A R C H I V E S O F M E T A L L U R G Y A N D M A T E R I A L S
Volume 56 2011 Issue 3
DOI: 10.2478/v10172-011-0079-8

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**THE INFLUENCE OF THE LASER TREATMENT ON MICROSTRUCTURE OF THE SURFACE LAYER OF AN X5CrNi18-10 AUSTENITIC STAINLESS STEEL**

**WPŁYW LASEROWEGO ODKSZTAŁCANIA NA MIKROSTRUKTURĘ WARSTWY WIERZCHNIEJ STALI AUSTENITYCZNEJ X5CrNi18-10**

The influence of laser shock processing (LSP) on microstructure of the surface layer of an X5CrNi18-10 austenitic stainless steel was studied. The laser treatment was performed using a Q switched Nd:YAG ReNOVAL laser.

It was found that the laser shock processing performed under the conditions of 230 MW/cm$^2$ laser power density and pulse duration of 18 ns produced an ablation and melting of the thin surface layer of the treated material, what indicated that the process of LSP was not purely mechanical but rather thermo-mechanical one. However SEM images of the sample cross sections showed that clusters of slip bands were formed during the treatment in the near surface region. Transmission electron microscopy of the laser-shock treated steel have also revealed a very high density of dislocations and stacking faults. The changes in microstructure came down to 70 $\mu$m.

It has been found that the laser shock processing induced plastic deformation of the surface layer of the investigated material.

*Keywords*: austenitic stainless steel, surface layer, microstructure, laser shock processing, LSP, SEM, TEM

Celem pracy była ocena wpływu laserowej obróbki odkształcającej na mikrostrukturę warstwy wierzchniej stali austenitycznej X5CrNi18-10. Proces laserowego odkształcania przeprowadzono za pomocą lasera impulsowego ReNOVALaser Nd:YAG z modulacją Q.

W wyniku laserowego odkształcania stali impulsem lasera o gęstości mocy 230 MW/cm$^2$ i czasie trwania impulsu 18 ns nastąpiło przetopienie cienkiej warstwy materiału, co wskazuje, że proces LSP nie był czysto mechaniczny, ale cieplno-plastyczny. Badania przeprowadzone za pomocą skaningowego i transmisyjnego mikroskopu elektronowego wykazały, że pod cienką warstwą przetopioną znajduje się materiał odkształcony. Na wytrawionych zgładach poprzecznych stali austenitycznej pod cienką warstwą przetopioną ujawniono obecność licznych pasm poślizgu. W mikrostrukturze warstwy wierzchniej stali austenitycznej po laserowej obróbce występowała duża gęstość dyslokacji oraz liczne błędy ułożenia.

Badania wykazały, że zastosowane parametry procesu LSP, powodują odkształcenie plastyczne warstwy wierzchniej badanej stali austenitycznej.

## 1. Introduction

Laser shock processing (LSP), also known as laser shot peening, is a new surface treatment technology rapidly developed in recent years [1,2]. The process is similar to shot peening, but the shots are replaced by laser pulses.

The LSP relay on irradiation a surface of a metal by a short and intense laser impulse. In most LSP experiments, the laser system is a Q-switched neodymium-glass laser with a very short pulse duration (around 30 ns) focused to produce laser power densities higher than 0.1 GW/cm$^2$ at the surface of the treated material. Before the LSP the treated sample is usually coated with a black paint (absorbing layer) and immersed in water (transparent layer) [3-5]. The scheme of the Laser Shock Processing is shown in Fig. 1. When the laser beam is directed onto the treated surface, it passes through the water which is transparent to the laser beam and strikes the black coating. The absorbing coating is instantly heated and vaporized, due to the absorption of laser beam energy. The vaporization of the black paint produces a rapidly expanding plasma, that is confined against the surface of the material by a constraining

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layer of water. The plasma causes a shock wave by its expansion and leads to the plastic deformation of the material. Water decreases the expansion of plasma in the surrounding atmosphere and produces up to ten times higher pressure on the material surface [6]. The pressure propagating into the treated material as a shock wave can induce microstructural changes, cause a high increase of dislocation density, influence the surface roughness of the material as well as produce high residual surface compressive stresses [7-9].

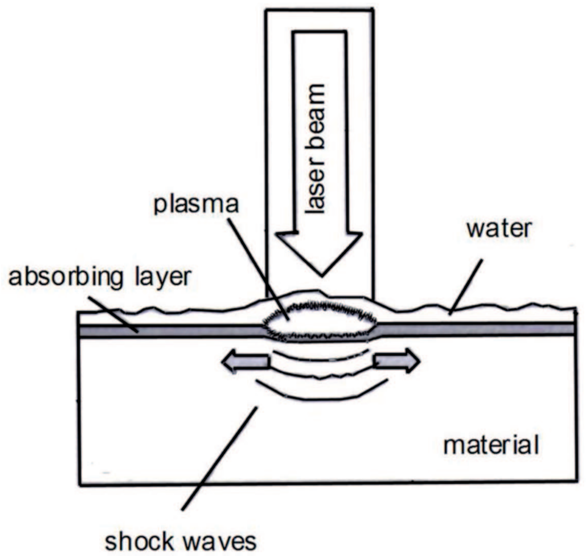


Fig. 1. The scheme of the Laser Shock Processing

## 2. Material and experimental procedure

The investigations were performed on the austenitic stainless steel X5CrNi18-10. Samples for the LSP were annealed at 1160°C for 1 hour, and next were mechanically ground on the sanding papers with the conservative gradation up to 2000. Prior to the laser treatment the investigated material was coated with a thin layer (50 $\mu$m) of a black paint and placed under a 3 mm layer of water.

The LSP was performed using a Q switched Nd:YAG ReNOVAL laser operating at a wavelength of a 1.064 $\mu$m and a pulse duration of 18 ns. The power density used in this study was 230 MW/cm$^2$. The experiment was carried out at room temperature in air. The laser beam spot size on the sample was 2 mm. During the LSP process the X5CrNi18-10 stainless steel was treated by series of overlapping spots – 15 subsequent laser pulses to the same spot.

The microstructure of the annealed material was investigated by means of light microscopy (Axio Imager MAT. M1m Carl Zeiss). Specimen preparation for the microstructural evaluation was carried out by standard metallographic techniques. Scanning electron microscopy (HITACHI S-3500) was used to investigate the topography of the laser treated surface as well as microstructure of the treated sample on the cross sections. The chemical composition of treated surface was determined by means of Energy Dispersive Spectrometry (EDS), attached to the SEM. Average roughness $R_a$ of the surface was measured before and after laser treatment by WYKO NT9800 equipment.

Detailed microstructural investigation of the modified surface layer was carried out by Transmission Electron Microscopy (TEM, Philips CM20). To prepare the foils, the discs with diameter of 3 mm and 0.5 mm thickness were cut out parallel to the treated surface. The discs were mechanically ground down to the thickness of about 80 $\mu$m. The centers of the disks were dimpled down to 30 – 50 $\mu$m. Finally, electrolytic etching was applied. The grinding and polishing were done only on the side opposite to the treated surface to preserve the microstructure. Thin foils were also cut out perpendicular to the treated surface and prepared using FEI focused ion beam (FIB) Quanta 3d system.

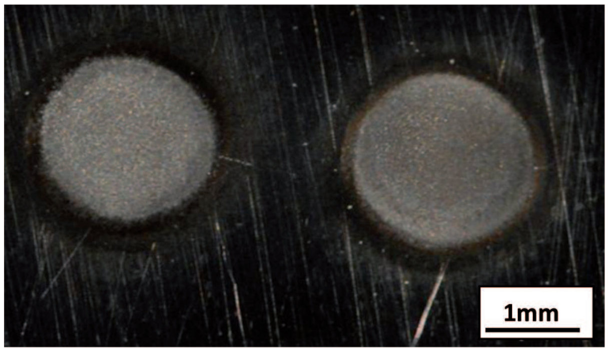


Fig. 2. A view of the surface of treated material after laser treatment

## 3. Results and discussion

Microstructure of the austenitic stainless steel after annealing is shown in Fig. 3. Only one phase (austenite) was distinguished by the light microscopy. The average grain size determined from micrographs was about 150 $\mu$m.

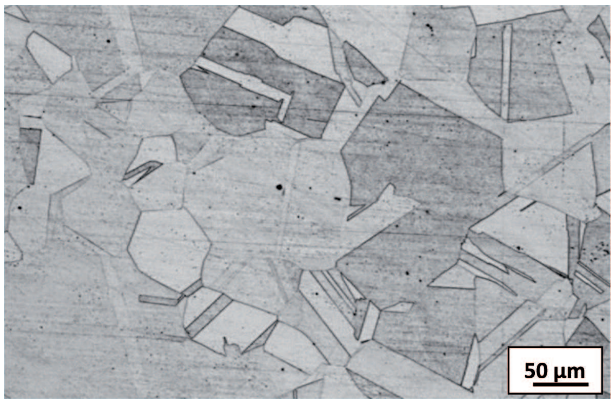


Fig. 3. Light microscopy image showing microstructure of the steel before the laser treatment

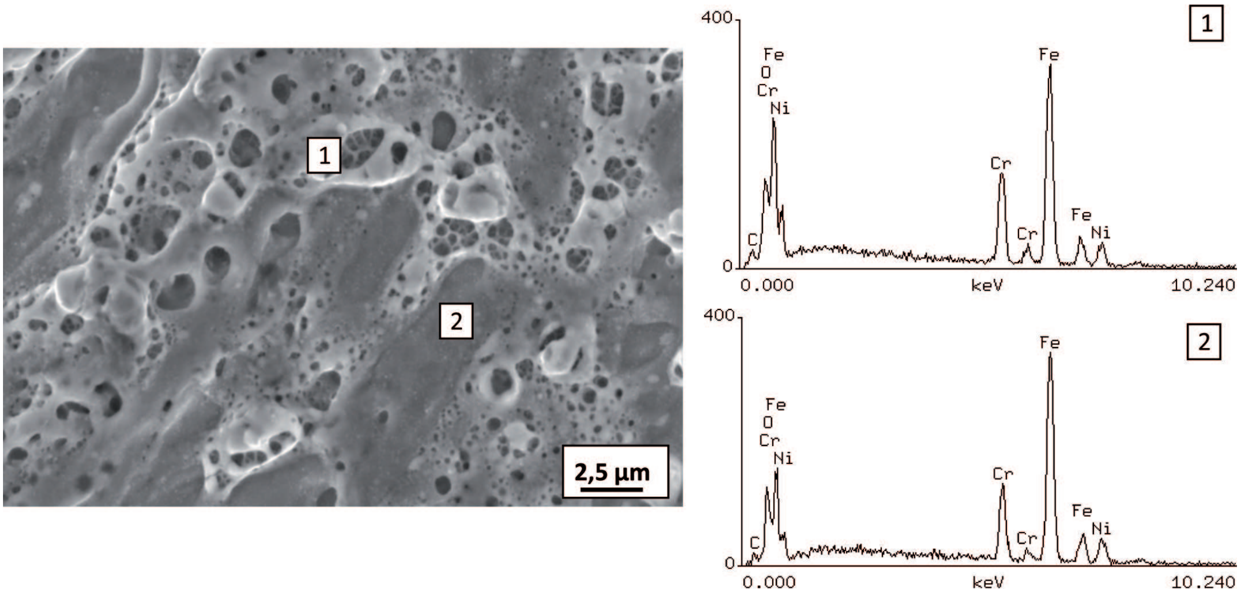


Fig. 4. Topography of the steel after LSP (SEM SE), the EDS spectras show the presence of iron, chromium, nickel as well as oxygen and carbon at the treated surface (points 1-2)

The surface of the austenitic stainless steel after laser treatment is presented in Fig. 4. The SEM images of the treated surfaces showed that the laser shock processing brought about ablation and melting of the surface layer of the investigated material. After initial laser pulses, a black paint was splattered from the treated surface probably, due to a high pressure of plasma. On the region without coating, the laser beam irradiates the material surface directly and leads to its ablation and melting. At the same time, after short time duration of laser pulses, due to an intensive cooling, the liquid metal has been frozen. It is worth to note that such heating and cooling cycle was repeated 15 times in the same area. The features most frequently observed on the surface after the LSP appear as craters, holes and solidified droplets. The surface layer after treatment also showed a high porosity level. Cracks have not been observed. An appearance of porosity is probably due to the ablation of the material during the process. The presence of droplets and porosity indicates that the process of the laser shock processing was thermo-mechanical rather than purely mechanical one.

The EDS analysis showed the occurance of Fe, Cr, Ni, C as well as O in the ablated treated surface (Fig. 4). The presence of oxygen indicates a possibility of the surface oxidation during laser processing, while the carbon peak comes likely from the black paint.

The typical roughness profile of the surface after laser treatment is shown in Fig. 5. The measurements indicated that Nd:YAG laser treatment produced an increase in the surface roughness. Ra (arithmetic average of the absolute values of all points of the profile) increasing from 0.1 $\mu$m before treatment to 0.33 $\mu$m after LSP.

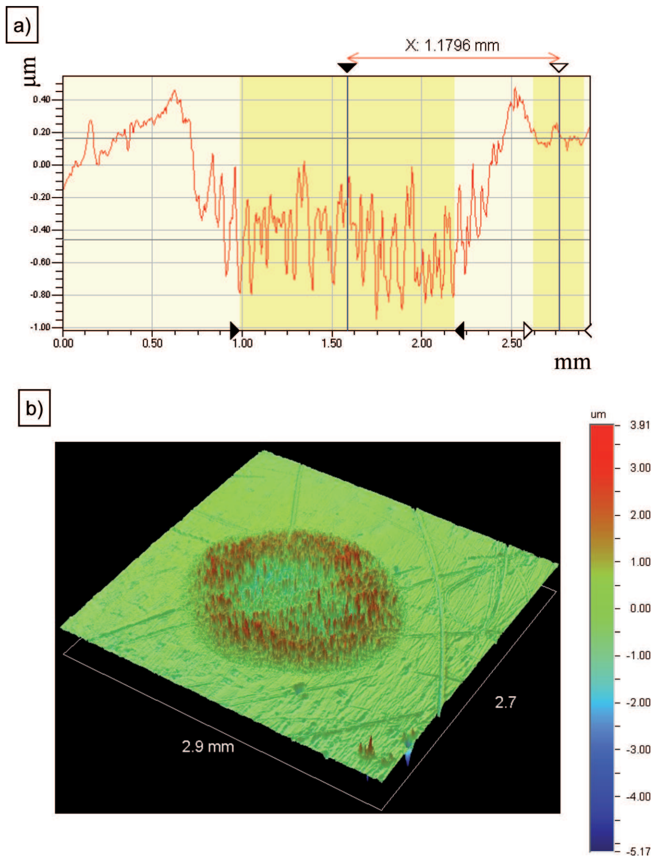


Fig. 5. Surface roughness of the steel after laser treatment (a) 2d (b) 3d

SEM images of the sample cross sections showed that clusters of slip bands were formed during the treatment in the near surface region (Fig. 6). Such a feature is usually observed in austenite after plastic deformation and is often associated with the formation of deformation twins and stacking faults. The changes in microstructure came down to 70 $\mu$m below the surface.

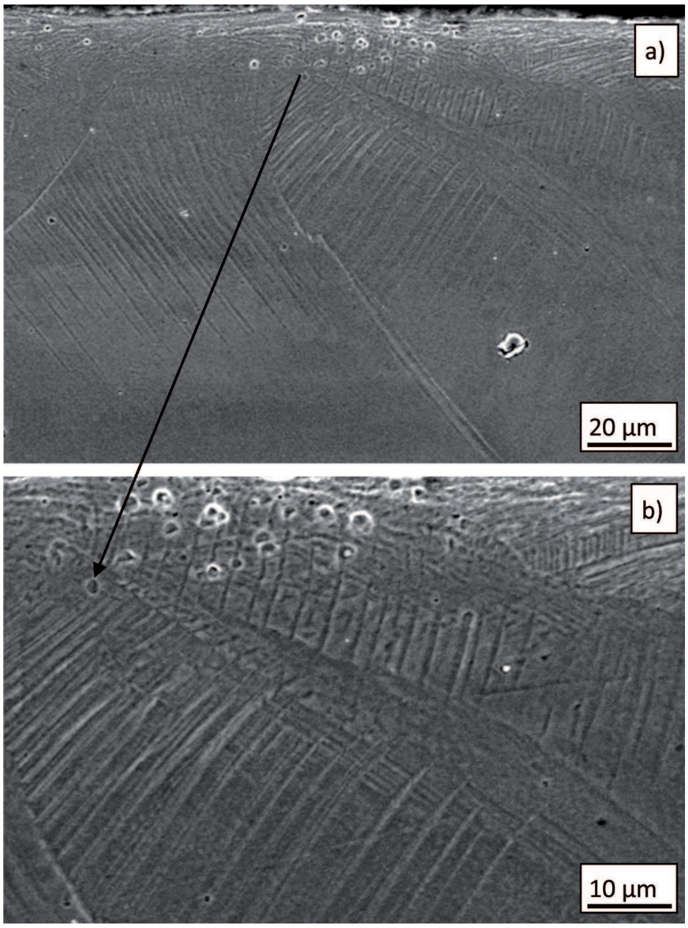


Fig. 6. SEM cross-section of the treated surface (a-b), clusters of slip band are visible

The TEM microstructure of the surface layer is presented in Fig. 7 and 8. The micrographs show very high density of dislocations and stacking faults. Transmission electron micrscopy of the laser-shock treated steel revealed neither deformation twins nor martensite. This is believed to be mainly due to low shock pressure. In previous LSP studies at higher power density (1 GW/cm$^2$) twinning was found [10].

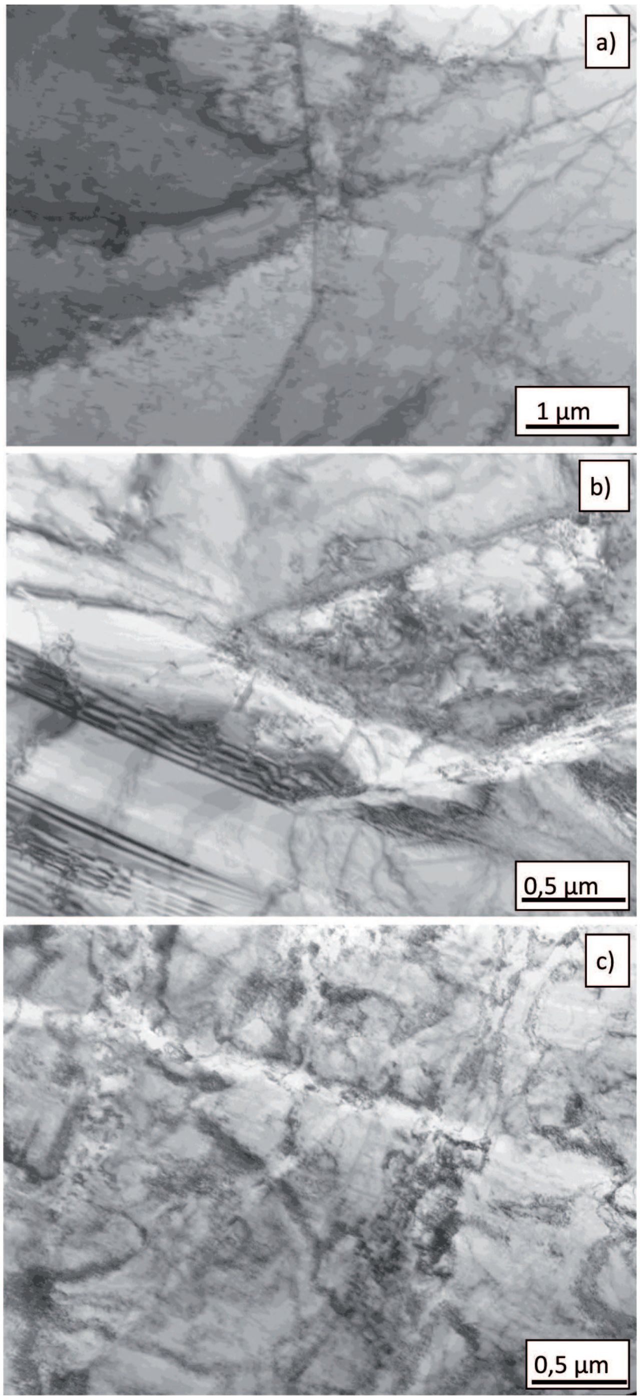


Fig. 7. TEM microstructure of the steel after LSP (TEM). High density of dislocations (a-c) and stacking faults (b) are visible

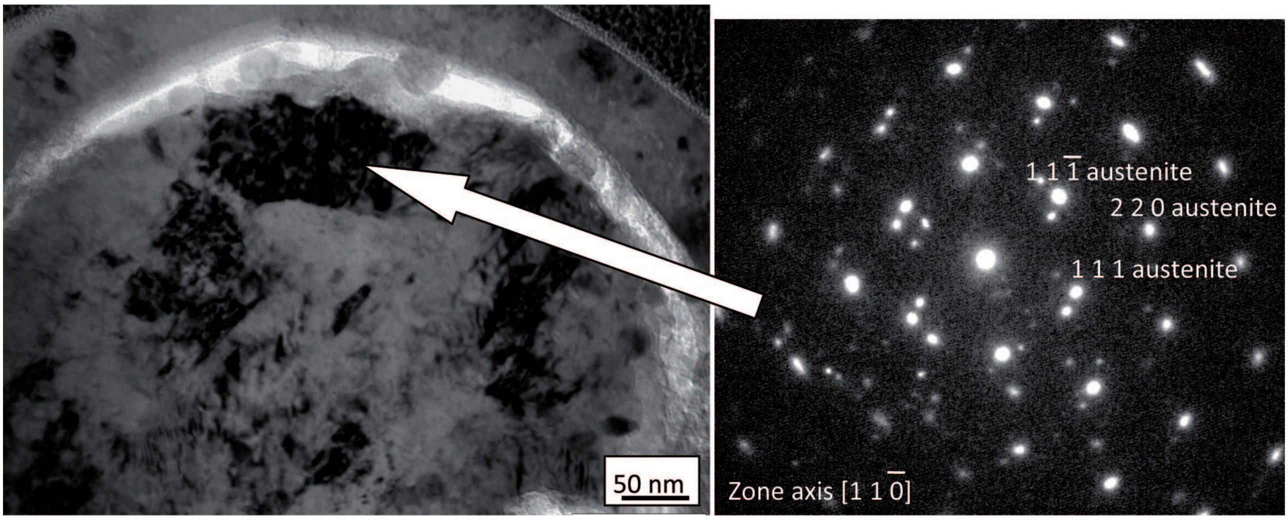


Fig. 8. Microstructure of the steel after LSP process in cross-section (TEM) and corresponding diffraction pattern

## 4. Conclusions

- It was found that the laser shock processing produced an ablation and melting of the surface layer of the treated material, what indicated that the process of the laser shock processing was not purely mechanical but rather thermo-mechanical one.
- In the surface layer of the steel after laser treatment, a high density of dislocations and stacking faults were visible. The changes in microstructure came down to 70 $\mu$m.
- It has been found that the laser shock processing induced plastic deformation of the surface layer of the investigated material.

### Acknowledgements

The study was supported by the AGH University of Science and Technology (grant no 11.11.110.792). The authors would like to acknowledge **Prof. Jan Marczak** from the Military University of Technology for the laser shot peening of the samples.

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*Received: 10 March 2011.*