Effects of laser shock processing on 316L stainless steel welds

I. B. ROMAN*, M. H. TIEREAN*, J. L. OCAÑA[a]
Transilvania University of Brasov, Romania,
[a]*Universidad Politecnica de Madrid, Spain*

This paper presents an experimental study on the effect of laser shock processing (LSP) on mechanical properties of 316 L stainless steel welds. A Q-switched Nd: YAG laser with a 1064 nm wavelength and maximum power of 3.3 kW was used for welding. The LSP energy 2.8 J/ pulse was produced by the same laser, having a spot diameter of 1.5 mm and 10 Hz frequency. We present the results for LSP surface treatments applied with two different pulse densities, 900 pulse/cm^2 and 1600 pulse/cm^2. The purpose of the work is to compare the effects on mechanical properties of untreated weld and LSP treated with both densities. The effect on microstructure was also investigated by optical microscopy. The results are discussed and plotted. The results show the advantages of LSP surface treatment.

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1. Introduction

Due to the numerous advantages laser shock processing start to be frequently used in industry as an effective method for improving the fatigue properties of a number of metals and alloys. Potential applications are directed to aerospace and automotive industries.

Laser shock processing (LSP), which is a cold machining process, is considered a recently developed technique, which has been successfully applied in improving fatigue life and strength of metal material by generating the greater depth of compressive residual stress comparable to shot peening or cold rolling.

The effect of LSP on the materials surface properties is mainly due to high-amplitude shock waves with a significantly lower influence of heating by the high-intensity laser beam. To protect from a temperature rise and to obtain compressive residual stress, a protective coating is usually used. However, recent studies have shown that micro-structural changes, a high density of dislocations and a high level of compressive stresses can also be produced by LSP either without a protective coating or by using lower power density lasers operating at higher frequencies [1-7].

The effect of LSP was investigated by many researchers in the last decades. P. Peyere et al investigate the influence of laser peening and shot-peening on pitting corrosion resistance of 316L stainless steel. The results prove that LSP can reduce the pit formation on surface inclusion due to the large compressive stress induced by it [8]. K.Y. Luo et al investigate the effect of the laser peening on nanohardness, elastic modulus, residual stress and phase transformation of ANSI 304 austenitic stainless steel. They concluded that, LSP can be improve the properties and induce compressive residual stress whose distribution differs from that by shot peening due to the fact that there is a absorbing layer which avoids the thermal effects [1].

In [9] is investigated the effect of multiple LSP impacts on mechanical properties of steel. It is prove that the technique improve the surface microhardness values by 60 % after 3 LSP impacts. Another work of C. Rubio Gonzalez et al, successfully demonstrated that LSP is an effective surface treatment technique to improve fatigue properties on duplex stainless steel [10]. They concluded that increasing the pulse density, due the residual stress field induced on the surface, the fatigue crack growth rate is reduced. The microstructure is not affected by LSP.

Effects of LSP on stainless steels welds were not thoroughly investigated. Mihaela Iordachescu et al. [11] investigate the effects of LSP on local properties of friction stir welded joints. They found that main advantage of LSP is the increasing of the yield strength of the friction stir welded joints. The effects on mechanical properties of stainless steel joints were investigated in [12] via the tensile test. L. Zhang et al. [12] show a significant increase of the yield strength from 240.74MPa (one side LSP) to 318.18 MPa (two-sided LSP).

The purpose of this work is to investigate and compare the effects on mechanical properties and micro-structure of untreated welds and LSP treated welds with two densities, 900 pulse/cm^2 and 1600 pulse/cm^2 respectively.

2. Experimental set-up

2.1. Material and test samples

In this experiment we used as the welding materials 316L stainless steel plates with 6 mm thickness. We used two kinds of samples, a simple plate welded for micro-structure analysis and fish bone sample for fatigue tests. The schematic representation is presented in fig.1. The chemical composition of the material is presented in Table 1.

Table 1. Chemical composition of the material

Chemical composition AISI 316L stainless steel (%)									
Casting	C	Cr	Mn	Mo	N	Ni	P	S	Si
T7C9	--	16.46	1.90	2.34	--	9.78	--	--	0.26

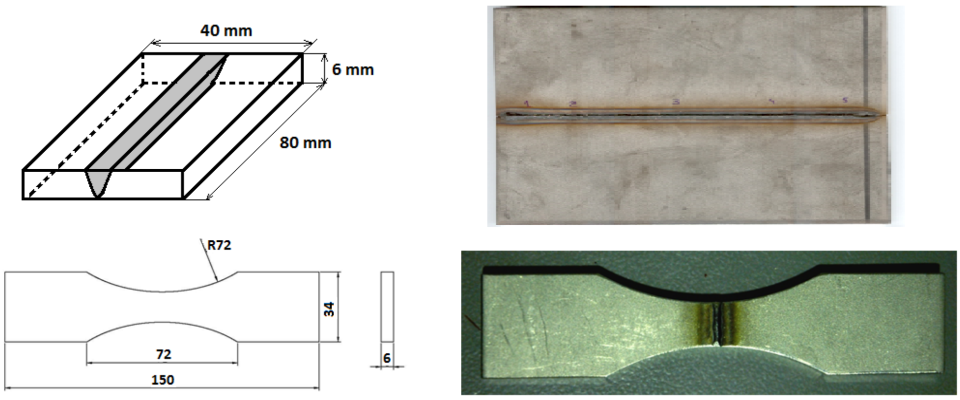


Fig.1. Dimensions and pictures of the samples

2.2 Welding process

Laser welding is well known for its deep penetration, high speed, small heat-affected zone, fine welding seam quality, low heat input per unit volume, fiber optic beam delivery and ease of inter face with robots. In order to achieve good welding quality, the parameters should be selected according to the material properties and to the absorption and reflection of the laser beam [12, 13].

The laser welding process was performed using a ROFIN Nd: YAG laser with a maximum power of 3.3 kW. The wavelength was 1064 nm. Helium was selected as the shielding gas. The flow rate of adding gas was between 15 and 20 l/min. The temperature of the work piece was around 20°-25° C, room temperature. The welding speed was selected in such way to obtain good and continuous penetrations of the laser beam in the material.

A schematic representation of the samples used for this work, is presented in fig.1. Both samples were welded with the same parameters which are presented in table 2.

2.3. Laser shock processing method

The next process after laser welding was LSP. During this process, the laser beams with the high power and short pulsed (ns) pass through the water confining layer and radiates the material surface. The rapidly expanding plasma with high temperature pressure is trapped due to the confining layer. A shock wave is generated and propagating into the material due to this trap. At last, the plastic deformation layer of the material surface appears and the uniform, beneficial compressive residual stress is gained to improve the mechanical property of the material [12].

Table 2. Parameters of the welding process

Parameter	Value	Units
Spot diameter	0.5	mm
Frequency	100	Hz
Power	3.3	kW
Welding speed	5	mm/sec
Gas (He)	15-20	l/min

This process was carried out using the Spectra-Physics Nd: YAG laser with a wavelength of 1054 nm, pulse duration around 9 ns and a spot diameter of 1.5 mm. The frequency was 10 Hz and the laser energy was 2.8 J/pulse. As a transparent confining layer a water layer was used with a thickness between 1-2 mm. No absorbing coating was used. The welded area of the samples was treated with two different overlap rates, 900 pulse/cm^2 and 1600 pulse/cm^2 on both sides. The swept direction of the irradiated area was perpendicular to the weld.

2.4. Micro-hardness and microstructure

The micro-hardness and microstructure was performed on the first type of samples. The sample was cut into three pieces in order to obtain an untreated surface, treated with 900 pulse/cm^2 and 1600 pulse/cm^2. The sample was polished with sand papers up to a gird number of 1200. After the polish process, the sample was immersed in a chemical mixture of 15 ml glycerine, 10 ml hydrochloric acid and 5 ml nitric acid.

2.5. Fatigue test

The fatigue test was performed on a MTS 800 tensile testing machine at room temperature. The load amplitude was between 90 and 260 MPa.

3. Results and discussions

Micro-hardness measurements were made with 1.2 kgf load. Micro-hardness profile of the specimen cross section is shown in figure 2. It can be noted that laser shock processing has no important effect on micro-hardness of the welded material. To obtain a notably effects on the micro-hardness, according to [14] it is necessary to increase the pulse density to 7500 pulse/cm2. An aluminium foil must be used as a protective coating.

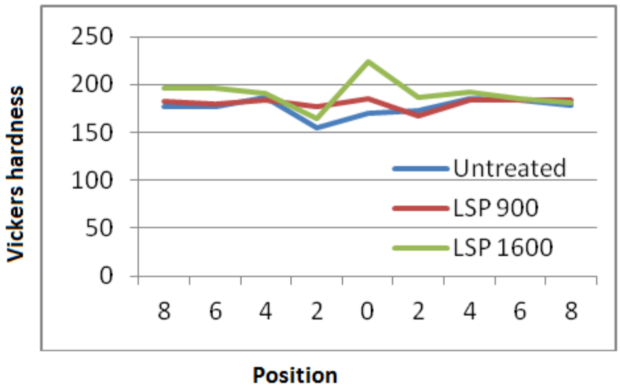


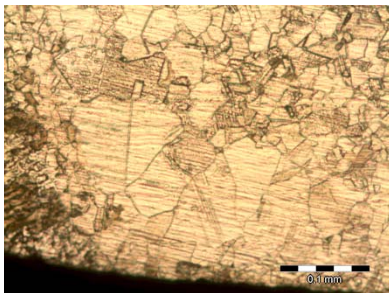
Fig. 2. Micro-hardness of the samples

Fig. 3 shows the microstructure on specimen cross section of stainless steel 316L for untreated welds and treated with different pulse densities. In this picture the surface near the treated area of the samples is presented.

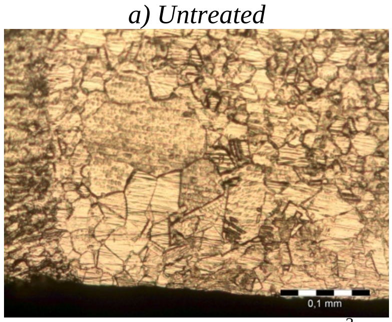
There is no noteworthy difference in microstructure due to the shock wave propagated by laser shock processing.

The microstructure changes due to the welding process are not affected by LSP process. The fusion zone and heat affected zone (HAZ) present a typical morphology of a welded area. Grains grow epitaxially with the adjacent HAZ grains in a columnar morphology.

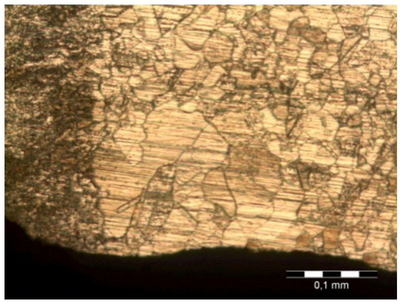
Fatigue test for not welded samples was presented in [15]. It was found that the fatigue limit for treated samples is 200 MPa. There is no high difference between LSP 900 and LSP 1600 treated samples as presented in Fig. 4.



a) Untreated



b) LSP treated 900 pulse/cm^2



c) LSP treated 1600 pulse/cm^2

Fig. 3. Microstructure of 316L stainless steel for untreated welds (a) and treated with different pulse densities (b=900 pulse/cm^2, c=1600 pulse/cm^2)

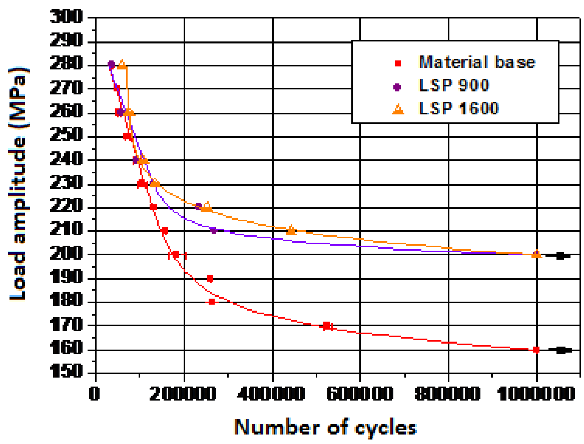


Fig. 4. Fatigue life for Stainless Steel 316L [15]

In our work we made the fatigue test for untreated welded samples and treated welded samples by laser shock processing with 900 pulse/cm^2. Figure 5 presents the difference between untreated and treated welded samples. The fatigue limit for untreated samples is 90 MPa and for

LSP treated samples is 130 MPa. The improvement is about 50 %.

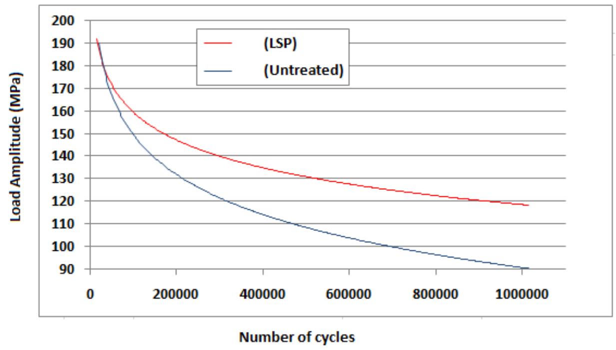


Fig. 5. Fatigue life for stainless steel welds

4. Conclusions

The purpose of this work was to investigate the effects of laser shock processing with different pulse density. The following conclusions were obtained:

- Laser shock processing is an effective surface treatment technique to improve the fatigue properties of stainless steel welds.
- With the energy delivered in this work and a low pulse density, LSP technology has no effect on the micro-hardness and on microstructure. To get better results we need to increase the pulse density and to use a protective coating.

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*Corresponding authors: boghiromion@yahoo.com, mtierean@unitbv.ro