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Effects of Al-Si/SiC_p powder on the sinterability and wear properties of Al-Zn-Mg powder

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ABSTRACT

Al-Zn-Mg alloys are widely used in the aerospace and automotive industries because of their high strength compared to other Al-based alloys. Unfortunately, the application of Al-Zn-Mg alloys in such industries has been limited to parts that are manufactured via powder metallurgy because of their poor sinterability. In this study, an Al-Si alloy powder, which has a relatively low melting point alloy compared to Al-Zn-Mg alloys, was added into an Al-Zn-Mg powder (Alumix 431) as a binder material to enhance the sinterability of the alloy. In addition, SiC particles (SiC_p) were added into the Al-Si alloy powder via gas atomization to improve the mechanical properties and wear resistance of the sintered Alumix 431 alloy. The mixed powder was sintered via hot pressing, and the wear properties of the sintered samples were analyzed with respect to two variables: vertical load and linear speed. The observed wear mechanisms included abrasion, adhesion, oxide-layer formation, and delamination. When the Alumix 431 powder was mixed with 5 wt% of the Al-Si/SiC_p alloy powder, the various aforementioned wear behaviors were delayed because of the increased densification of the sintered alloy and reinforcing effect of the SiC_p.

1. Introduction

Wear behavior is a complicated phenomenon that consists of oxide-layer formation, delamination wear, and adhesive wear. These diverse wear mechanisms are closely related to the applied load and sliding speed [1–3]. Recently, wear behavior has been studied by certain sectors of the transfer-machine industry. In particular, Al-Zn-Mg alloys are widely used in the aerospace and automotive industries because their wear resistance and strength are higher than those of other Al-based alloys. These improvements are caused by the dissolution of Zn and Mg and the subsequent precipitate strengthening. It is well known that the resulting $MgZn_2$ phase, which is an intermetallic compound, can improve the wear resistance of Al-Zn-Mg alloys [4,5].

However, Al-Zn-Mg alloys exhibit poor sinterability when fabricated via powder metallurgy (PM); this is due to the low plastic deformability of the powder and the formation of a surface oxide film [6,7]. PM technique has an advantage to give partial units on a mass production basis on the moldability with near-net-shape from simple shape to complicated shape. This manufacturing method can significantly reduce production cost by omitting additional treatment process. As results, PM technique is receiving the spotlight in engineering field as a one of high potential to be applied for mass production in parts of an automobile. Thus, methods for improving the sinterability of Al-Zn-Mg alloy powders include adding a binder, liquid-phase sintering, and performing a surface pre-treatment on the powder. In addition, uniformly dispersing particles of SiC, Al_2O_3, TiC, etc., as a role of reinforcements, throughout the Al-Zn-Mg alloy powder can enhance the wear resistance and mechanical properties [8–10]. Therefore, in this study, the addition of a gas-atomized Al-Si/SiC_p composite powder with the Al-Si alloy acting as a binder and the SiC particles (SiC_p) acting as a reinforcing agent into an Al-Zn-Mg alloy powder, was investigated. The mechanical properties of the resulting alloy were evaluated, with particular attention paid to the effect of the Al-Si/SiC_p powder on the wear behavior of the alloy under various vertical loads and linear speeds.

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Abbreviations

SiC_p	SiC particles
PM	powder metallurgy
FE-SEM	field emission scanning electron microscopy
EDS	energy dispersive X-ray spectroscopy
XRD	X-ray diffraction
UTM	universal testing machine
RT	room temperature
A5C	mixture of Al-Si/SiC_p and Alumix 431 powders (ratio = 5:95, respectively)
fcc	face-centered cubic
bcc	body-centered cubic
q	heat generated
μ	coefficient of friction
F	nominal load (N)
v	sliding velocity (m/s)
A_n	nominal contact area (m^2)
A_r	real contact area
k_{all} and k_{st}	thermal conductivities of the specimen and counter ball, respectively
l_{alf} and l_{st}	heat-diffusion distances of the specimen and counter ball, respectively
UTS	ultimate tensile strength (MPa)

2. Materials and methods

2.1. Fabricating the powders and alloys

The gas-atomized Al-Si/SiC_p composite powder was composed of an Al-Si alloy and SiC_p (20 vol%) with sizes ranging from 10 to 20 µm. The carrier gas was composed of N_2 and O_2 (80% and 20%, respectively), and the composite powder was fabricated under a uniaxial pressure of 2 MPa at 900 °C. A commercially available Al-Zn-Mg alloy powder (Alumix 431, ECKA Granules GmbH, Germany) was used in this study; it was manufactured via water atomization. Each chemical composition of powder shown Table 1. The composite and Alumix 431 powders were mixed (Al-Si/SiC_p:Alumix 431 ratio = 5:95) with a turbulent mixer at 45 rpm for 24 h. The Alumix 431 and Al-Si/SiC_p-Alumix 431 (A5C) powders were sintered via hot pressing at 610 °C for 30 min. Hot-pressing heating rate of 10 °C/min with uniaxial pressure for 70 MPa. It has been performed under isothermal heat treatments in vacuum atmosphere for 3×10^{-6} torr. The cooling for sintered specimens was adopted furnace cooling in this study.

2.2. Microstructural analysis

The sintered specimens, cross sections of the specimens, and microstructures of the wear tracks were observed via field emission scanning electron microscopy (FE-SEM, MIRA III LMH, Tescan, Brno, Czech Republic) with secondary electron image (SE) of observation modes. The phase compositions of the specimens were determined via energy dispersive X-ray spectroscopy (EDS) and X-ray diffraction (XRD, Ultima IV, Rigaku, Japan) using Cu Kα radiation at 30kv, 40 mA for a 2θ range of from 20 to 70°. In addition, density of the sintered specimens is measured by Archimedes' rule.

Table 1
Chemical composition of each powder.

wt%	Al	Si	Zn	Mg	Cu	Sn	SiC
Al-Si/SiC_p	Bal.	9	–	0.5	0.2	–	20 vol%
Alumix 431	Bal.	–	5.9	2.5	1.7	0.26	–

2.3. Mechanical properties

The tensile tests performed on the sintered specimens were carried out according to the ASTM E8 standard for plate-type subsize specimens (gage length = 13.2 mm, width and thickness = 2.0 mm) at a strain rate of 1.5×10^{-4} m/s with a universal testing machine (UTM) at room temperature (RT). The hardness of the sintered specimens was measured with a Rockwell hardness tester (Digital Rockwell Hardness Tester MV-1, Matsuzawa, Akita, Japan).

2.4. Wear properties

The wear tests performed on the specimens were conducted with a ball-on-disc-type tester, and two parameters were varied: linear velocity (0.1, 0.2, 0.5, 1.0, and 1.5 m/s) and vertical load (50, 100, 150, and 200 N). The total sliding distance was fixed at 500 m, and the tests were performed in air at RT. The balls used were composed of SUJ2 steel. The wear rate was estimated by obtaining the weight loss and true density of each specimen. In addition, the thermal conductivity, thermal diffusivity, and specific heat of the sintered specimens were measured with a laser flash system (LFA447 Nanoflash, NETZSCH, SELB, Germany).

3. Results and discussion

Fig. 1(a) shows that Al, Si, and SiC phases are present in the XRD patterns of the gas-atomized Al-Si/SiC_p powder, while Fig. 1(b) shows that the Alumix 431 powder contains Al and $Mg_{32}(Al, Zn)_{49}$ phases. The XRD pattern of the sintered Alumix 431 (Fig. 1(c)) shows that Al, $Mg_{32}(Al, Zn)_{49}$, and $MgZn_2$ phases are present, while the sintered A5C contains $Mg_{32}(Al, Zn)_{49}$, Si, SiC, Mg_2Si, and $MgZn_2$ phases (Fig. 1(d)). The peak positions in the XRD patterns agree

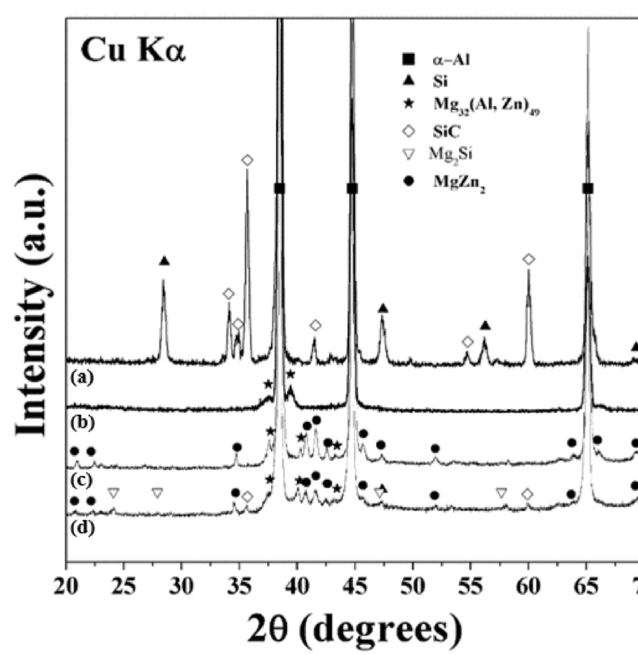

Fig. 1. XRD patterns of the (a) Al-Si/SiC_p powder, (b) Alumix 431 powder, (c) sintered Alumix 431 powder, and (d) sintered A5C powder.