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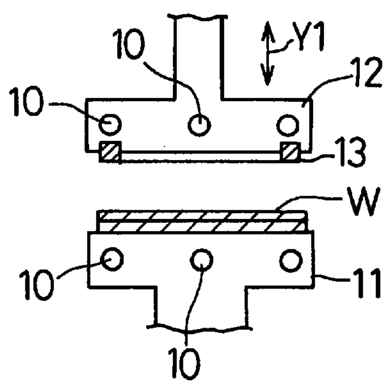
(54) **A1-based composite material having adhesion resistance property and process for producing the same**

(57) An Al alloy piston comprises a piston body and a reinforced portion forming a piston groove. The reinforced portion is composed of Al-based composite material. Namely, Al molten metal (AC8A) forming the piston body was impregnated to the powder compact which is non-sintered compact so as to be solidified so that the reinforced portion was formed. The powder compact is made by compressing atomized powder having the primary crystal Si particles whose mean particle diameter is 10 μm (microns). To the powder compact Fe-Cr powder particles may be added. Accordingly, the present invention provide Al-based composite material whose adhesion resistance property is improved and the process for producing the same.

FIG. 1



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Description

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to an Al (aluminum)-based composite material having adhesion resistance property and a process for producing the same. The present invention can be applied to an Al-based member which includes a reinforced portion formed by the Al-based composite material at a part thereof at least. The present invention can be applied to, for example, a sliding material, at the concrete, a ring-shaped portion having wear resistance property and being provided with a piston ring groove whose sliding conditions are severe among pistons used in an engine.

Description of the Related Art

Taking a piston used in an engine as an example, the prior art of Al-based composite material will be explained. In recent years, an engine has been improved its performance and rising of piston temperature has been unavoidable. Accordingly, there has been developed a technique utilizing an Al-based composite material at pistons.

A publication "Iron and Steel" (Association of Iron and Steel, the September number 1989, page 376) discloses a technique in which an Al-based composite material produces a ring-shaped portion having wear resistance property which forms a ring groove which maintains a piston ring in a piston. Based on this conventional technique, reinforced materials: such as titanate whiskers; carbon fibers; alumina fibers; alumina-silica fibers; $NiAl_3$ particles are used, and Al alloy (JIS AC8A) is impregnated in this reinforced material by high pressure casting so that the ring-shaped portion having wear resistance property is formed.

By using the ring-shaped portion having wear resistance property and which is formed by the above-mentioned Al-based composite material, it is possible to reduced its weight and to improve adhesion resistance property compared with the ring-shaped portion having wear resistance property and being made of niresist cast iron. However, as the performance of engines has been advanced in recent years, it has been expected to improve adhesion resistance property more.

SUMMARY OF THE INVENTION

The present invention has been developed in view of the above-mentioned problems. It is a primary object of the present invention to provide an Al-based composite material in which parting property of Al matrix is improved, and also in which adhesion resistance property is improved more so that the Al-based composite material can be suitable to be used as a sliding member whose adhesion resistance property is improved and whose sliding conditions are severe. It is also an object of the present invention to provide a process for producing the above-mentioned Al-based composite material.

The present inventors earnestly carried out development about Al-based composite materials. The present inventors found that if continuity of Al matrix is parted finely by Si particles, continuity of Al matrix is suppressed and transferring of Al components to the mating side is effectively suppressed so that adhesion resistance property in the Al-based composite materials is improved. By paying attention to this viewpoint, the present inventors completed the present invention.

Namely, according to a first aspect of the present invention, an Al-based composite material having adhesion resistance property comprises:

Al matrix including primary crystal Si particles whose mean particle diameter is not more than 20 μm (microns) and eutectic Si particles;

wherein said Si particles fall in a range of from 20 to 36% by volume. Al matrix means aluminum alloy or aluminum metal.

An Al-based composite material having adhesion resistance property according to a second aspect of the present invention comprises:

Al matrix including: first Si particles whose mean particle diameter is in an amount of 3 to 10 μm (microns); second Si particles which are made of eutectic Si and whose mean particle diameter is not more than 1 μm (micron); and third Si particles whose mean particle diameter is in an amount of 20 to 60 μm (microns),

wherein the total amount of the first and second Si particles fall in a range of from 20 to 40% by volume and the third Si particles fall in a range of from 1 to 6% by volume.

An Al-based composite material having adhesion resistance property according to a third aspect of the present invention comprises:

Al matrix including primary crystal Si particles and eutectic Si particles; and
Fe alloy fine pieces dispersed in the Al matrix;
wherein the total amount of the Si particles and the Fe alloy fine pieces fall in a range of from 20 to 74% by volume.

An Al-based composite material having adhesion resistance property according to a fourth aspect of the present invention comprises:

Al matrix including primary crystal Si particles and eutectic Si particles; and
Fe alloy fine pieces and ceramic particles dispersed in the Al matrix:
wherein the total amount of the Si particles, the Fe alloy fine pieces and ceramic particles fall in a range of from 25 to 73% by volume; and the ceramic particles fall in a range of from 2 to 10% by volume.

In an Al-based composite material having adhesion resistance property according to a fifth aspect of the present invention in the third or fourth aspect of the present invention, the hardness of Fe alloy fine pieces is not less than Hv 250.

In an Al-based composite material having adhesion resistance property according to a sixth aspect of the present invention in the first, third or fourth aspect of the present invention, the mean particle diameter of the primary crystal Si particles falls in the range of from 3 to 10 μm (microns).

A process for producing an Al-based composite material having adhesion resistance property employs a powder compact which is made of the aggregate of Al powder particles and which has pores, according to a seventh aspect of the present invention comprises the steps of:

an arranging step of placing the powder compact in a cavity of a molding die; and
a solidifying step of supplying Al molten metal to the cavity of the molding die, impregnating the Al molten metal into the pores of the powder compact by high pressure casting, and solidifying the Al molten metal.

According to the first aspect of the present invention, the mean particle diameter of the primary Si particles included in the Al matrix is not more than 20 μm (microns) and the primary Si particles are very minute; and also these Si particles are included in a large amount ranging from 20 to 36% by volume; so that the parting property of parting the continuity of Al matrix by using these Si particles is improved. Accordingly, even if the sliding condition are severe, transferring of Al components of the Al matrix to a mating side is effectively suppressed so that the adhesion resistance property thereof is improved.

Furthermore, Si particles take pavement effect on Al matrix so that the wear resistance property thereof is also secured. The Si particles generally are primary crystal Si particles and eutectic Si particles which were crystallized at the time when Al-Si molten metal is solidified.

According to the second aspect of the present invention, the first, second and third Si particles, all of which have different particle diameters, are included in the Al-based composite material so that the parting of Al matrix by using Si particles is improved more. Accordingly, transferring of Al components of the Al matrix to a mating member is effectively suppressed and adhesion resistance property thereof is improved. Generally, the first Si particles whose particle diameter is minute and the second Si particles whose particle diameter is extremely minute can be supplied in crystallizing phenomenon during the atomizing of powder particles constituting the powder compact. The third Si particles whose particle diameter is larger than that of the first Si particles can be supplied in crystallizing phenomenon of Al molten metal which is impregnated in the powder compact.

According to the second aspect of the present invention, the ratio of Si particles can be changed in response to the kinds of Al-based composite materials. For example, the upper limit of the total amount of the first Si particles and the second Si particles can be set to be 35% or 30% by volume; and the lower limit of the total amount the first Si particles and the second Si particles can be set to be 23% or 27% by volume. The upper limit of the third Si particles can be set to be 18% or 15% by volume and the lower limit of the third Si particles can be set to be 7% or 10% by volume.

According to the third aspect of the present invention, not only Si particles but also Fe alloy micro pieces are added. Therefore, the parting of Al matrix is secured more and the adhesion resistance property is improved. Not only Si particles but also Fe alloy micro pieces can be expected to take pavement effect and to improve the wear resistance property thereof. As Fe alloy micro pieces, they may be selected from shapes such as particles and fibers. When the Fe alloy micro pieces are in the shape of particles, the mean particle diameter may fall in the range of from 10 to 80 μm (microns). As the composition of Fe alloy micro pieces, as shown in the preferred embodiments mentioned later, Fe-Cr alloy, Fe-Mo alloy or stainless steel (SUS) may be adopted. In Fe alloy micro pieces, carbon as a carbide producing element may be included.

According to the fourth aspect of the present invention, not only Si particles but also Fe alloy micro pieces and ceramic particles are added. Therefore, the parting of Al matrix is secured more and the adhesion resistance property is improved. The hardness of Fe alloy micro pieces and ceramic particles are higher compared with that of Al matrix, so that Fe alloy micro pieces and ceramic particles can be expected to obtain pavement effect and wear resistance property thereof can be secured. As ceramic particles, oxide, nitride or carbide may be employed. The mean particle diameter of ceramic particles may fall in the range of from 1 to 80 μm (microns), especially from 3 to 50 μm (microns).

According to the fifth aspect of the present invention, Fe alloy micro pieces of more than Hv250 are used so that wear resistance property thereof is advantageously secured. In response to the using conditions of the Al-based composite material, as Fe alloy micro pieces, it may be selected from the group consisting of Fe alloy micro pieces whose hardness is more than Hv300, Hv 400, Hv500 Hv600 and Hv700.

According to the sixth aspect of the present invention, the minute primary crystal Si particles whose mean particle diameter is in an amount of 3 to 10 μm (microns), so that the parting of Al matrix by Si particles is easily secured and adhesion resistance property thereof is improved.

At the surface of Al powder particles, oxide films is easy to be existed. When the Al powder particles are bonded integrally each other, the oxide films existed on the surface of Al powder particles produce harmful effects. With regard to this, according to the seventh aspect of the present invention, even if the oxide films are existed on the surface of Al powder particles constituting a powder compact, the residual of oxide films on the surface of particles can be easily reduced and avoided. The oxide films there are assumed to be destroyed by the pressure at the time high pressure casting. The existence of oxide films, which exist at the boundary of between the solidified portion of Al molten metal impregnated in the powder compact by the high pressure casting and the Al powder particles constituting the powder compact, is suppressed or avoided. Therefore, after the high pressure casting, as shown in Figure 2 mentioned later, matrix structure having no boundary or less boundary can be obtained. The pressure at the time of the high pressure casting may be set from about 500 atmosphere to 1500 atmosphere. According to the process of the seventh aspect of the present invention, the Al-based composite materials in the first to sixth aspects of the present invention can be produced.

According to the first aspect of the present invention, a large amount of minute Si particles are included so that the parting property in which Si particles part the continuity of the Al matrix is improved. Accordingly, the transferring of the Al matrix to a mating member is effectively suppressed and adhesion resistance property is improved.

According to the second aspect of the present invention, a large amount of the first Si particles, second Si particles and third Si particles, all of which are minute and have different particles diameters, are included. Accordingly, the parting of Al matrix by using Si particles is improved more and therefore, adhesion resistance property thereof is improved.

According to the third aspect of the present invention, not only Si particles but also Fe alloy micro pieces are added. Therefore, the parting of Al matrix is secured more and the adhesion resistance property is improved. The hardness of Fe alloy micro pieces are higher compared with that of the Al matrix, the wear resistance property is also secured.

According to the fourth aspect of the present invention, not only Si particles but also Fe alloy micro pieces and ceramic particles are added. Therefore, the parting of Al matrix is secured more and the adhesion resistance property is improved. The hardness of Fe alloy micro pieces and ceramic particles are higher compared with that of Al matrix, Fe alloy micro pieces and ceramic particles can be expected to secure wear resistance property.

According to the fifth aspect of the present invention, Fe alloy micro pieces of more than Hv250 so that the above-mentioned effect is obtained and furthermore, wear resistance property thereof is advantageously secured.

According to the sixth aspect of the present invention, the minute primary crystal Si particles whose mean particle diameter is in an amount of 3 to 10 μm (microns), so that the parting of Al matrix by primary crystal Si particles is easily secured and adhesion resistance property thereof is improved.

According to the seventh aspect of the present invention, even if the oxide films are existed on the surface of Al powder particle, the oxide films are easy to be destroyed. As a result, the existence of oxide films, which exist at the boundary of between the solidified portion of Al molten metal impregnated by the high pressure casting and the Al powder particles constituting the powder compact, is suppressed or avoided. Therefore, Al matrix structure having no boundary or less boundaries is obtained so that not only adhesion resistance property of the Al-based composite material but also the strength thereof are improved.

According to the above-mentioned first to seventh aspects of the present invention, the present invention is advantageously applied to the sliding member whose sliding conditions are severe, for example, a region for forming a piston ring (top ring) groove of a diesel engine or a gasoline engine.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete appreciation of the present invention and many of its advantages will be readily obtained as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings and detailed specification, all of which forms a part of the disclosure:

Figure 1 is a block diagram showing typically the state in which adhesion resistance property is investigated;
Figure 2 is an electron microscope photograph showing metallographic structure of Al-based composite material;
Figure 3 is a block diagram showing the configuration for defining a parting coefficient;
Figure 4 is a graph showing the relation between mean particle diameter of primary crystal Si particles and the adhesion area; and
Figure 5 is a cross sectional view showing typically the application example to a piston.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Having generally described the present invention, a further understanding can be obtained by reference to the specific preferred embodiments which are provided herein for purposes of illustration only and are not intended to limit the scope of the appended claims.

First Preferred Embodiment

In a First Preferred Embodiment, Al-Si powder (atomized powder, made by Toyo Aluminium Kabushiki Kaisha, mean particle diameter 50 μm (microns)) comprising the composition of Al-38wt%Si; and Fe-Cr powder (crushed powder, made by Fukuda Metal Corporation, mean particle diameter 60 μm (microns), including 7.4wt%C) comprising the composition of Fe-63wt%Cr are used. In the former Al-Si powder, primary crystal Si particles (mean particle diameter 10 μm (microns)) and eutectic Si particles of less than sub-micron (that is, less than 1 μm (micron)) are generated.

Initially, the mixed power in which both of powder are mixed was inserted in a cavity of a metallic die for a forming green compact. After that, the mixed powder was pressed by metallic die compressing method so that a green compact having a predetermined porosity, that is a powder compact (size: diameter 100mm, length 10mm) was produced.

Furthermore, the powder compact was pinched by a ceramic-fiber compact (made by isolite Industry Co., Ltd., Vf7%, size: 100mm x 100mm x 5mm) equipped with a weight for preventing float, and furthermore, by preheating the powder compact at 350°C for 30 minutes and it was arranged in a part of a cavity (diameter 110mm, length 200mm) of a metallic mold-die for high pressure casting.

After that, Al molten metal (JIS-AC8A) at a temperature of 750°C was poured into the cavity of the metallic mold-die for high pressure casting method; the Al molten metal was impregnated in the pores at the inside of the powder compact by pressing by a plunger; that is, Al alloy was compounded by the high pressure casting so that a casting was molded.

The pressing pressure in the high pressure casting method falls in the range of from about 1200 to 1300 atmosphere The target composition of AC8A in JIS standard is as follows: Si falls in the range of from 11 to 13wt%; Cu falls in the range of from 0.8 to 1.3wt%; and Mg falls in the range of from 0.7 to 1.3wt%. In the First Preferred Embodiment of the present invention, Si amount of Al molten metal which was actually impregnated is 12wt%.

From the above-mentioned casting, a specimen (NO.1) made from the Al-based composite material was picked out and T7 heat treatment (maintained for three hours at a temperature of 490°C, then warm water hardening was conducted) was conducted on it. Similarly, specimens No. 2 to No. 19 were obtained and in the same way, T7 heat treatment was conducted on them. The data concerning from No. 1 to No. 19 are shown in Table 1.

In table 1, when the Al-based composite material is set to be 100%, Vf(Al-Si) means % by volume in which the powder compact formed by Al-Si powder particles occupies. When the Al-based composite material is set to be 100%, Vf(Fe-Cr) means % by volume in which Fe-Cr particles occupy. When the Al-based composite material is set to be 100%, Vf(Si) means % by volume in which primary crystal Si particles and eutectic Si particles in the powder compact occupy.

Vf (Total) means the sum of Vf(Fe-Cr) and Vf(Si). When the Al-based composite material is set to be 100%, Vf (Total) means % by volume in which the sum of primary crystal Si particles and Fe-Cr particles in the powder compact occupy. Accordingly, in specimens (NO. 2, NO. 4 and the like) including no Fe-Cr particles, Vf (Total) means % by volume of Si particles when the Al-based composite material is set to be 100%.

When the Al-based composite material is set to be 100%, Vf(MMC) means % by volume in which the sum of Si particles and Fe-Cr particles in the powder compact and Si in the AC8A alloy impregnated and solidified occupy.

For example, according to specimen No. 2 of Table 1, Vf(Al-Si) meaning the ratio of the powder compact is 50% by volume, and Vf(Si) meaning the ratio of primary crystal and eutectic Si particles is 21% by volume. Vf(MMC) including Si of Al molten metal impregnated is 28% by volume.

The adhesion resistance property of each of above-mentioned specimens (NO. 1 through NO.19) were evaluated. Namely, as shown typically in Figure 1, a testing machine comprising platforms 11 and 12 which are equipped with heaters 10 and which are facing each other. Considering the piston rings used in an engine, a nitride ring 13 made of Cr stainless steel including 17wt%Cr as a mating member is mounted on the platform 12; and furthermore, a specimen W (diameter 90 mm, thickness 10 mm) is maintained on the platform 11. In this state, the platform 12 was removed in the arrow Y1 direction in the reciprocating movement; the specimen W was beaten by the nitride ring 13 at 280°C, at a bearing pressure of 0.1MPa and for ten minutes; and after beating, the adhesion area at the specimen W was measured so that the adhesion resistance property was evaluated.

The results are shown in the column "ADHESION" of Table 1.

As shown in Table 1, specimen NO. 1 represents a comparative example in which the mount of Si particles (Vf(Si) = 17% by volume) is less. In specimen NO. 1 in this way, the adhesion was "YES".

Specimen NO. 2 (Vf(Si) : 21% by volume), specimen NO. 4 (Vf(Si) : 25% by volume) and specimen NO. 9 (Vf(Si) : 35% by volume) include no Fe-Cr particles, however, include a large amount of Si particles. Si particles, as mentioned above, are supplied from the atomized powder and Si particles comprises: the primary crystal Si particles whose mean particles diameter is 10 um; and the eutectic Si particles of less than submicron diameter.

In this way, based on specimens NO. 2, NO. 4 and NO. 9 which include a large amount of Si particles, the adhesion was "almost NO" as shown in Table 1. As is clear from this result, in the case when the large amount of minute Si particles are included, the parting property of Al matrix by Si particles is secured and it is found that the adhesion resistance property thereof is satisfactory.

As is clear from Table 1, in the other specimens, the adhesion was "NO" for they include both of minute Si particles and Fe-Cr particles.

Considering the specimen including both of Si particles and Fe-Cr particles, as shown in Table 1, in specimen NO. 3, Vf(Fe-Cr) meaning the mount including Fe-Cr particles is 4% by volume, and Vf(Si) meaning the amount including Si particles is 17% by volume. As a result, in specimen NO. 3, VF(Total) meaning the sum of volume rates of Si particles and Fe-Cr particles is 21% by volume. In this way, in specimen NO. 3 including both of Si particles (mean particle diameter 10 um (microns)) and Fe-Cr particles (mean particle diameter 60 um (microns)), the adhesion was "NO".

As shown in Table 1, Vf(Total) of specimens NO. 3 and NO. 2 are 21% by volume in both cases. However, specimen NO. 3 including both of Si particles and Fe-Cr particles has more improved adhesion resistance property compared with that of specimen NO. 2 including Si particles but including no Fe-Cr particles.

As shown in Table 1, Vf(Total) of specimens NO. 4 and NO. 5 are 25% by volume in both cases. However, specimen NO. 5 including both of Si particles and Fe-Cr particles has more improved adhesion resistance property compared with that of specimen NO. 4 including Si particles but including no Fe-Cr particles.

This result means that including both of Si particles and Fe-Cr particles is effective to improve adhesion resistance property.

Table 1

No.	Vf(Al-Si)	Vf(Fe-Cr)	Vf(Si)	Vf(Total)	Vf(MMC)	ADHESION
1	40	0	17	17	25	YES
2	50	0	21	21	28	ALMOST NO
3	40	4	17	21	28	NO
4	60	0	25	25	30	ALMOST NO
5	50	4	21	25	31	NO
6	40	10	17	27	34	NO
7	40	13	17	30	36	NO
8	50	9	21	30	36	NO
9	85	0	35	35	37	ALMOST NO
10	80	5	33	38	40	NO
11	70	10	29	39	42	NO
12	60	15	25	40	43	NO
13	70	15	29	44	46	NO
14	60	20	25	45	48	NO
15	60	25	25	50	52	NO
16	40	40	17	57	60	NO
17	30	50	12	62	65	NO
18	20	60	8	68	71	NO
19	20	65	8	73	75	NO

Figure 2 shows a metallographic structure. As mentioned above, AC8A molten metal was impregnated in the powder compact comprising: Al-Si powder whose composition is Al-38wt%Si; and Fe-Cr powder whose composition is Fe-63wt%Cr and they were solidified so as to get the specimen. Figure 2 is the photograph in which the metallographic structure (no etch) of thus obtained specimen was observed by the electron microscope photograph (SEM) after the specimen was conducted T7 treatment. Concretely, Figure 2 shows the metallographic structure of specimen NO. 14. At the right bottom of the photograph, the reference length (10 μm (microns)) is shown.

In this metallographic structure, large and whitish particles which are square are seem to be Fe-Cr particles; and blackish and minute particles included in Al matrix are assumed to be the primary crystal Si particles.

Based on the reference length (10 μm (microns)) shown in the photograph (Figure 2), it is clear that the mean particle diameter of the primary crystal Si particles is not more than 10 μm (microns). In general, the hardness of Al matrix falls in the range of from about Hv110 to 150 at Al portions; and the hardness of Al matrix is about Hv200 if the Si particles are included. The hardness of the primary crystal Si particles falls in the range of from Hv800 to 1000. The hardness of Fe-Cr powder, in the state of the powder, is about Hv1600.

In the case when the Al alloy including a large amount of Si is molded by a die casting method, the mean particle diameter of the primary crystal Si particles grows so as to exceed to be 50 μm (microns) generally. Namely, in the die casting method, the solidifying speed is relatively low compared with that of the atomizing method so that, the mean particle diameter of the primary crystal Si particles at least falls in the range of from 40 to 50 μm (microns) at the minimum, and therefore, it is impossible to obtain the primary crystal Si particles whose mean particle diameter is not more than 20 μm (microns). In this case, the mean particle diameter of Si particles is large so that the distance between neighboring Si particles is departed. Namely, the parting property of Al matrix by the Si particles is not sufficient so that Al components are easy to be transferred to a mating member side, and therefore, satisfactory adhesion property is not obtained.

In this regard, according to the First Preferred Embodiment of the present invention, the atomized powder costituting the powder compact comprises: minute primary crystal Si particles whose mean particle diameter is 10 μm (microns); and the eutectic Si particles of less than submicron diameter (= 1 μm (micron) and less). Accordingly, even if Si content is as same as that in the case of Al alloy molded by the castings such as die casting, based on the First Preferred Embodiment of the present invention, Si particles are minute so that the continuity of Al matrix is finely parted by Si particles in that amount and the parting property of Al matrix is improved. Therefore, the First Preferred Embodiment of the present invention is advantageously reduce the transferring of Al components to a mating side and adhesion resistance property thereof is improved.

The definition of the parting property will be conducted as follows. Picking up a point in Al matrix, and a plurality of Si particles which exist around that point are linked by straight lines so as to form a figure; and the longest distance in that figure is understood to be the parting property. For example, as shown in Figure 3, an attention was given to an arbitrary point M in Al matrix; six Si particles around the point M, for example, were connected by straight lines so as to be supposed to draw a figure of a polygonal shape; and then the average value of the longest distance L1 in the inside of that figure can be defined as a parting coefficient.

According to the First Preferred Embodiment of the present invention, this parting coefficient can be set to be 10 μm (microns) and less. However in the case when the die casting method in which the primary crystal Si particles are crystallized from the Al molten metal is adopted, the parting coefficient is generally about 30 μm (microns) at the minimum so that in this case satisfactory parting property cannot be expected.

Also based on the First Preferred Embodiment of the present invention, even if the oxide films are existed on the surface of the atomized powder particles constituting the powder compact, the oxide films are easy to be destroyed by the pressure at the time of the high pressure casting. As a result, it is suppressed or avoided that the oxide films are existed between the boundary of the solidified portion of Al molten metal impregnated in the powder compact by the high pressure casting and the atomized powder particles constituting the powder compact. Therefore, as shown in metallographic structure concerning Figure 2, there are no boundary or extremely less boundary in Al matrix structure so that the strength of the Al-based composite material is improved.

Second Preferred Embodiment

In a Second Preferred Embodiment of the present invention, as in the same way as that of the First Preferred Embodiment, powder whose composition is Al-38wt%Si (made by Toyo Aluminium Kabushiki Kaisha, atomized powder, mean particle diameter is 50 μm (microns) and mean particle diameter of the primary crystal Si particles is 10 μm (microns)) was used. Then the powder compact (size: diameter 100 mm, length 10 mm) was produced by a metallic die compressing method. Furthermore, in the same way as that of the First Preferred Embodiment, the powder compact was pinched by a ceramic (kaowool) compact equipped with a weight for preventing float; and by preheating the powder compact at 350°C for 30 minutes, it was arranged in a cavity of a metallic mold-die.

After that, instead of Al molten metal of AC8A used in the First Preferred Embodiment, Al molten metal including more Si compared with those of AC8A, that is Al molten metal whose composition is Al-25wt%Si was used. This Al molten metal (850°C) was poured into the cavity of the metallic mold-die; then this Al molten metal was impregnated and solidified in the pores of the powder compact by the high pressure casting; so that Al alloy was compounded and a casting was molded by this. The pressure at the time of the high pressure casting falls in the range of from 1200 to 1300 atmosphere.

From the above mentioned casting, a specimen (NO. 20) was derived. The shape factors of this specimen are shown in Table 2. In the case of this specimen, primary crystal first Si particles whose particle diameters are small; eutectic Si particles which are not more than submicron (= 1 micron) diameter; and primary crystal third Si particles whose particle diameters are large are dispersed.

That is to say, in the atomized powder constituting the powder compact, at the time of atomizing treatment, the primary crystal Si particles (= the first Si particles) whose mean particle diameter is small to be 10 μm (microns) and the eutectic Si particles (= the second Si particles) which are not more than submicron diameters, namely, not more than 1 μm (micron) are generated. Furthermore, when Al molten metal impregnated in the powder compact is solidified, the primary crystal Si particles (= third Si particles) whose mean particle diameters are 20 to 60 μm (microns) are crystallized.

In this Second Preferred Embodiment of the present invention, when the Al-based composite material was set to be 100 %, the sum volume of the first Si particles whose mean particle diameters are 10 μm (microns) and the second Si particles which are not more than submicron diameters amounted to be about 25% by volume; and the third Si particles whose mean particle diameters are 20 to 60 μm (microns) was 2 to 3% by volume.

T7 heat treatment was conducted to the specimen (NO. 20) and adhesion resistance property was evaluated as in the same way as that in the First Preferred Embodiment. The test results are shown in Table 2. As shown in the column of "ADHESION" in Table 2, it was found that adhesion was not generated.

Table 2

No.	Vf(Al-Si)	Vf(Fe-Cr)	Vf(Si)	Vf(Total)	Vf(MMC)	ADHESION
20	60	0	25	25	36	NO

A large number of pores are included in the inside of the powder compact and this specimen has the structure of three-dimensional grating. If the Al molten metal is forced to be impregnated to the above-mentioned powder compact, Al molten metal is forced to be contact with a grating surface of the three-dimensional grating structure of the powder compact. Furthermore, Al molten metal gets in contact with in the inside of the powder compact three-dimensionally so that between the powder compact and the Al molten metal, area of heat-transfer surface is increased. Accordingly, the solidifying speed of Al molten metal is increased and when the primary crystal Si particles are crystallized from the Al molten metal, it is advantageous to prevent the primary crystal Si particles from growing. Therefore, it is possible to control the mean particle diameter of the third Si particles, which are crystallized form the Al molten metal impregnated in the powder compact, to be 20 to 60 μm (microns) so as to be small. Also in this sense, the parting of Al matrix by Si particles can be secured.

Third Preferred Embodiment

In a Third Preferred Embodiment, the same type of test as that of Table 1 concerning the First Preferred Embodiment was conducted except that instead of Fe-Cr powder having the composition of Fe-63wt%Cr used in the First preferred Embodiment, Fe-63wt%Mo powder (made by Fukuda Metals. Ltd., crushed powder, mean particle diameter 60 μm (microns)) was used. In this case the same tendency was obtained with regard to the adhesion resistance property. The hardness of Fe-Mo particles is about Hv1000, however, after high pressure casting and T7 treatment were conducted, it was found that the hardness of the Fe-Mo particles is decreased to be Hv600 to 750.

Also the same type of test as that of Table 1 concerning the First Preferred Embodiment was conducted, except that SUS316 short fibers (made by Alsin Seiki Co., Ltd., average length: 700 μm (microns), mean particle diameter: 100 μm (microns) as Fe alloy fine pieces was used as the substitute for Fe-Cr powder used in the First Preferred Embodiment. In this case, also, there was found the similar tendency of adhesion resistance property. When the SUS316 short fibers were used, molding limit was 75% by volume.

The same type of test as that of Table 1 concerning the First Preferred Embodiment was conducted, except that the mixed powder (mixed ratio is 2 : 1 in volume ratio) of Fe-Mo powder and SKD61 powder (made by Mitsubishi Steel Mfg. Co., Ltd., mean particle diameter : 60 μm (microns)) was used as the substitute for the Fe-Cr powder used in the First Preferred Embodiment. In this case, also, the similar tendency of adhesion resistance property was found.

The same type of test as that of Table 1 concerning the First preferred Embodiment was conducted, except that the mixed powder (mixed ratio is 1 : 1 in volume ratio) of Fe-Cr powder and the above-mentioned Fe-Mo powder was used as the substitute for Fe-Cr powder used in the First Preferred Embodiment. In this case, also, the similar tendency of adhesion resistance property was found.

As a Comparative Example, a specimen was molded in the same configuration as that of the First Preferred Embodiment, except that SKD61 powder (made by Mitsubishi Steel Mfg. Co., Ltd., mean particle diameter 60 μm (microns), Hv500 to 600) was independently. The same type of test as that of the above-mentioned was conducted to the specimen concerning this Comparative Example. After the high pressure casting and T7 treatment were conducted to this Comparative Example, the hardness of SKD61 powder particles in the specimen was measured. There was found that hardness, which originally falls in a range of from Hv500 to 600, was greatly reduced to be about Hv200, so that it was found that hardness in the Comparative Example is soft compared with the hardness (more than Hv400) of the other powder particles. Accordingly, the hardness of Fe powder particles dispersed in the Al-based composite material in the state after treatments of high pressure casting and T7 treatment preferably amounts to HV250 and more .

Fourth Preferred Embodiment

In a Fourth Preferred Embodiment, Al-Si powder having the composition of Al-38wt%Si was used in 80% by volume ratio. Furthermore, the same type of test as that of the First Preferred Embodiment was conducted so as to evaluate adhesion resistance property, except that the Al_2O_3 particles (made by Showa Denko K.K., mean particle diameter 10 μm (microns)) as ceramic particles were used only in 5% by volume as the substitute for Fe-Cr powder used in the First Preferred Embodiment. Also in this case, it was found that no adhesion was generated.

The same type of test as that of the First Preferred Embodiment was conducted so as to evaluate adhesion resistance property, except that mullite particles (made by Showa Denko K.K., mean particle diameter 10 μm (microns)) as ceramic particles were used in only 5% by volume as the substitute for Fe-Cr powder used in the First Preferred Embodiment. Also in this case, it was found that no adhesion was generated.

The same type of test as that of the First Preferred Embodiment was conducted so as to evaluate adhesion property, except that SiC particles (made by Showa Denko K.K., mean particle diameter 10 μm (microns)) as ceramic particles were used only in 5% by volume as the substitute for Fe-Cr powder used in the First Preferred Embodiment. Also in this case, it was found that no adhesion was generated.

The same type of test as that of the First preferred Embodiment was conducted so as to evaluate adhesion resistance property, except that Si_3N_4 particles (made by Electric Chemical Co., Ltd., mean particle diameter 15 μm (microns)) as ceramic particles were used only in 5% by volume as the substitute for Fe-Cr powder used in the First Preferred Embodiment. Also in this case, it was found that no adhesion was generated.

Furthermore, the same type of test as that of the First Preferred Embodiment was conducted so as to evaluate adhesion property, except that $9Al_2O_3 \cdot 2B_2O_3$ particles (made by Shikoku Chemical Industry Co., Ltd., mean particle diameter 10 μm (microns)) as ceramic particles were used only in 5% by volume as the substitute for Fe-Cr powder used in the First Preferred Embodiment. Also in this case, it was found that no adhesion was generated.

Moreover, the same type of test as that of the First Preferred Embodiment was conducted so as to evaluate adhesion resistance property, except that TiC particles (made by Kyoritz Refractories Co., Ltd., mean particle diameter 10 μm (microns)) were used only in 5% by volume. Also in this case, it was found that no adhesion was generated.

The rate of the above-mentioned ceramics particles are not limited to the above-mentioned ratios, however, depending on the kinds of the Al-based composite material, the above-mentioned ceramics particles can be properly adjusted in the range of 2 to 10% by volume. The sum of Si particles, ceramics particles Fe alloy micro pieces can be adjusted in the range of from 25 to 73% by volume so as to secure adhesion resistance property.

Based on references, in general, the hardness of each of particles are mentioned as follows: the hardness of Al_2O_3 particles amount to about Hv1800; the hardness of mullite particles amount to about Hv1000; the hardness of SiC particles amount to about Hv2900; the hardness of Si_3N_4 particles amount to about Hv2300; and the hardness of TiC particles amount to about Hv1800.

Fifth Preferred Embodiment

In a Fifth Preferred Embodiment, Al-Si powder having the composition of Al-38wt%Si in which mean particle diameter varies in 3 μm, 10 μm and 15 μm. Except that Si is included only in 30% by volume, the specimen was produced under the same conditions as those of the specimen of NO. 4 in the First Preferred Embodiment; and the test was conducted so as to evaluate adhesion resistance property of that specimen. The test results are shown in Figure 4. As is understood from characteristic line X of Figure 4, when the mean particle diameter of the primary crystal Si particles is 15 μm (microns), the adhesion area thereof is not more than 9.5 mm^2; and when the mean particle diameter of the primary crystal Si particles is 10 μm (microns), the adhesion area thereof is not more than 7.5 mm^2.

When the mean particle diameter of the primary crystal Si particles is relatively large to be 25 μm (microns), the adhesion area thereof generally exceeds 25 mm^2. Accordingly, the mean particle diameter of the primary crystal Si particles is set to be not more than 20 μm (microns), the adhesion resistance property of the Al-based composite material is improved. Based on the characteristic line X of Figure 4, when the mean particle diameter of the primary crystal Si particles is not more than 10 μm (microns), it is clear that it is preferable to improve the adhesion resistance property.

(Application Example)

Figure 5 shows an application example. In this example, the present invention is applied to a piston used for a diesel engine. This piston 5 comprises: a piston body 50 having a piston head 50a and a cavity 50b; a reinforced portion 51b which is connected to the piston head 50a side in the piston 50 and which is in ring shaped. This reinforced portion 51 is composed of the above-mentioned Al-based composite material. Namely, the Al-based composite material constituting the reinforced portion 51 is selected from the group consisting of the Al-based composite material concerning Claims 1 through 7.

Cited as an example, the Al-based composite material constituting the reinforced portion 51 comprises Al matrix including the primary crystal Si particles and the eutectic Si particles whose mean particle diameter is not more than 20 μm (microns); and when the Al-based composite material constituting the reinforced portion 51 is set to be 100%, Si particles amount to 20 to 36% by volume.

At the outer periphery portion of this reinforced portion 51, a top ring groove 52 was formed by a cutting work method by the use of a cutting tool. At the top ring groove 52, a top ring is provided and when a diesel engine is driven, that is, in the state of high temperature, a groove forming surface of the top ring groove 52 and the top ring slide each other. In this application example, adhesion resistance property at the reinforced portion 51 made of the Al-based composite material was found to be satisfactory.

(Additional Remarks)

The following technical ideas can be seized from the above-mentioned Preferred Embodiments.

- o A sliding material which was molded in a way in which Al molten metal is impregnated, by the high pressure casting, to the powder compact which is non-sintered compact formed by Al-Si powder including the primary crystal Si particles so as to be solidified.
- o An Al-based member which is equipped with a reinforced portion composed of Al-based composite material in at least one part, wherein

  the Al-based composite material comprising Al matrix including the primary crystal Si particles whose mean particle diameter is not more than 20 μm (microns) and the eutectic Si particles; and when the Al-based composite material is set to be 100%, Si particles amount to 20 to 36% by volume.
- o An Al-based member which is equipped with a reinforced portion composed of Al-based composite material at a part thereof at least, wherein

  the Al-based composite material is molded by one of the Al-based composite material concerning Claims 2 through 7.

Having now fully described the present invention, it will be apparent to one of ordinary skill in the art that many changes and modifications can be made thereto without departing from the spirit or scope of the present invention as set forth herein including the appended claims.

An Al alloy piston comprises a piston body and a reinforced portion forming a piston groove. The reinforced portion is composed of Al-based composite material. Namely, Al molten metal (AC8A) forming the piston body was impregnated to the powder compact which is non-sintered compact so as to be solidified so that the reinforced portion was formed. The powder compact is made by compressing atomized powder having the primary crystal Si particles whose mean particle diameter is 10 μm (microns). To the powder compact Fe-Cr powder particles may be added. Accordingly, the present invention provide Al-based composite material whose adhesion resistance property is improved and the process for producing the same.

Claims

1. An Al-based composite material having adhesion resistance property, said Al-based composite material is characterized in that it comprises:

Al matrix including primary crystal Si particles whose mean particle diameter is not more than 20 μm (microns) and eutectic Si particles:

wherein said Si particles fall in a range of from 20 to 36% by volume.

2. An Al-based composite material having adhesion resistance property, said Al-based composite material is characterized in that it comprises:

Al matrix including: first Si particles whose mean particle diameter is in an amount of 3 to 10 μm (microns); second Si particles which are made of eutectic Si and whose mean particle diameter is not more than 1 μm (microns); and third Si particles whose mean particle diameter is in an amount of 20 to 60 μm (microns),

wherein the total amount of said first and second Si particles fall in a range of from 20 to 40% by volume and said third Si particles fall in a range of from 1 to 6% by volume.

3. An Al-based composite material having adhesion resistance property, said Al-based composite material is characterized in that it comprises:

Al matrix including primary crystal Si particles and eutectic Si particles; and
Fe alloy fine pieces dispersed in said Al matrix;

wherein the total amount of said Si particles and said Fe alloy fine pieces fall in a range of from 20 to 74% by volume.

4. An Al-based composite material having adhesion resistance property, said Al-based composite material is characterized in that it comprises:

Al matrix including primary crystal Si particles and eutectic Si particles; and
Fe alloy fine pieces and ceramics particles dispersed in said Al matrix;

wherein the total amount of said Si particles, said Fe alloy fine pieces and ceramics particles fall in a range of from 25 to 73% by volume; and said ceramics particles fall in a range of from 2 to 10% by volume.

5. An Al-based composite material having adhesion resistance property according to Claim 3 or 4, wherein the hardness of Fe alloy fine pieces is not less than Hv 250.

6. An Al-based composite material having adhesion resistance property according to Claim 1, 3 or 4, wherein the mean particle diameter of primary crystal Si particles falls in the range of from 3 to 10 μm (microns).

7. A process for producing an Al-based composite material having adhesion resistance property, employing a powder compact which is made of the aggregate of Al powder particles and which has pores,
said process is characterized in that it comprises the steps of:

an arranging step of placing said powder compact in a cavity of a molding die; and
a solidifying step of supplying Al molten metal to said cavity of said molding die and impregnating said Al molten metal into said pores of said powder compact by high pressure casting.

FIG. 1

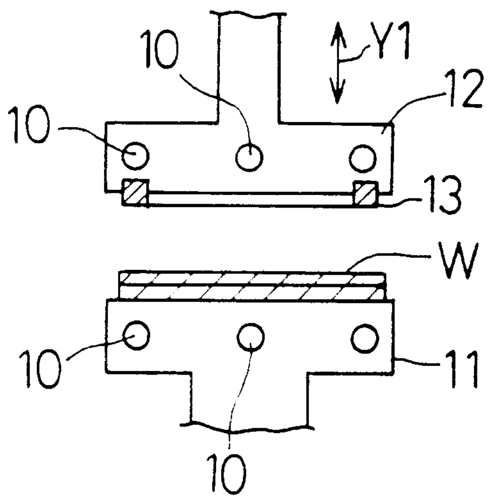


FIG. 2

FIG. 3

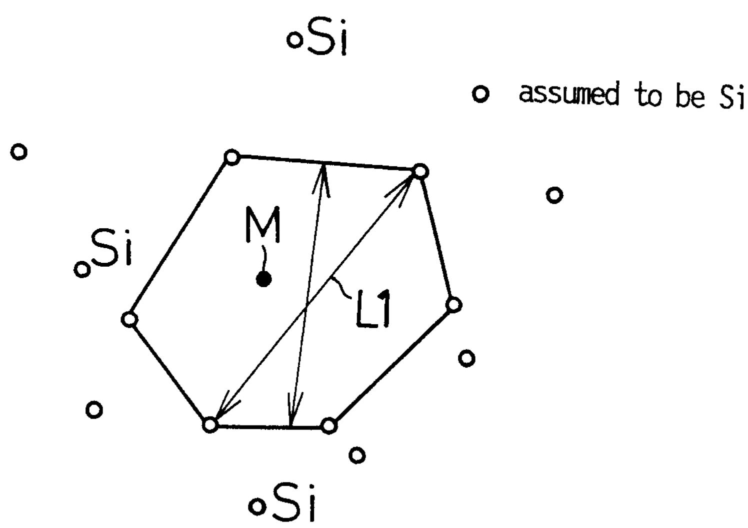

Si
o assumed to be Si
Si
M
L1
Si

FIG. 4

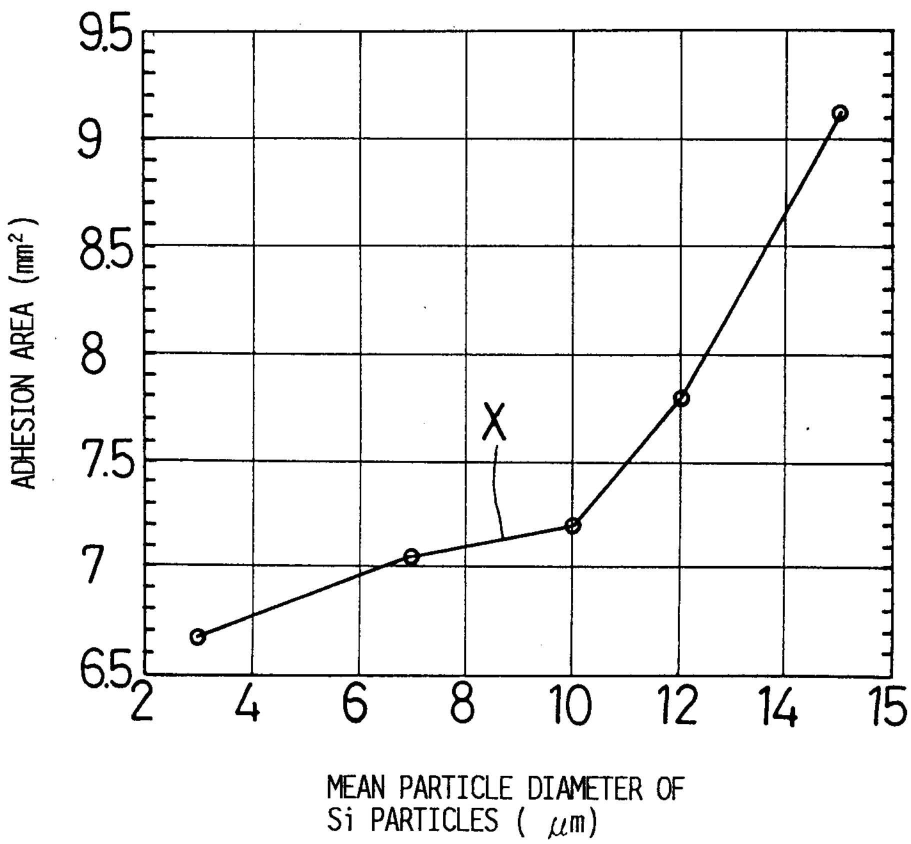
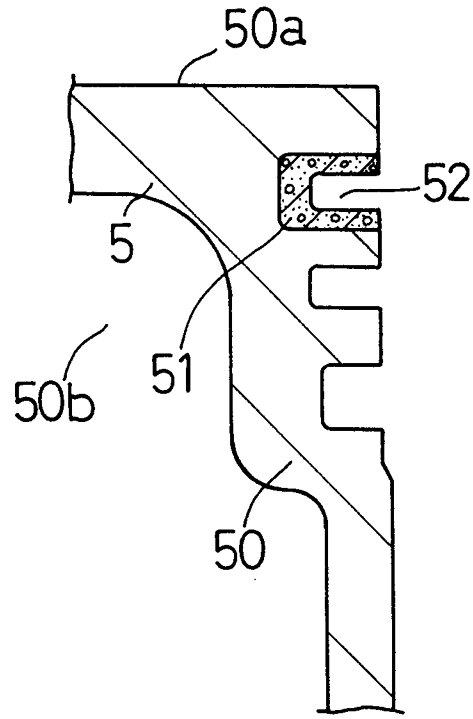

9.5
9
8.5
8
7.5
7
6.5
ADHESION AREA (mm²)
X
2
4
6
8
10
12
14
15
MEAN PARTICLE DIAMETER OF
Si PARTICLES (μm)

FIG. 5



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EUROPEAN SEARCH REPORT

Application Number
EP 96 10 8948

Category	DOCUMENTS CONSIDERED TO BE RELEVANT Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X A	DATABASE WPI Section Ch, Week 8707 Derwent Publications Ltd., London, GB; Class M26, AN 87-045608 XP002011236 & JP-A-62 001 839 (SKY ALUMINIUM KK) , 7 January 1987 * abstract * ---	1 2-6	C22C21/02
Y	DATABASE WPI Section Ch, Week 9201 Derwent Publications Ltd., London, GB; Class M22, AN 92-003616 XP002011237 & JP-A-03 257 128 (TOKAI CARBON KK) , 15 November 1991 * abstract * ---	7	
Y	DATABASE WPI Section Ch, Week 8531 Derwent Publications Ltd., London, GB; Class M22, AN 85-188088 XP002011238 & JP-A-60 118 367 (SUMITOMO ELEC IND KK) , 25 June 1985 * abstract * ---	7	TECHNICAL FIELDS SEARCHED (Int.Cl.6) C22C
A	EP-A-0 141 501 (SHOWA ALUMINUM CORP) 15 May 1985 * abstract * ---	1-6	
A	US-A-3 895 941 (BOLLING GUSTAF FREDERIC ET AL) 22 July 1975 * abstract * ---	1-6	
A	US-A-5 234 514 (DONAHUE RAYMOND J ET AL) 10 August 1993 * claim 1 * -----	1-6	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
MUNICH	21 August 1996	Ashley, G

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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A : technological background
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E : earlier patent document, but published on, or after the filing date
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