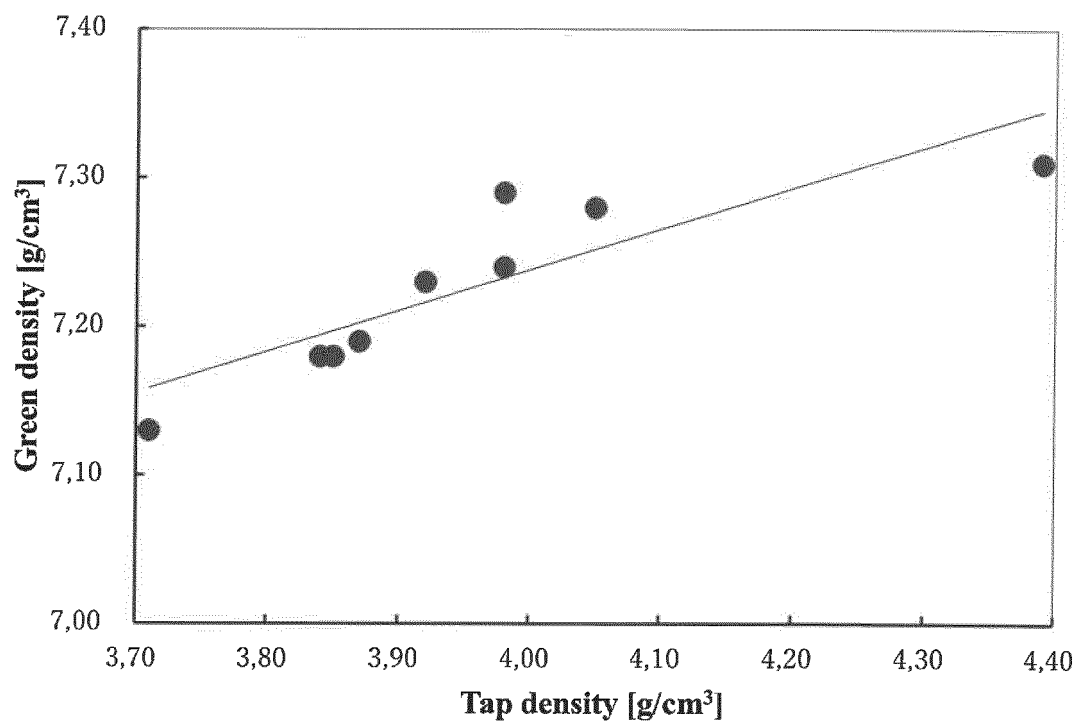


FIG.1

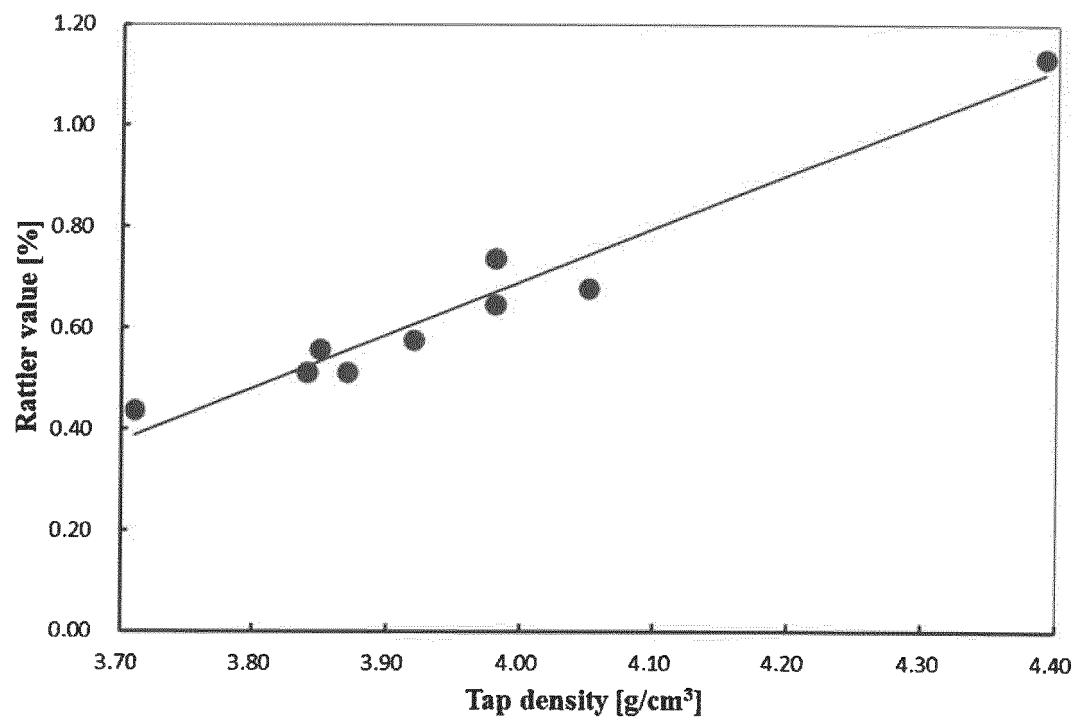


FIG.2

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2019/006090

A. CLASSIFICATION OF SUBJECT MATTER

Int.Cl. B22F1/00 (2006.01) i, B22F9/08 (2006.01) i, C22C38/00 (2006.01) i,
C22C38/58 (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)

Int.Cl. B22F1/00, B22F9/08, C22C38/00, C22C38/58

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

Published examined utility model applications of Japan	1922-1996
Published unexamined utility model applications of Japan	1971-2019
Registered utility model specifications of Japan	1996-2019
Published registered utility model applications of Japan	1994-2019

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	JP 2003-224010 A (SUMITOMO SPECIAL METALS CO., LTD.) 08 August 2003, paragraphs [0164]-[0183] & US 2004/0099346 A1, paragraphs [0197]-[0212] & EP 1447823 A1 & KR 10-0535947 B1	1-2
X	JP 7-126703 A (KAWASAKI STEEL CORP.) 16 May 1995, claims, paragraph [0007], examples (Family: none)	1-2
X	JP 7-157803 A (KAWASAKI STEEL CORP.) 20 June 1995, claims, paragraph [0029], examples & US 5462577 A1, claims, column 5, lines 30-35, examples & US 5534045 A1 & EP 625392 A1 & CN 1104570 A	1-2



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

24 April 2019 (24.04.2019)

Date of mailing of the international search report

14 May 2019 (14.05.2019)

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2019/006090

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 49-78669 A (KOBE STEEL, LTD.) 29 July 1974, page 2, lower left column, line 16 to page 3, upper left column, line 2, examples (Family: none)	1-2
A	JP 2013-26356 A (TAIYO YUDEN CO., LTD.) 04 February 2013 & US 2013/0176098 A1	1-2
A	JP 2013-204075 A (TAIWAN POWDER TECHNOLOGIES CO., LTD.) 07 October 2013 (Family: none)	1-2
A	JP 6-256802 A (KAWASAKI STEEL CORP.) 13 September 1994 (Family: none)	1-2

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REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP H04173901 B [0003] [0005]