Materials and Design 53 (2014) 373–382

Contents lists available at ScienceDirect

Materials and Design

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

Wear properties of high pressure torsion processed ultrafine grained Al–7%Si alloy

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ARTICLE INFO

Article history:
Received 23 April 2013
Accepted 12 July 2013
Available online 25 July 2013

Keywords:
Severe plastic deformation
High pressure torsion
Ultrafine grained materials
Grain refinement
Wear
Al–Si alloy

ABSTRACT

In this paper, Al–7 wt% Si alloy was processed via high pressure torsion (HPT) at an applied pressure 8 GPa for 10 revolutions at room temperature. The microstructure and hardness of the HPT samples were investigated and compared with those of the as-cast samples. The wear properties of as-cast and the HPT samples under dry sliding conditions using different sliding distances and loads were investigated by reciprocated sliding wear tests.

The HPT process successfully resulted in nanostructure Al–7 wt% Si samples with a higher microhardness due to the finer Al matrix grains and Si particles sizes with more homogeneous distribution of the Si particles than those in the as-cast samples.

The wear mass loss and coefficient of friction values were decreased after the HPT process. The wear mechanism was observed to be adhesive, delamination, plastic deformation bands and oxidization in the case of the as-cast alloy. Then, the wear mechanism was transformed into a combination of abrasive and adhesive wear after the HPT process. The oxidization cannot be considered as a mechanism that contributes to wear in the case of HPT samples, because O_2 was not detected in all conditions.
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1. Introduction

The wear properties of engineering materials have significant effects on the serviceability and durability of their components. Hence, the wear properties must be taken into account in the design of engineering parts. It is generally known that the wear resistance of metals and alloys is proportional to their hardness. The enhancement of the wear resistance of materials can be attained by various methods, typically heat treatment and surface coating.

Its light weight makes Al alloys superior substitutes for the other metallic materials in many applications. A reduction in the weight of engineering components contributes to reducing the energy consumption and fuel in the final product.

Al–Si alloys are widely used in automotive, communication equipments and instrumentation due to their light weight, high specific strength and wear resistance.

Various works have shown improved wear resistance in Al–Si alloys through grain refinement by using the grain refiner and/or modifier additions [1–4].

Kori et al. investigated the effect of grain refiner and or modifier on the microstructure and wear behavior of hypoeutectic (Al–0.2, 2, 3, 4, 5 and 7Si) and eutectic (Al–12Si) by using a pin-on-disc machine [1]. Further work was also performed in order to investigate the effect of the grain refiner and or modifier on the wear behavior of Al–7%Si alloy [2]. Moreover the effect of the addition of the Cu was studied [2]. Shi et al. continue the investigation of the addition of the grain refiner on the wear, friction and wear surface morphology of the hypereutectic Al–20%Si alloy through the addition of Nd [3]. Further investigation about the wear properties improvement of the hypereutectic Al–20%Si was also attempted through the addition of strontium [4]. It was interestingly observed that the wear properties were improved and coefficient was decrease due to the decrease in the grain size after the addition of the grain refiner [1–4].

Materials with nanometer or submicrometer sized grains produced by severe plastic deformation (SPD) have been the subject of considerable interests over the last decade due to their unusual mechanical and physical properties and their high performance levels. Equal Channel Angular Pressing (ECAP) and high pressure torsion (HPT) are considered the most popular among SPD processes.

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http://dx.doi.org/10.1016/j.matdes.2013.07.045

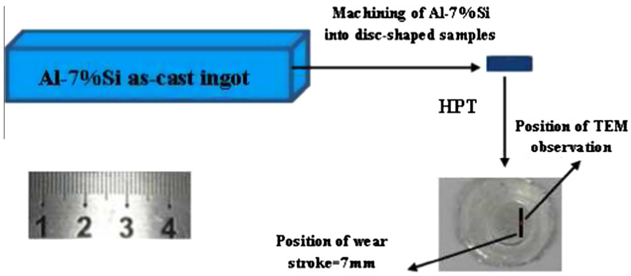

Fig. 1. Macrographs of Al–7 wt% Si alloy before and after the HPT process and the positions of the TEM observation and wear stroke.

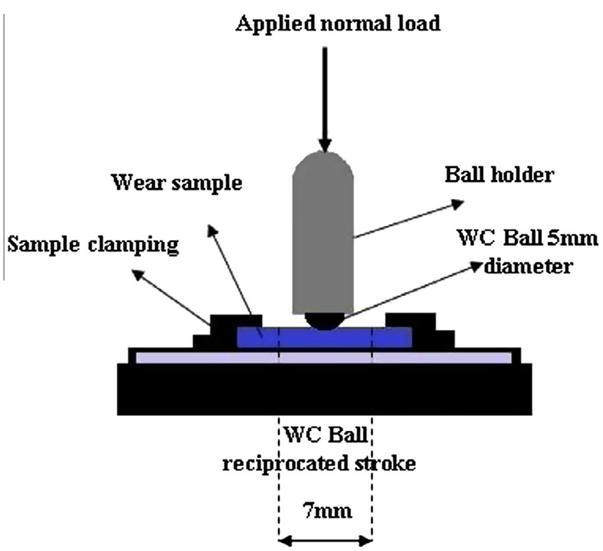

Fig. 2. Macrographs of the ball-on-flat surface reciprocating sliding wear test.

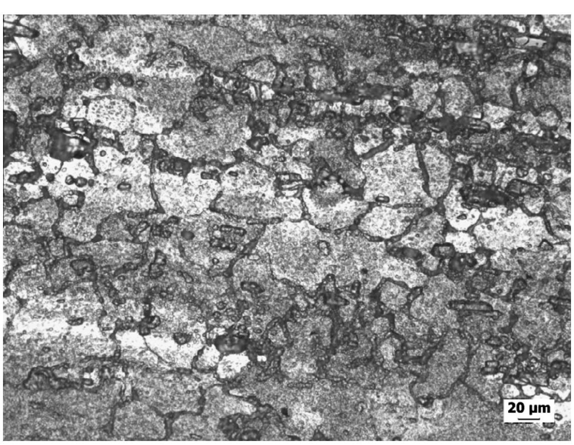

Fig. 3. OM micrographs of the microstructures of as-cast Al–7 wt% Si alloy deep etched sample.

The effect of ECAP on the wear properties was investigated for several materials: Cu–10%Al–4%Fe alloy, Al–Cu alloys and Al–Mg–Si alloy [5–9]. Gao et al. investigated the effect of the grain refinement of the Cu–10%Al–4%Fe alloy processed up to 6 and 2 passes of ECAP [5,6]. Further investigations were also performed in the effect of the grain refinement by ECAP on the wear and friction properties of Al–Cu alloys and Al–Mg–Si alloy [7–9]. It was noted that the wear rate and coefficient of friction were reduced as the hardness increase due to the grain refinement with the increase of the ECAP number of passes [5–9].

Recently Wang et al. [10] study the effect of HPT on the wear properties and friction of Ti. The wear test was carried out under small applied loads of 100–200 mN. The applied loads were observed to be very small relative to those applied over the mechanical components in actual applications. So the needs of further investigations about the effect of the HPT on the wear properties are still needed.

The present research was undertaken in order to achieve three main objectives. The first objective was to investigate the effect of HPT on the microstructure evolution and microhardness of the Al–7 wt% Si alloy. The second was to investigate the effect of the HPT on the wear properties and friction of the Al–7 wt% Si alloy. Finally, the third objective was to investigate the worn surfaces morphologies in the case of the HPT and as-cast (coarse grain) Al–7 wt% Si alloy samples.

2. Experimental work

Al–7 wt% Si alloy ingots were prepared using commercial purity aluminum (99.8%) and Al–20 wt% Si master alloy. Melting of the alloy was carried out in a resistance furnace at 700 °C. The Al–7 wt% Si alloy was poured into a metallic mould. The Al–7 wt% Si alloy ingots were annealed at 540 °C for 20 h followed by slow cooling. The Al–7 wt% Si alloy ingots were machined into disc-shaped samples with a diameter of 10 mm and thickness of 2 mm.

The alloy ingots were turned with cutting tool has tool nose radius of 0.25 mm. The cutting tool top rake, side rake, front clearance, side clearance, end cutting edge, side cutting edge angles were 15°, 20°, 10°, 8°, 5° and 9° respectively. The cutting conditions of speed, feed, and depth of cut were 200 m/min, 0.1 mm/rev, and 0.4 mm, respectively. The turning process was conducted under the use of cutting fluid (coolant).

It is already known that the 70% percent of the generated heat during the cutting process is removed by the chip. But for further elimination of the effect of the generating cutting heat on the microstructure and mechanical properties of the original ingot, the selected cutting conditions were used. As the decrease of the cutting speed, there is more time for the heat generated to be dissipated, hence cutting temperature decrease. Moreover lower values of feed and the depth of cut decrease the chip is thinner. With thinner thickness-to-surface area of the chip, there is higher opportunity for the heat to be dissipated, hence cutting temperature decrease. Finally the using of the cutting fluid plays significant role in reducing the cutting temperature. So the heat generated during the machining process will not influence microstructure and mechanical properties of the original ingot.

Then, the samples were mechanically ground with 4000 emery papers. The HPT processing was performed for 10 revolutions at room temperature and a speed of 1 rpm. The applied pressure was 8 GPa, using a semi-constrained HPT die [11] with a total depth of 1 mm and a diameter of 10 mm. The shape of samples before and after the HPT process is shown in Fig. 1.

The microstructure observations of the Al matrix and Si particle sizes were performed before and after the HPT process. The as-cast samples were polished and deep etched using Keller's reagent. An optical microscope model NIKON equipped with an automatic microscope camera was used. The microstructure observations of the Si particles sizes and distribution after the HPT process were performed using a field emission scanning electron microscope (FE-SEM; model JEOL JSM-6330F, JEOL, Japan) operated at a voltage of 15 keV.

The ultrafine Al matrix grains and Si particles of the Al–7 wt% Si alloy samples processed using the HPT process were investigated using a transmission electron microscopy (TEM). The TEM samples

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