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# Effect of Severe Plastic Deformation on Wear Properties of Aluminum Matrix Composites

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The influence of severe plastic deformation on wear properties of Al-5wt.%Grp and Al-5wt.%B<sub>4</sub>Cp reinforced aluminum matrix composites was studied. Al matrix composites were produced by solid state processing via powder metallurgy route that provides good incorporation and distribution of the reinforcement particles in the matrix. Wear tests were performed by dry sliding using a pin on disk wear tester. Scanning electron microscope was used to examine worn surfaces to study the wear mechanism. Severely deformed specimens exhibited better wear resistance due to the increase of surface hardness of both Al-5wt.%Grp and Al-5wt.%B<sub>4</sub>Cp composites. Al-B<sub>4</sub>Cp reinforced composite has higher hardness value through the excellent hardness of B<sub>4</sub>C particulates. Al-Grp reinforced composites exhibited better wear resistance due to the solid lubricant effect of Gr particulates.

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## 1. Introduction

Severe plastic deformation (SPD) methods have been applied to metallic materials in order to improve the mechanical and physical properties. Nanograins obtained after SPD, have intensified misoriented subgrain boundaries and high density of dislocations [1]. The structure provides unique characteristics to the materials. SPD methods have been applied to entire bulk or to merely the surface of the materials [2]. Shot peening with higher Almen intensity is one of the most important types of surface severe plastic deformation (SSPD) [3]. Severe shot peening improves wear and fatigue properties by creating fine grained layer on metallic part surfaces. Fine grained layer is formed by creating high dislocation density and surface hardening. If the fatigue, corrosion and wear properties have to be considered, selection of such SSPD as severe shot peening could be beneficial for such applications [4, 5].

Aluminum and its alloys are used in practical applications due to the advantage of small density, although the tribological properties of aluminum alloys are worse than those of iron- and titanium-based materials [6, 7]. Therefore, hard ceramic compounds have been added to aluminum matrix in order to improve such properties as strength, stiffness, wear and fatigue resistance [8]. Aluminum-based composites have high specific strength and high wear resistance due to the involvement of hard ceramic particles. However, the aluminum matrix has a much lower strength and hardness. This can be assessed as the major challenge of Al-based composites [7]. This

paper presents an approach to meet the mentioned challenge by the application of SSPD via severe shot peening, directly on the Al matrix, in order to improve hardness, and thus the wear resistance and the stiffness. The aim of this study is to determine influence of severe plastic deformation on wear properties of Al-5wt.%Grp and Al-5wt.%B<sub>4</sub>Cp reinforced aluminum matrix composites.

## 2. Materials and equipment

Al matrix composites were produced by solid state processing using powder metallurgy route that leads to considerable incorporation and uniform distribution of the reinforcement particles in the matrix. The powder metallurgy composite parts have been manufactured as Al-5wt.%Grp (graphite) and Al-5wt.%B<sub>4</sub>Cp reinforced aluminum matrix composites. The sintering was carried out at 650 °C for 4 h in argon atmosphere. The specimens have been exposed to shot peening treatment with 18A Almen intensity (Table I). The intensity is a bit higher than the Almen intensity of aircraft applications (14–16A). The selection of 18A is chosen to create severe plastic deformation on the surface.

TABLE I

Severe shot peening parameters of the specimens.

| Intensity | Shot size | Air pressure [kPa] | Coverage | Duration [s] |
|-----------|-----------|--------------------|----------|--------------|
| 18A       | S230      | 482                | 200%     | 20           |

The specimens microstructure has been analysed by means of optical microscopy and field emission scanning electron microscopy (FESEM). Nikon Eclipse MA100 was used for optical microscopy and Carl Zeiss Gemini Sigma

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was used for FESEM analysis. The phase analysis was carried out on the surface via Rigaku SmartLab diffractometer using Cu  $K_{\alpha}$  radiation (scanning speed: 20 min; voltage: 40 kV, scanning angle: 200–900 and current: 30 mA). Qness GmbH Q10 microhardness tester was used for analysis of the microhardness alteration from shot peened surface to the interior. Finally, the specimens were subjected to wear-abrasion process using the free ball microabrasion test. The 800 mesh SiC particles solution with approximately 25% SiC have been used for the tests.

### 3. Results and discussion

Figure 1a shows optical micrographs of Al-5wt.%Grp composite before polishing and Fig. 1b shows the same composite after mechanical polishing. The optical micrograph analysis shows that the size measurements are compatible with pre-selected particle size.

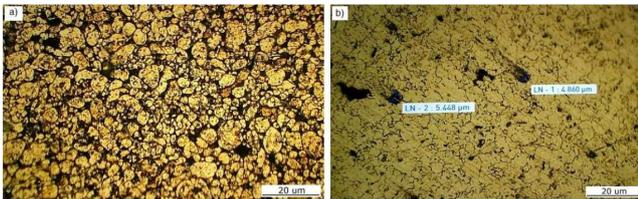


Fig. 1. Al-5wt.%Grp composite (a) before polishing and (b) after polishing.

Application of shot peening, as a severe plastic deformation, leads to a decrease of the XRD peak intensities compared to the as-received ones (Fig. 2). The intensity decrease and increase of FWHM indicate on grain refinement after cold plastic deformation. In literature, most of studies show the grain size reduction via FWHM analysis after severe shot peening [9–11].

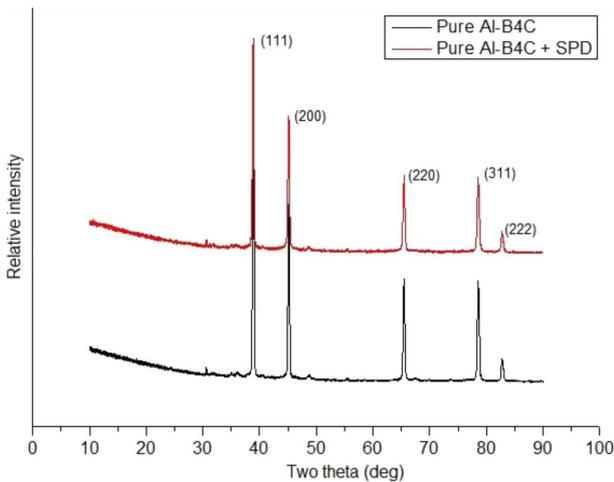


Fig. 2. XRD analysis of as-received and shot peened Al-5wt.%B<sub>4</sub>Cp composite.

Surface hardness of both as-received and severe plastically deformed specimen is higher than that of the core. However, in graphite-reinforced specimen the SPD effect can be easily observed up to 200  $\mu\text{m}$  (Fig. 3a). For Al-5wt.%B<sub>4</sub>Cp the surface hardness improvement has been observed regardless of SPD application. However, the hardness of severely shot peened Al-5wt.%Grp surface layer was much higher than the hardness of the as-received one (Fig. 3b). The beneficial effect also can be observed in wear tests. The reason of lack of alteration in Al-5wt.%B<sub>4</sub>Cp can be anticipated, because of the heterogenous distribution of B<sub>4</sub>Cp particles throughout the surface.

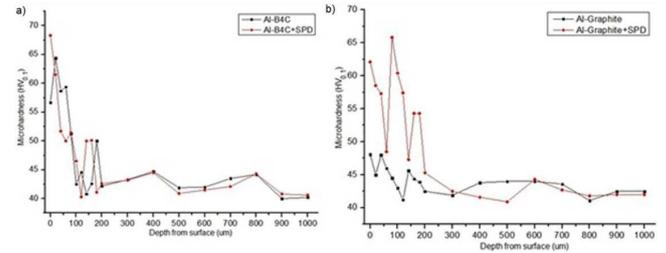


Fig. 3. Microhardness of as-received and shot peened (a) Al-5wt.%B<sub>4</sub>Cp and (b) Al-5wt.%Grp composite.

Although the hardness alteration is minimal in the Al-5wt.%B<sub>4</sub>Cp composite powder metallurgy parts, severe shot peening has decreased effectively the wear volume loss rate (Fig. 4). This is due to the condensed and grain-refined surface, compared to as-received material. In addition, Al-5wt.%Grp composite presents the best response to severe shot peening. Although the volume loss of the composite has the maximum value among the specimens, severe shot peening provides the minimum volume loss, compared to both as received Al-Grp and also B<sub>4</sub>C composites. Edalati et al. [12] have investigated Al-Al<sub>2</sub>O<sub>3</sub> composites consolidated by high-pressure torsion. Similar to these results, high pressure torsion induces wear improvement on the surface of the materials.

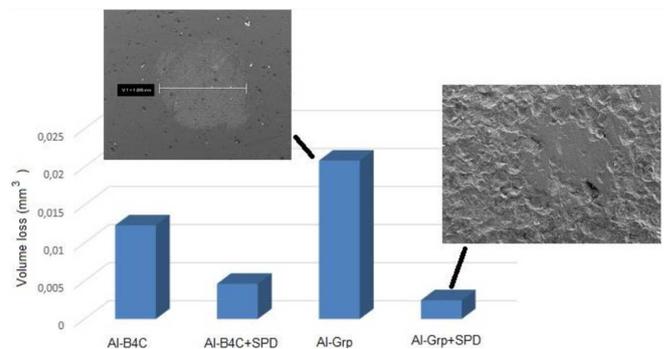


Fig. 4. The wear volume loss rates of both Al-Grp and B<sub>4</sub>C composites after severe shot peening.

#### 4. Conclusions

The conclusions of the study can be summarized as follows

- Severe shot peening leads to decrease of volume wear loss rate effectively due to the increase of surface hardness of both Al-B<sub>4</sub>C and Al-graphite composites. The hardness alteration of only Al-graphite supports the wear results.
- Severe shot peening creates severe plastic deformation on the surface and induces a hard layer on the surface, compared to core of the material.
- According to XRD results of the peened specimens, the XRD peak intensities of these specimens are reduced and FWHM increases. The results reveal grain refinement on the surface.

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