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# Investigation of the effect of Al–5Ti–1B grain refiner on dry sliding wear behavior of an Al–Zn–Mg–Cu alloy formed by strain-induced melt activation process

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ABSTRACT

This study was undertaken to investigate the influence of Al–5Ti–1B master alloy and modified strain-induced melt activation process on the structural characteristics, mechanical properties and dry sliding wear behavior of Al–12Zn–3Mg–2.5Cu aluminum alloy. The optimum amount of Ti containing master alloy for proper grain refining was selected as 2 wt.%. The alloy was produced by modified strain-induced melt activation (SIMA) process. Reheating condition to obtain a fine globular microstructure was optimized. The optimum temperature and time in strain-induced melt activation process are 575 °C and 20 min, respectively. T6 heat treatment was applied for all specimens before tensile testing. Significant improvements in mechanical properties were obtained with the addition of grain refiner combined with T6 heat treatment. After the T6 heat treatment, the average tensile strength increased from 283 MPa to 587 MPa and 252 MPa to 564 MPa for samples refined with 2 wt.% Al–5Ti–1B before and after strain-induced melt activation process, respectively. Dry sliding wear performance of the alloy was examined in normal atmospheric conditions. The experimental results showed that the T6 heat treatment considerably improved the resistance of Al–12Zn–3Mg–2.5Cu aluminum alloy to the dry sliding wear.

The results showed that ultimate strength and dry sliding wear performance of globular microstructure specimens was a lower value than that of Ti-refined specimens without strain-induced melt activation process.

## 1. Introduction

In this research, we focused on high strength 7xxx series wrought aluminum alloy which is typically used in aircraft structural parts and other highly stressed applications where very high strength and good resistance to corrosion are required [1,2]. Grain refinement has become a standard melt treatment practice in aluminum foundries world-wide with well documented technical and economical advantages [3,4]. Commercial refiners are manufactured from the Al–Ti–B ternary system, often with more Ti than that required to form $TiB_2$ [4–10]. Hence, the microstructure of these alloys typically comprises, in addition to the insoluble $TiB_2$, the soluble $Al_3Ti$ particles dispersed in an aluminum matrix. The former act as heterogeneous nucleation sites while $Al_3Ti$ particles readily dissolve in the melt and provide solute Ti, the portioning of which between the solid and liquid phases during solidification, slows down the growth process [11,12].

The very popular excess-Ti Al–Ti–B refiners are known to per-form adequately for wrought aluminum alloys except when the alloy to be inoculated contains one or more of the elements whose borides are more stable than $TiB_2$ [13,14]. However, they fail to perform as efficiently in the case of foundry alloys with adverse effects on the as-cast structure and inferior properties in cast parts [15–18].

Strain induced melt activation (SIMA) process has been used to enhance the mechanical properties of Al alloy in recent years. For this method, residual strain is stored in a billet and a global structure is evolved by the strain energy stored in the billet after reheating [19]. In this route, the material is deformed by extrusion or other processes and then reheated to semisolid state which recrystallization occurs and liquid metal penetrates in the recrystallized grain boundaries thus resulting in solid globular particles surrounded by liquid. The SIMA route involves hot working while RAP method includes warm working with same steps. The advantages of these routes are that some alloys are supplied in the extruded state in any case and the spheroids are more fully rounded.

Since poor tribological performance limits the use of aluminum and its alloys in wear related applications, many efforts including modification of bulk [20,21] and surface properties [22,23] have been made to improve their wear and corrosion wear resistance. Recently Xu et al. have investigated the effect of pre-aging

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temperature and a slow retrogression heating rate on the properties of AA7150 [24].

The main object of this investigation is to study the effect of Al–5Ti–1B and modified SIMA process on the microstructure, tensile properties and dry sliding wear behavior of the Al–12Zn–3Mg–2.5Cu alloy.

## 2. Experimental procedure

Al–12Zn–3Mg–2.5Cu alloy was prepared by melting commercially pure Al (99.87%), Mg (99.99%), Zn (99.996) and Cu (99.9%) in a small electrical resistance furnace (with accurate temperature measuring system, ±5 °C) in order to prepare alloys with different amounts of Ti. The melting temperature was held at 720 °C. After degassing with submerging dry $C_2Cl_6$ containing broken tablets (0.3 wt.% of the molten alloy), master alloy including titanium (Al–5Ti–1B) chips were added to the melt for grain refinement at 750 °C. The melt was stirred for about 1 min by graphite rod and cleaning off the dross after the addition of grain refiner and/or modifier. Melts were held for 8 min and poured into a ductile iron mold. The chemical composition of the Al–12Zn–3Mg–2.5Cu aluminum alloy studied in this work is given in Table 1.

SIMA process was applied to the unrefined and Ti-refined by optimum amount of the master alloy, i.e. 0.1% Ti (2 wt.% Al–5Ti–1B). For the modified SIMA process (Fig. 1), the cylindrical cast specimens (∅30 mm × 50 mm) were homogenized at 460 °C for 24 h then quenched in water (25 °C). After reheating the homogenized specimens to 300 °C, warm deformation was conducted. For all specimens, a constant deformation (40%) in height was selected to provide adequate strain in SIMA process.

The deformed samples were then heated to various temperatures within the range of the mushy zone (500–600 °C) and maintained at these temperatures for various holding times in the range of 10–40 min as listed in Table 2 [25,26].

For microstructure studies, samples were selected from 20 mm of the bottom of each casting. Grain size analysis was carried out by an image analysis system (Clemex Vision Pro. Ver.3.5.025) after etching the polished surface with Keller's reagent (2 ml HF, 3 ml HCl, 5 ml $HNO_3$ and 190 ml $H_2O$). Microstructure was taken after etching for about 30 s. The average grain size of the specimens was measured using an optical microscope according to the ASTM: E112-10. Further microstructural characteristics of the specimens were examined by scanning electron microscopy (SEM) performed in a Cam Scan MV2300 SEM, equipped with an energy dispersive X-ray analysis (EDX) accessory. For tensile tests, specimens were machined according to ASTM: B557M-10 (Fig. 2).

**Table 1**
Chemical composition of the primary ingots (wt.%).

| Al | Zn | Mg | Cu | Fe | Si |
|---|---|---|---|---|---|
| Rem. | 12.12 | 3.15 | 2.49 | 0.15 | 0.02 |

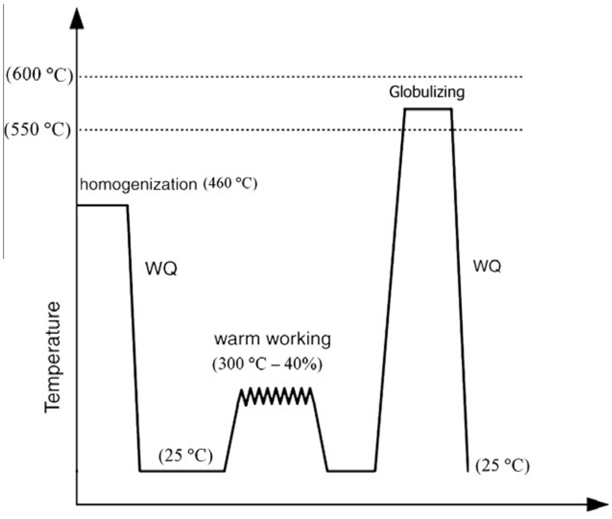

**Fig. 1.** Schematic illustration of new modified SIMA process.

**Table 2**
The heat treatment conditions of warm-worked alloys for SIMA process.

| Temperature (°C) | 550 | 550 | 550 | 575 | 575 | 575 | 600 | 600 | 600 |
|---|---|---|---|---|---|---|---|---|---|
| Time (min) | 10 | 20 | 40 | 10 | 20 | 40 | 10 | 20 | 40 |
| Predeformation (%) | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 |

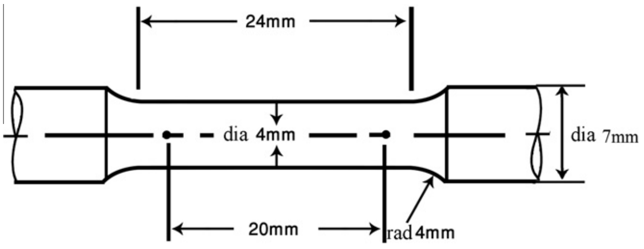

**Fig. 2.** Tensile specimen geometry and dimensions.

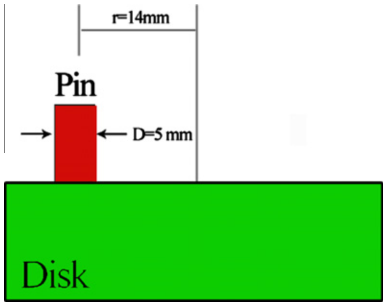

**Fig. 3.** Schematic of pin-on-disk configuration.

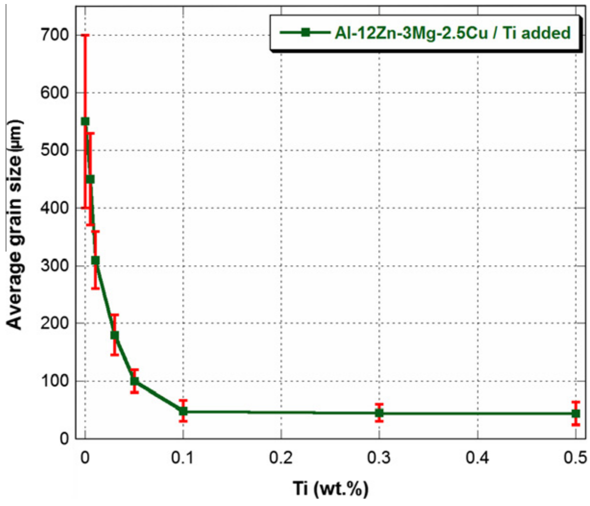

**Fig. 4.** Grain size variation with Ti contents.