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Surface Integrity Analysis of Laser Peen Micro-bending without Protective Coating

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Abstract

Laser peen micro-bending is a novel non-contact forming process for sheet metals using a nanosecond pulsed laser. In this study, laser peen micro-bending experiments are conducted for three engineering materials, Aluminum alloy 1060, OHFC Copper, and commercially pure Titanium, in both air and water without using a protective coating. Surface integrity is investigated in terms of surface texture, surface morphology, mechanical properties, and chemical composition change for these three engineering materials. Improved surface mechanical properties are achieved for all materials. The laser-material interaction for different material is discussed based on the significant experimental findings for different materials.

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Keywords: Laser peen micro-bending, Sheet metal, Surface integrity, Surface morphology, Mechanical properties, Chemical analysis.

1. Introduction

Laser peen micro-bending is a novel non-contact micro-forming process recently developed for sheet metals. It can be used to accurately bend, shape, precision align, or repair micro-components with a bending angle less than 10°. Positive (towards laser beam) or negative (away from laser beam) bending angles can be achieved by controlling the laser operation parameters for a sheet metal component [1,2]. The bending mechanism during the process is driven by the high-pressure shock waves induced by a nanosecond-pulsed laser [3][4]. Although an ablative coating is usually applied on the component surface during the laser shock peening process in order to generate a greater shock compression and protect the component surface, it adds a great process difficulty by applying the ablative coating on the treated components. The remaining coating also needs to be carefully removed after the treatment. Therefore it is much preferred to perform laser peen micro-bending directly on the component surface without any protective coating [2].

It is critical to investigate the surface modification after laser peen micro-bending. Changes of surface integrity attributes such as surface morphology, hardness and chemical composition by the laser peen micro-bending process significantly affect the performance of treated components. Also, the effect confinement medium on surface modification during laser peen micro-bending has not been well understood in literature.

In this work, surface modification and integrity of three metal materials are evaluated using an experimental analysis of laser peen micro-bending using an Nd:YAG nanosecond laser. Surface integrity is investigated in terms of surface texture, surface morphology, mechanical properties, and chemical composition change for these three engineering materials. The effect of confinement media is discussed for the different surface morphologies of various materials.

2. Experiments of Laser Peen Micro-Bending

A Q-Switched Nd:YAG laser (wavelength of 1064 nm) was used with a repetition rate of 10 Hz and a pulse duration of 6-8 ns. A 1.5 mm focused beam spot was used in the micro-beding test. The laser fluence was set to two levels of 17 and 22.4 J/cm^2, which corresponds to two pulse energies of 0.3 and 0.4 J. During the experiment, the laser scanned the specimens in a cross-raster pattern under water or air as the confinement medium. During the experiment, the laser scanned the top

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surface of specimens in a raster pattern as illustrated in Fig. 1b. A constant raster width and scanning speed were applied, 0.35 mm and 2.8 mm/s, respectively. Multiple sheet metal samples were tested of three materials, i.e., Aluminum Alloy 1060 (Al), OHFC Copper (Cu), and commercially pure Titanium (cpTi). The specimens with various thicknesses were cut into 76 × 13 mm^2 in area. The surface roughness, R_a, of the specimens before tests were 0.08 µm, 0.26 µm, and 1.63 µm for Al, Cu, and cpTi, respectively.

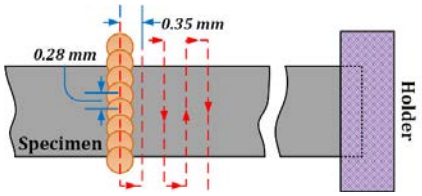

Fig. 1 The schematic of laser scanning path.

The change in mechanical properties after the laser peen micro-bending tests were investigated on surface microhardness and residual stress. Surface microhardness was measured using a LECO LM-300AT Vickers micro-indentation hardness tester. The average hardness of the as-received specimens were 125.6 HV, 62.8 HV, and 255.6 HV for Al, Cu, and cpTi, respectively. After the process, the surface hardness averages increased to 173.3 HV (by 38.0%), 114.8 HV (by 82.8%), and 374.5 HV (by 46.5%) for Al, Cu, and cpTi, respectively. The material hardness was increased significantly in the peened area for all three materials.

Residual stresses for the Al specimens under laser fluence of 22.4 J/cm^2 were measured by X-ray diffraction using the sin2ψ technique. The Co-K_α radiation was applied with the voltage of 22 kV and current of 6.0 mA. Two residual stress components of σ_{xx} (transverse) and σ_{yy} (longitudinal) were measured. Fig. 2 shows the high compressive residual stresses in both components for Al specimens with various thickness. For σ_{xx} and σ_{xy}, the compressive residual stress can reach the level of -200 MPa under all conditions. The minimum of σ_{xx} is -276 MPa for 1.75 mm thick specimens. For σ_{yy}, the compressive residual stress ranges from -207 to -400 MPa, while the minimum occurred for the 0.88 mm thick specimens.

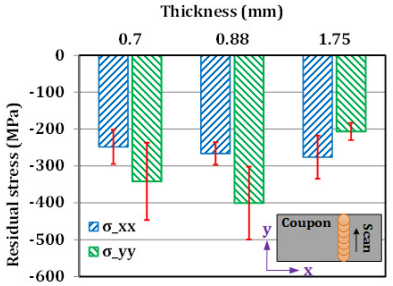

Fig. 2 Residual stress measurement of Al under water.

3. Surface Morphology Analysis

Fig. 3 shows the optical microscopy of treated surface of Cu specimens by five scans under laser fluence of 22.4 J/cm^2 in water and air. The Cu specimen surface under water shows uniform surface texture in Fig. 3a, while obvious feed marks are observed on the last scan track in Fig. 3b. They appeared darker than regions between any adjacent feed marks. The previous four scan tracks were labeled with significant different appearance. The different appearances were likely resulted from different degrees of oxidization during or after scanning in air. For the other materials, similar uniform texture under water and clear feed mark patterns under air were observed. The change in surface profile and roughness were hypothesized as the main reason for different surface texture under water and air as confinement medium.

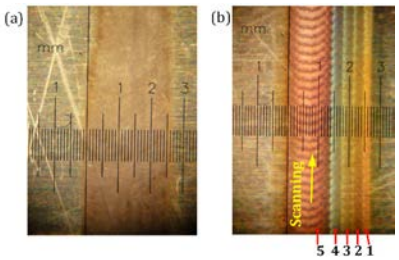

Fig. 3 Scanned Cu specimen surface: (a) in water; (b) in air.

3.1 Surface Profile Produced in Water

The two-dimensional (2D) surface profiles over a 2.5 mm evaluation length were obtained by Taylor Hobson® Surtronic 25 surface roughness profilometer using a diamond stylus with a tip radius of 5 µm. The resolution of height profile was 0.01 µm and the sampling increment is 0.5 µm. Fig. 4 shows the 2D surface profiles of specimens treated under water along the scanning direction. For Al and cpTi, there were many spikes with very random heights about 5-15 µm. The Cu specimen has a much smoother surface than those of Al and cpTi. Fig. 5 shows the surface roughness R_a and R_z of the scanned surface in comparison with those of the original surface. The scanned Al surface had the roughest profile, increased by over 20 folds. R_z and R_a values for scanned cpTi and Cu surface were very close to those of the original surface. All the attributes above were responsible for the uniform surface texture treated under water for all three materials.

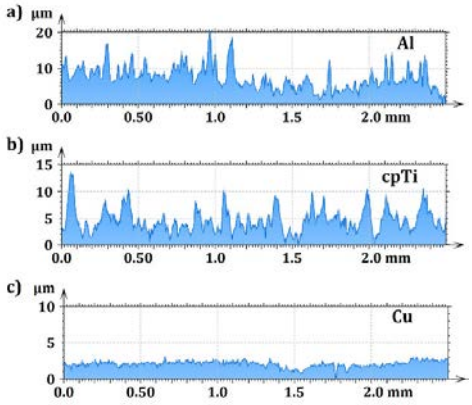

Fig. 4 Scanned surface profiles in water: (a) Cu; (b) Al; (c) cpTi.