Bulletin of the *Transilvania* University of Braşov
Series I: Engineering Sciences • Vol. 4 (53) No. 2 - 2011

A REVIEW ON MECHANICAL PROPERTIES OF METALLIC MATERIALS AFTER LASER SHOCK PROCESSING

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Abstract: *The surface treatment technologies have become more and more important in industry to cut costs and avoid the need for expensive materials. Demonstrated a few decades ago, laser shock processing (LSP) is now emerging as a viable surface treatment technique. This technique improves the mechanical properties by inducing a compressive residual stress field. This paper presents the operating principles of LSP and makes a review of mechanical properties after laser shock processing.*

Key words: *laser, surface treatments, material properties.*

1. Introduction

More recently, surface treatment technologies have become more and more important in industry to cut costs and avoid the need for expensive materials. Demonstrated approximately 30 years ago, Laser Shock Processing (LSP) is now emerging as a viable surface treatment technique. The compressive residual stresses in the metal material treated by LSP can extend deeper below the surface than those from shot peening [2].

LSP has been shown to be effective in improving the fatigue properties of a number of metals and alloys. Potential applications are directed to aerospace and automotive industries [10]. Similarly to conventional shot peening, the LSP has been proposed as an effective alternative to traditional methods for properties improvement of metallic materials, as fatigue, corrosion and wear resistance, due to the compressive residual stress induced.

The LSP is a technique for strengthening metals because it induces a compressive residual stress field which increases fatigue crack initiation life and reduces fatigue crack growth rate. Laser beams can be easily directed to fatigue-critical areas without masking. Laser pulse may come directly from the laser apparatus or may be delivered using an optical fiber [1].

2. Principle of Laser Shock Processing

Laser shock processing originates from the ability to drive a high amplitude shock wave into a material surface irradiated with very short, high energy laser pulses. Typical application of the process utilizes a pulsed Nd:YAG (solid state) laser providing a high-intensity beam, up to several GW/cm^2. The duration of the laser pulses is generally within the range of 6 to 40 ns, mostly in the range of 15 to 25 ns.

The metallic surface to be treated is first locally coated with an overlay, opaque to

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the laser beam (typically a black paint) and then covered with a dielectric material transparent to the laser beam (such as water). The opaque overlay acts as a sacrificial material to avoid a thermal effect from the heating of the surface by the laser beam and a thin layer of it vaporizes on absorption of laser energy.

The transparent overlay confines the thermally expanding vapour and plasma against the surface of the target material, thus generating higher pressure than in the direct ablation mode. The large amplitude shock waves induce plastic deformation and favourable residual compressive stresses at the surface, which can increase the fatigue life of the target material [3]. The principle of laser shock processing is shown in Figure1.

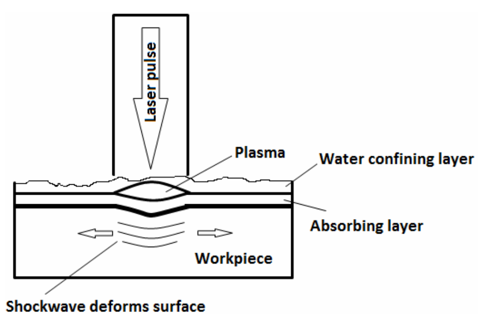

Fig. 1. *The principle of laser shock processing* [3]

3. Review on Mechanical Properties

Zhang Y.K. et al. investigated the effects of LSP on fatigue performance of LY2 aluminum alloy, from turbojet engines blades [16]. They prove that the specimen treated by the two impacts in LSP at one side exhibits the highest fatigue life. They compared it with the untreated specimen and show that the specimens are respectively increased by 131.4% and 132.5% after the single impact and two impacts in LSP. The phenomenon may be attributed to the next two reasons: first, the material below the irradiated surface is submitted to an elasto-plastic wave generating uniaxial plastic strain and second, the surface roughness of the specimen is relatively low. Since the high surface roughness may induce numerous stress concentrations, the low fatigue lives of the untreated specimen may be due to the high surface roughness. The fatigue lives of the treated and untreated specimen using LSP are shown in Figure 2.

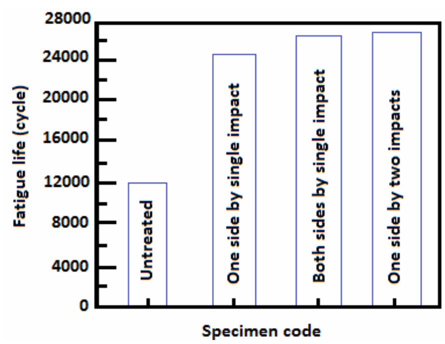

Fig. 2. *Fatigue properties comparison with different LSP parameters, the maximum applied stress σ_{max} was kept to be 255 MPa* [16]

Lu J.Z. et al. [4], prove that the LSP can improve the ultimate tensile stress (UTS), the flow stress and the elongation of the tensile sample manufactured by LY2 Al alloy. It is shown that, the grain in the shocked region subjected to LSP was clearly refined and the grain size is about 100-200 nm at the top surface, which has an obvious attribution to the improvement of UTS and elongation the tensile sample manufactured by LY2 Al alloy.

The other study of Lu J.Z. et al. investigated the effect of LSP on nano-hardness, elastic modulus and surface residual stress of the Fe-Ni alloy specimens [5]. The mechanisms underlying the improved nano-hardness, elastic modulus and surface residual stress by LSP is also investigated here. They concluded that the values of nano-hardness and elastic modulus in the laser-shocked region and the laser-affected region are clearly higher than those in the non-shocked region. Other conclusion is that the contact depths in the laser-shocked and the laser-affected region is lower than the corresponding values in the non-shocked region, which is favourable for improving foreign object damage of the Fe-Ni alloy.

Ren X.D. et al. researched the effect of laser shock processing on the fatigue crack initiation and propagation of 7050-T7451 aluminum alloy and showed that the LSP is effective in introducing deep residual compressive stress, which have a strong influence on fatigue properties [8]. Greater depth of the residual compressive stress induced by LSP results in a slower fatigue crack growth rates and the crack propagation life is considerably longer than that of the non-LSP case. The fatigue strength of the prefabricated crack samples increase straight after LSP respectively.

In another paper, Ren X.D. et al. [7] using a Q-switched high power neodymium-doped glass laser, prove that LSP reduces the expansion rate of fatigue, so the fatigue life of materials is increased; while raising the temperature would increase the expansion rate of fatigue, thereby the fatigue life of materials is reduced. The phenomenon is due to the significant plastic strain induced during the first fatigue cycle. Fatigue also causes a greater reduction of the integral width relative to the solely thermal case, indicating that high temperature isothermal relaxation at 600 ºC is perhaps driven by creep.

Rubio-Gonzales C. et al. [9] showed that the laser shock processing is a surface treatment technique to improve fatigue properties of 2205 duplex stainless steel. This is due to the residual stress field induced on surface. They showed that increasing pulse density, fatigue crack growth rate is reduced. Microstructure is not affected by LSP, ferrite and austenite phases are not altered by the laser peening. In conclusion it has been shown that LSP treatment improves this mechanical property.

Luo K.Y. et al. [6] researched the effects of a single LSP impact on the nano-hardness, elastic modulus, residual stress and phase transformation of ANSI 304 stainless steel. They prove that the LSP can improve the nano-hardness and elastic modulus of the LSP region in near-surface layer and the nano-hardness and elastic modulus gradually decrease with the increase of the distance to the treated surface. In the near-surface layer of the sample, LSP can generate compressive residual stress whose distribution differs from that by shot peening, and not cause deformation-induced martensitic transformation. This phenomenon may be due to the fact that there is an absorbing layer which avoids the thermal effect from heating of the surface by the laser beam during LSP. A single LSP impact can refine the original grain in the near - surface layer mainly by MTs in a single direction, which is the direct reason why LSP can improve the nano-hardness, elastic modulus, residual stress of ANSI 304 stainless steel.

Sanchez-Santana U. et al. [11] investigated the effect of LSP surface treatment on the wear and friction of 6061-T6 aluminum alloy. They showed that LSP reduces wear rate due to the compressive residual stress field induced. Wear rate was being reduced about 68% using 5000 pulse/cm^2. It has been observed that with LSP the time to reach the same wear depth may be increased by as much as 100%, depending on the applied load and pulse density. It has been shown as well, that wear mechanisms are due to adhesion and abrasion and when the wear depth increases, the wear mechanism is due to delamination originating debris with laminar morphology. Under dry conditions, there is a mass transfer (galling) from the specimen to the roll. The mass transfer decreases as the LSP pulse density increases.

Zhang L. et al. investigated the fatigue fracture morphologies by using SEM analysis [13]. They divided the samples into two groups according to these different paths. The first group was treated by two paths, while the second group was treated by four paths. By comparing it with the first group, the distance of the fatigue crack origin far away from the top surface of the second group is a little larger, the ridge is denser and the fracture morphology is brighter and more delicate. At the fatigue crack growth area, the layers of cleavage steps and fatigue striations of the second group are many more, the fatigue striations are denser and the distance between fatigue striations is smaller and more secondary cracks appear. The dimples of the second group become smaller and denser. By comparing with the fatigue life of the sample treated by two paths, there is an obvious improvement of that by four paths and the fatigue crack initiation and growth of the sample treated by four paths can be restrained more effectively during two-sided LSP.

In other papers Zhang Y. et al. [15] researched the effects of laser shock processing on stress corrosion cracking susceptibility of AZ31B magnesium alloy. They conclude that the LSP is successfully used to achieve a reasonably homogeneous fine-grained microstructure for the AZ31B Mg alloy. By increasing the number of laser impacts, the initial coarse grained structure in the as-extruded material is gradually transformed into a fine-grained microstructure. LSP introduces a compressive residual stress filed on the surface of AZ31B Mg alloy. By increasing the number of laser impacts in the LSP, the compressive residual stresses at the surface of the specimen increases obviously. The depth of the compressive residual stress exceeded 0.8 mm from the surface in AZ31B Mg alloy. LSP obviously retards the SCC initiation and the propagation of small pre-cracks on AZ31B Mg alloy in 1 wt.% Na OH solution.

Wang F. et al. [12] demonstrated that LSP is an effective surface treatment technique to improve the microhardness and wear resistance of H62 brass. In their study to examine the effects on the microhardness LSP profile, roughness and microstructure of brass, they showed that LSP treatment improved the mechanical property. The treated region was checked with an optical microscope and no visible ablation was observed. It is a mechanical process without obvious thermal effects. The grain has no visible change. After LSP treatment, the highest microhardness values are HV 127 and 121, corresponding to the applied densities of 1000 and 3000 pulses cm^2, respectively. The wear test experiment shows that the wear mass loss reduced by about 46% with the laser of 3000 pulses/cm^2. This proves that LSP technology can effectively improve the wear resistance.

In other papers Zhang L. et al. [14] investigated via the tensile test the effects of different shocked paths during LSP on the mechanical properties of laser welded 304 stainless steel. The fracture morphology of the tensile samples was also analyzed by SEM.

They obtained the following conclusions:

1. Through the tensile test, the yield strength of the laser welded samples subjected to single-sided LSP impacts was 240.74 MPa and the tensile strength was 683.10 MPa. While the average yield strength of the welded sample subjected to two-sided LSP was 318.18 MPa and its tensile strength was 763.10 MPa. The mechanical properties during two-sided

LSP impacts had the edge over that during single-sided LSP impacts.

2. Compared to the fracture morphology of the laser welded samples by two-sided LSP impacts, the phenomenon of delamination splitting occurred with some cracks in the sharp corner of the laser welded samples by single-sided LSP impacts. The dimples were more and deeper in the two-sided LSP impacts condition. On the whole, the ductility after two-sided LSP impacts was improved than that after single-sided LSP impacts.

4. Conclusions

The study of the previous work reviews the improvement of mechanical properties and their causes. Most of researchers investigate the influence of the compressive residual stress field induced by LSP, which increases fatigue crack initiation life and reduces fatigue crack growth rate. They prove by experimental procedure the effects of LSP on different materials and alloys. Some of them demonstrated that the LSP can improve the mechanical properties as fatigue, corrosion and wear resistance. Laser shock processing has a wide field of using, including automotive and aerospace industry. In conclusion, the LSP will be the new technique to improve the properties of metals.

Acknowledgements

This paper supported by the Sectoral Operationl Programme Human Resources Development (SOP HRD), ID76945 financed from the European Social Fund and by Romanian Government.

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