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Mechanical and Wear Properties of Al-10Mg-Si Alloys Produced by Rapid Solidification and Powder Metallurgy Process

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Bulk materials of Al-10Mg-Si (mass%) alloys with different compositions in the hypo and hyper eutectic ranges were produced by a combination of rapid solidification and powder metallurgy (PM) process. Effects of Si contents on mechanical and wear properties of the bulk materials were investigated by Vickers hardness test, tensile test and pin-on-disc wear test, respectively. The hardness and tensile strength of the PM materials increased as increasing Si contents up to 10 mass%. Wear loss were dramatically decreased when the Si content was within 10 mass%. Wear properties of the PM materials were significantly superior compared to those of conventional AC9A and ADC12 alloys.

Keywords: *rapid solidification, wear properties, Al-Mg-Si alloy, mechanical properties.*

1. Introduction

Powder metallurgy (P/M) materials of rapidly solidified aluminium alloys have extensively studied during last three decades [1, 2]. Aluminium alloys produced by a combination of rapid solidification (RS) and extrusion processes exhibit superior mechanical properties at room and elevated temperatures compared to materials produced by a conventional ingot metallurgy (I/M) process [1]. Due to high cooling rate of the order 10^3 to 10^5 K/s, alloy design in materials can be manupulated freely in terms of amounts of adding elements. Microstructures in the P/M materials contain fine scale of intermetallic compounds that are uniformly distributed in the matrix together with fine grain sizes. As a result of such manipulate microstructures, rapidly solidified P/M bulk materials possess unique properties.

Age-hardenable Al-Mg-Si alloys have been widely used in the field of transportation and building industries due to a medium level of strength with low density [3]. Recently, this alloy system is thought to be applied for structural components of automobiles in order to reduce emission gas. When this alloy system is used much widely, a further increase in the strength should be achieved as well as having different aspects of properties, such as wear properties. In this regards, a novel P/M material produced by RS processes is required.

Magnesium silicide (Mg_2Si) intermetallic compounds in is one of the useful reinforcements of the Al-Mg-Si alloys because of its low density of 1.91 g/cm^3, high melting point of 1358 K, 120G Pa Young's modulus, high Vickers microhardness of approximately 650 HV, and low coefficient of thermal expansion of 7.5×10^{-6} K^{-1} [4, 5]. In the I/M process, the needle like Mg_2Si compounds distributed in the matrix caused the reduction of mechanical properties. On the other hand, fine Mg_2Si particles obtained by the RS processes are effective for improving the strength and tribological properties.

The aim of the present work thus was to fabricate a novel Al-Mg-Si based P/M materials produced by RS processes and hot extrusion. Mechanical and wear properties of the bulk P/M materials were examined by hardness measurements, tensile tests and pin-on disc wear tests. In addition, the properties of the P/M and I/M materials were compared.

2. Experimental Procedures

2.1 Material preparations

Nominal composition (mass%) and chemical analysis of the P/M materials of the tested alloys are listed in Table 1. The ingots of the Al-10 mass% Mg based alloys with different amounts of silicon for RS were initially prepared from high purity aluminium (99.99 %), pure magnesium (99.9 %) and pure silicon (99.999 %) under an air. The ingots were then remalted under an argon atomospehere prior to RS. This RS technique combines atomization of molten alloy and rapid quenching of the atomised droplets on a single cooper roll. The produced RS powders (RS flake) are about 5 mm in diameter and approximately 50 μm in thickness at the centre with thickness ranging from 80 to 140 μm near the edge. The RS flakes were consolidated using the following process; cold pressing, vacuum degassing at 623 K for 7.2 ks and hot extrusion at 673 K at a reduction ratio of 25:1. Finally, the extruded rod 7 mm in diameter were obtained as the P/M materials. The results of chemical analysis of the P/M materials in Table 1 were a good agreement of the nominal compositions.

Table 1 Nominal and analyzed compositions of tested materials

Nominal composition (mass%)	Analyzed composition (mass%)
Al-10Mg	Al-10.0Mg
Al-10Mg-1Si	Al-10.5Mg-1.04Si
Al-10Mg-5Si	Al-10.2Mg-5.01Si
Al-10Mg-10Si	Al-10.1Mg-10.1Si
Al-10Mg-15Si	Al-10.6Mg-14.8Si
Al-10Mg-20Si	Al-10.6Mg-20.2Si
Al-10Mg-25Si	Al-10.9Mg-24.8Si

2.2 Material evaluations

The Vickers microhardness of the rapidly solidified flakes was measured with a Vickesrs microhardness tester using an applied load of 10 g. The Vickers hardness of the as-extruded materials was measured with a Vickers hardness tester using an applied load of 1 kg.

Pin-on-disk type wear test was used to evaluate the tribological properties of the as-extruded materials under without oil lubrication conditions at room temperature. Pin specimens of 5 mm in diameter and 10 mm in length were machined from the as-extruded materials. Medium carbon steel (S45C) disks were employed as the counterpart materials. The surface of the counterpart face was treated by grinding to be the *R*max value was 0.81～ 0.93 μ m. The applied load on the pin specimen, sliding speed and sliding distance were 24.5 N, 0.63 ～ 1.89 m/s and 5 km, respectively. The changes in friction coefficient during wear test were evaluated. The wear loss of the pin specimens was investigated by measuring the change of the pin weight. The sliding surfaces of the pin and disk specimens were observed by scanning electron microscope to investigate wear behavior of each as-extruded materials.

3. Results and Discussion

XRD analyses revealed that both Mg_2Si and Al_3Mg_2 were detected in Al-10Mg-1Si alloys. When Si content increased over 5 % of Si contents, both Mg_2Si and Si was identified.

Optical micrographs of the as-extruded I/M and P/M Al-Mg-Si alloys containing hypereutectic Si contents are shown in Fig. 1. Both primary Si and Mg_2Si particles in the P/M materials were refined significantly by the combination of rapid solidification and hot extrusion process compared to those in the I/M materials. This effect was also obtained for hypoeutectic composition of Si contents in the P/M materials.

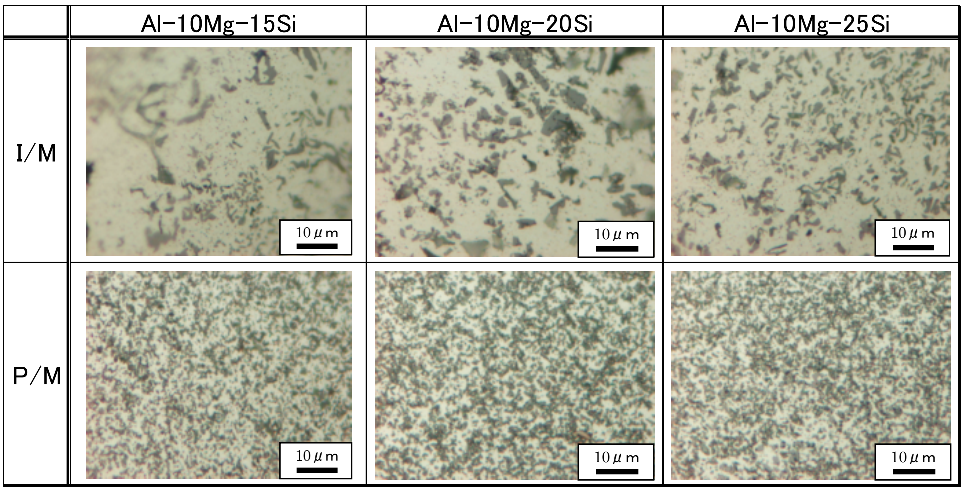

Fig. 1 Optical micrographs of the as-extruded I/M and P/M materials of Al-Mg-Si alloys containing hypereutectic Si contents.

Figure 2 presents the change in Vickers hardness of the as extruded P/M Al-10 mass% Mg alloys as a function of silicon contents. The hardness of the P/M materials increased from 120 HV to 140 HV for the Al-10 Mg and Al-10 Mg-1 Si alloys respectively. As increasing Si contents in the range of hypereutectic region, the hardness of the P/M materials decreased sharply to approximately 90 HV. However, the hardness steady increased to 158 HV as increasing Si contents in the region of hypoeutectic region. The hardness of the P/M materials was significantly higher than that of the I/M materials in the all Si contents due to the effects of higher cooling rate. It is interesting to note that the differences of the hardness between P/M and I/M materials became larger in the hypoeutectic region.

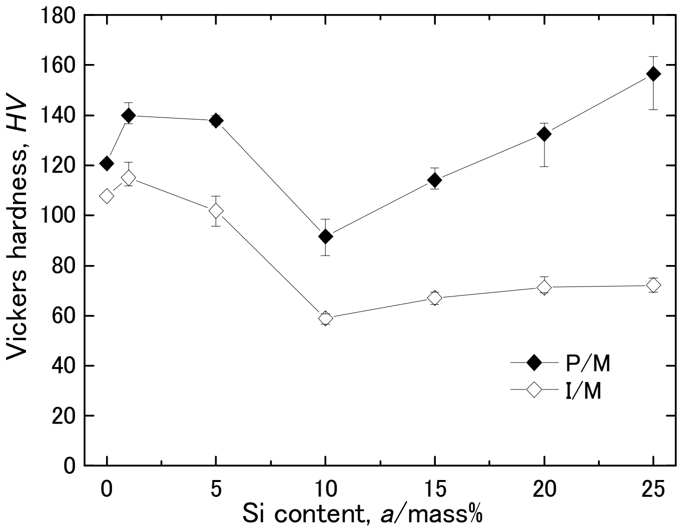

Fig. 2 Vickers hardness of Al-10Mg alloys containing various Si contents produced by P/M and I/M processes.

Figure 3 presents changes in the wear loss of the pin specimens at a load 24.5 N and a sliding distance of 5 km as a function of Si contents. No dramatic changes of the wear loss for both P/M and I/M materials the all rang of Si contents Si were observed within the sliding speed of 0.94 m/s. However, when the sliding speed increased to 1.26 m/s, 1.57 m/s and 1.89 m/s, the wear loss increased rapidly at the 10 % Si, which is near the eutectic composition, and decreased sharply at the 15 % Si. The reason for such the phenomena is not clear yet, but shape and distribution of eutectic Si in the matrix may be influenced. A difference of wear loss between P/M and I/M materials is relatively small.

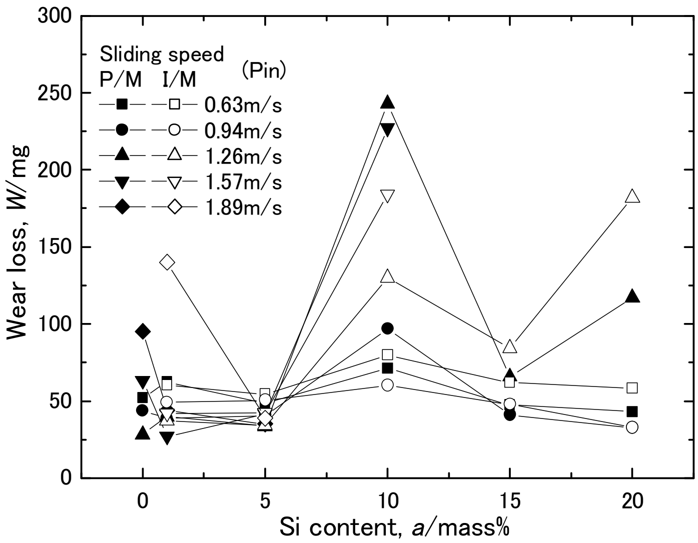

Fig. 3 Wear loss of the pin as a function of Si content for Al-Mg-Si alloys (load 24.5 N and sliding distance 5 km).

4. Conclusions

(1) Due to uniform distribution of fine-scale both Mg_2Si and eutectic Si by the RS process, the hardness of the P/M materials with hypereutectic Si content was higher than that of the I/M materials.
(2) The P/M materials with both hypo and hypereutectic Si contents exhibited better wear properties than that with eutectic Si contents all different sliding speeds.

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