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Effects of laser shock processing and strain rate on tensile property of LY2 aluminum alloy

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ABSTRACT

The effects of laser shock processing (LSP) on tensile property of LY2 aluminum (Al) alloy were investigated, and strain rate sensitivity of the untreated and treated samples by LSP was studied at the strain rates ranging from 0.00001 s^{-1} to 0.1 s^{-1}. In both conditions, fracture morphologies were observed by field emission scanning electron microscope (FESEM), and the microstructure in the near-surface region was characterized by transmission electron microscopy (TEM), respectively. Experimental results showed that LSP can obviously improve the ultimate tensile stress and elongation of LY2 Al alloy, and the strain rate sensitivity of the treated sample appeared to be remarkable. The improvement of tensile properties may be explained by the fact that the grain in the LSP-shocked region was obviously refined. Dynamic strain aging was found in the treated sample at the strain rate ranging from 0.00001 s^{-1} to 0.0001 s^{-1}, and the underlying formation mechanism was revealed.

1. Introduction

Aluminum (Al) alloy has been widely applied in the automobile and aircraft/aerospace industries due to its outstanding specific strength, electrical conductivity, thermal conductivity, easily forming and making, etc. However, the lower tensile resistance of Al alloy confines its wide application.

Laser shock processing (LSP) has many advantages such as ease of operation, local treatment and short processing duration, and it is now emerging as a novel industrial treatment to improve the fatigue lives of alloys and steels [1,2]. During LSP, the action on the surface and subsurface of the materials is achieved through the mechanical effect arisen from the laser shock wave, as schematically shown in Fig. 1. The region at the metal surface to be shocked is covered by a laser absorbing layer, over which a curtain of water which acts as a confining layer is run. A high-energy laser pulse is directed on to the surface, which passes through the water confining layer and is absorbed by the absorbing layer. The surface of the absorbing layer is vaporized, and continues to absorb energy, forming a plasma. The hydrodynamic expansion of the heated plasma in the confined region between the metal target and the water confining layer creates a high-amplitude and short-duration pressure pulse. The shock wave can be much larger than the dynamic yield strength of the material (>1 GPa) and cause plastic deformation near the target surface and compressive residual stresses which can extend to a deep depth in the subsurface [3,4]. The maximum depth can reach 1.5 mm, depending on the material properties of the metal and the processing parameters used in LSP [5–7]. The plastic deformation in the sample subsurface occurs due to the consequent modification of the near-surface microstructure and properties [8,9].

Considerable researches have been carried out to examine the effects of the strain-rate on the tensile properties of metal materials or mechanical property at a certain strain-rate by different treatment methods. Garcia-Bernal et al. [10] have investigated the effect of five FSP (Friction Stir Processing) conditions on the high-temperature deformation properties of a continuous cast Al–Mg alloy at a strain-rate of 3×10^{-2} s^{-1}. Results showed that FSP can refine the grain size to less than 3 μm and enable the tensile elongation. Garcia-Infanta et al. [11] have found that 7075 Al alloy has an upstanding elongation after high-pressure torsion up to five turns at 6 GPa. Boyce et al. [12] have examined the strain-rate sensitivity of four high-strength, high-toughness steels at strain-rates ranging from 0.0002 s^{-1} to 200 s^{-1}. Fan et al. [13] have investigated the effect of deformation behavior of an ultrafine-grained Al–Mg alloy at different strain-rates. Kaibyshev et al. [14] have investigated the high strain-rate superplasticity in an Al alloy subjected to simple thermomechanical processing. Han et al. [15] have investigated the strain-rate-dependent deformation behavior of bimodal 5083 Al alloys processed by cryomilling and pointed out that crack blunting/bridging by ductile coarse grains plays a significant role at lower strain-rates. Most of the above researches reveal that the strain-rate

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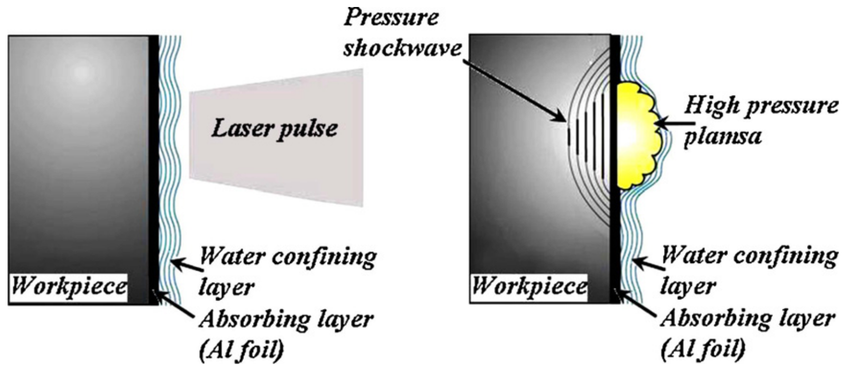

Fig. 1. Schematically principle of LSP.

Table 1
Composition of LY2 Al alloy.

Composition	Cu	Mg	Mn	Si	Fe	Ti	Be	Cr	Zn	Al
Percent (wt.%)	2.6–3.2	2.0–2.4	0.45–0.7	0.3	0.3	0.15	0.05	0.05	0.05	other

has an important influence on the tensile properties and the fatigue lives of materials under different work conditions. In the aeronautical industry, key mechanical components are constructed from Al alloy. LSP can improve the fatigue life and strength of Al alloy, and reliable design of structural components requires an understanding of the dynamic mechanical properties and the relation between their tensile properties and facture morphologies at relevant strain-rates. However, in spite of numerous published studies on the influences of LSP on tensile properties at a certain strain-rate, little attention has been focused on the investigations into the dynamic tensile properties at relevant strain rates and the effects of strain rate on the ultimate tensile stress (UTS) of Al alloy subjected to LSP. Further studies of LSP on the tensile property for Al alloy are still necessary.

With the above background in mind, the present work focused on the tensile properties of the untreated and treated LY2 Al alloy samples by LSP at the broad strain-rate from 0.00001 s^{-1} to 0.1 s^{-1}. The engineering stress–strain curves were investigated, and the UTS (the flow stress) and strain rate sensitivity were also analyzed in both conditions. These topics discussed in the present work can provide some important insights on the engineering application of Al alloy subjected to LSP.

2. Experimental procedures

2.1. Experimental material and technique parameters

The tensile sample was cut into the dog-bone shaped tensile sample, whose dimension was shown in Fig. 2(a). LY2 Al alloy was chosen for the metal tensile sample, whose composition and mechanical property were listed in Tables 1 and 2, respectively. To ensure the tensile data for comparison, fifty samples were cut from the same LY2 Al alloy plate.

All samples were cleaned in deionized water followed by ultrasonic vibration in ethanol to degrease their surfaces, of which twenty-five samples were treated shortly by LSP, and the other twenty-five samples were not been treated. The samples were treated by the laser shock wave along the center line, and the top surface of each sample was only treated, as schematically illustrated in Fig. 2(a), while Fig. 2(b) was the partial enlarged drawing of the treated area subjected to LSP. The diameter of the laser spot was 3 mm and the distance between the adjacent laser spots at the center line was 1.5 mm, namely, the overlapping rate was 50% during LSP. In LSP, the shockwaves were induced by a Q-switched repetition-rate laser with a wavelength of 1054 nm, a pulse duration of 20 ns and a pulse energy of around 3 J. Water with a thickness of 2 mm was used as the transparent confining layer and the 3 M Al foil with a thickness of 50 μm was used as the absorbing layer to protect the sample surface from the thermal effect. The processing parameters used in LSP were shown in Table 3 in detail.

Table 2
Mechanical properties of LY2 Al alloy.

Type	Value
Specific gravity, d, g/cm^3	2.8
Tensile strength, δb, MPa	470
Elongation, δ, %	14
Vickers-hardness, HV	120

2.2. Measurement of tensile property

The tensile properties of the treated and untreated samples were measured on a MTS880-10 servo-hydraulic material testing

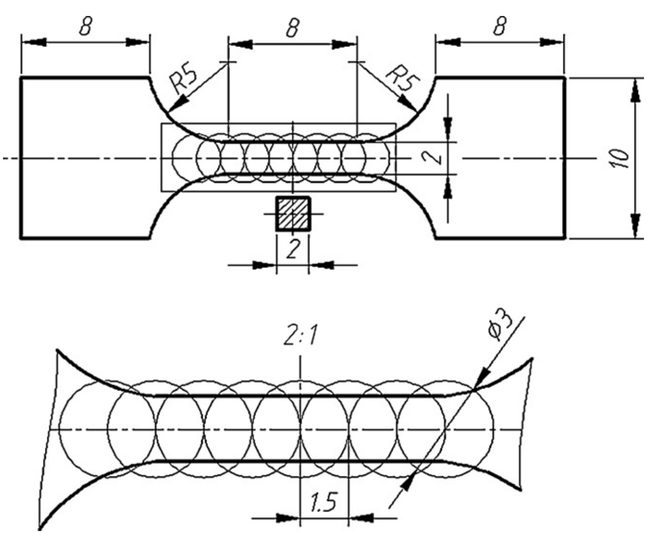

Fig. 2. The dimensions of the tensile sample subjected to LSP (unit: mm). (a) The dimensions of the tensile sample, and (b) the partial enlargement drawing of the treated area subjected to LSP.