

(19)



Europäisches Patentamt  
European Patent Office  
Office européen des brevets



(11) Publication number:

**0 341 714 B1**

(12)

**EUROPEAN PATENT SPECIFICATION**

(45) Date of publication of patent specification: **19.01.94** (51) Int. Cl.<sup>5</sup>: **C22C 1/04**, B22F 3/20,  
//C22C21/02

(21) Application number: **89108490.7**

(22) Date of filing: **11.05.89**

The file contains technical information submitted  
after the application was filed and not included in  
this specification

(54) **Method of forming large-sized aluminum alloy product.**

(30) Priority: **12.05.88 JP 115625/88**  
**10.04.89 JP 91587/89**

(43) Date of publication of application:  
**15.11.89 Bulletin 89/46**

(45) Publication of the grant of the patent:  
**19.01.94 Bulletin 94/03**

(84) Designated Contracting States:  
**DE FR GB IT SE**

(56) References cited:  
**EP-A- 0 100 470 EP-A- 0 144 898**  
**EP-A- 0 180 144 EP-A- 0 265 307**  
**GB-A- 912 959 GB-A- 2 167 442**  
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**PATENT ABSTRACTS OF JAPAN, vol. 12, no.**  
**40 (C-474)[2887], 5th February 1988 & JP-A-62**  
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## Description

The present invention relates to a method of forming aluminum alloy product.

Products of aluminum alloys prepared by the powder metallurgy process (hereinafter referred to as "P/M process") exhibit highly improved heat resistance, wear resistance, and like properties in comparison with the products prepared by the ingot metallurgy process (hereinafter referred to as "IM process") because the products obtained by the P/M process can contain additional elements in larger amounts with no segregation and much more uniformly dispersed in the aluminum matrix than the products prepared by the IM process.

Conventional P/M aluminum alloy products are usually produced by extruding a powdery, flaky or ribbon-like material to obtain a billet and processing the billet to the desired shapes or forms. During the hot extrusion step, the oxide films on the surfaces of the powder particles, flakes or ribbons are fractured and the exposed inner aluminum portions are pressed against each other to form a strong bonding. In the powder-rolling process and powder-forging process which also belong to a general category of the P/M process, the aluminum oxide films are fractured; however, since the shearing force is relatively small and the deformation of each particle is not so large and uniform as in the case of extrusion, the bond between the particles is not so strong as in the extruded product.

The extrusion ratio in conducting the above extrusion by the P/M process is usually 10 or more, preferably 20 or more to obtain a strong bonding of each particle. The extrusion by the P/M process usually requires much higher forces than the extrusion by the IM process because the aluminum alloys used in the former process contain larger amounts of alloying elements. For these limitations, aluminum alloy materials obtained by the P/M process are difficult to employ for producing large-sized products.

EP-A-0 144 898 discloses a P/M process for preparing an aluminum alloy product at an extrusion ratio not less than 4, exemplified is an extrusion ratio of 6.5. The preferred extrusion ratio mentioned in EP-A-0 144 898 is higher than 10. In this document is said that extrusion ratios of less than 4 were not possible because the materials obtained would not have the sufficient strength.

The object of the invention is to provide a process capable of producing a strong product by extrusion of a P/M aluminum alloy even under an extremely low extrusion ratio of 2 to 5, provided that the extrusion ratios of 4 and more are excluded.

The solution of this object is based on the finding that these problems can be markedly alleviated by use of powdery aluminum alloy comprising specific alloying elements.

The present invention provides:

a process for preparing a P/M aluminum alloy product comprising:

extruding, at a temperature between 350 and 500 °C and at an extrusion ratio of 2 to 5, provided that the extrusion ratios of 4 and more are excluded an aluminum alloy powder consisting of (a) 5 to 30% by weight of Si, (b) 0.5 to 10% by weight of at least one of the elements Cu, Mg, Fe, Ni, Cr, Mn, Mo, Zr and V with the proviso that the total amount of these elements does not exceed 30% by weight, and (c) aluminum in the remaining amount, apart from impurities

In the drawings:

Fig. 1 is a schematic cross section showing the relationship between the direction of the highest centrifugal force and the flow direction of the powdery material during the extrusion; and

Fig. 2 is a schematic side view showing the shape of the extruded and die-forged product obtained in Example 4 of the invention.

The aluminum alloys used in the invention are in a powdery form and contain as alloying elements (a) 5 to 30% by weight of Si and (b) 0.5 to 10% by weight of at least one of the elements Cu, Mg, Fe, Ni, Cr, Mn, Mo, Zr and V with the proviso that the total amount of these elements does not exceed 30% by weight. When the aluminum alloys of the invention with the above specific components are extruded, the powder particles are strongly bonded each other even at a low extrusion ratio and the extruded material exhibits substantially uniform strength and elongation irrespective of the extrusion ratio. If an aluminum alloy powder with the composition outside the above specified range is used, an extruded material with strong bonding cannot be obtained at a low extrusion ratio of 2 to 5, provided that the extrusion ratios of 4 and more are excluded at a temperature of 350 to 500 °C.

Stated more specifically, if the amount of Si is less than 5% by weight of the alloy, the bonding strength of the particles is low; whereas the use of Si of more than 30% by weight results in the excess volume of primary Si particles in the matrix which leads to a reduction in the toughness of the alloy. Preferably, the amount of Si is 10 to 14% by weight of the alloy.

An amount of Cu, Mg, Fe, Ni, Cr, Mn, Mo, Zr and V of less than 0.5% by weight results in inferior heat resistance and strength of the extruded material whereas an amount of more than 10% by weight results in

lower toughness with the formation of intermetallic compounds. The total amount of these alloying elements in excess of 30% by weight also leads to a reduction of toughness of the alloy.

The aluminum alloy powder of the invention preferably contains 3 to 5% by weight of Fe, 3 to 5% by weight of Ni; 0.5 to 2.5% by weight of Mo and 0.5 to 2.5% by weight of Zr, the total amount of Mo and Zr being 2 to 5% by weight. With use of the aluminum alloy of the preferable composition, an excellent strength of extruded material at elevated temperatures of up to about 300 °C and a high critical upset reduction are achieved.

The extruded material prepared according to the invention using an aluminum alloy powder of specified composition has a high critical upset reduction of up to 60 or 70% irrespective of the extrusion ratio. The extruded material of the invention can be upset forged in the radial directions with an upset reduction of 30 to 80% at 400 to 530 °C. When an aluminum alloy having a composition outside the specified range of the invention is used, a billet produced at a low extrusion ratio of 2 to 5 provided that the extrusion ratios of 4 and more are excluded does not show good forgeability and cannot be upset forged at a temperature between 400 and 530 °C to a upset reduction of 30 to 80%.

The extruded material prepared according to the invention can be further die-forged to a shape as indicated in Fig. 1 which has an enlarged diameter more than 1.5 times the initial diameter of the extruded material. The forged product thus obtained is free from internal defects and has a theoretical density of 100%. When the forged product produced in this manner is used as a rotating part, the direction indicated with the arrow in Fig. 1 (the direction of centrifugal force) coincides with the flow direction of the alloy powder during the extrusion (the direction of the highest strength) with the most favorable result.

According to the invention using an aluminum alloy of a specific composition, a very strong bond can be produced in an extruded material at a low extrusion ratio of 2 to 5, provided that the extrusion ratios of 4 and more are excluded.

When the extruded material of the invention is further upset forged under a heated condition, products with a large diameter such as a large rotor rotating at a high speed at an elevated temperature and the like can be obtained.

## EXAMPLES

Given below are Examples to clarify the features of the invention in greater detail.

### Example 1

Aluminum alloys containing alloying elements as indicated in Table 1 below were air-powdered into particles and sieved to prepare powders of less than 140 μm particle size (minus 100 mesh).

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Table 1

No.	Alloying Elements (wt.%)									
	Cu	Si	Fe	Ni	Cr	Mn	Mo	Zr	V	Mg
1		12				8			1	
2		12		8			1			
3		15	5	3						
4		15		3	3					
5	4	20			4					
6		20	5					1		
7		25	3	5			1			
8			7		2			1.5		
9	5		2	5						3
10	1.5			1.5	3	1.5		1.5		
11		12	4	4			2	0.5		
12		12	4	4			1.5	1		
13		12	4	4			2	1.5		
14		12	5							2
15		3	8	2						
16		35	5			3				

Each of the aluminum alloy powders thus prepared was cold pressed to a preform 30 mm in diameter and 80 mm in height and then extruded at 450 °C at varying extrusion ratios. Test pieces were prepared from the extruded materials, and tensile tests were conducted at room temperature and at 300 °C respectively.

Tensile strength and elongation at room temperature are given in Table 2-A (extrusion ratio = 3:1), Table 2-B (extrusion ratio = 5:1) and Table 2-C (extrusion ratio = 20:1).

Tensile strength and elongation at 300 °C are given in Table 3-A (extrusion ratio = 3:1), Table 3-B (extrusion ratio = 5:1) and Table 3-C (extrusion ratio = 20:1).

Table 2-A

No.	Tensile strength MPa (kg/mm <sup>2</sup> )	Elongation (%)
1	416,50 (42.5)	2.4
2	433,16 (44.2)	2.2
3	424,34 (43.3)	1.9
4	424,34 (43.3)	0.4
5	460,75 (48.5)	0.5
6	429,40 (45.2)	0.3
7	430,22 (43.9)	0.3
8	433,16 (44.2)	1.4
9	381,22 (38.9)	0.2
10	394,94 (40.3)	1.0
11	475,30 (48.5)	0.5
12	482,16 (49.2)	0.5
13	490,98 (50.1)	0.4
14	403,76 (41.2)	1.2
15	344,96 (35.2)	0.1
16	550,76 (56.2)	0.1

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Table 2-B

No.	Tensile strength MPa (kg/mm <sup>2</sup> )	Elongation (%)
1	409,64 (41.8)	2.9
2	425,32 (43.4)	2.1
3	431,20 (44.0)	1.7
4	423,36 (43.2)	0.5
5	469,42 (47.9)	0.5
6	448,84 (45.8)	0.3
7	434,14 (44.3)	0.2
8	442,96 (45.2)	2.1
9	433,16 (44.2)	1.9
10	446,88 (45.6)	1.2
11	474,32 (48.4)	0.5
12	482,16 (49.2)	0.5
13	490,00 (50.0)	0.5
14	411,6 (42.0)	1.1
15	359,66 (36.7)	2.5
16	453,74 (46.3)	0.1

Table 2-C

No.	Tensile strength MPa (kg/mm <sup>2</sup> )	Elongation (%)
1	412,58 (42.1)	2.6
2	425,32 (43.4)	2.4
3	426,30 (43.5)	1.9
4	430,22 (43.9)	0.5
5	475,30 (48.5)	0.3
6	446,88 (45.6)	0.3
7	433,16 (44.2)	0.2
8	529,20 (54.0)	6.0
9	509,60 (52.0)	2.5
10	509,60 (52.0)	1.3
11	476,28 (48.6)	0.5
12	481,18 (49.1)	0.4
13	491,96 (50.2)	0.5
14	407,74 (41.3)	1.3
15	392,98 (40.1)	4.5
16	453,74 (46.3)	0.1

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Table 3-A

No.	Tensile strength MPa (kg/mm <sup>2</sup> )	Elongation (%)
1	155,82 (15.9)	16.2
2	156,80(16.0)	14.1
3	191,10(19.5)	9.0
4	175,42(17.9)	11.2
5	186,20(19.0)	12.1
6	181,30(18.5)	10.2
7	197,96 (20.2)	8.2
8	216,58 (22.1)	3.1
9	122,50 (12.5)	2.2
10	140,14 (14.3)	4.3
11	220,50 (22.5)	7.3
12	223,44 (22.8)	6.5
13	240,10 (24.5)	6.4
14	157,78 (16.1)	12.5
15	109,76 (11.2)	2.0
16	453,74 (46.3)	0.1

Table 3-B

No.	Tensile strength MPa (kg/mm <sup>2</sup> )	Elongation (%)
1	158,76 (16.2)	15.9
2	147,98 (15.1)	18.0
3	189,14 (19.3)	9.2
4	175,42 (17.9)	11.5
5	185,22 (18.9)	11.2
6	175,42 (17.9)	11.2
7	200,90 (20.5)	7.5
8	256,76 (26.2)	4.3
9	133,28 (13.6)	3.8
10	148,96 (15.2)	5.3
11	221,48 (22.6)	7.2
12	233,44 (22.8)	7.0
13	238,14 (24.3)	6.2
14	156,80 (16.0)	11.9
15	149,34 (15.3)	4.0
16	205,80 (21.0)	3.5

Table 3-C

	No.	Tensile strength MPa (kg/mm <sup>2</sup> )	Elongation (%)
5	1	154,84 (15.8)	14.2
	2	147,98 (15.1)	16.2
	3	189,14 (19.3)	8.9
	4	177,38 (18.1)	11.1
	5	189,14 (19.3)	11.5
10	6	175,42 (17.9)	10.1
	7	196,00 (20.0)	7.9
	8	298,90 (30.5)	6.5
	9	161,70 (16.5)	16.3
	10	178,36 (18.2)	16.2
15	11	220,50 (22.5)	7.0
	12	222,46 (22.7)	6.5
	13	239,12 (24.4)	6.6
	14	155,82 (15.9)	12.3
	15	208,74 (21.3)	6.5
20	16	200,90 (20.5)	3.8

Tables 2-A, 2-B, 2-C, 3-A, 3-B and 3-C indicate that the extruded materials obtained from the aluminum alloys of the invention (Nos.1 to 7 and Nos.11 to 14) have substantially uniform strength and elongation independent of the extrusion ratio. The aluminum alloys of the invention give sufficient strength and elongation even at a low extrusion ratio of 3.

In contrast, when aluminum alloys contain alloying elements in amounts outside the range of the invention (Nos.8 to 10), the desired strength and/or elongation at low extrusion ratio is not achieved.

#### Example 2

Test pieces (7 mm in diameter and 10.5 mm in length) were prepared from the extruded materials obtained in the same manner as in Example 1.

Upset tests were conducted at 450°C following the procedures of "Test method for cold upset properties of metals" (tentative standards by Cold Forging Subcommittee of The Japan Society for Technology of Plasticity).

The results are given Table 4 below as critical reduction (%) of each of test pieces at varying extrusion ratios.

Table 4

Alloy	Critical reduction (%) at varying extrusion ratio			
	3	5	10	20
1	65	64	64	64
2	63	68	68	68
3	66	65	66	66
4	60	61	61	61
5	65	65	64	64
6	65	66	64	64
7	63	62	64	64
8	40	55	65	65
9	52	66	85<	85<
10	44	53	68	68
11	63	62	61	61
12	62	63	62	62
13	60	61	60	60
14	62	62	61	61
15	45	51	58	60
16	53	52	53	53

Table 4 shows that extruded materials produced from aluminum alloys of the invention (Nos. 1 to 7 and Nos. 11 to 14) have about 60 to about 70% of critical reduction irrespective of the extrusion ratio.

In comparison therewith, the extruded materials produced from comparative aluminum alloys do not exhibit satisfactory forgeability at a low extrusion ratio of 3 to 5.

#### Example 3

An aluminum alloy in a powder form less than 140  $\mu\text{m}$  particle size (minus 100 mesh)) containing 15% by weight of Si, 5% by weight of Fe and 3% by weight of Ni was cold pressed to a preform 200 mm in diameter (density = 75%) and then extruded at 450 °C at an extrusion ratio of 3 to produce a rod 115 mm in diameter.

The rod was cut to prepare a test piece of a length of 175 mm and the test piece was upset forged at 480 °C at an upset reduction of 60%. After the upset forging, the test piece was found to exhibit no cracking and a forged material 175 mm in diameter and 60 mm in height could be produced from the piece.

The same procedures of the above cold pressing, extrusion and upset forging were followed using an aluminum alloy containing 7.5% by weight of Fe, 2% by weight of Cr and 1.5% by weight of Zr (which corresponded to aluminum alloy No.8 of Example 1). However, large cracks were formed at a low upset reduction of less than 10% and the further enlargement of diameter by forging was impossible.

#### Example 4

An aluminum alloy containing 12% by weight of Si, 4% by weight of Fe, 4% by weight of Ni, 2% by weight of Mo and 1.5% by weight of Zr was powdered to prepare a powdery product (less than 140  $\mu\text{m}$  particle size (minus 100 mesh)). The powder was cold pressed to a preform 230 mm in diameter (density = 75%) and the preform was extruded at 450 °C at an extrusion ratio of 2.4 to produce a rod 150 mm in diameter.

The rod was cut to a length of 300 mm and die-forged in two stages at 480 °C to obtain a product which had the shape and sizes as shown in Fig. 2.

Although the projected portion of the product (the portion having a diameter of 250 mm) had an upset reduction of about 70%, no cracks were found.

The product shown in Fig. 2 was machined to prepare standard tensile strength test pieces from the portions indicated as (a), (b) and (c).

Table 5 shows tensile strength and elongation of the test pieces at 300 °C.



Table 5

Test piece	Tensile strength MPa (kg/mm <sup>2</sup> )	Elongation (%)
(a)	200,90 (20.5)	6.3
(b)	202,86 (20.7)	6.4
(c)	211,68 (21.6)	6.0

As seen from Table 5, the portion (c) which was worked in the highest degree exhibited higher tensile strength than the portions (a) and (b).

A rotating part machined from the forged product of the invention is especially useful for various devices or equipments operating at high rotating speed since the portion where the highest centrifugal force is exerted has highest strength.

### Claims

1. A process for preparing a P/M aluminium alloy product comprising:  
extruding, at a temperature between 350 and 500 °C and at an extrusion ratio of 2 to 5, provided that the extrusion ratios of 4 and more are excluded, an aluminium alloy powder consisting of:  
(a) 5 to 30% by weight of Si,  
(b) 0.5 to 10% by weight of at least one of the elements Cu, Mg, Fe, Ni, Cr, Mn, Mo, Zr and V with the proviso that the total amount of these elements does not exceed 30% by weight, and  
(c) aluminium in the remaining amount, apart from impurities.
2. A process according to claim 1 wherein the aluminium alloy contains 5 to 30% by weight of Si, 3 to 5% by weight of Fe, 3 to 5% by weight of Ni, 0.5 to 2.5% by weight of Mo and 0.5 to 2.5% by weight of Zr and the total amount of Mo and Zr is 2 to 5% by weight.
3. A process according to claim 1 which further comprises forging the extruded material at a temperature of 400 to 530 °C.
4. A process according to claim 3 wherein the extruded material is die-forged in the radial directions.
5. A process according to claim 3 wherein the extruded material is upset forged in the radial directions.

### Patentansprüche

1. Verfahren zur Herstellung eines P/M-Erzeugnisses aus einer Aluminiumlegierung, welches das Extrudieren einer pulverförmigen Aluminiumlegierung, bestehend aus  
(a) 5 bis 30 Gew.-% Si,  
(b) 0,5 bis 10 Gew.-% mindestens eines der Elemente Cu, Mg, Fe, Ni, Cr, Mn, Mo, Zr und V mit der Maßgabe, daß die Gesamtmenge dieser Elemente 30 Gew.-% nicht übersteigt, und  
(c) Aluminium in der verbleibenden Menge mit Ausnahme von Verunreinigungen,  
bei einer Temperatur zwischen 350 und 500 °C und mit einem Extrusionsverhältnis von 2 bis 5 umfaßt, mit der Maßgabe, daß Extrusionsverhältnisse von 4 und mehr ausgeschlossen sind.
2. Verfahren nach Anspruch 1, wobei die Aluminiumlegierung 5 bis 30 Gew.-% Si, 3 bis 5 Gew.-% Fe, 3 bis 5 Gew.-% Ni, 0,5 bis 2,5 Gew.-% Mo und 0,5 bis 2,5 Gew.-% Zr enthält und die Gesamtmenge von Mo und Zr 2 bis 5 Gew.-% ist.
3. Verfahren nach Anspruch 1, das ferner das Schmieden des extrudierten Materials bei einer Temperatur von 400 bis 530 °C umfaßt.
4. Verfahren nach Anspruch 3, wobei das extrudierte Material in den radialen Richtungen gesenkgeschmiedet wird.
5. Verfahren nach Anspruch 3, wobei das extrudierte Material in den radialen Richtungen gestaucht wird.

## Revendications

1. Méthode de fabrication d'un produit en alliage d'aluminium en métallurgie des poudres, comprenant:  
l'extrusion, à une température comprise entre 350 et 500 °C et à un rapport d'extrusion compris  
entre 2 et 5, étant entendu que les rapports d'extrusion de 4 et plus sont exclus, d'une poudre d'alliage  
d'aluminium composée de :
  - (a) 5 à 30% en poids de Si,
  - (b) 0,5 à 10% en poids d'au moins un des éléments Cu, Mg, Fe, Ni, Cr, Mn, Mo, Zr et V à condition  
que la quantité totale de ces éléments ne dépasse pas 30% en poids, et
  - (c) aluminium pour la quantité restante, en dehors des impuretés.
2. Méthode suivant la revendication 1, dans laquelle l'alliage d'aluminium contient 5 à 30% en poids de  
Si, 3 à 5% en poids de Fe, 3 à 5% en poids de Ni, 0,5 à 2,5% en poids de Mo et 0,5 à 2,5% en poids  
de Zr, et la quantité totale de Mo et Zr est de 2 à 5% en poids.
3. Méthode suivant la revendication 1, qui comprend en outre le forgeage de la matière extrudée, à une  
température de 400 à 530 °C.
4. Méthode suivant la revendication 3, dans laquelle la matière extrudée est forgée par matriçage dans les  
directions radiales.
5. Méthode suivant la revendication 3, dans laquelle la matière extrudée est forgée par refoulement dans  
les directions radiales.

FIG. 1

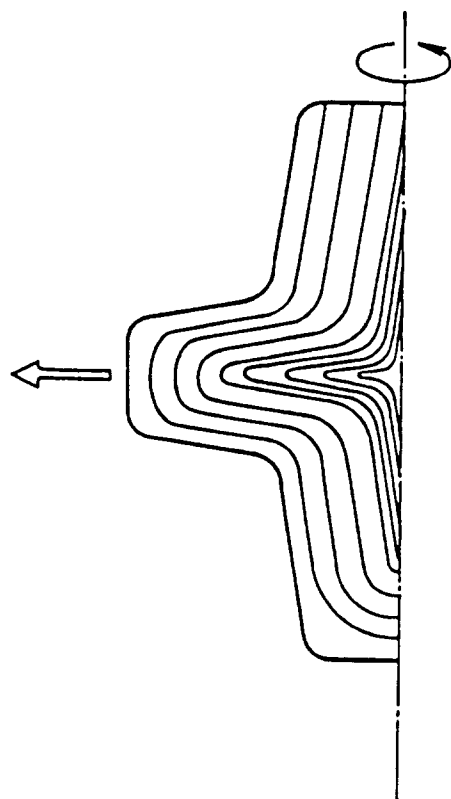


FIG. 2

