Materials and Design 54 (2014) 361–367

Contents lists available at ScienceDirect

Materials and Design

journal homepage: www.elsevier.com/locate/matdes

# Effect of grain refinement on mechanical properties and sliding wear resistance of extruded Sc-free 7042 aluminum alloy

M. Vasheghani Farahani [a], E. Emadoddin [a,*], M. Emamy [b], A. Honarbakhsh Raouf [a]

[a] Faculty of Materials and Metallurgy, Semnan University, Semnan, Iran
[b] School of Metallurgy and Materials Engineering, College of Engineering, University of Tehran, Tehran, Iran

ARTICLE INFO

*Article history:*
Received 10 June 2013
Accepted 12 August 2013
Available online 26 August 2013

*Keywords:*
Aluminum alloys
Grain refinement
Mechanical properties
Wear resistance

ABSTRACT

The present study deals with an investigation on dry sliding wear behavior of grain refined Sc-free 7042 aluminum alloy by using a pin-on-disc wear test machine. Al–5Ti–1B and Al–15Zr master alloys were used as grain refining agents. The optimum amounts of added Ti and Zr in the alloy were found to be 0.03 wt.% and 0.3 wt.%, respectively. Extrusion was carried out and T6 heat treatment ware applied for all rod specimens before testing. Significant improvement in mechanical properties was obtained with the addition of grain refiners. The worn surfaces were characterized by energy dispersive X-ray spectrometry microanalysis. Results showed that the wear resistance of unrefined alloy increased with the addition of both grain refiners. Furthermore, the worn surface studies showed a mixed type of wear mechanisms; delaminating, adhesive and abrasive which took place at higher applied load.



## 1. Introduction

The Al–Zn–Mg–Cu alloys are attractive engineering materials for aerospace, aircraft and defense industries, because of their low density, low cost, high strength and good resistance to corrosion [1,2]. Many studies of the tribological behavior of aluminum based alloys have been carried out because of poor tribological properties of aluminum alloys [3].

Grain structure is an important and readily observable feature in aluminum alloy casting. Grain refining is one of the predominant techniques in improving metallurgical characteristics and mechanical properties of castings [4]. Grain refiner leads to formation of fine equiaxed grain structure in castings, which otherwise solidify with a coarse columnar grain structure, by heterogeneous nucleation [5]. An extensive review work has been done on the effect of grain refinement and modifier elements on the microstructure and mechanical properties of Al–Zn–Mg–Cu alloys. It is reported that Ce and Ti addition cause formation of $Al_4Ce$ and $Al_3Ti$ which can serve as nucleus for inhomogeneous nucleation and significantly improve the mechanical properties with precipitation strengthening [6,7]. Also, addition of Zr, Sc, Yb, Cr and Pr can improve the strength, ductility and fracture toughness, the reason is producing the fine coherent dispersoids that can pin the dislocations and subgrain boundaries, and enhance the resistance to recrystallization of Al–Zn–Mg–Cu alloys [8–13]. However, there is limited published data concerning the effect of grain refinement on wear resistance of Al 7xxx alloys. Alipour et al. have demonstrated addition of Al–5Ti–1B and Al–8B grain refiners improve wear properties of Al–12Zn–3Mg–2.5Cu alloy, therefore the weight loss of the T6-tempered alloy is lower than those of untreated alloys in dry sliding wear tests [14,15].

Mondal et al. [16] have reported that the wear resistance of Al–Zn alloys increases with decrease in Zn-concentration under abrasive wear condition. Also, Mondal et al. [17] in earlier studies have found the addition of 10% Al–TiB is sufficient to get considerable extent of wear resistance and strength of 7178 alloy. Mindivan et al. [18] have reported that the retrogression and re-aging (RRA) treatment is more effective than the T6 heat treatment in increasing the wear resistance of 7039 alloy.

In the present work an attempt has been made to investigate the effect of Al–5Ti–1B and Al–15Zr master alloy as grain refiners on tensile properties and wear behavior of free scandium Al 7042 alloy.

## 2. Experimental procedure

The chemical composition of Sc-free 7042 aluminum alloy studied in this work is given in Table 1. Melting of the alloy was carried out in an electrical resistance furnace using a SiC crucible (10 kg capacity). Commercially pure elemental Al (99.87%), Mg (99.99%), Zn (99.996) and Cu (99.9%) were used as starting materials to prepare the ingots. Then the chopped ingots were re-melted in a small electrical resistance furnace (with an accurate temperature measuring system, ±5 °C) in order to prepare alloys with different amounts of Ti and Zr. Then the master alloys containing titanium

* Corresponding author. Tel./fax: +98 231 3354 119.
*E-mail address:* emadoddin@semnan.ac.ir (E. Emadoddin).

0261-3069/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.matdes.2013.08.044

**Table 1**
Chemical composition of the experimental alloy (in wt.%).

| Al | Zn | Mg | Cu | Mn | Fe | Si |
|---|---|---|---|---|---|---|
| Bal. | 7.0 | 3.0 | 1.5 | 0.3 | 0.3 | 0.05 |

(Al–5Ti–1B) and zirconium (Al–15Zr) were added to the molten alloy at 780 °C. After stirring with a graphite rod for about 1 min and cleaning off the dross, molten alloy was poured at 780 °C into a cylindrical ductile iron mould with dimensions of 34 mm in inner dia., 40 mm in outer dia. and height of 45 mm.

The specimens were cut from 20 mm of the bottom of each casting and polished and grain size measurement was carried out by an image analysis system (Clemex Vision Pro. Ver. 3.5.025) after etching the polished surface for about 30 s with Keller's reagent (2 ml HF, 3 ml HCl, 5 ml $HNO_3$ and 190 ml $H_2O$). The average grain size of the specimens was obtained using an optical microscope according to ASTM: E-112 standard.

The as-cast ingots were homogenized at 460 °C for 20 h, followed by air cooling to room temperature. The purpose of homogenization was dissolving the soluble phases which were formed during solidification in Al–Zn–Mg–Cu alloys [19]. Round bars were extruded by using a hydraulic press at 465 °C with a ram speed of 1 mm/s and an extrusion ratio of 6:1. Extrusion process was carried out applying graphite based lubricant between metal and dies. After extruding the specimens, the extruded bars were heat treated (T6 temper) through the following schedule: (1) solution heat treatment at 460 °C for 1 h followed by an additional hour at 480 °C, (2) rapid quench in water at room temperature, and (3) age at 120 °C for 19 h [20]. The tensile test specimens were machined along the extrusion direction according to ASTM: E8 standard as shown in Fig. 1.

Tensile tests were carried out in SANTAM-STM20 machine (2 tons LOAD CELL) with a constant cross-head velocity of 1 mm/min at room temperature. The average of at least three experimental results was taken as the tensile strength and total elongation. Hardness test was carried out according to ASTM: E10 standard using an Eseway tester machine with Brinell hardness method by applying 187.5 kg force on spherical indentor with 2.5 mm in diameter and their hardness was taken as the average of five readings.

Dry sliding wear experiments were performed using a pin-on-disk apparatus to evaluate the wear behavior of processed alloys according to ASTM: G99 standard against an AISI/SAE 52100 steel disk with a hardness of 60 HRC. The heat treated rods were machined and pins, 5 mm × 5 mm, were prepared by polishing to 0.5 μm (Ra). The pins were in a conformal contact with the disk. The wear tests were conducted under nominal loads of 20, 30, 50 N at a constant sliding speed of 1 m/s for a sliding distance of 1000 m. The samples were cleaned with acetone and weight loss of the samples was determined by a precision of 0.1 mg. Furthermore, the specimens wear rate was calculated from mass difference which was measured before and after each test, divided by the sliding distance. All weight-loss data were converted to volume loss using the density of the material. Also, the friction force is determined according to voltage changes. Friction coefficient is calculated as the ratio of friction force to normal force. An electrical sensor was used for measuring the friction force; this sensor is like a capacitor which is sensitive to gap between load arm and sensor, can register the resultant voltage of the gap change at any moment.

Throughout the testing program, the relative humidity (RH) of the atmosphere was hold 29 ± 2%. Fig. 2 shows the schematic of the pin-on-disk configuration used in current research. The worn surfaces were studied by a Vega©Tescan scanning electron microscope (SEM) at 15 kV equipped with an energy dispersive X-ray spectrometer (EDX).

## 3. Results and discussion

### 3.1. Structural characterization

Fig. 3a and b shows the effect of various amounts added Ti and Zr, by using Ti Al–5Ti–1B and Al–15Zr grain refiners, on the average grain size of the alloy specimens. Fig. 4 shows typical optical photograph of the refined alloy.

It was necessary to find optimum levels of the additive refiners, because the study of refined structure of specimens shows the presence of different macro and microstructural features [7]. The optimum amounts of Ti and Zr were selected as 0.03 wt.% and 0.3 wt.% respectively. It has been reported that the nucleation mechanism in the case of Al–Ti–B master alloys is a two-step process. When Al–Ti–B master alloys are added to the alloys, two kinds of intermetallic particles ($Al_3Ti$ and $TiB_2$) are formed and dispersed in the melt and act active sites during solidification [21]. While the refinement mechanism of aluminum–zirconium melts depend on content of Zr. At low Zr concentration, the Zr mainly interacts with atom clusters, forms stable atom clusters, and then grow to finally become nuclei and at higher Zr concentration the formation of α-Al depends on the peritectic reaction: L + $Al_3$-Zr = α-Al (solid solution), Zr solid solubility is about 0.28% at the equilibrium temperature [22]. Fig. 4a and c shows the optical photograph of the Al–7Zn–2.5Mg–1.5Cu alloy in unrefined and refined specimens with optimum Ti and Zr concentrations. It can be seen that Al–5Ti–1B and Al–15Zr are very effective. Fig. 5 shows the optical micrographs of the unrefined and refined alloys.

It can be seen the changes in dendrite morphology of the unrefined alloy after adding of the grain refining agents. The optical

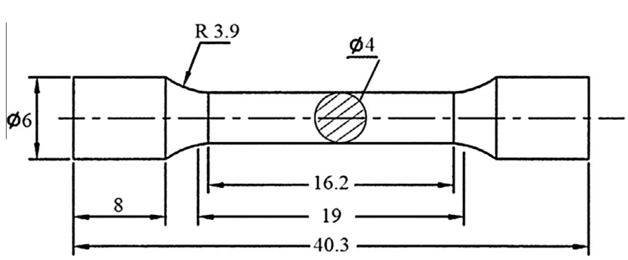


**Fig. 1.** The schematic of tensile test specimen dimensions.

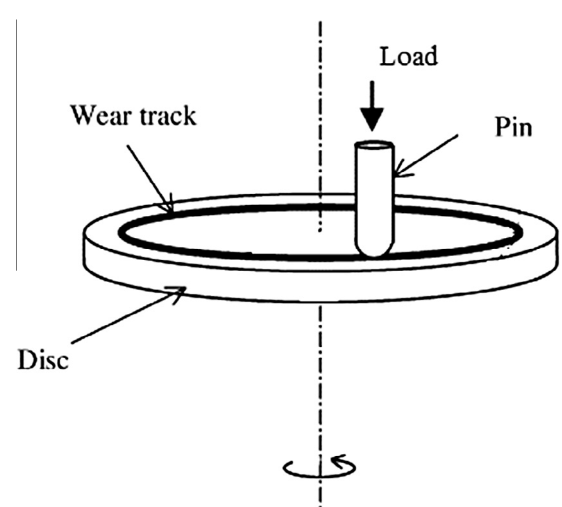


**Fig. 2.** The schematic of pin-on-disk test configuration.