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

(11) EP 1 213 366 A2

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
12.06.2002 Bulletin 2002/24

(51) Int Cl.⁷: **C22C 21/02**, B22D 17/00

(21) Application number: **01307824.1**

(22) Date of filing: **14.09.2001**

(84) Designated Contracting States:
AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE TR
Designated Extension States:
AL LT LV MK RO SI

(30) Priority: **26.09.2000 JP 2000293086**

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(54) Aluminum alloy for high pressure die-casting, product and method

(57) An aluminum alloy for die-casting capable of being used in high pressure die-casting method, and capable of providing a product having a sufficiently high strength and elongation without T6 treatment after casting and endurable under a corrosive atmosphere. Such aluminum alloy is used as a material of a subordinate frame for an automobile. The aluminum alloy contains from 8.0 to 9.0 mass % of Si, from 0.35 to 0.45 mass % of Mg, from 0.3 to 0.4 mass % of Mn, from 0.002 to 0.008 mass % of Be, less than 0.20 mass % of Fe, not more than 0.2 mass % of Cu, not more than 0.1 mass % of Zn, not more than 0.1 mass % of Ni, not more than 0.1 mass % of Sn, and remainders of Al and inevitable impurities. High pressure die casting is performed with this alloy by a die-casting machine provided with a seal ring disposed over a plunger tip, liquidized gaskets, a sealing rubber and a pin seal plate those being capable of providing high sealability and high vacuum in a mold cavity.

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Description

[0001] The present invention relates to an aluminum alloy for high pressure die-casting (hereinafter simply referred to as "Al alloy"), a subordinate frame for an automobile, and a high pressure die-casting method, and more particularly, to the Al alloy for die casting available for high pressure die casting without thermal seizure or soldering of the alloy to a metal mold, and to the subordinate frame for the automobile produced by the high pressure die-casting with the Al alloy, and to the high pressure die-casting method using the Al alloy.

[0002] Relatively high strength and elongation are required in an Al alloy used as a raw material of a subordinate frame available for a wheel suspension member and a structural member of an automobile. Further, such material should provide corrosion resistance at low temperature because the subordinate frame is in the corrosive atmosphere at a low temperature. Conventionally, JIS-AC4CH alloy is recognized as a material capable of meeting with such requirements and is used as the casting material for the subordinate frame. Further, casting defect should preferably be minimized for casting the wheel suspension member as the subordinate frame. To this effect, a low speed injection casting method such as gravity die-casting, low pressure die-casting and squeeze die-casting has been employed. Furthermore, the cast product was subjected to T6 treatment in order to provide a predetermined mechanical property of the subordinate frame.

[0003] However, because of the requirement of light weight product for the reduction of fuel consumption, a further reduction in thickness of the subordinate frame has been required. High pressure die-casting method is the uppermost method for producing a thin product. However, AC4CH alloy is not available for the high pressure die-casting method because thermal seizure of the alloy to a metal mold may occur due to insufficient content of Fe. On the other hand, the subordinate frame produced by gravity die casting must be subjected to T6 treatment after casting, which lowers productivity.

[0004] Japanese patent publication No.Sho-59-43539 discloses a high toughness alloy available for high pressure die-casting. However, this alloy is not preferable as material of the subordinate frame used under corrosive atmosphere because of its extremely high Fe content such as from 0.2 to 0.4 mass %.

[0005] It is therefore, an object of the present invention to provide an Al alloy for die-casting capable of being used in the high pressure die-casting method, and capable of providing a product having a sufficiently high strength and elongation without T6 treatment after casting and endurable under a corrosive atmosphere, and to provide a subordinate frame produced through the high pressure die-casting method while using the Al alloy, and to provide a high pressure die-casting method for producing such product.

[0006] In order to attain the above object, the present invention provides an aluminum alloy for high pressure die-casting containing from 8.0 to 9.0 mass % of Si, from 0.35 to 0.45 mass % of Mg, from 0.3 to 0.4 mass % of Mn, from 0.002 to 0.008 mass % of Be, less than 0.20 mass % of Fe, not more than 0.2 mass % of Cu, not more than 0.1 mass % of Zn, not more than 0.1 mass % of Ni, not more than 0.1 mass % of Sn, and remainders of Al and inevitable impurities.

[0007] With this arrangement, high pressure die-casting can be performed with the Al alloy in spite of the fact that the Al alloy provides the composition similar to that of AC4CH alloy unavailable for high pressure die-casting. Accordingly, resultant cast product provides high strength and high elongation those being required for a cast product used under the severe working condition such as a subordinate frame of an automobile in spite of elimination of T6 treatment after casting, and a thin product can result with high productivity at low cost.

[0008] In another aspect of the invention, there is provided a subordinate frame for an automobile produced through high pressure die-casting method, the subordinate frame being made from an aluminum alloy containing from 8.0 to 9.0 mass % of Si, from 0.35 to 0.45 mass % of Mg, from 0.3 to 0.4 mass % of Mn, from 0.002 to 0.008 mass % of Be, less than 0.20 mass % of Fe, not more than 0.2 mass % of Cu, not more than 0.1 mass % of Zn, not more than 0.1 mass % of Ni, not more than 0.1 mass % of Sn, and remainders of Al and inevitable impurities.

[0009] The subordinate frame can be produced by high pressure die-casting, because the Al alloy, which is the raw material of the subordinate frame, contains suitable composition available for high pressure die-casting, even though the composition is similar to that of AC4CH alloy incapable of being used in high pressure die-casting. Because the subordinate frame is produced by high pressure die-casting, a thin product can result with high productivity at low cost.

[0010] In still another aspect of the invention, there is provided a high pressure die-casting method including the steps of using an aluminum alloy containing from 8.0 to 9.0 mass % of Si, from 0.35 to 0.45 mass % of Mg, from 0.3 to 0.4 mass % of Mn, from 0.002 to 0.008 mass % of Be, less than 0.20 mass % of Fe, not more than 0.2 mass % of Cu, not more than 0.1 mass % of Zn, not more than 0.1 mass % of Ni, not more than 0.1 mass % of Sn, and remainders of Al and inevitable impurities, injecting the aluminum alloy into a mold cavity, and evacuating the mold cavity by means of highly vacuum gas vent means to a level not more than 10 kPa during the injection step.

[0011] With this arrangement, high pressure die-casting can be performed with using Al alloy whose composition is similar to that of AC4CH alloy unavailable for high pressure die-casting because Al alloy contains proper composition. Because the used Al alloy contains composition similar to that of AC4CH alloy, a product providing high strength and high elongation can be produced in spite of elimination of T6 treatment after casting. Further, because high vacuum level can be provided in the mold cavity during injection, a stabilized quality results in the resultant cast product at low cost.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] In the drawings;

Fig. 1 is a graph representing a change in sludge factor in accordance with the change in Mn content in the alloy when segregation amount of Fe and Mn at a surface of a cast product becomes three times as high as that at an interior thereof at a casting temperature of 680°C;
Fig. 2 is a graph representing a change in sludge factor in accordance with the change in Mn content in the alloy when segregation amount of Fe and Mn at a surface of a cast product becomes three times as high as that in an interior thereof at Fe content of 0.15 mass %;
Fig. 3 is microscopic photographs showing surface structures of test pieces 1 and 2;
Fig. 4 is a cross-sectional view showing a die-casting machine used in a high pressure die-casting method according to the present embodiment;
Fig. 5 is a photographic view showing a surface, after blister test, of a subordinate frame produced by the high pressure die-casting method according to the present embodiment;
Fig. 6 is a photographic view showing a surface, after blister test, of a subordinate frame produced by a conventional vacuum high pressure die-casting method with a conventional vacuum level; and
Fig. 7 is a photographic view showing a surface, after welding test, of a subordinate frame produced by the high pressure die-casting method according to the present embodiment.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0013] A subordinate frame for an automobile in accordance with one embodiment of the present invention will be described. The subordinate frame is coupled to a body of an automobile for reinforcing a part of the body in order to enhance rigidity at a portion where a suspension mechanism is attached. The subordinate frame for the automobile according to the present embodiment can be produced by high pressure die-casting, because the Al alloy provides proper composition ratio. Further, the subordinate frame can provide high strength and elongation those required in the automobile even without T6 treatment and, a thin product can be produced at high productivity to lower production cost because of high pressure die-casting.

[0014] The Al alloy in accordance with the present embodiment will next be described, the Al alloy being used for raw material of the subordinate frame and used in high pressure die-casting. The Al alloy contains from 8.0 to 9.0 mass % of Si(silicon), from 0.35 to 0.45 mass % of Mg(magnesium), from 0.3 to 0.4 mass % of Mn(manganese), from 0.002 to 0.008 mass % of Be(beryllium), less than 0.20 mass % of Fe(iron), not more than 0.2 mass % of Cu(copper), not more than 0.1 mass % of Zn(zinc), not more than 0.1 mass % of Ni(nickel), not more than 0.1 mass % of Sn(tin), and remainders of Al(aluminum) and inevitable impurities.

[0015] If the amount of Si is less than 8.0 mass %, fluidity of the alloy will be reduced to cause misrun. Therefore, the amount of Si is set not less than 8.0 mass %. On the other hand, if the Si amount is more than 9.0 mass %, elongation and toughness of a resultant alloy will be lowered. Therefore, the Si amount is set not more than 9.0 mass %. By setting the Si amount ranging from 8.0 to 9.0 mass %, castability can be enhanced so that a thin product can be produced.

[0016] If the amount of Mg is less than 0.35 mass %, strength and load at the 0.2% proof stress will be lowered, and therefore, the resultant alloy will not meet with requirements for the subordinate frame. Thus, the Mg amount is set not less than 0.35 mass %. On the other hand, if Mg amount is more than 0.45 mass %, elongation will be reduced, and therefore the alloy will not provide sufficient strength required for the subordinate frame. Thus, Mg amount is set not more than 0.45 mass %. Amount of Mn will be described later.

[0017] Function of Be is to prevent the concentration of Mg in the alloy from being lowered due to oxidation of Mg during melting and holding of the molten metal in the furnace. If Be amount is less than 0.002 mass %, such function does not exhibit. Therefore, Be amount is set not less than 0.002 mass %. On the other hand, if Be amount is more than 0.008 mass %, crystallization of unwanted compound occurs to lower the strength. Therefore, Be amount is set not more than 0.008 mass %.

[0018] If Fe amount is not less than 0.20 mass %, corrosion resistance of the alloy will be lowered. Therefore, Fe amount is set less than 0.20 mass %. If Cu amount exceeds 0.2 mass %, corrosion resistance of the alloy will be lowered. Therefore, Cu amount is set not more than 0.2 mass %. If Zn amount exceeds 0.1 mass %, corrosion resistance of the alloy will be lowered. Therefore, Zn amount is set not more than 0.1 mass %. If Ni amount exceeds 0.1 mass %, crystallization of unwanted compound will occur to lower the mechanical strength of the alloy. Therefore, Ni amount is set not more than 0.1 mass %. If Sn amount exceeds 0.1 mass %, hot cracking may occur in the cast product. Therefore, Sn amount is set not more than 0.1 mass %. Incidentally, Fe, Cu, Zn, Ni, and Sn are impurities inevitably exist in the alloy. Accordingly, these are not requisite elements in the alloy.

[0019] Next, Mn content will be described. As described above, in the Al alloy for the high pressure die-casting according to the present invention, Fe content is limited to a low level such as less than 0.20 mass % in order to enhance corrosion resistance of the alloy. In order to avoid thermal seizure of the alloy at the metal mold due to the shortage of Fe content, one conceivable method is the formation of crystallization of sludge (which is Al-Si-Fe-Mn compound) at a surface of the cast product. However, if Mn amount is less than 0.3 mass %, crystallization of the sludge at the surface of the cast product does not occur, which cannot obviate thermal seizure of the alloy to the metal mold. Accordingly, Mn amount is set not less than 0.3 mass %. On the other hand, if Mn amount exceeds 0.4 mass %, crystallization amount of the sludge becomes excessive, and sludge are also generated in an interior of the cast product. Sludge themselves are rigid and high hardness particles. Therefore, mechanical strength of the cast product may be lowered if the sludge exists in the interior of the cast product. Consequently, the crystallization amount of sludge should be restrained to a low level. Thus, Mn content is set not more than 0.4 mass %.

[0020] Next, the relationship between Mn content and crystallization of sludge will be described in detail. SF value (sludge factor) can be obtained by the following equation (1) in order to acknowledge the fact whether or not crystallization of sludge appears during casting with the alloy.

$$SF=\%Fe+[3.34-(T-630)/714]\%Mn \qquad (1)$$

[0021] Here, "%Fe" designates Fe content (mass %) in the alloy, "%Mn" designates Mn content (mass %) in the alloy, and "T" designates casting temperature (°C). If the sludge factor exceeds a sludge formation limit SF_H, sludge will be crystallized. The sludge formation limit SF_H is computed by the following equation (2):

$$SF_H=2.39 + (T-630)/152 \qquad (2)$$

[0022] Table 1 shows various sludge factors computed by the equation (1) provided that amounts of Mn and Fe are varied at a casting temperature of 680 °C . Unit of all values is mass %. Here, sludge formation limit SF_H at the casting temperature of 680°C is computed to 2.72 mass % according to the equation (2). Thus, it is understood that no sludge is formed in the interior of the cast product even if the Mn content in the alloy is 0.6 mass %.

Table 1

%Fe / %Mn	0.05	0.1	0.15	0.2
0.1	0.38	0.43	0.48	0.53
0.2	0.70	0.75	0.80	0.85
0.3	1.03	1.08	1.13	1.18
0.4	1.36	1.41	1.46	1.51
0.5	1.68	1.73	1.78	1.83
0.6	1.91	2.06	2.11	2.16

[0023] However, in case of the high pressure die casting, inverse segregation occurs at the surface of the cast product, and it is understood that Fe density and Mn density at the surface becomes twice to three times as high as those in the interior of the cast product due to the reverse segregation. With this understanding, in order to investigate the crystallization of the sludge at the surface of the cast product, sludge factors at the surface are shown in Table 2 where the Fe and Mn contents at the surface of the cast product are twice as high as those in the interior thereof, and sludge factors at the surface are shown in Table 3 where the Fe and Mn contents at the surface of the product are three times as high as those in the interior thereof. Units in Tables 2 and 3 are mass %. Incidentally, the sludge factors in Tables 2 and 3 are computed from the following equations (3) and (4), respectively:

$$SF = \%Fe \times 2 + \{3.34 - (T-630)/714\} \%Mn \times 2 \qquad (3)$$

$$SF = \%Fe \times 3 + \{3.34 - (T-630)/714\} \%Mn \times 3 \qquad (4)$$

Table 2

%Fe %Mn	0.05	0.1	0.15	0.2
0.1	0.75	0.85	0.95	1.15
0.2	1.41	1.51	1.61	1.71
0.3	2.06	2.16	2.26	2.36
0.4	2.72	2.82	2.92	3.02
0.5	3.36	3.47	3.57	3.67
0.6	4.02	4.12	4.22	4.32

Table 3

%Fe %Mn	0.05	0.1	0.15	0.2
0.1	1,13	1.28	1.43	1.58
0.2	2.11	2.26	2.41	2.56
0.3	3.09	3.24	3.39	3.54
0.4	4.07	4.22	4.37	4.52
0.5	5.05	5.20	5.35	5.50
0.6	6.04	6.19	6.34	6.49

[0024] As described above, the sludge formation limit SF_H at the casting temperature of 680°C is 2.72 mass %. As is apparent from Table 2, the sludge factor exceeds 2.72 mass % when the Mn amount is not less than 0.4 mass % in a case where the segregation of Fe and Mn at the surface is twice as high as that in the interior at the casting temperature of 680°C. And as is apparent from Table 3, the sludge factor exceeds 2.72 mass % when the Mn amount is not less than 0.3 mass % in a case where the segregation of Fe and Mn at the surface are three times as high as that in the interior at the casting temperature of 680°C.

[0025] In order to provide crystallization of the sludge at the surface of the cast product, the sludge factor should exceed the sludge formation limit SF_H. In this connection, Mn content must be set so that the sludge factor can exceed the sludge formation limit SF_H. On the other hand, if Mn amount is excessive, crystallization amount of the sludge becomes excessive to undesirably form the sludge even in the interior of the cast product. Thus, the Mn amount is set to from 0.3 to 0.4 mass %, where the sludge factor just exceeds the sludge formation limit SF_H.

[0026] Incidentally, according to the equation (1), the sludge factor is not only dependent on Mn content but also dependent on Fe content. However, as is apparent from Tables 2 and 3, the sludge factor does not exceed the sludge formation limit SF_H 2.72 mass % at the casting temperature of 680°C if the Fe amount is less than 0.2 mass %, but exceeds the sludge formation limit SF_H when the Mn amount exceeds 0.4 mass % in a case where the segregation of Fe and Mn at the surface is twice as high as that in the interior and when the Mn amount exceeds 0.3 mass % in a case where the segregation of Fe and Mn at the surface is three times as high as that in the interior. Therefore, Mn content is the predominant factor to determine the sludge factor in case where Fe amount is less than 0.2 mass %.

[0027] Fig. 1 shows the graphical representation showing the relationship between the sludge factor and the Mn content in the alloy in a case where the segregation amount of Mn and Fe at the surface of the cast product becomes three times as high as that at the interior thereof at the casting temperature of 680 °C. The sludge factors with the parameter of Fe content of 0.10 mass %, 0.15 mass % and 0.20 mass % are almost the same, and therefore, it is understood that the sludge factor is not hardly dependent on Fe content. Further, it is understood that sludge factor does not exceed the sludge formation limit SF_H in case where Mn amount is not more than 0.2 mass % despite the fact that Fe amount is 0.20 mass %. On the other hand, sludge factor exceeds the sludge formation limit SF_H in case where Mn amount is not less than 0.3 mass % despite the fact that Fe amount is 0.10 mass %. Accordingly, it is apparent from Fig. 1 that sludge factor is not dependent on Fe content in the alloy, and Mn content ranging from 0.3 to 0.4 mass % is preferable. Incidentally, the sludge is made up from Al-Si-Fe-Mn compound. However, a sludge not including Fe can also be crystallized as Al-Si-Mn compound. Therefore, Fe can be dispensed with in the resultant alloy. This is the case where %Fe is zero in the theoretical equation (1).

[0028] As is understood from the equation (1) sludge factor is also dependent on the casting temperature T. However, in case of the preferable range of the die-casting temperature ranging from 680°C to 700°C, sludge factor is not greatly changed in spite of the change in the casting temperature T within the above range. Table 4 shows the sludge factors provided by the change in casting temperature T such as 660°C, 680°C and 700°C and Mn amount in a condition where Fe content is 0.15 mass % and Fe and Me segregation amount at the surface of the cast product becomes twice as high as that in the interior thereof. Further, Table 5 shows the sludge factors provided by the change in casting temperature T such as 660°C, 680°C and 700°C and Mn amount in a condition where Fe content is 0.15 mass % and Fe and Me segregation amount at the surface of the cast product becomes three times as high as that in the interior thereof. Units in Tables 4 and 5 are mass %.

Table 4

T / %Mn	660	680	700
0.1	0.96	0.95	0.95
0.2	1.62	1.61	1.60
0.3	2.28	2.26	2.25
0.4	2.94	2.92	2.89
0.5	3.60	3.57	3.54
0.6	4.26	4.22	4.19

Table 5

T / %Mn	660	680	700
0.1	1.44	1.43	1.42
0.2	2.43	2.41	2.40
0.3	3.42	3.39	3.37
0.4	4.41	4.37	4.34
0.5	5.40	5.35	5.31
0.6	6.39	6.34	6.29

[0029] Upon computation from the equation (2), sludge formation limit SF_H is slightly changed such as 2.59 mass %, 2.72 mass %, and 2.85 mass %, when the casting temperature is 660°C, 680°C, and 700°C, respectively. However, as is apparent from Table 4, the sludge factor exceeds respective sludge formation limit SF_H when the Mn amount is not less than 0.4 mass % in a case where the segregation of Fe and Mn at the surface is twice as high as that in the interior. And as is apparent from Table 5, the sludge factor exceeds respective sludge formation limit SF_H when the Mn amount is not less than 0.3 mass % in a case where the segregation of Fe and Mn at the surface is three times as high as that in the interior.

[0030] Fig. 2 shows the graphical representation showing the relationship between the sludge factor and the Mn content in the alloy in a case where the segregation amount of Mn and Fe at the surface of the cast product becomes three times as high as that in the interior thereof with the constant Fe amount of 0.15 mass %. The sludge factors with the parameter of casting temperature of 660°C, 680°C, and 700°C are almost the same, and therefore, it is understood that the sludge factor is not greatly dependent on the casting temperature T. Further, even though the sludge formation limit SF_H is slightly changed by the change of the casting temperature, it is understood that sludge factor does not exceed the sludge formation limit SF_H even in a case where Mn content is not more than 0.2 mass % and the casting temperature is set to 660 °C , which provides a minimum sludge formation limit. On the other hand, sludge factor exceeds the sludge formation limit SF_H in a case where Mn content is not less than 0.3 mass % and the casting temperature is set to 700°C, which provides a maximum sludge formation limit. Accordingly, Mn content ranging from 0.3 to 0.4 mass % is preferable for any casting temperature of high pressure die-casting.

[0031] Several test pieces in accordance with ASTM standard for tensile strength test were produced by high pressure die-casting with an alloy X which is the Al alloy in accordance with the present embodiment and with an alloy Y in which Mn content is greater than Mn content of the present embodiment. Test piece 1 was the alloy X in accordance with the present embodiment, test piece 2 was the alloy Y containing Mn amount greater than that of the Al alloy of the present embodiment, test piece 3 was made from the material the same as Test piece 1 (alloy X) , and test piece 4 was made from the material the same as Test piece 2 (alloy Y) . Table 6 shows compositions of the alloy X and alloy Y. For casting the test pieces 1 through 4, a metal mold for simultaneously casting two test pieces, one for tensile strength test piece and another for impact strength test piece, was used, and 90 tons cold chamber type die-casting machine was used. Casting temperature was 700°C, and injection speed was 1.2 m/s. The test pieces 3 and 4 were subjected to T5 treatment at temperature of 180°C for 3 hours after casting.

Table 6

	Cu	Si	Mg	Zn	Fe	Mn	Ni	Be	Sn
Alloy X	0.0	8.0	0.43	0.0	0.12	0.40	0.0	0.005	0.0
Alloy Y	0.0	9.0	0.36	0.0	0.15	0.47	0.0	0.005	0.0

[0032] Table 7 shows test results of tensile strength test with respect to test pieces 1 through 4. The test piece 2 made from the alloy Y provided tensile strength and 0.2% proof stress higher than those of the test piece 1 made from the alloy X, but provided elongation lower than that of the test piece 1. Judging from these facts, crystallization of the sludge occurred even in the interior of the test piece 2 and the breakage of the test piece 2 may be easily started from the sludge portion. Because higher elongation is considered to be more important than the higher tensile strength and higher 0.2% proof stress for the subordinate frame such as suspension components of an automobile, the alloy X can be more suitable for the suspension components of the automobile than the alloy Y can. Incidentally, even though the test piece 1 (alloy X) provided the tensile strength and 0.2% proof stress lower than those of the test piece 2 (alloy Y), these are sufficient for the suspension components such as the subordinate frame of the automobile. If much improvement on the tensile strength and 0.2% proof stress are required, T5 treatment appears to be effective. If comparison is made between the test pieces 3 and the test piece 4 both being subjected to T5 treatment, reduction in elongation can be restrained to a small level in case of the test piece 3 made from the alloy X, whereas elongation was greatly reduced in case of the test piece 4 made from the alloy Y. Accordingly, alloy X appears to be much suitable than the alloy Y as the material of the subordinate frame of the automobile such as the suspension component.

Table 7

	Tensile Strength(MPa)	Load at the 0.2% proof stress(MPa)	Elongation (%)
Test Piece 1	270	138	9.4
Test Piece 2	310	151	8.1
Test Piece 3	314	197	8.4
Test Piece 4	340	228	6.0

[0033] Test pieces 1 and 2 were cut to observe internal structure thereof. Microscopic views at cut surfaces of the test pieces 1 and 2 are shown in Fig. 3. Left upper photograph is 200 times magnification of the cut surface of the test piece 2, right upper photograph is 500 times magnification thereof. Left lower photograph is 200 times magnification of the cut surface of the test piece 1, and right lower photograph is 500 times magnification thereof. As is understood from these photographs, the cut surface of the test piece 2 shown in upper left and right views contains large crystallization volume of sludge those appearing in black. On the other hand, no sludge appears in the cut surface of the test piece 1 shown in lower left and right views.

[0034] Further, ASTM test pieces were produced with the compositions shown in Table 8. Unit in Table 8 is mass %. Thermal seizure of the alloy to the metal mold did not occur with the Mn content of 0.3 mass %.

Table 8

Cu	Si	Mg	Zn	Fe	Mn	Ni	Ti	Be
0.0	8.9	0.40	0.0	0.15	0.30	0.0	0.04	0.003

[0035] A high pressure die-casting method and a die-casting machine performing the method in accordance with the present embodiment will be described with reference to Fig. 4. In the embodiment, casting is performed using the above-described Al alloy according to the above-described embodiment.

[0036] A die-casting machine 1 includes a movable platen 2 and a fixed platen 3. The movable platen 2 has a side in confrontation with the fixed platen 3, the side being fixed with a movable holder 4. The fixed platen 3 has a side in confrontation with the movable platen 2, the side being fixed with a fixed holder 5.

[0037] The movable holder 4 is formed with a recessed portion open to the fixed holder 5, and a movable die 6 is fixed in the recessed portion. The movable holder 4 and the movable die 6 provide a gap therebetween where a liquidized gasket 7 made from a silicone rubber is injected from the surface confronting the fixed holder 5, thereby enhancing sealability. A recess 6a is formed at a surface of the movable die 6, the surface being in confrontation with the fixed holder 5. A flow passage for directing the molten metal to a mold cavity is defined by the recess 6a and the fixed holder 5 when the movable holder 4 is brought into abutment with the fixed holder 5.

[0038] A recess open to the movable holder 4 is formed in an interior of the fixed holder 5, and a fixed die 8 is fixed in the recess. The fixed holder 5 and the fixed die 8 provide a gap therebetween where a liquidized gasket 9 made from a silicone rubber is injected from the surface confronting the movable holder 4, thereby enhancing sealability. A recess 8a is formed at a side of the fixed die 8, the side being in confrontation with the movable holder 4. A mold cavity is defined between the recess 8a and the movable die 6 when the movable holder 4 is brought into abutment with the fixed holder 5. Incidentally, in Fig. 4, the flow passage for directing the molten metal to the mold cavity is delineated as being in non-communication with the mold cavity. This is due to the fact that Fig. 4 is the cross-sectional diagram. The flow passage is in communication with the mold cavity at other cross-sectional portions.

[0039] The fixed platen 3 and the fixed holder 5 form a molten metal supplying passage 10 for supplying a molten metal to the flow passage defined by the recess 6a. Further, a plunger tip 11 is slidably disposed in the supplying passage 10 for injecting the molten metal into the mold cavity. The plunger tip 11 has a sliding surface provided with a ring 11A formed from a stainless steel in order to maintain hermetic seal between the supplying passage 10 and the tip 11.

[0040] The fixed platen 3 and the fixed holder 5 are formed with a suction passage 12 in communication with the recess 8a for discharging air in the mold cavity to outside. The suction passage 12 is connected to a vacuum tank 13 which is connected to a vacuum pump 14. Thus, air in the mold cavity is sucked by the vacuum pump 14 by way of the suction passage 12 and the vacuum tank 13. A rotary pump is available as the vacuum pump 14.

[0041] A sealing rubber 15 is attached at the surface of the fixed holder 5, the surface confronting the movable holder 4. The sealing rubber 15 has a configuration to surround the recess 8a and the recess 6a formed at the movable die 6 of the movable holder 4. The sealing rubber 15 is made from a silicone rubber. The sealing rubber 15 can maintain airtight seal of the mold cavity, the suction passage 12, the molten metal flow passage and the molten metal supply passage 10 when the movable holder 4 is brought into abutment with the fixed holder 5.

[0042] Ejector pins 16 are slidably disposed in the movable holder 4 for ejecting the cast product from the metal mold. The ejector pins 16 extend through the movable holder 4 and the movable die 6. Each one end of each ejector pin 16 is fixed to a pin fixing plate 17 positioned close to the movable platen 2. Further, each another end of each ejector pin 16 is protrudable from the surface of the movable die 6 toward the fixed holder 5. A pin seal plate 18 is provided at another side of the movable holder 4 so as to surround the ejector pins 16, the other side being opposite to the one side confronting the fixed holder 5. The pin seal plate 18 is adapted for maintaining air-tightness at a gap between the ejector pins 16 and the movable die 6. Incidentally, in Fig. 4, the lowermost ejector pin 16 is not in confrontation with the mold cavity, but in confrontation with the molten metal flow passage for directing the molten metal to the mold cavity. Therefore, the lowermost ejector pin 16 is adapted to eject a runner portion formed at the molten metal flow passage.

[0043] In the high pressure die-casting method according to the present embodiment, the die-casting machine 1 is used, and air in the mold cavity is sucked by the vacuum pump 14 during injection of the molten metal in the mold cavity. High vacuum level of 4kPa is applied to the mold cavity for casting, which vacuum level is 1/10 or less than the conventional vacuum level in die-casting machine. Vacuum level of not more than 10kPa is necessary in the cavity to avoid lowering of the mechanical strength of cast product. In the die-casting machine 1, sealability of the mold cavity is enhanced by the ring 11A of the plunger tip 11, the liquidized gaskets 7, 9, the sealing rubber 15 and the pin seal plate 18. With these arrangement, vacuum level can be enhanced in comparison with the conventional arrangement, and gas entrapment in the molten metal can be obviated. A combination of the ringed tip 11, the liquidized gaskets 7, 9, the sealing rubber 15, the pin seal plate 18, the suction passage 12, the vacuum tank 13 and the vacuum pump 14 constitute a highly vacuum gas vent means.

[0044] The subordinate frame produced by the above-described high pressure die-casting method according to the present embodiment was held at the casting temperature of 500°C for 3 hours for blister test where generation of blister was investigated. Further, similar blister test was performed with respect to another subordinate frame produced by a conventional vacuum high pressure die-casting method providing the conventional vacuum level in the cavity while using the alloy the same as the alloy of the subordinate frame according to the present embodiment. Fig. 5 shows a surface of the subordinate frame according to the present embodiment after the blister test, and Fig. 6 shows a surface of the subordinate frame produced by the conventional high pressure die-casting method with the conventional vacuum level after the blister test.

[0045] Judging from Fig 6, blisters are observed at the surface of the subordinate frame produced by the conventional vacuum high pressure die-casting method with the conventional vacuum level. On the other hand, judging from Fig. 5, no blisters are observed at the surface of the subordinate frame produced in accordance with the casting method of the present embodiment. Consequently, in accordance with the high pressure die-casting method of the present embodiment, casting defect due to gas involvement during casting can be greatly reduced while using the Al alloy according to the present embodiment. Therefore, variation in mechanical strength of the cast product can be greatly reduced. On the other hand, as a result of the conventional vacuum high pressure die-casting method with the conventional vacuum level while using the Al alloy, casting defect occurred due to gas involvement, which does not attain a sufficient mechanical strength required in the cast product such as the subordinate frame used under the severe working condition.

[0046] Further, welding test was performed with respect to the subordinate frame produced by the high pressure die-casting method of the present embodiment. Fig. 7 shows a surface of the subordinate frame after welding test. Only slight blisters were generated due to the welding, and this fact revealed that variation in mechanical strength of the cast product due to gas involvement can be greatly reduced. Further, it is found that the cast product produced by the high pressure die-casting method of the present embodiment can undergo welding with no problem.

[0047] Advantage of the subordinate frame attendant to the high pressure die-casting method will be described. For a tensile strength test, the subordinate frame was produced by high pressure die casting method with the alloy of the present embodiment, and the cast subordinate frame was cut out into a shape of a test piece regulated by JIS No. 7. The test piece will be referred to as test piece 5. Further, another cut-out test piece regulated by JIS No. 7 was produced by a conventional gravity die-casting method and a subsequent T6 treatment using a conventional AC4CH alloy for the tensile strength test. The latter test piece will be referred to as test piece 6. Incidentally, in order to make use of the characteristic of high pressure die-casting, the surface of the test piece 5 was not subjected to machining but as-cast surface remained. Result of tensile strength test is shown in Table 9.

Table 9

	Strength (MPa)	Load at the 0.2% proof stress (MPa)	Elongation (%)
Test piece 5	255	145	8
Test piece 6	270	230	8

[0048] The test piece 5 provided the tensile strength lower than that of the test piece 6, and the elongation approximately the same as that of the test piece 6. That is, even though the product made from the A1 alloy according to the present embodiment and produced by high pressure die-casting method was not subjected to T6 treatment, the product provided the elongation approximately the same as that of the conventional product subjected to T6 treatment. Consequently, the subordinate frame according to the present embodiment is available for mass production because of the application of high pressure die-casting method, and can also reduce cost because of elimination of T6 treatment.

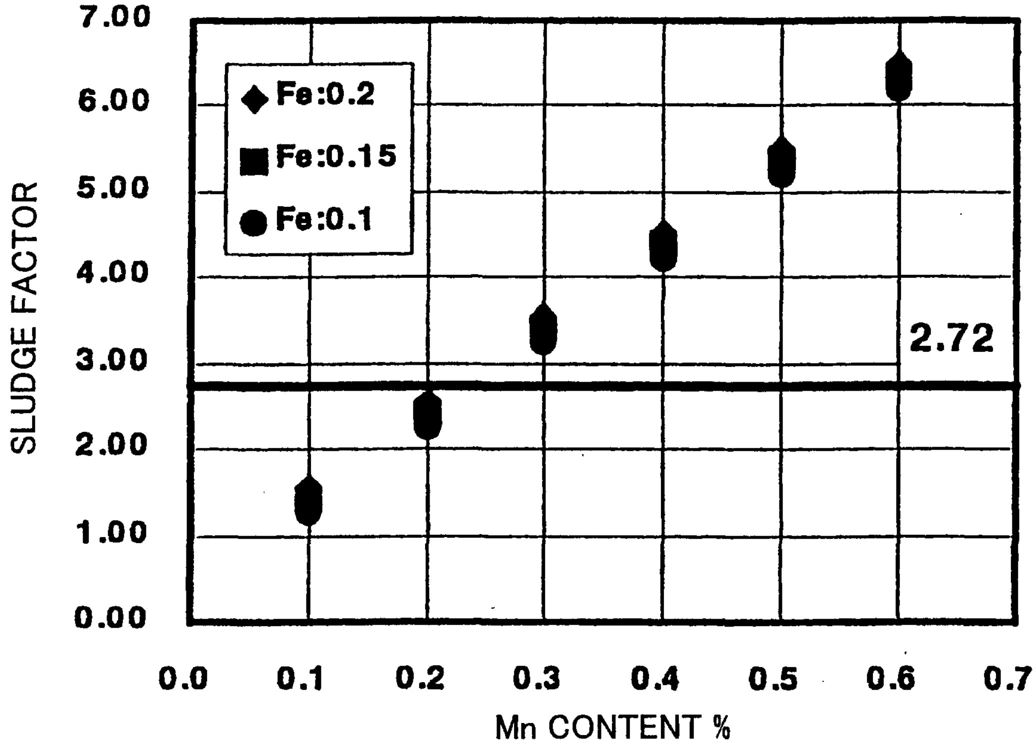
Claims

1. An aluminum alloy for high pressure die-casting containing from 8.0 to 9.0 mass % of Si, from 0.35 to 0.45 mass % of Mg, from 0.3 to 0.4 mass % of Mn, from 0.002 to 0.008 mass % of Be, less than 0.20 mass % of Fe, not more than 0.2 mass % of Cu, not more than 0.1 mass % of Zn, not more than 0.1 mass % of Ni and not more than 0.1 mass % of Sn, the remainder being Al and inevitable impurities.

2. A subordinate frame for an automobile produced through high pressure die-casting method, the subordinate frame being made from an aluminum alloy according to claim 1.

3. A high pressure die-casting method including the steps of:

injecting an aluminum alloy according to claim 1 into a mold cavity; and
evacuating the mold cavity by means of highly vacuum gas vent means to a level not more than 10 kPa during the injection step.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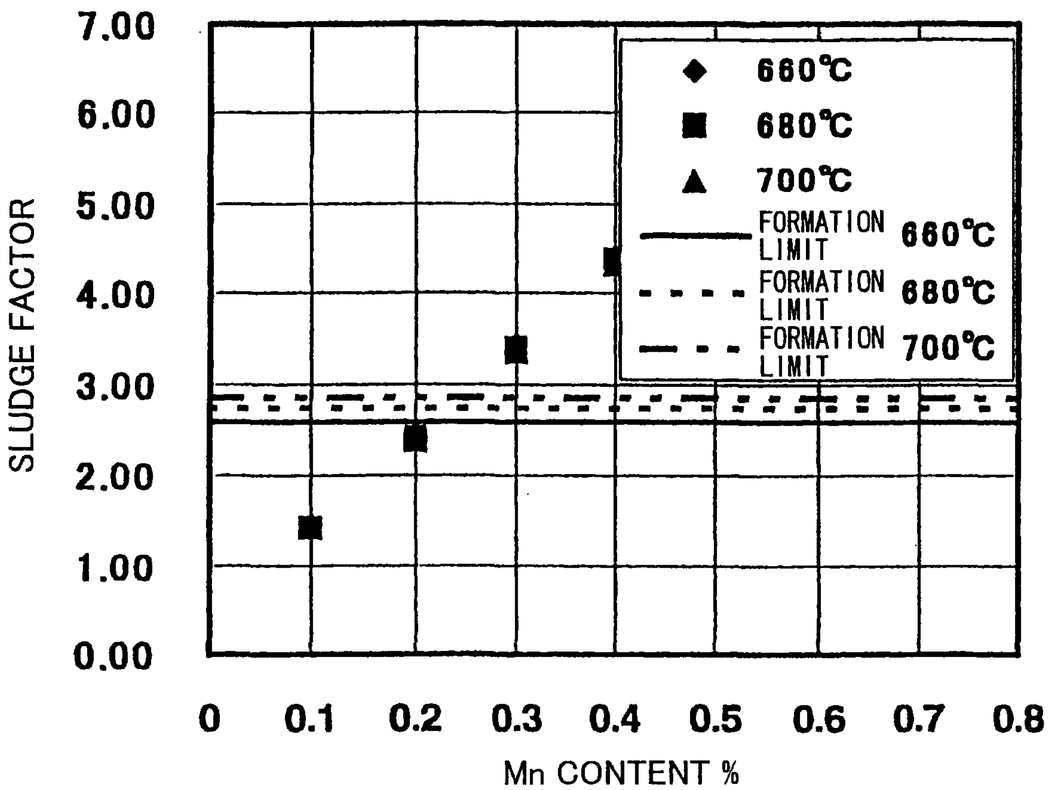
0.7
Mn CONTENT %

FIG. 1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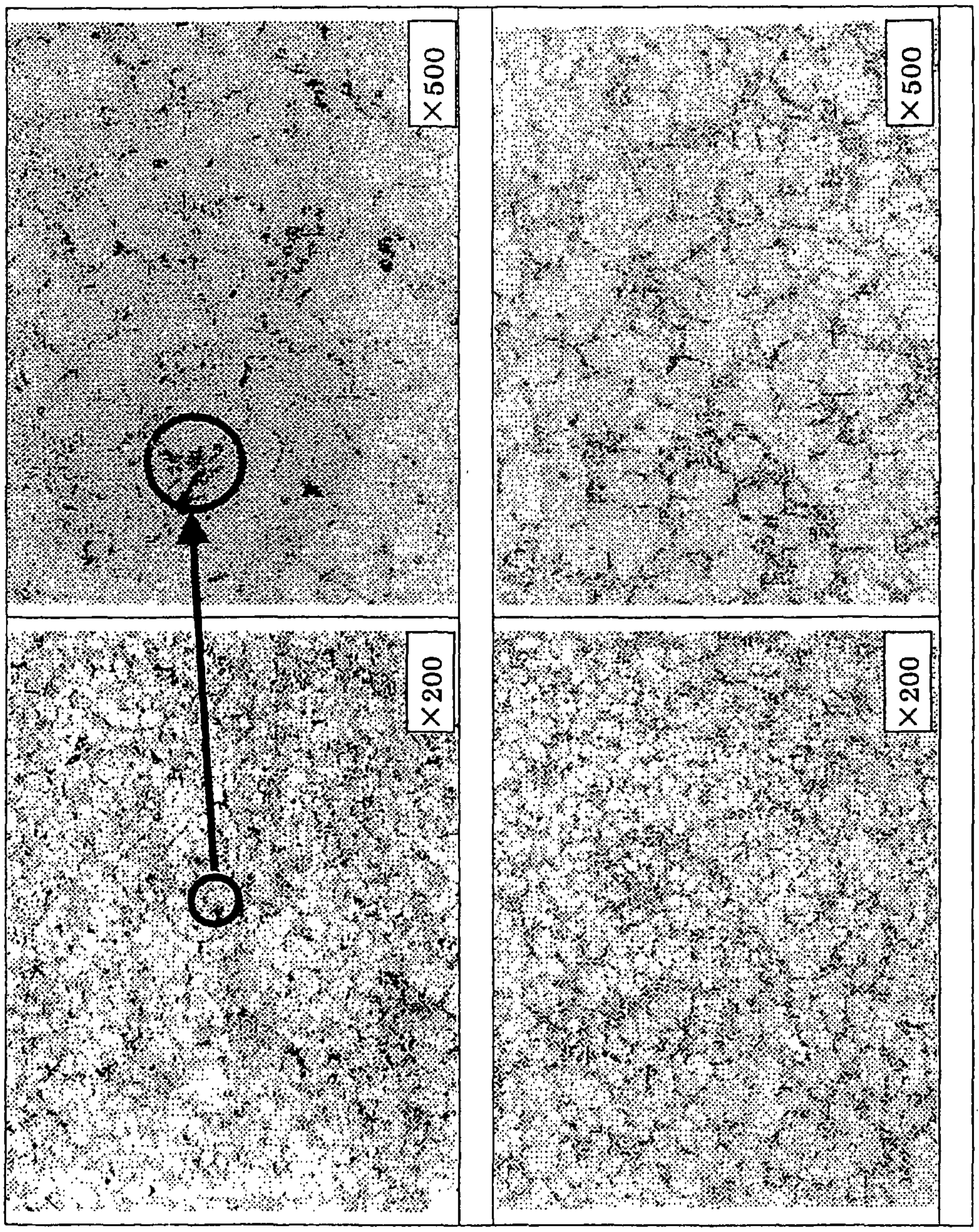
Mn CONTENT %

FIG. 2

FIG. 3



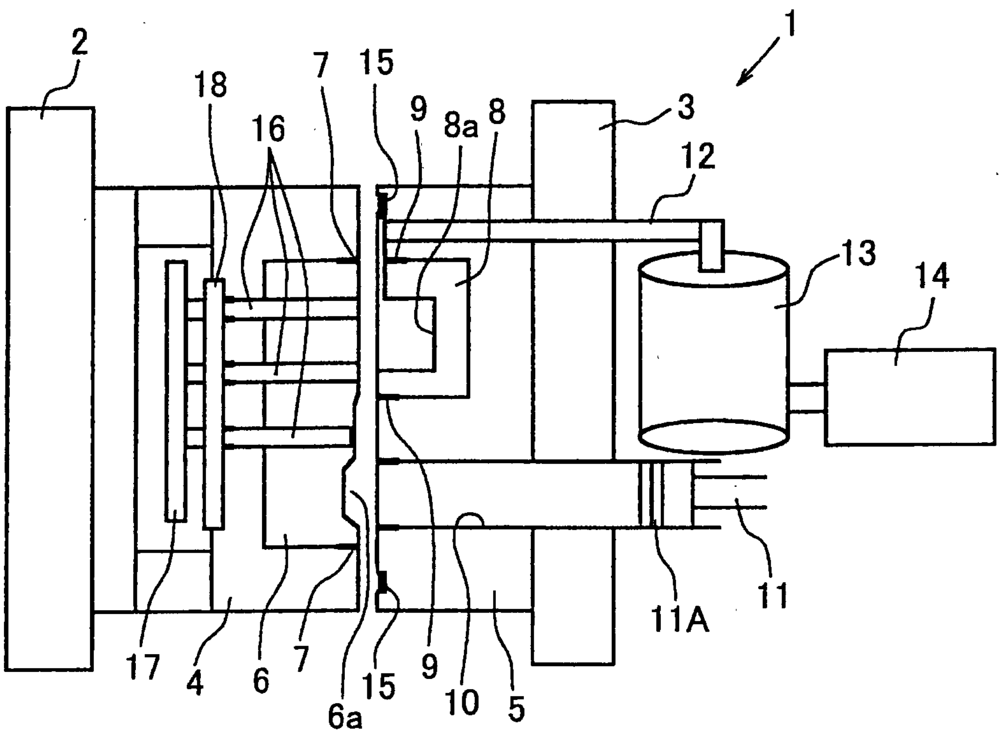


FIG. 4

FIG. 5

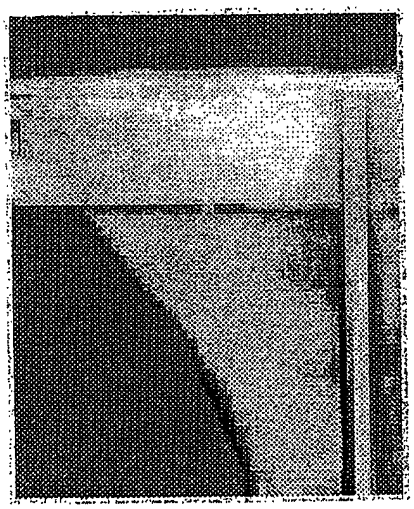


FIG. 6

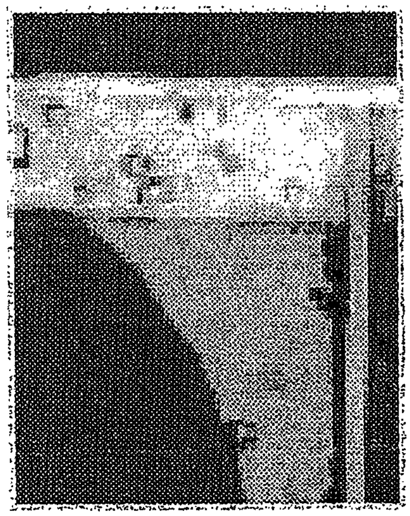


FIG. 7