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Residual stress characteristics of a metal surface by a laser peening

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1. Introduction

Laser peening is a surface treatment technology, which consists of irradiating a metallic target with a short and intense laser pulse in order to generate, through a high-pressure surface plasma, a plastic deformation and a surface strengthening [1-2]. The aircraft and nuclear power industries have been studying how to improve the mechanical properties in critical areas of materials and especially at their contact surfaces: the fatigue failures generally propagate from the free surface and start in a region which is subject to a tensile stress. Laser peening, which is better than the conventional shot peening technique, has been proven to extend the fatigue lifetime of metal and alloy components [3]. In the laser peening process, a high-energy laser beam creates an intense pressure wave on the surface of the metal, straining the metal and leaving a residual compressive stress both on the top and inside of the metal surface.

We present a configuration and the results of the laser peening concept for a metal surface treatment for an underwater laser irradiation at 532 nm in stainless steel 304 samples. The objective of this work is to examine the effect of a laser peening to induce a very high compressive residual stress in stainless steel specimens and the capability to penetrate deeper into the sample. Process parameters such as the pulse density are varied.

2. Experiment

The experimental setup of a laser peening is shown in Fig. 1. The samples of the rectangular plate of 50 X 200 mm with a thickness of 2 mm were used as target materials. The samples were attached to a holder for a rigid support and easy handling. The holder was driven along the (X, Y)-directions in the water jacket during laser irradiation using a 2-D motorized actuator and a multi-axis servo amplifier system. The sample was covered with metal foil as an opaque overlay. The treated area (15 X 15 mm) was created by a sample displacement in the X-Y plane. The sample was immersed in a water jacket with a 50mm water thickness between the sample surface and the input window.

As a laser source the Nd:YAG Q-switched second harmonic oscillator and an amplifier (Spectra Physics) were used to produce a laser pulse of 8 ns pulse duration with an energy of 0.4 J at a repetition rate of 10 Hz. The focusing lens (f=100mm) was placed in front of the input window of the water jacket. The laser peening of the sample was carried out during the sample scanning in the X-Y plane in such a way as to provide a laser spot two-dimensional overlapping of more than 80% of the spot diameter. This means that the laser pulses affected each point of the treated area approximately four times. The diameter of the single shot area was 1.0 mm.

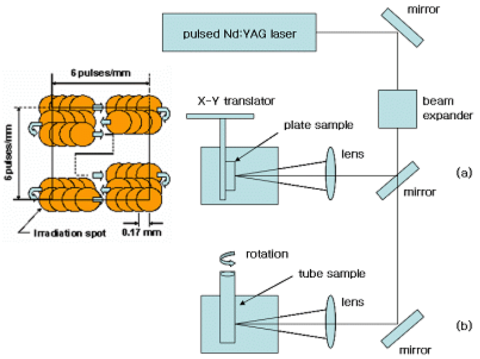

Fig. 1 Experimental setup of a laser peening, (a) for a plate sample, (b) for a tube sample.

The maximum principal compressive residual stresses were measured at the center of the irradiated area by the hole drilling method [4-5]. The hole drilling method required drilling a small hole, 1.6 mm in diameter for this work, to a depth approximately of 2 mm. A specialized three element rosettes measured the surface strain relief in the material around the outside of the hole. Residual stresses existing in the material before a hole drilling can be calculated from the measured relieved strains. Strain gage rosettes EA-13-062RE-120 along with a RS-200 Milling Guide from the Measurements Group were used.

The residual stresses as a function of the depth for the stainless steel 304 sample, treated with 2500 pulses/cm^2 are shown in Fig. 2 and Fig. 3. Note that a high tensile residual stress is observed in the sample with no opaque overlay (Fig 2). Opaque overlays in a typical laser peening operation are used to protect the substrate from the thermal effects of an ablation and can be used to increase the shock wave amplitude on the surface of a substrate. As shown in Fig. 3, while the specimens with an opaque overlay have high compressive stresses in the surface, the uncoated specimens have very high tensile stress values even with a water overlay. This tensile stress was attributed to a severe surface melting during the laser shock processing.

In a laser peening with no transparent overlay, the laser induced plasma absorbs the incident laser energy and rapidly expands away from the solid surface.

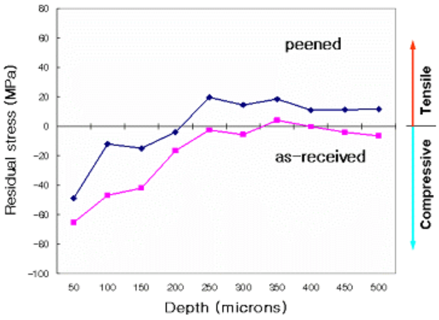

Fig. 2 Residual stress profiles in stainless steel 304 without an opaque overlay coating

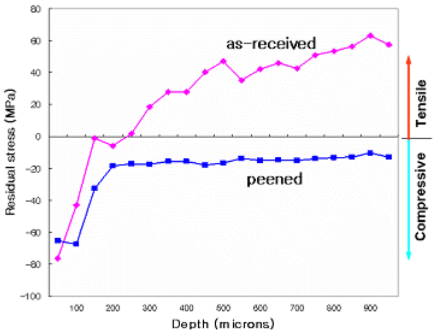

Fig. 3 Residual stress profiles in stainless steel 304 with an opaque overlay coating

Consequently, the absorbed, incident laser energy cannot be efficiently converted into a pressure pulse and therefore it cannot effectively induce compressive stresses in the substrate by a shock wave. The opaque overlay serves to protect the part's surface from a direct thermal contact with the laser-induced plasma, and it provides a consistent surface condition for an interaction with the laser beam, independent of the actual material being treated. Direct contact of a metal surface with the plasma will, in most cases, form a thin melt layer on the surface of the metal, ranging from a surface discoloration to a surface melt layer up to 15 to 25 μm thick, depending on the laser irradiation conditions and the metal properties. The transparent overlay serves to confine the plasma generated at the surface of the opaque overlay against the surface being treated and it can be any material transparent to the laser beam. The water is not used to cool the part but serves as a key function of confining the plasma generated when the laser beam interacts with the opaque overlay surface. The confinement increases the pressure developed by the plasma on the surface by up to 10 times over the surface pressure being developed if the plasma is unconfined and allowed to accelerate away freely from the material surface.

3. Conclusion

Laser peening can produce a compressive residual stress on the metal surface up to 1 mm deep using by commercially available optical and mechanical equipment and a Nd:YAG laser. Moreover, a laser peening has been shown to apply on the various shape of samples including square and tube shapes. The hole drilling analysis was done for the plate and the tube samples, which showed that compressive residual stresses of up to -60 Mpa in stainless steel 304 could be produced by a laser peening. It has been shown that the residual stress by a laser peening is much deeper than that achieved by a conventional shot peening. This is very important because this method may improve significantly a wear and a contact fatigue resistance. Laser peening is an effective surface treatment technique to improve the fatigue properties of metal.

Acknowledgements

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