Proceedings of the 12th International Conference on
Aluminium Alloys, September 5-9, 2010, Yokohama, Japan

pp. 2421-2426

Effect of Mg , Si and Mn Content on Castability in Al-Mg Alloy

Youhei KANO[1], Mitsuaki FURUI[2] and Susumu IKENO[2] ,
Masaki MIURA[3] and Seiji SAIKAWA[3]

[1] Student, Department of Material Systems Engineering and Life Science, University of TOYAMA, 3190 Gofuku, Toyama, 930-8555, JAPAN

[2] Graduate School of Science and Engineering Research, University of TOYAMA, 3190 Gofuku, Toyama, 930-8555, JAPAN

[3] Ahresty Corporation, 1-2 Nakagawara, Sanya, Toyohashi city, Aichi prefecture, 441-3114, JAPAN

Aluminum die-castings are widely used for automobile parts mainly owing to light weighting. To enlarge their coverage more, development of various die-casting alloys and processes for improving function and /or reducing production cost is expected. In recent years, Al-Mg alloys which have relatively excellent mechanical properties without heat treatment attract attention to be applied to die-casting. On the other hand, it is well-known that Al-Mg alloys are difficult to cast due to less fluidity and other problems. Thus it is required that they are improved but there are few reports about castability of Al-Mg alloys. It is difficult to determine the characteristics of alloys in die-casting process because of including effects of molten flow and pressurized segregation. In this study, castability of Al-Mg alloys containing a small amount of Mg, Si and Mn were investigated using a spiral mold for fluidity test and an iron mold with Y-shaped cavity for shrinkage behavior test to obtain fundamental knowledge.

Keywords: *die-casting, Al-Mg, castability, fluidity, contraction*

1. Introduction

Die-casting has been widely used for automobile parts mainly owing to high productivity, better accuracy dimensions casting surface and high specific strength. In recent years, More light weight automobiles are expected because more fuel efficient cars are required for protection of the environment. At present, steel is widely used as materials for the automobile and a light weight alloy such as Aluminum is less used. Expectations for aluminum are high owing to more easy recycling compared with steel and resin.

In recent years, interest in Al-Mg alloys in die-casting have increased because of excellent mechanical properties without heat treatment. However, it is well known that Al-Mg alloys are difficult to cast due to less fluidity and there are few reports about castability of these alloys. In the present study, fluidity and shrinkage behavior of Al-Mg alloys were investigated when the additive amount of Mg, Si and Mn were changed, and fundamental knowledge was obtained.

2. Experiment

2. 1 Material

In this study, the castability of Al-2~6mass%Mg-0~3mass%Si-0~0.7mass%Mn-2.5ppmBe alloys were evaluated. For the casting we used pure Al, Al-10mass%Mg, Al-20mass%Si, Al-10mass%Mn and Al-2.5mass%Be ingot. The chemical composition of these alloys are shown in Table 1.

Table. 1 Chemical composition of Al-Mg alloys used (mass%)

Alloy	Cu	Si	Mg	Mn	Fe	Zn	Ni	Cr	Ti	Pb	Sn	Be	Al
Al-2%Mg-2.5ppmBe	<0.01	0.05	1.80	<0.01	0.08	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.0020	bal.
Al-2%Mg-1%Si-2.5ppmBe	<0.01	0.85	2.12	<0.01	0.10	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.0021	bal.
Al-2%Mg-2%Si-2.5ppmBe	<0.01	1.93	1.88	<0.01	0.11	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.0019	bal.
Al-2%Mg-3%Si-2.5ppmBe	<0.01	2.87	1.95	<0.01	0.12	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.0025	bal.
Al-4%Mg-2.5ppmBe	<0.01	0.04	3.76	0.01	0.11	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.0047	bal.
Al-4%Mg-1%Si-2.5ppmBe	<0.01	0.99	3.84	0.01	0.12	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.0022	bal.
Al-4%Mg-2%Si-2.5ppmBe	<0.01	2.13	3.30	0.01	0.12	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.0025	bal.
Al-4%Mg-3%Si-2.5ppmBe	<0.01	3.11	3.19	0.01	0.13	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.0023	bal.
Al-6%Mg-2.5ppmBe	<0.01	0.07	6.13	0.01	0.15	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.0027	bal.
Al-6%Mg-1%Si-2.5ppmBe	<0.01	0.79	6.76	0.02	0.15	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.0032	bal.
Al-6%Mg-2%Si-2.5ppmBe	<0.01	1.62	6.40	0.02	0.15	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.0032	bal.
Al-6%Mg-3%Si-2.5ppmBe	<0.01	2.79	6.09	0.02	0.16	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.0039	bal.
Al-2%Mg-0.7%Mg-2.5ppmBe	<0.01	0.04	1.97	0.73	0.10	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.0019	bal.
Al-2%Mg-1%Si-0.7%Mn-2.5ppmBe	<0.01	1.05	1.67	0.78	0.12	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	0.0016	bal.
Al-2%Mg-2%Si-0.7%Mn-2.5ppmBe	<0.01	1.87	1.84	0.74	0.12	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	0.0028	bal.
Al-2%Mg-3%Si-0.7%Mn-2.5ppmBe	<0.01	3.13	1.88	0.72	0.13	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	0.0017	bal.

2. 2 Fluidity test

Pure Al, Al-10mass%Mg, Al-20mass%Si, Al-10mass%Mn and Al-2.5mass%Be ingots were melted at 973K in an electrical furnace. The temperature of molten metal was up to 973K, and then poured in a spiral mold heated to about 473K. The five samples were produced and measured in full length and fill length respectively.

At three points, 1mm, 6mm and 11mm from the edge of these samples were etched with an aqueous 0.5%HF. Then the microstructure was observed by using optical microscopy and cell size was measured. In addition, solidus and liquidus lines was measured with Difference scanning calorimetry (DSC).

Fig. 1 Spiral mold and spiral castings

2.3 Contraction behavior test

When the temperature of molten metal was heated to 973K, it was poured in an iron mold with a Y-shaped cavity heated to about 423K. When the temperature of casting was down to between 573K and 423K, it was knocked out and then air-cooled. Three Y shaped castings were produced and the width of the longer direction of the castings of the rate of contraction such as Fig.1 was measured. In addition, the rate of internal contraction and external contraction which is defined in Fig.3 at the center section of the casting was measured with an image analyzing computer. Then, the microstructure of the central portion of casting was observed by using optical microscopy. Then, the content of hydrogen in their casting was measured by vacuum melting and the extracting technique of Lanzulay.

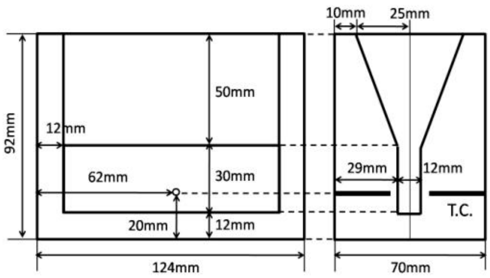


Fig. 2 Iron mold with Y shaped cavity

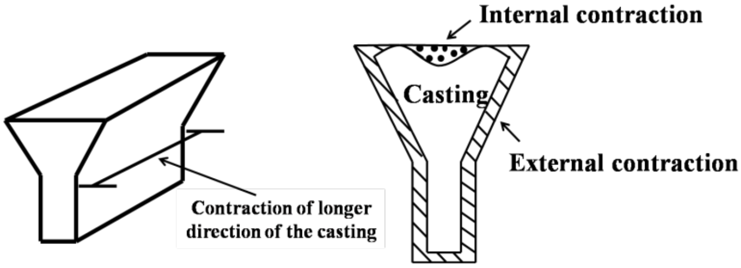


Fig. 3 Contraction of longer direction, internal contraction and external contraction in Y shaped castings

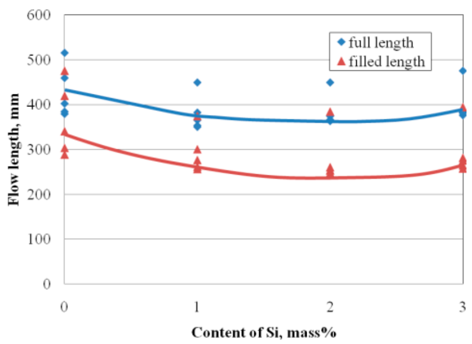
3. Result and Discussion

3.1 Fluidity test

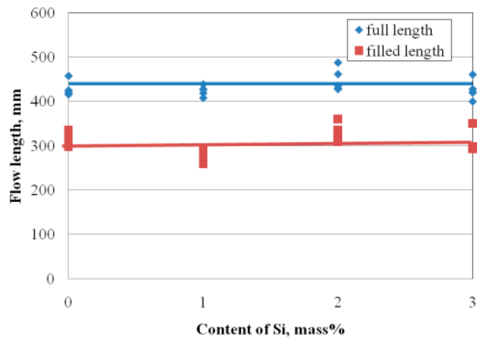
Fig.4 shows the result of the fluidity test. When 2mass%Mg was added, full length and filled length decreased with increasing the additive amount of Si. When 4mass%Mg was added, full length and filled length were constant with the additive amount of Si. When 6mass%Mg was added, those lengths increased with increasing the additive amount of Si in contrast with the case of 2mass%Mg added.

In addition, the effect of Mn content on fluidity was investigated. In contrast with the case of 2mass%Mg added, full length and filled length were increased overall with increasing the additive amount of Si.

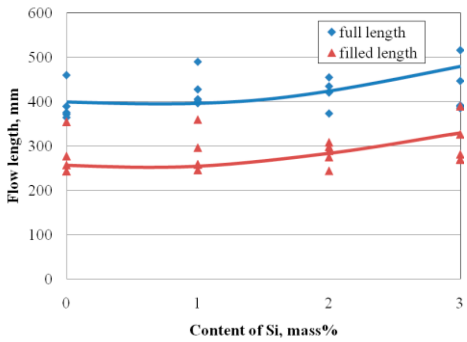
Fig.5 shows the effect of Mg, Si and Mn content on microstructure at the edge of spiral castings. When 2mass%Mg was added, the microstructure changed from cellular structure to cellular- dendrite and cell size was fined. This morphological change of crystallization of primary α-Al phase affects fluidity. That is we think, viscosity of the tip of molten metal increased due to fine crystallization of primary α-Al phase and contributed to the increase of fluidity. In addition, Fig.6 shows section diagrams of Al-2mass%Mg-0~3mass%Si alloy which is made from value of literature due to diagram of Al-Mg and Al-Mg-2mass%Mg alloy and result of DSC. The region of between liquidus and solidus lines are broadened out, and solidus and semi-solidus line dropped with increasing the additive amount of Si. So, we think full length and filled length would increase, but these lengths decreased. For this reason, we think that morphological change of crystallization of primary α-Al phase affects fluidity much more than change of liquidus and solidus line. In case of 4mass%Mg added, the microstructure changed from cellular-dendrite to dendrite and cell-size fined slightly with increasing the additive amount of Si. This behavior is similar to the case of 2mass%Mg added, we thought fluidity would be improved, but in this study, it didn't improve as shown in Fig.7. In section diagrams of Al-4mass%Mg-0~3mass%Si alloy, liquidus and solidus line were flat. For this reason, we think in the case of 4mass%Mg added, the behavior of liquidus and solidus has a large influence on fluidity more than the morphological change of crystallization of primary α-Al phase. In the case of 6mass%Mg added, the microstructure changed from cellular-dendrite to complete dendrite and cell-size fined similar to the case of 4mass%Mg contained with the additive amount of Si increase. However, fluidity was improved. In section diagrams of an Al-6mass%Mg-0~3mass%Si alloy, the region of between liquidus and solidus line decreased and we think it close in ternary eutectic point of Al-Si-Mg_2Si with the additive amount of Si increase. This caused delay of solidification due to momentary solidification and this is the main factor that fluidity length increased. In the case of 0.7mass%Mn added to Al-2mass%Mg-2.5ppmBe, the microstructure changed from cellular-dendrite to dendrite and cell-size fined and expected to Al_6Mn or $Al_{12}Mn_3Si$ crystallized out on the grain boundary we think the crystallization of these chemical compounds caused delay of solidification and fluidity improved. However, in section diagrams of an Al-2mass%Mg-0~3mass%Si alloy, liquidus and solidus temperature correspond to additive free Mn in the case of 3mass%Si added, so we need further discussion. Fig.9 shows DSC curves of Mn added and additive free of Mn in Al-2mass%Mg-3mass%Si-2.5ppmBe. The alloy added Mn had a little higher endothermic value than additive-free of Mn. That is, we think this high release of value of latent heat is one of the reasons which fluidity improved.



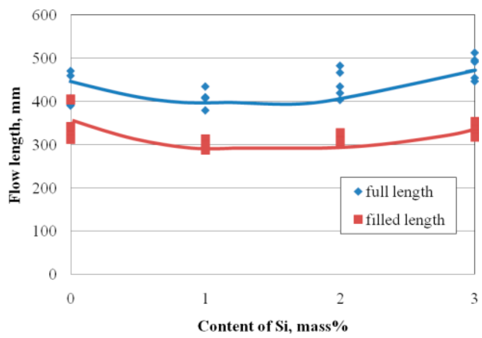
(a) 0mass%Mg



(b) 4mass%Mg



(c) 6mass%Mg



(d) 2mass%Mg-0.7mass%Mn

Fig. 4 Effect of Mg, Si and Mn contents on flow length in Al-2.5ppmBe alloy

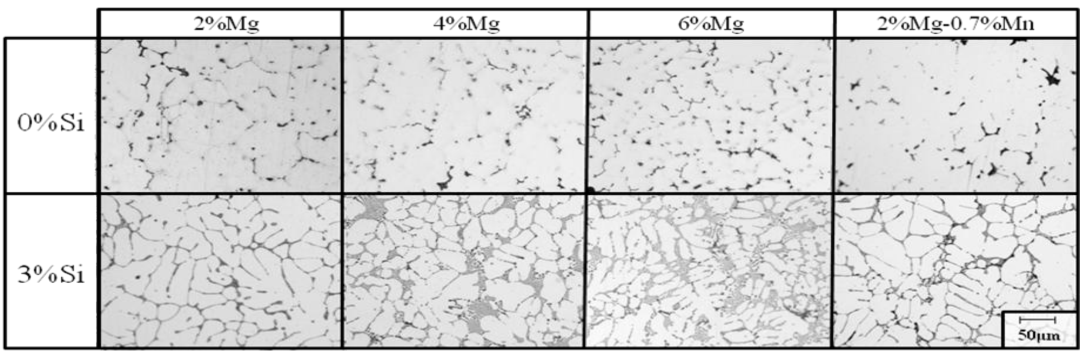


Fig. 5 Optical micrographs of the tip of spiral fluidity castings

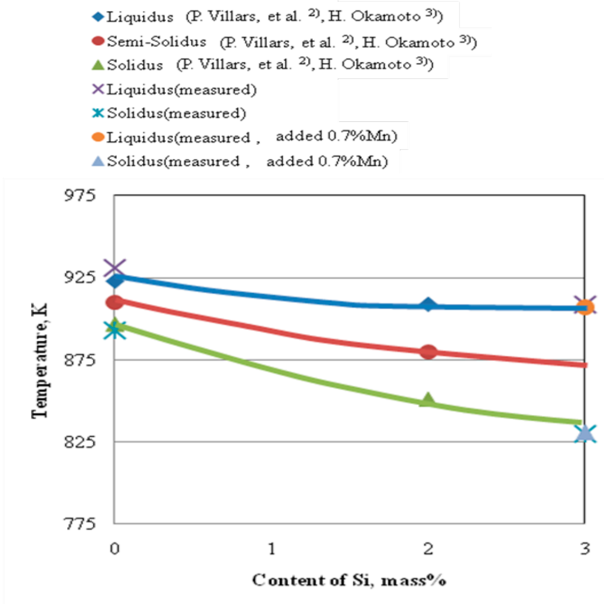
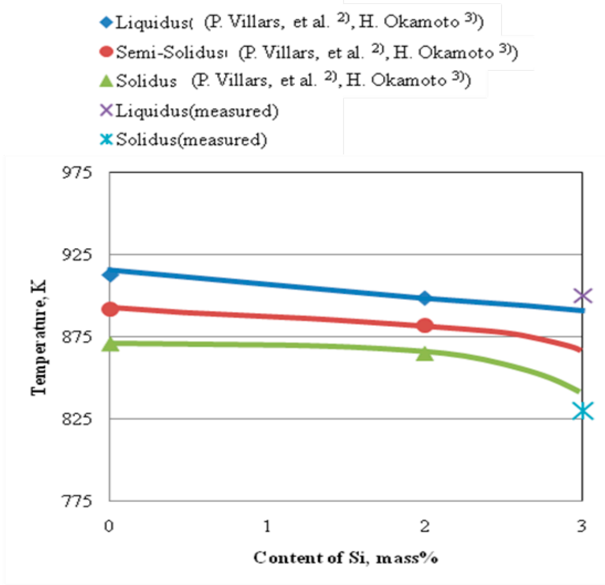


Fig. 6 Section diagram of an Al-2mass%Mg-0~3mass%Si alloy



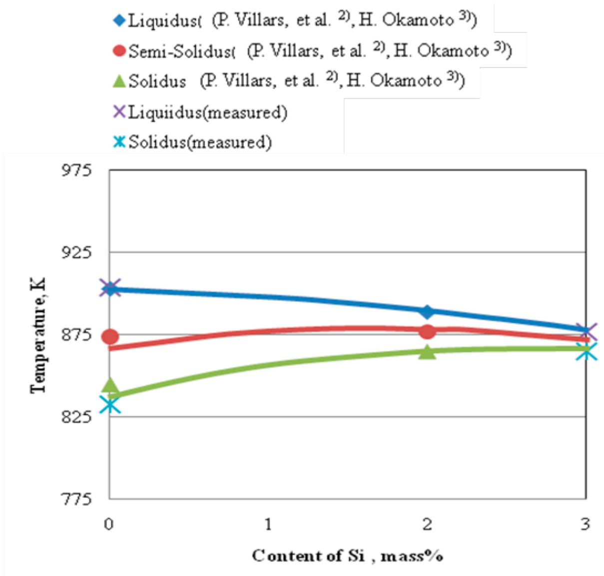


Fig. 8 A section diagram of Al-6mass%Mg-0~3mass%Si alloy

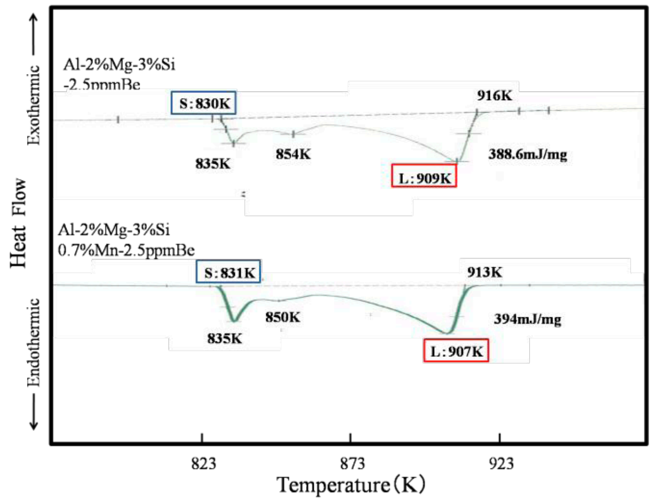


Fig. 9 DSC curves with and without Mn in Al-2mass%Mg-3mass%Si-2.5ppmBe alloy.

3.2 Contraction behavior test

Fig.10 shows a change of hydrogen content when we added 0~3mass%Si to Al-2, 4, 6mass%Mg-2.5ppmBe. In each of content of Mg, the hydrogen content increased with additive amount of Si increase. Generally, contents of hydrogen affect contraction behavior strongly and contents of contraction reduction. For this reason, we considered only about the case of additive free which have equal hydrogen content regardless of the Mg contents.

Fig.11 shows the result of contraction behavior test for 2~6mass%Mg added Al-2.5mass%Be alloy. The rate of internal contraction decreased slightly, while the internal contraction rate increased and contraction rate which was the width of the longer direction of the casting decreased and the microstructure changed its cellular structure to cellular-dendrite with additive amount of Mg increase (see Fig.12). We think that quantity of produced nuclear increased due to an increase in concentration of solute and changed skin-formation type solidification to mushy solidification.

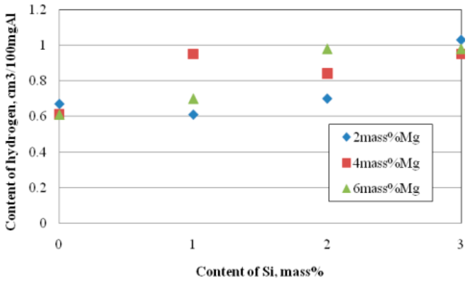


Fig. 10 Effect of Mg and Si on hydrogen content in Al-2.5ppmBe alloy.

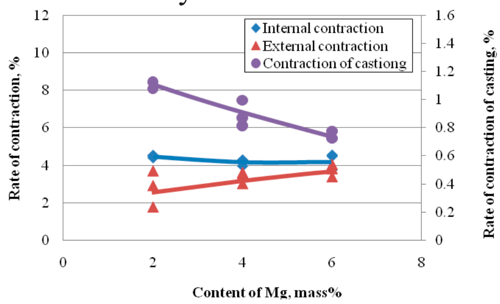


Fig. 11 Effect of Mg and Si on contraction behavior in Al-2.5ppmBe alloy.

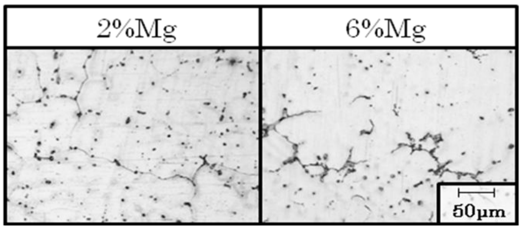


Fig. 12 Optical micrographs of central portion in Y-shaped casting

4. Conclusion

When we added 0~3mass%Si to Al-2mass%Mg-2.5ppmBe, the fluidity length decreased. That is, we think viscosity of the tip of molten metal increased due to fine crystallization of primary α-Al phase.

When we added 0~3mass%Si to Al-4mass%Mg-2.5ppmBe, the fluidity length was constant. That is, we think behavior of liquidus and solidus had a large influence on the fluidity.

When we added 0~3mass%Si to Al-6mass%Mg-2.5ppmBe, the fluidity length increased. That is we think a region of between liquidus and solidus lines decreased and close in ternary eutectic point of Al-Si-Mg_2Si with additive amount of Si increase.

When we added 0.7mass%Mn to Al-2mass%Mg-2.5ppmBe, fluidity length generally improved with additive amount of Si increase compare with additive-free of Mn. That is, we think delay of solidification due to crystallization of Al_6Mn or $Al_{12}Mn_3Si$ is one of the reason which fluidity improved.

When we added Al-2.5ppmBe to 2~6mass%Mg, the rate of internal contraction decreased slightly and the rate of external contraction increased. That is we think quantity of produced nuclear increased due to an increase in concentration of solute and changed skin-formation type solidification to mushy solidification.

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