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(54) Refractory alloy for metal injection molding

(57) Refractory alloy for metal injection molding including 0.08-0.20 wt % C, 0-0.25 wt % Mn, 0-0.015 wt % S, 0.2-1.0 wt % Si, 12.0-14.0 wt % Cr, 3.80-5.20 wt % Mo, 0-0.1 wt % Ti, 5.50-6.50 wt % Al, 2.58-4.74 wt % Nb, 0-2.5 wt % Fe, 0-0.015 wt % B, 0-1.00 wt % Co and the balance being Ni and unavoidable impurities.

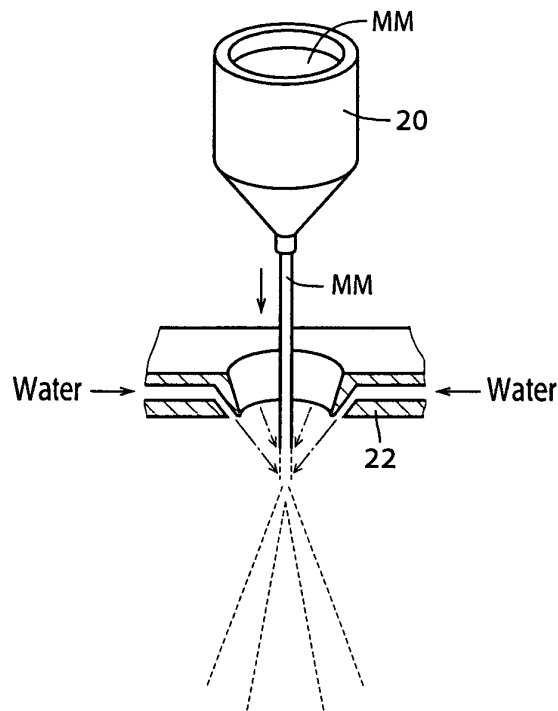


FIG. 1

EP 1 634 972 A2

Description

[0001] This application is based on Japanese Patent Application No. 2004-171078 filed June 9, 2004, the contents of which are incorporated hereinto by reference.

BACKGROUND OF THE INVENTION**1. Field of the Invention**

[0002] The present invention relates to a refractory alloy for metal injection molding, especially, to a refractory alloy for metal injection molding having similar composition to Inconel® 713C.

2. Description of Related Art

[0003] In general, refractory parts are manufactured by casting or forging, and metal injection molding (hereinafter, referred to as MIM) spreads in recent days for manufacturing the same.

[0004] The MIM is a method in which a mixture of a metal impalpable powder and a resin binder is injected into a mold to be molded. The metal impalpable powder causes high filling factor and the surface of the product to be smooth, and permits manufacturing a three-dimensional complex shape in a near net shape. Then such as a vane of a turbo charger is manufactured by MIM.

[0005] The metal impalpable powder is generally manufactured by an atomization method, especially, by a water atomization method using water as a fluid. In the atomization method, molten alloy streams from the outlet or teeming nozzle at the bottom of a tundish in a narrow stream, the stream of the molten alloy goes through an annular nozzle, the fluid is jetted from outlets in the circumference of the annular nozzle to the stream of the molten alloy, and energy of a jet of the fluid allows the molten alloy to be atomized and coagulated.

[0006] The refractory alloys for MIM today such as SUS series (310, etc.), Hastelloy® series and Nimonic® series are all insufficient in strength.

[0007] Inconel® 713C may be used as an atomized refractory alloy for MIM because it has higher strength than Nimonic® 90 as a material for casting. Inconel® 713C has the composition of 0.08-0.20 wt % C, 0.25 max wt % Mn, 0.015 max wt % S, 0.50 max wt % Si, 12.0-14.0 wt % Cr, 3.80-5.20 wt % Mo, 0.50-1.00 wt % Ti, 5.50-6.50 wt % Al, 2.5 max wt % Fe, 1.80-2.80 wt % Nb, 0.05-0.15 wt % Zr, 0.005-0.015 wt % B, 1.00 max wt % Co and the balance Ni.

[0008] However, Inconel® 713C makes the nozzle blocked up in the atomizing step of the atomization method. That is, the outlet at the bottom of the tundish becomes blocked and the stream of molten alloy is stopped. This prevents from manufacturing impalpable powders for MIM.

[0009] It is therefore an object of the present invention to provide a refractory alloy having similar composition to Inconel® 713C and which is capable of becoming impalpable powders for MIM in the atomizing step.

[0010] It is found that a certain range of the content of Ti in Inconel® 713C causes the block of the molten alloy stream in the atomizing step of the atomization method. In detail, the concentration of Ti of more than 0.1 wt % and not more than 1 wt % causes the block of the molten alloy stream.

[0011] In this invention, the content of Ti is set to be other than the above-described range and the concentration of Nb is regulated such that the total of Ti atoms and Nb atoms be approximately equal to that in Inconel® 713C. Nb atoms are added for the purpose of development of solidifying.

SUMMARY OF THE INVENTION

[0012] The object indicated above may be achieved according to a first aspect of the invention, which provides refractory alloy for metal injection molding characterized by comprising: 0.08-0.20 wt % C, 0-0.25 wt % Mn, 0-0.015 wt % S, 0.2-1.0 wt % Si, 12.0-14.0 wt % Cr, 3.80-5.20 wt % Mo, 0-0.1 wt % Ti, 5.50-6.50 wt % Al, 2.58-4.74 wt % Nb, 0-2.5 wt % Fe, 0-0.015 wt % B, 0-1.00 wt % Co and the balance being Ni and unavoidable impurities.

[0013] The object indicated above may be achieved according to a second aspect of the invention, which provides refractory alloy for metal injection molding characterized by comprising: 0.08-0.20 wt % C, 0-0.25 wt % Mn, 0-0.015 wt % S, 0.2-1.0 wt % Si, 12.0-14.0 wt % Cr, 3.80-5.20 wt % Mo, 1.00-2.44 wt % Ti, 5.50-6.50 wt % Al, 0-2.5 wt % Fe, 0-0.015 wt % B, 0-1.00 wt % Co, (from β_1 to β_2) wt % Nb, and the balance being Ni and unavoidable impurities; where β_1 represents $(1.43-\alpha) \times 92.91/47.88$, β_2 represents $(2.44-\alpha) \times 92.91/47.88$ and α represents the concentration of Ti.

[0014] The object indicated above may be achieved according to a third aspect of the invention, which provides the refractory alloy according to the first or second aspect of the invention, which is atomized by a water atomization method that allows molten metal atomized by jetting high pressure water.

[0015] The object indicated above may be achieved according to a fourth aspect of the invention, which provides a

method of manufacturing a part made of refractory alloy comprising: (a) a mixing step of mixing an atomized material of the refractory alloy according to any one of the first to third aspects of the invention and a resin binder, (b) an injection molding step of filling a molding cavity of a predetermined mold with a mixture of the atomized material and the resin binder by injecting the mixture into the molding cavity, and molding a product which has a shape substantially corresponding to a shape of the molding cavity, (c) a binder removing step of removing the resin binder in the product by heat treatment, (d) a sintering step of sintering the product at a predetermined temperature.

[0016] The object indicated above may be achieved according to a fifth aspect of the invention, which provides the method according to the fourth aspect of the invention, wherein the product is sintered at 1,250-1,280 °C to be a part made of refractory alloy having a density of not less than 7.8 g/cm³ in the sintering step.

[0017] The object indicated above may be achieved according to a sixth aspect of the invention, which provides the method according to the fourth or fifth aspect of the invention, wherein the part made of refractory alloy is a part that is to be exposed to exhaust fumes generated by an engine.

[0018] The object indicated above may be achieved according to a seventh aspect of the invention, which provides the method according to the sixth aspect of the invention, wherein the part is a vane of a turbine of a turbo charger

[0019] According to the first aspect of the invention, the concentration of 0-0.1 wt % Ti permits manufacturing impalpable powder for MIM by the atomization method without blocking the stream of molten alloy.

[0020] According to the second aspect of the invention, the concentration of more than 1.00 wt % Ti permits manufacturing impalpable powder for MIM by the atomization method without blocking the stream of molten alloy.

[0021] According to the third aspect of the invention, the molded product of the refractory alloy prior to sintering has an advantage in strength due to its irregular shape of the atomized alloy by the water atomization method in which molten alloy jetted with high pressure water becomes the impalpable powder.

[0022] According to the fourth aspect of the invention, the method of manufacturing a part made of refractory alloy comprising: (a) a mixing step of mixing an atomized material of the refractory alloy according to any one of the first to third aspects of the invention and a resin binder, (b) an injection molding step of filling a molding cavity of a predetermined mold with a mixture of the atomized material and the resin binder by injecting the mixture into the molding cavity, and molding a product which has a shape substantially corresponding to a shape of the molding cavity, (c) a binder removing step of removing the resin binder in the product by heat treatment, (d) a sintering step of sintering the product at a predetermined temperature. Therefore, the refractory alloy part having the similar performance of refractoriness or heat resistance and in strength to Inconel® 713C is obtained.

[0023] According to the fifth aspect of the invention, since the molded product is sintered at 1,250-1,280 °C to be a part made of refractory alloy having a density of not less than 7.8 g/cm³ in the sintering step according to the fourth aspect of the invention, the refractory alloy part having the high density and high strength is obtained.

[0024] According to the sixth aspect of the invention, since the refractory alloy part provided in the fourth or fifth aspect of the invention is a part that is to be exposed to exhaust fumes generated by such as an engine, the refractory alloy part having high heat resistance and high durability is obtained.

[0025] According to the seventh aspect of the invention, since the refractory alloy part provided in the sixth aspect of the invention is a vane of a turbine of a turbo charger, the turbo charger having high heat resistance and high durability is obtained.

[0026] The composition of the alloy of the present invention is based on Inconel® 713C and the rates of Si, Ti, Nb, B and Zr differ from those of Inconel® 713C as follows.

[0027] Si is added for preventing oxidation of the molten alloy. Less than 0.2 wt % Si causes insufficient anti-oxidation effect and the previously-described block of the molten alloy stream. Excessive addition of Si causes cracks due to increase in hardness. Less than 0.1 wt % Si is preferable for preventing the lowering of heat-resistant temperature due to the lowering of the melting point.

[0028] B (boron) is added in Inconel® 713C so that crystal grains may not grow larger in the casting step. And B (boron) may not necessarily be added in MIM because the alloy is in a form of an impalpable powder. However, the same content of B (boron) as that in Inconel® 713C may be added for the purpose of reinforcement of the grain boundary. Therefore, the concentration of B (boron) ranging from 0-0.015 wt % is preferable in this invention.

[0029] Zr is not added in this invention because the nozzle is likely to be clogged with the zirconium oxide generated by cooling in the atomization method.

[0030] Inconel® 713C has 0.50-1.00 wt % Ti and 1.80-2.80 wt % Nb as described above. If Nb atoms of the atomic weight 92.91 are all replaced by Ti atoms of the atomic weight 47.88, the concentration of Ti is given as the following Expressions 1 and 2, that is, 1.80 wt % Nb corresponds to 0.93 wt % Ti and 2.80 wt % Nb corresponds to 1.44 wt % Ti,

$$1.80 \times (47.88/92.91) = 0.93 \dots (\text{Expression 1})$$

$$2.80 \times (47.88/92.91) = 1.44 \dots (\text{Expression 2})$$

[0031] And the lower limit of the concentration of Ti is 1.43 wt % (= 0.50 + 0.93) and the upper limit of the concentration of Ti is 2.44 wt % (= 1.0 + 1.44) if Nb atoms are all replaced by Ti atoms. The concentration of Nb is determined by the addition of Ti then. Since the concentration of Ti should be in the range of 1.43-2.44 wt % if the added Nb atoms are all replaced by Ti atoms, Nb atoms corresponding to from (1.43- α) to (2.44- α) wt % Ti, where α represents the concentration of Ti, should be added. The lower limit (β_1) and the upper limit (β_2) of the concentration of Nb is given by the following Expression 3 and 4, respectively.

$$\beta_1 = (1.43 - \alpha) \times 92.91/47.88 \dots (\text{Expression 3})$$

$$\beta_2 = (2.44 - \alpha) \times 92.91/47.88 \dots (\text{Expression 4})$$

[0032] The concentration of Nb is given as 2.58-4.74 wt % by the above Expressions 3 and 4 substituting 0.1 and 0 for α , that is, $\alpha = 0.1$ and $\alpha = 0$, if the concentration of Ti is 0-0.1 wt %.

[0033] The upper limit of the concentration of Ti is 2.44 wt % as described above if the concentration of Ti is not less than 1.0 wt %. It is the case that Nb atoms are all replaced by Ti atoms. The range of the concentration of Nb is given by the above Expressions 3 and 4 if the concentration of Ti is not less than 1.0 wt %. Then α is not less than one (1) and the concentration of Nb should be regarded as zero (0) if α is not less than 1.43 and then Expression 3 gives the value less than zero.

[0034] In the mixing step the atomized material or the powder of the refractory alloy for metal injection molding according to the first or second aspect of the invention is used as an atomized metal. Such as polypropylen resin, polyethylene resin, acrylic resin, polystyrene resin, kinds of waxes or the mixture of a plurality of these materials is used as a resin binder. The mixture may consist of each of the predetermined rate of the material. The rate of the atomized metal and the resin binder is appropriately determined considering the kinds of the atomized metal and the resin binder such that the mixture has proper flowability for molding upon heating and the binder removed product keeps its shape without being broken.

[0035] In the injection molding step the mixture of the atomized metal and the resin binder is heated at a predetermined temperature to have high flowability, is injected into the molding cavity or molding space in the mold, and is refrigerated in the mold to be solidified.

[0036] In the binder removing step the resin binder in the molded product is removed by heating below the sintering temperature and over the evaporation, decomposition or burn-off temperature of the resin binder in the vacuum, the predetermined depressurized atmosphere or the atmosphere. The heating temperature and the heating speed in the binder removing step are appropriately determined considering kinds of the atomized metal and the resin binder so as to prevent reaction of the resin binder component and the atomized metal or so as to prevent the damage of the molded product due to sudden evaporation or decomposition of the resin binder.

[0037] The sintering temperature and sintering duration in the sintering step are appropriately determined so as to obtain the refractory alloy part of the sintered metal product having the desired density without perfect melting of the atomized refractory alloy for MIM according to the first or second aspect of the invention and with sufficient or appropriate shrinking of the molded product in the vacuum or the predetermined depressurized atmosphere. The refractory alloy part sintered at 1,250-1,280 °C obtained the density of not less than 7.8 g/cm³ in the sintering step.

[0038] The refractory alloy part as the sintered product in the sintering step is preferably used as a part that is exposed to the exhaust fumes in the internal combustion engine such as the gasoline engine and the diesel engine, the external combustion engine, the combustion device such as the burner. Especially the refractory alloy part is preferably used as a part that requires the property of heat resistance such as the turbine vane of the turbo charger and the refractory nozzle.

BRIEF DESCRIPTION OF THE DRAWINGS

[0039] Fig. 1 illustrates a main of a device used for the water atomization method to produce the atomized alloy. Fig. 2 illustrates steps for producing the refractory alloy part using the atomized alloy produced in an embodiment of the present invention.

Fig. 3 illustrates a shape of a test piece for the tensile test.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

[0040] The followings are embodiments of the present invention with comparative examples. First, there are described experiments showing that it is possible to produce the atomized alloy or metal impalpable powder in the atomization method using the alloy having the composition according to the present invention.

[0041] Table 1 lists the results of the atomized metal production test with embodiments and comparative examples by the atomization method (the water atomization method). The conditions for the atomization method are described below. Fig. 1 illustrates a main of an atomization device. The molten alloy MM in a tundish 20 streams through a teeming nozzle or outlet at the bottom of the tundish 20 in a narrow stream. The diameter of the teeming nozzle is conditioned as below. An annular nozzle 22 is provided through which the narrow stream of the molten alloy M M passes. From outlets in the circumference of the annular nozzle 22 the pressurized water is jetted to the stream of the molten alloy MM. The pressure and the quantity of water is determined as below. The energy of the jetted water makes the molten alloy MM atomized and solidified.

Conditions in Atomization Method

[0042]

- 1) Pressure of Pressurized Water: 750 kgf/cm² (7,350 N/cm²)
- 2) Quantity of Pressurized Water: 540 liter/min
- 3) Diameter of Teeming Nozzle: 5 mm
- 4) Temperature of Molten Alloy: 1,730 °C

Table 1

	C	Si	Mn	S	Cr	Mo	Al	Ti	Nb	B	Fe	Possible or Not Possible to Produce Atomized Alloy by Atomization Method
Embodiment 1	0.121	0.50	0.10	0.008	12.46	4.23	6.08	0.003	2.78	0.003	2.01	Possible
Embodiment 2	0.125	0.49	0.08	0.009	12.48	4.23	6.07	0.002	4.72	0.002	2.03	Possible
Embodiment 3	0.119	0.48	0.11	0.010	12.53	4.21	6.18	1.32	0.22	0.001	2.08	Possible
Embodiment 4	0.119	0.52	0.15	0.009	12.54	4.20	6.09	1.32	2.17	0.003	1.98	Possible
Embodiment 5	0.120	0.51	0.09	0.008	12.52	4.22	6.11	0.003	2.78	0.012	2.00	Possible
Embodiment 6	0.122	0.49	0.13	0.006	12.50	4.23	6.12	2.39	0.10	0.013	1.99	Possible
Embodiment 7	0.125	0.51	0.12	0.005	12.49	4.19	6.13	1.32	0.22	0.011	2.05	Possible
Embodiment 8	0.128	0.47	0.16	0.009	12.51	4.22	6.10	0.002	3.68	0.002	2.03	Possible
Embodiment 9	0.125	0.29	0.07	0.006	12.42	4.16	6.17	0.001	3.71	0.003	1.99	Possible
Embodiment 10	0.120	0.24	0.11	0.007	12.63	4.25	6.03	1.26	1.85	0.004	1.97	Possible
Comparative Example 1	0.120	0.11	0.13	0.010	12.46	4.21	6.13	0.003	2.78	0.001	2.04	Not Possible
Comparative Example 2	0.123	0.32	0.10	0.013	12.50	4.19	6.11	0.13	2.49	0.003	2.00	Not Possible
Comparative Example 3	0.127	0.31	0.17	0.013	12.49	4.20	6.09	0.18	4.40	0.002	1.97	Not Possible
Comparative Example 4	0.124	0.29	0.12	0.012	12.51	4.21	6.08	0.51	1.98	0.003	2.08	Not Possible
Comparative Example 5	0.123	0.34	0.13	0.009	12.52	4.23	6.10	0.93	0.10	0.001	1.97	Not Possible
Comparative Example 6	0.122	0.32	0.13	0.008	12.47	4.18	6.12	0.93	1.98	0.002	1.95	Not Possible
Comparative Example 7	0.119	0.13	0.16	0.006	12.49	4.17	6.11	1.35	0.32	0.002	2.05	Not Possible
Comparative Example 8 (Nimonic® 90)	0.076	0.54	0.07	0.01	20.50	0.01	1.47	2.67	Co 18.31		0.15	—

[0043] In Embodiment 1, the Ti concentration is slightly higher than zero (0) and the Nb concentration is the minimum value given by Expression 3 with the above Ti concentration substituted. It was possible to produce the atomized alloy by the atomization method using the alloy having this composition. In Embodiment 2, the Ti concentration is substantially the same as that in Embodiment 1 and the Nb concentration is the maximum value given by Expression 4 with this Ti concentration substituted. It was also possible to produce the atomized alloy by the atomization method using the alloy having this composition. In Embodiment 8, the Nb concentration is an intermediate value between those in Embodiment 1 and Embodiment 2 and the balance is substantially the same as that in Embodiment 1 or Embodiment 2. It was also possible to produce the atomized alloy by the atomization method using the alloy having this composition. These show that it is possible to produce the atomized alloy by the atomization method using the alloy having all the range of the Nb

concentration determined according to Expression 3 and 4 when the Ti concentration is very low.

[0044] In Comparative Example 2, the Ti concentration is a little higher than that in Embodiment 1 and the Nb concentration is the minimum value given by Expression 3 with the above Ti concentration substituted as in Embodiment 1. Since this resulted in the block of the molten alloy stream at the teeming nozzle, it was not possible to produce the atomized alloy by the atomization method using the alloy having this composition in Comparative Example 2. In Comparative Example 3, the Ti concentration is a little higher than that in Embodiment 2 and the Nb concentration is the maximum value given by Expression 4 with the above Ti concentration substituted as in Embodiment 2. Since this also resulted in the block of the molten alloy stream at the teeming nozzle, it was not possible to produce the atomized alloy by the atomization method using the alloy having this composition in Comparative Example 3. Comparing Comparative Example 2 with Embodiment 1 and comparing Comparative Example 3 with Embodiment 2, these show that it is not possible to produce the atomized alloy by the atomization method using the alloy in which the Ti concentration is higher than 0.1 wt % if the total of Ti atoms and Nb atoms does not vary.

[0045] In Comparative Example 4, the Ti concentration is an intermediate value between the upper limit of the first aspect of the invention and the lower limit of the second aspect of the invention. Since this resulted in the block of the molten alloy stream at the teeming nozzle, it was not possible to produce the atomized alloy by the atomization method using the alloy having this composition.

[0046] In Embodiment 3, the Ti concentration is a little higher than one (1) and the Nb concentration is the minimum value given by Expression 3 with the above Ti concentration substituted. It was possible to produce the atomized alloy by the atomization method using the alloy having this composition. In Embodiment 4, the Ti concentration is substantially the same as that in Embodiment 3 and the Nb concentration is the maximum value given by Expression 4 with this Ti concentration substituted. It was also possible to produce the atomized alloy by the atomization method using the alloy having this composition. These show that it is possible to produce the atomized alloy by the atomization method using the alloy having all the range of the Nb concentration determined according to Expression 3 and 4 when the Ti concentration is higher than 1 wt %.

[0047] Comparative Examples 5 and 6 have substantially the same composition as Embodiment 3 and 4, respectively, other than slightly different Ti concentration and the following slightly different Nb concentration. That is, in Comparative Example 5, the Ti concentration is a little lower than one (1) and the Nb concentration is the minimum value given by Expression 3 with the above Ti concentration substituted as in Embodiment 3. In Comparative Example 6, the Ti concentration is substantially the same as that in Comparative Example 5 and the Nb concentration is the maximum value given by Expression 4 with the above Ti concentration substituted as in Embodiment 4. Since these resulted in the block of the molten alloy stream at the teeming nozzle, it was not possible to produce the atomized alloy by the atomization method using the alloy having the composition in Comparative Examples 5 and 6. These show that it is not possible to produce the atomized alloy by the atomization method using the alloy having all the range of the Nb concentration determined according to Expression 3 and 4 when the Ti concentration is not higher than 1 wt %. (Even in this range, it is possible to produce the atomized alloy by the atomization method when the Ti concentration is not higher than 0.1 wt % as described above.)

[0048] The composition of Comparative Example 1 is substantially the same as that in Embodiment 1 other than the addition of Si. Since this resulted in the block of the molten alloy stream at the teeming nozzle, it was not possible to produce the atomized alloy by the atomization method using the alloy having this composition. Embodiment 9 has the slight Ti concentration as Embodiment 1 and has the lower Si concentration than Embodiment 1. It was possible to produce the atomized alloy by the atomization method using the alloy having this composition in Embodiment 9. These show that the concentration of at least 0.2 wt % Si is required for the atomization method.

[0049] In Comparative Example 7, the Ti and Nb concentrations are substantially the same as those in Embodiment 3, respectively, and the addition of Si is lower than 0.2 wt %. Since this resulted in the block of the molten alloy stream at the teeming nozzle, it was not possible to produce the atomized alloy by the atomization method using the alloy having this composition. In Embodiment 10, the Ti concentration is substantially the same as that in Embodiment 3 or Comparative Example 7 and the addition of Si is between those in Embodiment 3 and Comparative Example 7. It was possible to produce the atomized alloy by the atomization method using the alloy having this composition in Embodiment 10. These show that the concentration of not lower than 0.2 wt % Si is required for the atomization method even when the Ti concentration is higher than 1.0 wt %.

[0050] In Embodiments 5 and 7, the B (boron) concentration is approximately equal to the upper limit defined in Inconel® 713C. In Embodiment 6, almost all of Nb atoms are replaced by Ti atoms and the B (boron) concentration is approximately equal to the upper limit defined in Inconel® 713C. Since it was possible to produce the atomized alloy by the atomization method using the alloy having the composition in Embodiments 5, 6 and 7, these show that the B (boron) concentration within the range defined in Inconel® 713C exercises no influence to the block of the molten alloy stream at the teeming nozzle in the whole range of Ti and Nb concentration defined in the present invention.

[0051] Table 2 lists the measured results of the properties of the sintered product manufactured by MIM using the atomized alloy prepared in the above Embodiments with the properties of the sintered product of Nimonic® 90 (Com-

parative Example 8) that is known as a material for a high strength sintered product by MIM. The main of the manufacturing method of the sintered product is shown in the following explanation of Fig. 2. The part that is exposed to the exhaust fumes in the internal combustion engine such as the gasoline engine and the diesel engine, the external combustion engine, the combustion device such as the burner, especially, the turbine vane of the turbo charger and the refractory nozzle are manufactured using the atomized alloy prepared in the above Embodiments in a set of these steps in Fig. 2.

Method of Manufacturing Sintered Product

[0052] In Fig. 2 the mixture for injection molding is prepared in the mixing step P1. The resin binder of 60 vol % including 55 wt % polypropylen, 30 wt % paraffin wax, 13.5 wt % carnauba wax and 1.5 wt % dioctyl phthalate and the atomized alloy prepared in the above Embodiments are mixed at 160 °C for 30 minutes in the mixing step P1. In the injection molding step P2 the mixture of the atomized material and the resin binder that is heated at a predetermined temperature is injected into the molding cavity or molding space in the mold for molding using such as a 50-ton injection molding machine. Then the mixture is refrigerated in the mold to be solidified and then to be a molded product. The shape of the molded product substantially corresponds to the shape of the molding cavity. The molded product is drawn from the mold. In the binder removing step P3 the resin binder in the molded product is removed by a solvent removal of removing the binder using a solvent in a hexane flow at 67 °C for 24 hours and then by a heat removal of removing the binder with heating in Ar (argon) flow under the atmospheric pressure at 440 °C for an hour. In the sintering step P4 the binder removed product is sintering at a predetermined temperature so that the sintering density is substantially constant such as 1,250-1,280 °C in the Ar atmosphere. A round bar of the sintered product was manufactured in the present test following these steps. The diameter of the round bar is 13 mm in diameter and 60 mm in length.

Table 2

	Sintering Density (g/cm ³)	Tensile Strength (MPa)	Tensile Strength at High Temperature (MPa)		Increase by Oxidation (mg/cm ²)	
			850 °C	1,000 °C	850 °C x 100 hr	1,000 °C x 100 hr
Embodiment 1	7.83	1048	641	257	0.23	0.45
Embodiment 2	7.83	1053	648	270	0.20	0.45
Embodiment 3	7.82	1064	621	253	0.18	0.51
Embodiment 4	7.78	1062	658	241	0.19	0.45
Embodiment 5	7.84	1062	622	238	0.17	0.48
Embodiment 6	7.78	1070	655	264	0.24	0.63
Embodiment 7	7.80	1035	654	267	0.19	0.48
Embodiment 8	7.84	1058	644	264	0.25	0.47
Comparative Example 8	8.02	990	385	72	0.61	2.71

[0053] The values in the column of Tensile Strength in Table 2 were measured according to the method of tensile test defined in JIS Z 2241 of Method of Tensile Test for Metallic Materials with a bar test piece No. 4 defined in JIS Z 2201 of Test Pieces for Tensile Test for Metallic Materials prepared from the round bar. The shape and dimensions are shown in Fig. 3. The values in the columns of Tensile Strength at High Temperature were measured at high temperatures of 850 °C and 1,000 °C in the tensile test. The values in the columns of Increase by Oxidation were measured and given by the following Expression 5.

Increase by Oxidation (mg/cm^2) = Increase in Weight (mg) / Surface Area of Test Piece
 (cm^2) (Expression 5)

A test piece of 13 mm in diameter and 10 mm in length was prepared from the above round bar, the test piece was disposed in an alumina crucible lidded, heat treatment was carried out in an atmospheric furnace at the temperature and duration shown in Table 2 and the increase in weight between the values before and after the heat treatment. The surface area of the test piece is calculated based upon the diameter and the height of the test piece.

[0054] Table 2 shows that the sintered products in Embodiments 1-8 have similar or superior properties to that in Comparative Example 8, especially, in oxidation resistance and tensile strength at high temperature.

[0055] As described above, the alloy having the composition based upon Inconel® 713C other than the Ti concentration of 0-0.1 wt % or 1.00-2.44 wt % and the regulated addition of Nb to be substantially the same total of Ti atoms and Nb atoms as Inconel® 713C is capable of being utilized for manufacturing the atomized alloy in the atomization method. And the sintered product manufactured in MIM using the atomized alloy has similar or superior properties to that manufactured in MIM using conventional Nimonic® 90.

[0056] It is to be understood that the present invention may be embodied with other changes, improvements, and modifications that may occur to a person skilled in the art without departing from the scope and spirit of the invention defined in the appended claims.

Refractory alloy for metal injection molding including 0.08-0.20 wt % C, 0-0.25 wt % Mn, 0-0.015 wt % S, 0.2-1.0 wt % Si, 12.0-14.0 wt % Cr, 3.80-5.20 wt % Mo, 0-0.1 wt % Ti, 5.50-6.50 wt % Al, 2.58-4.74 wt % Nb, 0-2.5 wt % Fe, 0-0.015 wt % B, 0-1.00 wt % Co and the balance being Ni and unavoidable impurities.

Claims

1. Refractory alloy for metal injection molding **characterized by** comprising:

0.08-0.20 wt % C, 0-0.25 wt % Mn, 0-0.015 wt % S, 0.2-1.0 wt % Si, 12.0-14.0 wt % Cr, 3.80-5.20 wt % Mo, 0-0.1 wt % Ti, 5.50-6.50 wt % Al, 2.58-4.74 wt % Nb, 0-2.5 wt % Fe, 0-0.015 wt % B, 0-1.00 wt % Co and the balance being Ni and unavoidable impurities.

2. Refractory alloy for metal injection molding **characterized by** comprising:

0.08-0.20 wt % C, 0-0.25 wt % Mn, 0-0.015 wt % S, 0.2-1.0 wt % Si, 12.0-14.0 wt % Cr, 3.80-5.20 wt % Mo, 1.00-2.44 wt % Ti, 5.50-6.50 wt % Al, 0-2.5 wt % Fe, 0-0.015 wt % B, 0-1.00 wt % Co, (from β_1 to β_2) wt % Nb, and the balance being Ni and unavoidable impurities;

where β_1 represents $(1.43-\alpha) \times 92.91/47.88$, β_2 represents $(2.44-\alpha) \times 92.91/47.88$ and α represents the concentration of Ti.

3. The refractory alloy according to claim 1 or 2, which is atomized by a water atomization method that allows molten metal atomized by jetting high pressured water.

4. A method of manufacturing a part made of refractory alloy **characterized by** comprising:

a mixing step of mixing an atomized material of the refractory alloy according to any one of claims 1 to 3 and a resin binder
 an injection molding step of filling a molding cavity of a predetermined mold with a mixture of the atomized material and the resin binder by injecting the mixture into the molding cavity, and molding a product which has a shape substantially corresponding to a shape of the molding cavity,
 a binder removing step of removing the resin binder in the product by heat treatment,
 a sintering step of sintering the product at a predetermined temperature.

5. The method according to claim 4, wherein the product is sintered at 1,250-1,280 °C to be a part made of refractory

alloy having a density of not less than 7.8 g/cm³ in the sintering step.

6. The method according to claim 4 or 5, wherein the part made of refractory alloy is a part that is to be exposed to exhaust fumes generated by an engine.

7. The method according to claim 6, wherein the part is a vane of a turbine of a turbo charger.

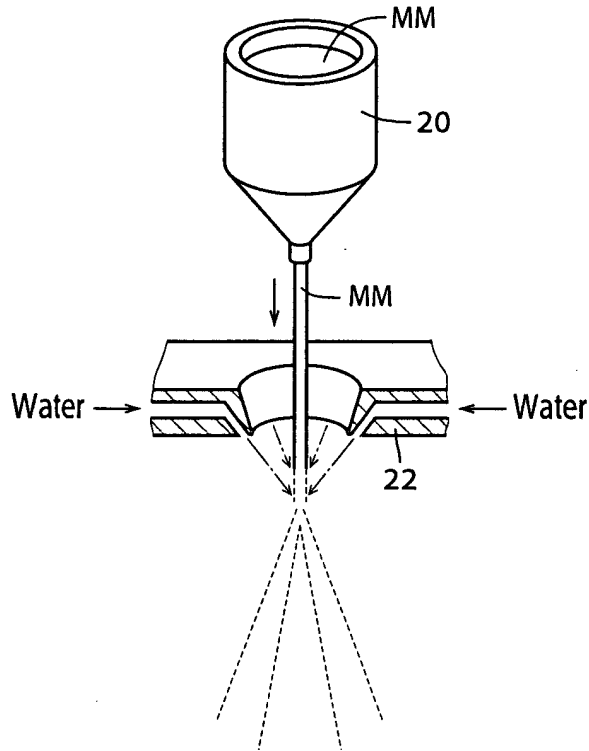


FIG. 1

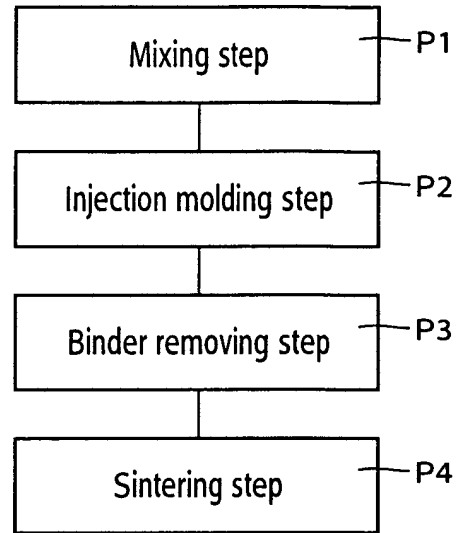


FIG. 2

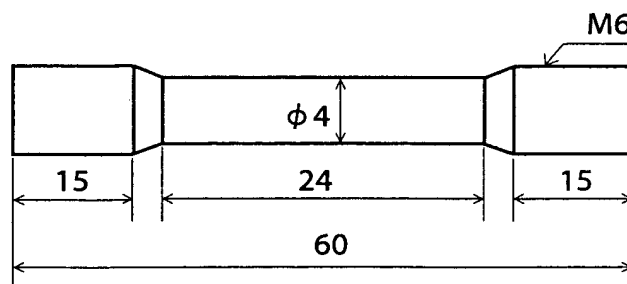


FIG. 3