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Wear 260 (2006) 847–854
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Wear and friction of 6061-T6 aluminum alloy treated by laser shock processing

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Received 29 July 2004; received in revised form 11 March 2005; accepted 6 April 2005
Available online 9 June 2005

Abstract

Laser shock processing (LSP) is becoming an important surface treatment to induce a compressive residual stress field, which improves fatigue and fracture properties of components. In this work, we examine the effect of laser shock processing on the wear and friction behavior of 6061-T6 aluminum alloy. Wear rate and friction coefficient evolution are investigated for different process parameters of LSP. Roll-on-flat tribometer is used with different loading conditions. Hardness and residual stresses are assessed as well. It is observed that wear rate decreases as pulse density increases; this is explained in light of residual stress distribution.

Keywords: Laser shock processing; Residual stresses

1. Introduction

Aluminum alloys are still subject of intense studies. Their low density gives an additional advantage in aerospace and automotive industries. These alloys started to replace cast irons and bronzes to manufacture wear resistant parts [1]. Aluminum alloys are versatile and may be manufactured by different conventional techniques, such as forging, extrusion and lamination. Wear is defined as surface damage resulting from relative motion between surfaces. That damage may be a loss of material micro-cracks or localized plastic deformation [2]. Wear is one of the three most common problems found in industry, which leads to replacement of industrial parts and components, the other two problems are fatigue and corrosion. Although wear is rarely catastrophic, it may reduce operative efficiency, increasing loss of power, oil consumption and frequency of component replacement. Wear is not an intrinsic material property, but a system property; thus, any change in loading, speed or environmental conditions will modify wear rate. The assessment of wear rate is becoming necessary especially to evaluate the effect of surface treatments.

Several technological processes to improve surface wear properties are available. Among them we can mention cold and hot rolling, shot peening, and more recently, laser shock processing and ultrasonic peening [3]. All of these processes have in common the introduction of a micro-structural barrier from surface to some millimeters into the material in order to increase wear life. Among the mentioned barriers we find the compressive residual stress field induced in the material, which is one of the main mechanisms to affect the delay in wear of metallic materials. Potential applications are directed to aerospace and automotive industries. The beneficial effects of laser shock processing (LSP) on static, cyclic, fretting fatigue [4] and stress corrosion performance of aluminum alloys [5–7], steels [8] and nickel based alloys [9] have bee demonstrated.

When a metallic target (see Fig. 1) is irradiated with a laser pulse of intensity > 1 GW/cm^2, a thin surface layer vaporises immediately, generating a high temperature and high-pressure (1–10 GPa) plasma, interaction time is too short

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doi:10.1016/j.wear.2005.04.014

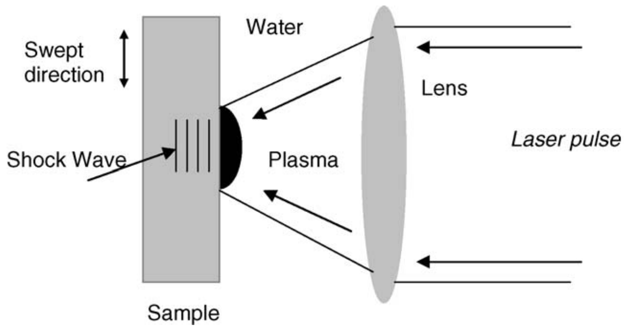

Fig. 1. Principle of laser shock processing.

(<100 ns) and strain rate is high (>100,000 s^{-1}). This plasma induces shock waves travelling though the target inducing plastic deformation [10]. Even though strain hardening and micro-structural distortion generated at the surface and some layers inside the material, may contribute to decrease wear rate [1], it has been reported that LSP produces less plastic distortion over the surface and the residual stresses penetrate deeper inside the material. That is the reason why this process is being accepted for industrial applications [11].

The aim of this paper is to examine the effect of laser shock processing on the wear and friction behavior of the 6061-T6 aluminum alloy. Wear rate and friction coefficient evolution are investigated for different process parameters of LSP. Roll-on-flat tribometer is used with different loading conditions.

2. Experimental procedure

2.1. Material

Specimens were obtained from a 6.3 mm thick commercial laminated plate of aluminium 6061-T6, and then treated with LSP. The T6 condition consists of a solution treatment and natural aging. Its chemical composition (wt%) was: 0.52 Si, 0.27 Fe, 0.13 Cu, 0.03 Mn, 0.46 Mg, 0.011 Zn, 0.27 Cr and 0.022 Ti. This composition was determined using a spark emission spectrometer [12].

2.2. Laser shock processing

The LSP experiments were performed using a Q switched Nd:YAG laser operating at 10 Hz with a wavelength of 1064 nm and the FWHM of the pulses was 8 ns. A convergent lens is used to deliver 1.2 J. Spot diameter was 1.5 mm. Three pulse densities were used: 900, 2500 and 5000 pulses/cm^2. Specimens were submerged into a water bath when they were irradiated. Water was the confined medium. A 2D motion system was used to control specimen position and generate the pulse swept as shown in Fig. 2(a). Controlling the velocity of the system led to the desired pulse density. Plate rolling direction (L) was perpendicular to LSP swept direction and to sliding direction. Fig. 2(a) shows these directions.

2.3. Characterization of the effects induced by LSP

Micro-hardness measurement was made with a 50 g load and 10 s hold time. Residual stress distribution was determined by the hole drilling method according to the ASTM standard E837 [13]. The hole drilling method requires drilling a small hole, 1.6 mm in diameter for this work, to a depth approximately of 1.4 mm. A specialized three-element rosette measures the surface strain relief in the material around the outside of the hole. Residual stresses existing in the material before hole drilling can be calculated from the measured relieved strains. Strain gage rosettes EA-13-

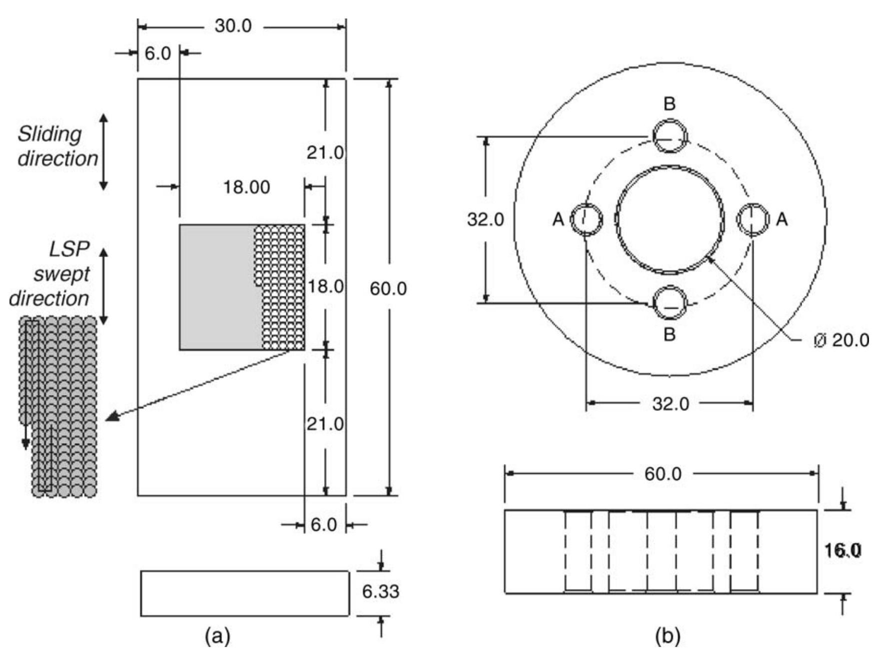

Fig. 2. (a) Aluminum specimen used in the wear test. Note the treated zone and LSP swept direction; (b) steel roll used in the wear tests. Dimensions in mm.