(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 2 450 462 B1

(12) **EUROPEAN PATENT SPECIFICATION**

(45) Date of publication and mention of the grant of the patent:
22.03.2017 Bulletin 2017/12

(21) Application number: **10794039.7**

(22) Date of filing: **23.06.2010**

(51) Int Cl.:
C22C 21/02 *(2006.01)*

(86) International application number:
PCT/JP2010/060644

(87) International publication number:
WO 2011/001870 (06.01.2011 Gazette 2011/01)

(54) **WEAR-RESISTANT ALUMINUM ALLOY EXTRUDED MATERIAL HAVING EXCELLENT FATIGUE STRENGTH AND CUTTING PROPERTIES**

VERSCHLEISSFESTES AUS EINER ALUMINIUMLEGIERUNG EXTRUDIERTES MATERIAL MIT HERVORRAGENDER ERMÜDUNGSRESISTENZ UND HERVORRAGENDEN SCHNEIDEEIGENSCHAFTEN

MATÉRIAU EXTRUDÉ D'ALLIAGE D'ALUMINIUM RÉSISTANT À L'USURE AYANT UNE EXCELLENTE RÉSISTANCE À LA FATIGUE ET D'EXCELLENTES PROPRIÉTÉS DE COUPE

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO SE SI SK SM TR

(30) Priority: **29.06.2009 JP 2009154439**

(43) Date of publication of application:
09.05.2012 Bulletin 2012/19

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(56) References cited:
EP-A1- 1 479 785
WO-A1-99/23266
WO-A1-03/072839
WO-A1-2005/024079
JP-A- 9 176 769
US-A1- 2005 252 581

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Description

TECHNICAL FIELD

[0001] The present invention relates to a wear-resistant aluminum alloy extruded material that exhibits excellent fatigue strength in addition to excellent machinability.

BACKGROUND ART

[0002] When using an aluminum alloy extruded material for automotive brake parts and the like, the aluminum alloy extruded material is required to exhibit wear resistance against sliding parts, and may also required to exhibit high cutting (machining) accuracy and high caulking accuracy.

[0003] For example, a cylinder, a hydraulic circuit groove, and the like are machined when producing an actuator body (ABS body) used for an automotive antilock brake system, an electronic stability control (ESC) body used for an antiskid brake system, and the like, and a caulking seal is provided after assembly.

[0004] Therefore, an aluminum alloy extruded material used for such applications is required to exhibit strength, wear resistance against sliding parts, machinability that allows processing into a complicated shape, pressure resistance against a hydraulic oil and the like (caulking section), and high fatigue strength against cyclic (repetitive) load.

[0005] An aluminum alloy extruded material used for such parts is provided with wear resistance and machinability by dispersing Si particles and Fe particles in the metal structure. However, such an aluminum alloy extruded material exhibits insufficient fatigue strength.

[0006] In recent years, a further reduction in size and weight of the ABS body has been desired to reduce the weight of automobiles. However, an aluminum alloy extruded material that meets such a demand has not been proposed.

[0007] For example, Patent Document 1 discloses a wear-resistant aluminum alloy extruded material that exhibits excellent machinability and corrosion resistance. However, the aluminum alloy extruded material disclosed in Patent Document 1 exhibits insufficient caulking properties, fatigue strength, and the like.

Patent Document 1: Japanese Patent No. 3886270

[0008] The published US patent application US 2005/252581 A1 discloses Al-Si alloys that have been designed for use in sliding wear applications such as automotive brake parts.

DISCLOSURE OF THE INVENTION

Problems to be Solved by the Invention

[0009] An object of the invention is to provide a wear-resistant aluminum alloy extruded material that exhibits excellent fatigue strength and excellent machinability.

Means for Solving the Problems

[0010] According to one embodiment of the invention, there is provided a wear-resistant aluminum alloy extruded material that exhibits excellent fatigue strength and machinability, the aluminum alloy extruded material being formed using an aluminum alloy that comprises 3.0 to 8.0 mass% of Si, 0.1 to 0.5 mass% of Mg, 0.01 to 0.5 mass% of Cu, 0.1 to 0.5 mass% of Zr, 0.4 to 0.9 mass% of Fe, 0.01 to 0.5 mass% of Mn, 0.01 to 0.5 mass% of Cr, and 0.01 to 0.1 mass% of Ti, with the balance being Al and unavoidable impurities.

[0011] It has been known that the crystal grains of an extruded material are refined by adding small amounts of Zr, Mn, and Cr.

[0012] The inventor of the invention conducted extensive studies, and found that the fatigue strength of the extruded material is not improved to the desired extent by merely refining the crystal grains.

[0013] The inventor compared the effects of Zr, Mn, and Cr in detail, and found that Si particles contained in the metal structure (texture) are refined by adding a specific amount of Zr. Mn and Cr did not exhibit a significant Si particle refinement effect, but Zr exhibited a significant Si particle refinement effect.

[0014] The fatigue strength was improved by thus suppressing fatigue propagation.

[0015] It is preferable that the extruded material have an average Si particle size of 20 μm or less, and an average crystal grain size of 30 μm or less.

[0016] The content range of each component of the aluminum alloy is adjusted for the following reasons.

Si and Mg

[0017] Si forms an Mg_2Si precipitate with Mg, and provides the aluminum alloy with strength through age hardening. The Si particles contained in the metal structure also provide the aluminum alloy with wear resistance.

[0018] Therefore, it is necessary to add Mg in order to provide the aluminum alloy with strength. Since Si forms Mg_2Si with Mg, the number (amount) of Si particles that contribute to wear resistance is significantly affected by the amount of Mg.

[0019] The Mg content is set to 0.1 mass% or more taking account of these effects. The Mg content is preferably set to 0.3 mass% or more when it is desired to provide the aluminum alloy with higher strength.

[0020] If the Mg content is too high, a decrease in caulking properties and extrudability may occur. Therefore, the Mg content is set to 0.5 mass% or less, and preferably 0.45 mass% or less.

[0021] When the Mg content is set within the above range, the Si content is set to 3.0 mass% or more. The Si content is preferably set to 4.1 to 6.1 mass% when it is desired to provide the aluminum alloy with stable wear resistance.

[0022] When a large number of hard and fine Si particles are present in the metal structure, chips are dispersed from the Si particles. Therefore, the Si content is set to 8.0 mass% or less.

[0023] Since fatigue cracking occurs from the Si particles, it is necessary to refine the Si particles (described later).

Cu

[0024] Cu improves the strength of the aluminum alloy while ensuring caulking properties. Since Cu is solid-dissolved to a certain extent, the strength and the machinability of the aluminum alloy are improved due to solid-solution hardening.

[0025] The Cu content is set to 0.01 mass% or more taking account of these effects. If the Cu content is too high, potential difference corrosion tends to occur. Therefore, the Cu content is set to 0.50 mass% or less. The Cu content is preferably set to 0.10 to 0.20 mass%.

[0026] The upper limit of the Cu content is more preferably set to 0.14 mass% or less.

Fe

[0027] Fe particles are dispersed at the crystal grain boundaries, and chips break from the Fe particles. As a result, the machinability of the aluminum alloy is improved.

[0028] The Fe content is preferably set to 0.40 mass% or more taking account of these effects. If the Fe content exceeds 0.9 mass%, a large number of Fe particles may precipitate at the crystal grain boundaries. In this case, the caulking properties of the aluminum alloy may deteriorate due to a decrease in toughness.

[0029] Therefore, the Fe content is set to 0.4 to 0.9 mass%, and preferably 0.5 to 0.8 mass%.

Zr

[0030] Zr suppresses recrystallization, and refines the crystal grains. Moreover, fatigue propagation is suppressed due to refinement of the Si particles, so that the fatigue strength and the machinability of the aluminum alloy are improved.

[0031] The Zr content is set to 0.1 mass% or more in order to obtain these effects. If the Zr content exceeds 0.5 mass%, Zr may produce a primary crystal product, so that the caulking properties of the aluminum alloy may deteriorate.

[0032] Therefore, the Zr content is set to 0.1 to 0.5 mass%. The Zr content is set to 0.14 mass% or more when it is desired to further refine the Si particles. The Zr content is set to 0.3 mass% or less from the viewpoint of caulking properties.

Mn

[0033] Mn has a small Si particle refinement effect. However, Mn suppresses recrystallization, and refines the crystal grains.

[0034] Specifically, Mn contributes to an improvement in fatigue strength and machinability through refinement of the crystal grains.

[0035] The Mn content is set to 0.01 mass% or more in order to obtain these effects. If Mn precipitates at the crystal grain boundaries, potential difference corrosion and a decrease in caulking properties may occur. Therefore, the Mn content is set to 0.5 mass% or less.

[0036] The Mn content is preferably set to 0.05 to 0.15 mass%.

Cr

[0037] Cr has a small Si particle refinement effect. However, Cr suppresses recrystallization, and refines the crystal grains.

[0038] The Cr content is set to 0.01 mass% or more in order to obtain these effects. Since Cr may produce a primary crystal product, and may cause a decrease in caulking properties, the Cr content is set to 0.5 mass% or less.

[0039] The Cr content is preferably set to 0.05 to 0.15 mass%.

Ti

[0040] Ti refines the crystal grains. The machinability of the aluminum alloy is improved when the Ti content is small. If the Ti content exceeds 0.1 mass%, the life of a cutting tool may decrease.

[0041] Therefore, the Ti content is set to 0.01 to 0.1 mass%.

Effects of the Invention

[0042] The wear-resistant aluminum alloy extruded material according to one embodiment of the invention exhibits caulking properties and machinability while maintaining wear resistance as a result of adjusting the content of Si, Mg, Fe, Cu, Mn, and Cr. Moreover, the Si particles can be refined by adjusting the Zr content, so that the fatigue strength of the aluminum alloy extruded material can be improved.

BRIEF DESCRIPTION OF THE DRAWINGS

[0043]

FIG. 1 shows the alloy composition of each extruded material that was evaluated.

FIG. 2 shows the evaluation results.

FIG. 3 shows a comparison between the S-N curve of the extruded product obtained in Example 1 and the S-N curve of the extruded material obtained in Comparative Example 1.

FIG. 4 shows examples of a micrograph used to measure the crystal grain size and the Si particle size.

FIG. 5 shows examples of a micrograph used to measure the surface recrystallization depth.

FIG. 6 shows corrosion resistance evaluation conditions.

BEST MODE FOR CARRYING OUT THE INVENTION

[0044] An 8-inch billet was cast at a casting speed of 70 to 100 mm/min (see FIG. 1) using a molten metal containing the chemical components shown in FIG. 1 (balance: aluminum and unavoidable impurities), and homogenized at 460 to 590°C for 6 hours or more.

[0045] Note that Zn shown in FIG. 1 is regarded as impurities. No problem occurs if the Zn content is 0.05 mass% or less.

[0046] The billet was preheated to 450 to 510°C, and extruded into a rectangular extruded material having dimensions of about 40×100 mm at an extrusion speed of 5 to 10 m/min.

[0047] A T6 heat treatment was performed by quenching the extruded material at the end of the die through water-cooling immediately after extrusion, and subjecting the extruded material to artificial aging at 160 to 195°C for 2 to 8 hours.

[0048] The resulting extruded material was evaluated under the following conditions. The results are shown in FIG. 2.

Fatigue properties

[0049] A JIS No. 1 (1-8) specimen (rotating bending fatigue test specimen) was prepared using the extruded material in accordance with JIS Z 2274. The specimen was subjected to a fatigue test using an Ono-type rotating bending fatigue tester conforming to the JIS standard. The fatigue strength of the specimen was calculated from the resulting S-N curve.

Tensile properties

[0050] A JIS No. 13B tensile test specimen was prepared using the extruded material in accordance with JIS Z 2241. The specimen was subjected to a tensile test using a tensile tester conforming to the JIS standard to measure the tensile strength, the 0.2% proof stress, and the elongation at break of the specimen.

HRB hardness

[0051] The surface hardness of the extruded material was measured using a Rockwell B scale hardness tester.

Caulking properties

[0052] The caulking properties were measured using a cold upsetting test method.

[0053] A specimen (diameter: 14 mm, height: 21 mm) was sampled from the extruded material, and subjected to cold upsetting press in the axial direction to determine the critical upsetting ratio when microcracks started to occur in the side surface of the specimen.

[0054] The critical upsetting ratio was calculated by the following expression.

$$\varepsilon hc=[(h0-hc)/h0]\times 100$$

εhc: critical upsetting ratio (%), h0: original height of specimen, hc: height of specimen when cracks occurred

[0055] The test was performed at room temperature and a compression rate of 10 mm/s using a tester "Autograph" (25 t) (manufactured by Shimadzu Corporation).

Machinability

[0056] The cutting length (20 mm or less) shown in FIG. 2 refers to the maximum chip length. The maximum chip length refers to the maximum length of chips produced under the following test conditions.

[0057] Chip test conditions: cutting tool: step drill (4.2×6.8 (diameter)), rotational speed: 1200 rpm, feed: 0.05 mm/rev, processing amount: 15 mm, number of holes formed: 3, cutting oil: used

Wear resistance

[0058] The wear resistance was measured using a frictional wear tester ("EFM-III-F" manufactured by Orientec Co., Ltd.).

[0059] Specifically, two cylindrical samples (pin and specimen disk) were rotated around the centerline, and a constant load was applied to the pin so that the pin was pressed against the disk (frictional wear occurred).

[0060] The pin (diameter: 5 mm, height: 8 mm) was formed of an SCr20 (carburized quenched) material.

[0061] The specimen disk (diameter: 60 mm, height: 5 mm) was cut from the extruded material, and processed to have a surface roughness of 1.6 Z or less and a flatness of 0.01 or less.

[0062] A brake fluid was used as a lubricant. The rotational speed was 160 rpm, the testing time was 50 hours, and the applied load was 20 MPa.

[0063] The wear rate of the wear-out part of the specimen disk was measured using a roughness measuring instrument.

Corrosion resistance

[0064] A specimen (35 (L) × 35 (W) × 35 (H)) (see FIG. 6) was cut from the extruded material. A dacrotized bolt was assembled to the center threaded portion of the specimen. The basic cycle shown in FIG. 6 was repeated ten times.

[0065] The corrosion resistance was evaluated by measuring the corrosion depth of the contact surface with the dacrotized bolt and an area around the contact surface.

Crystal grain size and Si particle size

[0066] A sample was cut from the center area of the extruded material, mirror-finished, etched, and then observed using an optical microscope (magnification: 400). The crystal grain size and the Si particle size were measured at twenty (n=20) average areas displayed on a monitor, and the average crystal grain size and the average Si particle size were calculated.

[0067] When the crystal grains or the Si particles have an elliptical or elongate shape, the measured value in the lengthwise direction was used as the crystal grain size or the Si particle size.

Surface recrystallization depth

[0068] A sample was cut from the surface area of the extruded material, mirror-finished, etched, and then observed using an optical microscope (magnification: 50) to measure the surface recrystallization depth in an average area.

Discussion

[0069] Each property target value shown in FIG. 2 indicates a value that is expected to be required to reduce the size and the weight of an automotive ABS body.

[0070] The extruded materials obtained in the examples according to the invention had a high fatigue strength (i.e., 130 MPa or more) as compared with the extruded materials obtained in the comparative examples.

[0071] In Comparative Examples 1 to 7 in which Mn and Cr were added, the average crystal grain size was not reduced to 30 μm or less, and the average Si particle size was not reduced to 20 μm or less. In Examples 1 to 3 in which Zr was added in addition to Mn and Cr, the average crystal grain size was reduced to 30 μm or less, and the average Si particle size was reduced to 20 μm or less. It is considered that fatigue propagation was thus suppressed, so that the fatigue strength was improved.

[0072] For example, the target average Si particle size was not achieved in Comparative Example 6 in which Mn was added in an amount of 0.50 mass%, and Comparative Examples 5 and 6 in which Cr was added in an amount of 0.30 mass%.

[0073] The extruded material obtained in Example 1 was compared with the extruded material obtained in Comparative Example 1. FIG. 3 shows the measurement results for the S-N curve, FIG. 4 shows the measurement results for the average crystal grain size and the average Si particle size, and FIG. 5 shows the measurement results for the surface recrystallization depth.

[0074] As is clear from the evaluation results shown in FIG. 2, it was confirmed that the extruded products obtained in the examples according to the invention had improved machinability.

[0075] Note that the extruded materials obtained in Comparative Examples 1, 2, 5, 6, and 7 had poor machinability since the Fe content was less than 0.4 mass%.

[0076] The extruded materials obtained in Comparative Example 7 had poor wear resistance due to low Si content and high Mg content.

[0077] The target fatigue strength was not achieved in Comparative Examples 3 and 4 although the composition was similar to those of the examples except that Zr was not added.

INDUSTRIAL APPLICABILITY

[0078] Since the aluminum alloy extruded material according to the invention exhibits excellent wear resistance, caulking properties, machinability, and fatigue strength, the aluminum alloy extruded material may be used for automotive brake parts, hydraulic control parts of industrial machines, and the like.

Claims

1. A wear-resistant aluminum alloy extruded material that exhibits excellent fatigue strength and machinability, the aluminum alloy extruded material being formed using an aluminum alloy that comprises 3.0 to 8.0 mass% of Si, 0.1 to 0.5 mass% of Mg, 0.01 to 0.5 mass% of Cu, 0.1 to 0.5 mass% of Zr, 0.4 to 0.9 mass% of Fe, 0.01 to 0.5 mass% of Mn, 0.01 to 0.5 mass% of Cr, and 0.01 to 0.1 mass% of Ti, with the balance being Al and unavoidable impurities.

2. The aluminum alloy extruded material according to claim 1, a metal structure of the extruded material having an average Si particle size of 20 μm or less.

3. The aluminum alloy extruded material according to claim 1 or 2, the extruded material having an average crystal grain size of 30 μm or less.

Patentansprüche

1. Verschleissfestes extrudiertes Material aus einer Aluminiumlegierung mit hervorragender Ermüdungsfestigkeit und Bearbeitbarkeit, wobei das aus der Aluminiumlegierung extrudierte Material unter Verwendung einer Aluminiumlegierung gebildet ist, welche 3,0 bis 8,0 Massen% von Si, 0,1 bis 0,5 Massen% von Mg, 0,01 bis 0,5 Massen% von Cu, 0,1 bis 0,5 Massen% von Zr, 0,4 bis 0,9 Massen% von Fe, 0,01 bis 0,5 Massen% von Mn, 0,01 bis 0,5 Massen% von Cr und 0,01 bis 0,1 Massen% von Ti mit

einem Restanteil Al und unvermeidbaren Verunreinigungen aufweist.

2. Extrudiertes Material aus einer Aluminiumlegierung nach Anspruch 1,
wobei eine Metallstruktur des extrudierten Materiales eine durchschnittliche Partikelgröße von Si von 20 μm oder weniger aufweist.

3. Extrudiertes Material aus einer Aluminiumlegierung nach Anspruch 1 oder 2,
wobei das extrudierte Material eine durchschnittliche Kristallitkorngröße von 30 μm oder weniger aufweist.

Revendications

1. Matériau extrudé en alliage d'aluminium résistant à l'usure présentant une excellente résistance à la fatigue et usinabilité, le matériau extrudé en alliage d'aluminium étant formé à partir d'un alliage d'aluminium comprenant 3.0 à 8.0 % en masse de Si, 0.1 à 0.5 % en masse de Mg, 0.01 à 0.5 % en masse de Cu, 0.1 à 0.5 % en masse de Zr, 0.4 à 0.9 % en masse de Fe, 0.01 à 0.5 % en masse de Mn, 0.01 à 0.5 % en masse de Cr, et 0.01 à 0.1 % en masse de Ti, le reste étant composé d'Al et des impuretés inévitables.

2. Matériau extrudé en alliage d'aluminium selon la revendication 1, une structure métallique du matériau extrudé ayant une taille de particules de Si moyenne de 20 μm ou moins.

3. Matériau extrudé en alliage d'aluminium selon la revendication 1 ou 2, le matériau extrudé ayant une taille moyenne de grains cristallins de 30 μm ou moins.

FIG. 1

Extruded material No.		Alloy component (%)									Casting speed
		Si	Fe	Cu	Mn	Mg	Cr	Zn	Zr	Ti	
Example	1	4.64	0.53	0.13	0.10	0.40	0.10	0.00	0.18	0.03	80mm/min
	2	6.00	0.54	0.14	0.10	0.41	0.10	0.00	0.20	0.03	80mm/min
	3	4.65	0.55	0.14	0.10	0.40	0.10	0.00	0.14	0.03	80mm/min
Comparative Example	1	4.65	0.28	0.13	0.09	0.38	0.09	0.00	0.00	0.03	80mm/min
	2	4.58	0.27	0.13	0.10	0.38	0.09	0.00	0.00	0.03	60mm/min
	3	4.73	0.53	0.14	0.10	0.44	0.09	0.00	0.00	0.03	80mm/min
	4	4.73	0.70	0.14	0.10	0.38	0.09	0.00	0.00	0.03	80mm/min
	5	4.70	0.30	0.15	0.09	0.38	0.30	0.00	0.00	0.02	80mm/min
	6	4.70	0.30	0.15	0.50	0.51	0.30	0.00	0.00	0.02	80mm/min
	7	0.73	0.19	0.15	0.15	0.98	0.14	0.00	0.00	0.06	65mm/min

FIG. 2

Critical upsetting ratio: 33% or more

Pitting corrosion: 1 mm or less

Overall

Extruded material No.		Fatigue strength (MPa)		Tensile strength (MPa)		Proof stress (MPa)		Elongation (%)		Hardness		Machinability (mm)		Caulking properties (%)		Wear resistance (μm)		Corrosion resistance (mm)		Surface recrystallization depth		Crystal grain size (μm)		Si particle size (μm)		
Target value		130 MPa or more		270 MPa or more		220 MPa or more		8% or more		HRB55±10		Cutting length: 20 mm or less				10 μm or less				0.5 mm or less		30 μm or less		20 μm or less		
Example	1	136	○	307	○	267	○	10.9	○	57.9	○	16.9	○	45.7	○	6.8	○	0.35	○	0.1	○	15.8	○	16.6	○	○
	2	136	○	310	○	272	○	10.0	○	60.0	○	6.3	○	46.3	○	5.3	○	0.37	○	0.1	○	16.0	○	16.1	○	○
	3	134	○	304	○	264	○	10.4	○	58.9	○	18.9	○	45.7	○	7.0	○	0.36	○	0.1	○	18.0	○	18.8	○	○
Comparative Example	1	116	×	293	○	254	○	11.0	○	53.2	○	60.0	×	53.8	○	7.2	○	0.35	○	0.3	○	32.3	×	21.6	×	×
	2	110	×	303	○	264	○	11.2	○	53.9	○	72.0	×	50.2	○	7.6	○	0.35	○	0.3	○	45.0	×	45.0	×	×
	3	111	×	306	○	268	○	10.1	○	58.8	○	30.7	×	46.3	○	7.1	○	0.21	○	0.3	○	31.4	×	21.4	×	×
	4	118	×	310	○	274	○	9.6	○	58.8	○	30.7	×	46.3	○	7.7	○	0.77	○	0.3	○	32.4	×	21.4	×	×
	5	122	×	331	○	228	○	12.5	○	58.2	○	36.9	×	46.0	○	6.0	○	0.98	○	0.3	○	33.3	×	24.6	×	×
	6	126	×	345	○	304	○	11.0	○	64.7	○	36.0	×	40.7	○	5.6	○	0.75	○	0.2	○	33.3	×	23.6	×	×
	7	122	×	343	○	305	○	13.0	○	60.0	○	20.1	×	50.2	○		×	0.90	○	0.4	○	40.0	×		×	×

Could not be measured

Could not be measured

FIG. 3

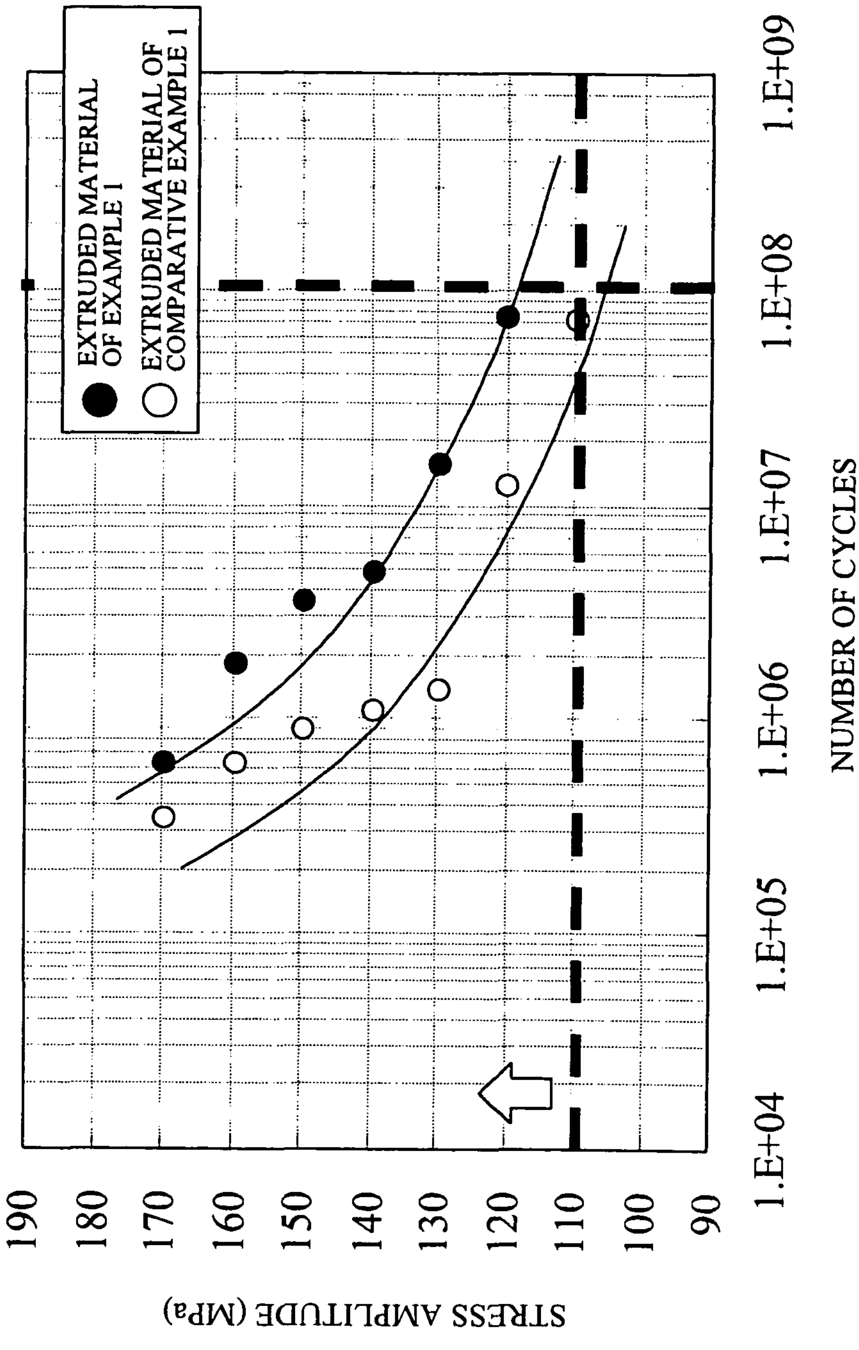

EXTRUDED MATERIAL OF EXAMPLE 1
EXTRUDED MATERIAL OF COMPARATIVE EXAMPLE 1
STRESS AMPLITUDE (MPa)
190
180
170
160
150
140
130
120
110
100
90
NUMBER OF CYCLES
1.E+04
1.E+05
1.E+06
1.E+07
1.E+08
1.E+09

FIG. 4

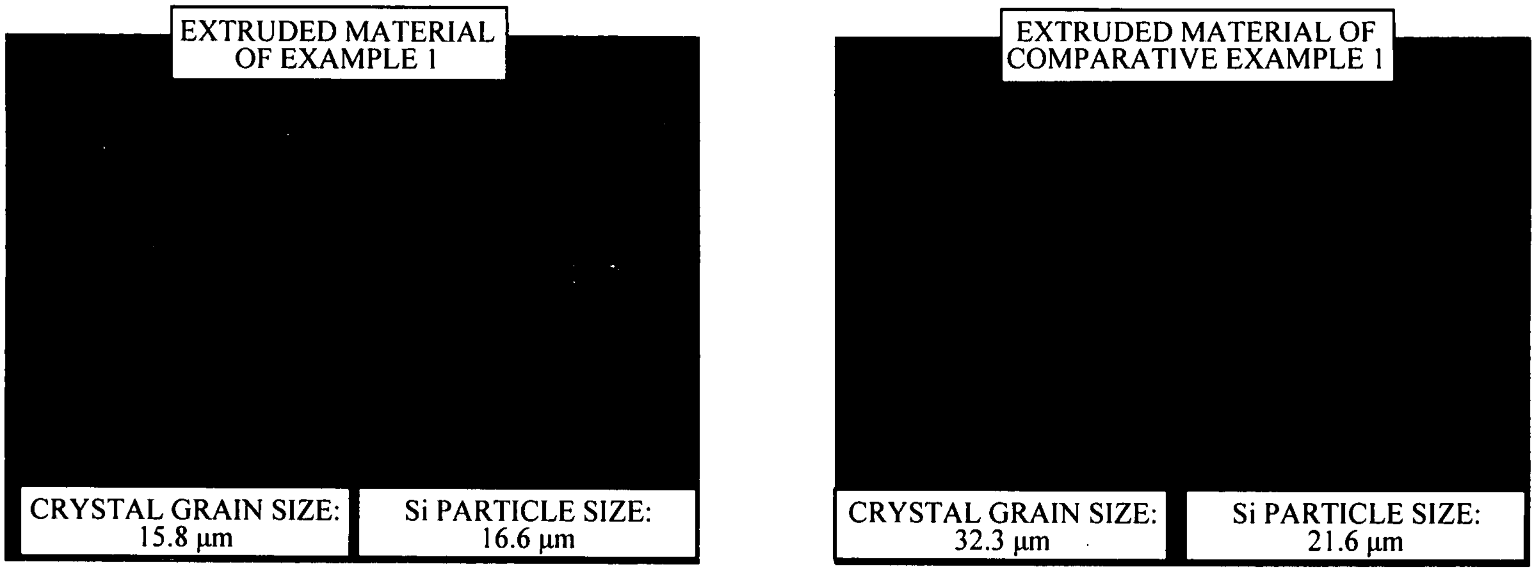

EXTRUDED MATERIAL OF EXAMPLE 1
CRYSTAL GRAIN SIZE: 15.8 μm
Si PARTICLE SIZE: 16.6 μm
EXTRUDED MATERIAL OF COMPARATIVE EXAMPLE 1
CRYSTAL GRAIN SIZE: 32.3 μm
Si PARTICLE SIZE: 21.6 μm

FIG. 5

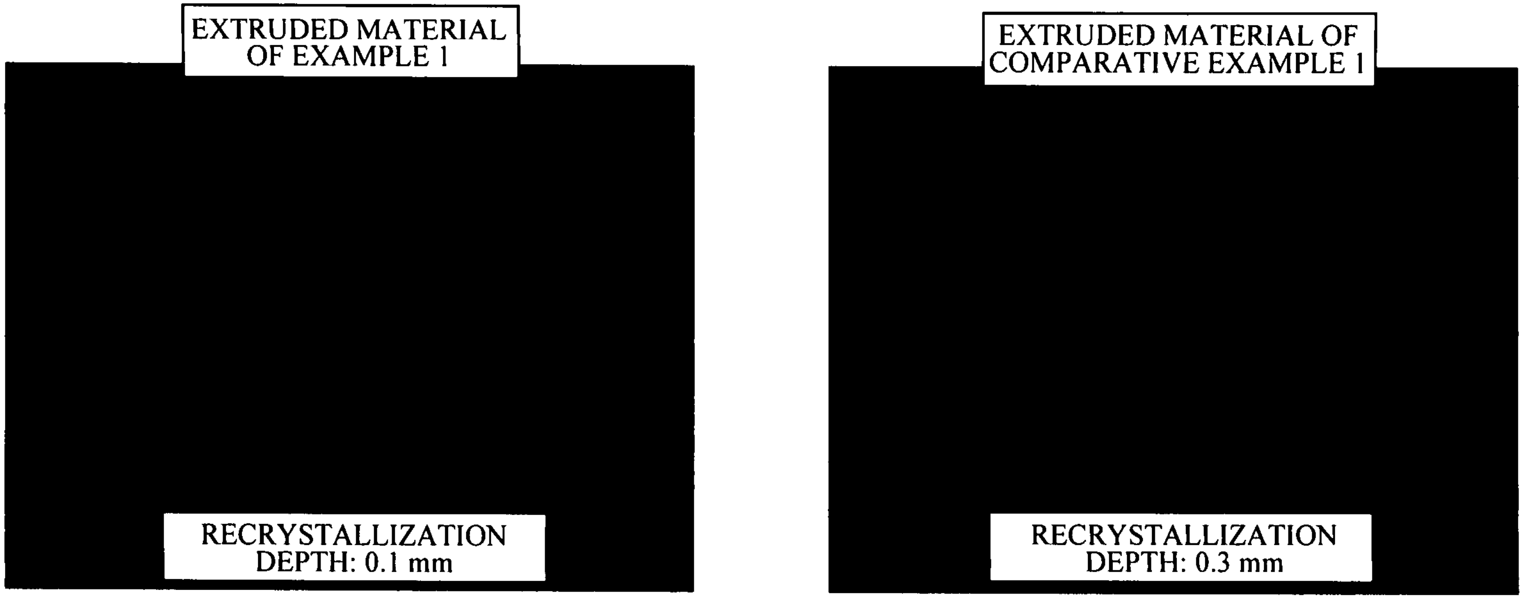
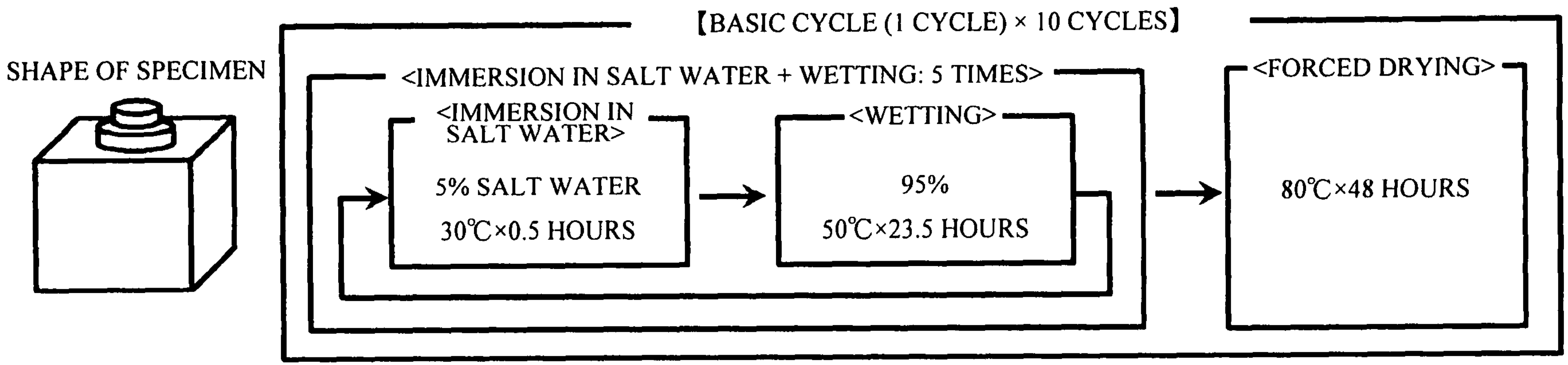

EXTRUDED MATERIAL
OF EXAMPLE 1
RECRYSTALLIZATION
DEPTH: 0.1 mm
EXTRUDED MATERIAL OF
COMPARATIVE EXAMPLE 1
RECRYSTALLIZATION
DEPTH: 0.3 mm

FIG. 6


SHAPE OF SPECIMEN
【BASIC CYCLE (1 CYCLE) × 10 CYCLES】
<IMMERSION IN SALT WATER + WETTING: 5 TIMES>
<IMMERSION IN SALT WATER>
5% SALT WATER
30℃×0.5 HOURS
<WETTING>
95%
50℃×23.5 HOURS
<FORCED DRYING>
80℃×48 HOURS

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 3886270 B **[0007]**
- US 2005252581 A1 **[0008]**