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SURFACE MODIFICATION OF LASER WELDED NIMONIC 263 SHEETS

POVRŠINSKA OBRADA LASEROM ZAVARENIH NIMONIK 263 LIMOVA

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Keywords
- Nimonic 263
- laser welding
- surface modification
- microstructure
- profilometry

Abstract

Laser surface treatment is both a thermomechanical and mechanical process, based on the ability of a high energy laser pulse to generate shock waves and plastic deformation in metallic materials. Laser welding is a high energy density process with many advantages such as narrow heat affected zone, lower heat input and lower heat/energy distortion compared to conventional welding processes.

In this paper, Nimonic 263 alloy sheets are laser welded by Nd:YAG laser using different laser processing parameters. The microstructure, surface roughness and mechanical properties are investigated. Welded joints are mechanically treated by laser in order to improve the surface and mechanical characteristics. Mechanical characteristics are determined by tensile test, and fractures and laser treated weld surfaces are observed by scanning and optical microscopy. Surface topography is analysed by optical profilometry and micro hardness is measured by Vickers method.

Ključne reči
- Nimonik 263
- lasersko zavarivanje
- površinska obrada
- mikrostruktura
- profilometrija

Izvod

Površinska obrada laserom je termomehanički i mehanički proces, baziran na sposobnosti laserskog impulsa visoke energije da generiše udarne talase i plastične deformacije u metalnim materijalima. Zavarivanje laserom je proces velike gustine energije sa mnogo prednosti kao što su uska zona uticaja toplote, manja uneta toplota i manja distorzija toplote/energije u odnosu na konvencionalne metode zavarivanja.

Limovi superlegure Nimonik 263 zavareni su Nd:YAG laserom različitim parametrima procesa. Ispitivana je mikrostruktura, površinska hrapavost i mehaničke osobine nakon zavarivanja. Zavareni spojevi su mehanički obrađeni laserom radi poboljšanja površinskih i mehaničkih osobina. Mehaničke karakteristike su ispitane zatezanjem, a prelomne površine posmatrane optičkim i skenirajućim elektronskim mikroskopom. Topografija površine je analizirana profilometrom, a mikrotvrdoća merena metodom Vikers.

INTRODUCTION

Laser welding is a high energy density, low heat-input process. It offers many advantages over the conventional methods such as: high welding speed, narrow heat-affected zone, low distortion, ease of automation, single pass thick section capability and enhanced design flexibility. Considerable analytical and experimental work has been carried out on laser welding of different materials, /1-3/. High power density gives the high depth to width ratio bead and together with the low heat input and rapid solidification, lead to/cause low distortions and excellent mechanical properties, /4, 5/. Annon /6/ performed the welding of four different nickel alloys, material thickness up to 2 mm, using CO_2 gas laser. Tensile testing showed that repeatedly high values could be obtained in all four materials. Guo et al. /7/ compared the microstructure and mechanical properties obtained by laser and arc welding. Bucksons et al. /8/ investigated influence of laser welding on fatigue crack growth behaviour of a nickel-base superalloy. One of the many features of laser welding is the capability to weld without filler materials (autogenous welding). In this paper, Nimonic 263 superalloy sheets, thickness of 2 mm, are welded without filler material in two passes. Sheets are welded by Nd:YAG laser as it has various advantages such as high energy absorption rate due to a low reflectivity, high welding speed and a low residual stress compared to CO_2 laser, /5/.

Laser shock processing of metallic surfaces and its applications were presented by Devaux et al. /9/, theoretically and experimentally. Effects of laser-induced shock waves on metals were studied by Clauer et al. /10/. They reported the effect on material properties, such as improved hardness, tensile strength and fatigue life. Laser shock peening is not a thermal, but a mechanical treatment, unlike laser welding. Laser shock peening improves fatigue characteristics, intergranular corrosion resistance, wear and oxidation resistance, as well as mechanical properties of the material, /11/. A review on laser-shock processing was carried out by Peyre and Fabbro, /12/. They presented physical principles of laser shock and induced mechanical effects. Their finding is that higher pressures can be achieved with confinement as compared to direct ablation. If LSP is successfully applied, the fatigue performance of metallic components – the fatigue strength and fatigue life can be remarkably increased. This effect is the result of the presence of compressive residual stresses in the material.

MATERIALS AND EXPERIMENT

Nimonic 263 is a nickel based superalloy, developed to withstand high pressure and temperature. It has been developed for welded assemblies that require better ductility. This superalloy has good corrosion resistance, optimal thermal properties, strength coupled with ductility, creep and fatigue resistance, as well as optimal impact and wear resistance, /13/.

Samples of superalloy Nimonic 263 are welded by Nd:YAG laser by various parameters: laser energy varied 220 to 270 A, pulse duration from 7.0 to 9.0 ms, spot size from 0.8 to 1.3 mm, and pulse frequency from 3.0 to 5.0 Hz. The welded joints are laser peened by laser Nd:YAG EKSPLA, model SL212P with following characteristics: wavelength 1064 nm, pulse duration 150 ps, mode about TEM00, repetition rate 10 Hz. Laser peening is performed by pulse energy of 1 mJ, speed 0.01 m/s, and spot size 0.1 mm. Tensile testing is performed with tensile testing machine Shimadzu with a grip capacity 250 kN.

The resulting surface changes are determined by scanning electron microscopy, SEM model JEOL JSM-5800 and compared with non-treated surface. Elemental analysis of the surface is done by EDS. Microhardness measurements are performed by Vickers using the apparatus model semiautomatic Hauser 249A and under load of 0.5 N.

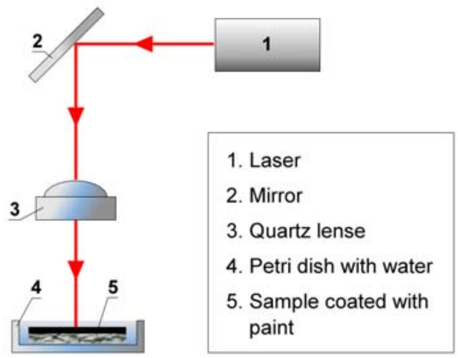

Figure 1. Testing arrangement.

Also, surface morphology changes in the irradiated areas are analysed by Zygo NewView 7100 optical profiler and characteristic surface parameters are calculated using MetroPro software. The non-contact profilometry measurements are based on the interference between white light reflected from the sample surface and the reference surface.

RESULTS AND DISCUSSION

In this work, the laser welding of Nimonic 263 sheets is performed using various laser parameters. The optimal parameters provided crack-free weldments, determined by radiography. The mechanical properties, morphology and surface profilometry are improved using laser shock peening. Figure 2 shows the fracture surface of Nimonic 263 weld seam after the tensile test.

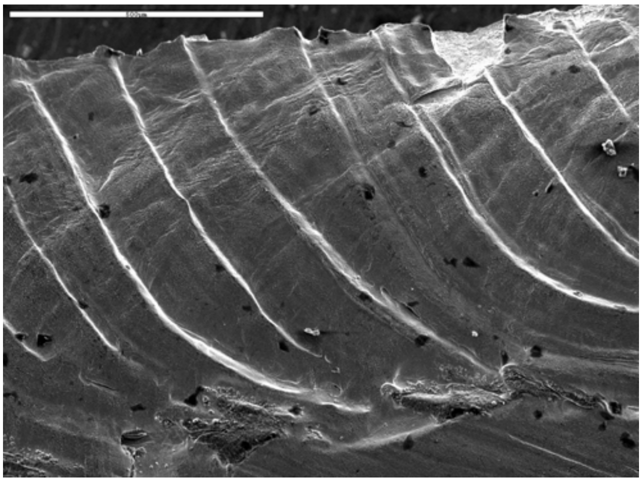

Figure 2. Fracture surface of Nimonic 263 weld seam.

Results of tensile strength tests show that fractures occurred within the welded seam. The tensile strength is 432 MPa, which is about 85% of base material. The reason for this could be found in different joining morphology during the laser welding process and forming of particles observed in microvoids.

As expected, all specimens fractured in the weld seam due to the welding process without the filler material. Also, the mechanical behaviour of weldments may be different from the base material because of the inhomogeneous distribution of second-phase precipitate particles in the weldment as well as microsegragation in the interdendritic region and other.

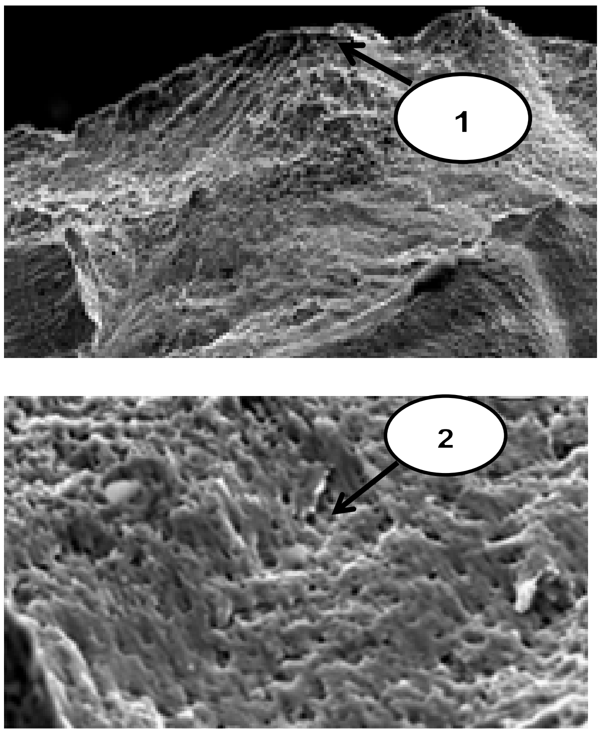

Figure 3. Microstructures of fracture surfaces of Nimonic 263 weld seam: 1) 20 μm; 2) 10 μm.

Figure 3 presents the fracture surface of Nimonic 263 weld seam. By visual observation of micrographs, it can be noticed that the fracture surface is rather uniform, with dimples size up to 2 μm. The dimples indicate that composition phases possess certain ductility. Dimpled rupture features show no preferential fracture path, and there are some clearly visible particles and rarely observed gaps.

Table 1. Results of EDS analyses of spots 1 and 2 in Fig. 3.

Elem.	Al	Si	Ti	Cr	Mn	Fe	Co	Ni	Mo
Spot 1	15.8	0.69	2.15	14.52	0.55	0.41	18.51	42.92	4.15
Spot 2	4.91	0.79	2.55	16.81	0.43	0.53	19.21	46.25	7.25

In Table 1 the results of energy dispersive spectrometry of spots denoted in Fig. 3 are listed. Results show increased content of Al. The size and morphology suggest Al oxide formation. The existence of these particles on the fracture surfaces suggests that microvoids have begun at the particles/matrix interfaces.

Figure 4 shows the fracture surface of welded joints laser peened after welding. Fracture surface is less uniform than the fracture surface of the non-peened weld seam. There are dimples as well, suggesting ductile structure, but their shape is more elliptical. Their size is up to 7 μm. It is consistent with tensile testing results – yield stress of peened weld specimen is 442 MPa – very similar to non-peened ones, but the elongation of the peened laser weld specimen is about three times longer than of the non-peened weldment.

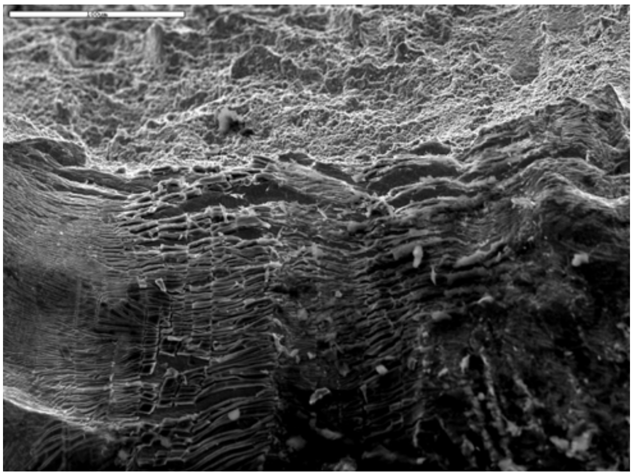

Figure 4. Microstructure of fracture surfaces of Nimonic 263 weld seam after laser shock peening.

Figure 5 shows the front side of welded seam subsequently laser shock peened. It can be noticed that after tensile testing, the first layer, obviously performed during laser peening, is laminated. The small plates are rather similar in shape and geometry, as well as size. The size of these lamellas is up to 10 μm.

Table 2 shows results of EDS in spots 1 and 2 and whole area is presented in Fig. 5. The increased content of Al and Ti suggest forming of various phases. According to the size and shape, and the results in Table 2, there is a possibility of Ti carbides and Al oxide formation.

Microhardness tests are performed by Vickers under the load of 10 N for indentation time of 10 seconds. Figure 6 shows microhardness results for base material (238.1 HV1). After laser welding, microhardness has increased. In the heat affected zone the measured microhardness is 248 HV1, while 258 HV1 in the welded seam.

Table 2. Results of EDS analysis of the surface in Fig. 5

Elem.	Al	Si	Ti	Cr	Mn	Fe	Co	Ni	Mo
	5.86	0.49	8.91	18.15	0.65	0.58	18.18	43.02	4.95

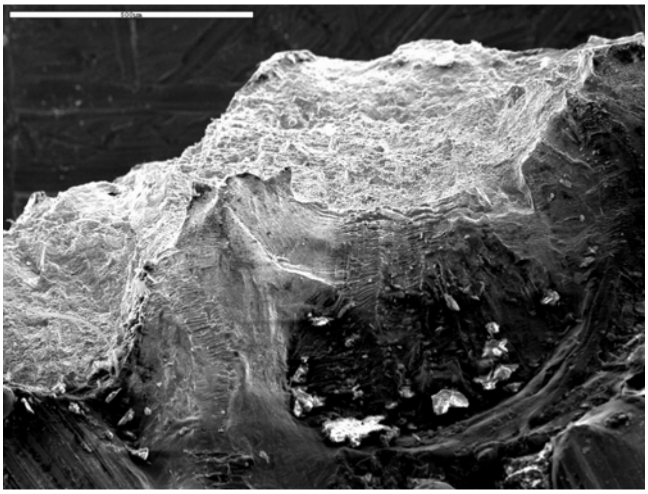

Figure 5. Microstructure of front side surface of Nimonic 263 weld seam after laser shock peening.

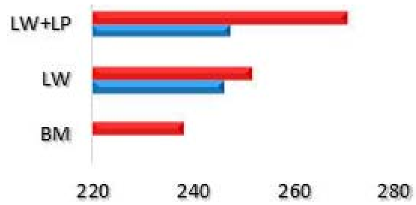

Figure 6. Microhardness test results of base material, welded material and laser peened welded material.

Welded seam microstructure is significantly refined because laser beam welding induced non-equilibrium rapid solidification and, hence, increased its hardness.

Laser shock peening increases the microhardness of the surface. Heat affected zone and welded seam microhardness after laser shock peening are 251 and 278 HV1, in respect.

LSP improved the surface quality and microhardness and caused favourable microstructure transformation, theoretically indicating possible improvements of mechanical properties and fatigue strength.

Surface morphology/topography plays an important role in the performance of parts of various machines. Surface roughness implies the surface is not perfectly flat, and consequently, small-sized stress concentration occurs along the material surface. Under fatigue loading, cracks always nucleate from the free surface. Cracks nucleate at positions where plastic strain concentration is high. High surface roughness generates local stress concentration and accelerates crack initiation. For wear resistance applications, removal of the roughened surface is necessary. That is why a significant part of this research is dedicated to the surface roughness analysis. Two-dimensional profiles and 3D maps of areas after laser welding (A) and laser peened welding (B) are presented in Fig. 7.

Results presented in Fig. 7 show that the PV ratio (peak to valley ratio) is 374.15 μm, root mean square (rms) is 37.5 μm and average surface roughness is 31.3 μm.

It can be noticed that SP processing of the welded surface caused relatively homogeneous modification of the surface throughout the interaction area. No significant ablation or hydrodynamic effects are detected due to low value of fluence and presence of the protective dye layer.

Results presented in Fig. 7 show that the PV ratio is 316.15 μm, root mean square is 32.6 μm and average roughness is 29.1 μm.

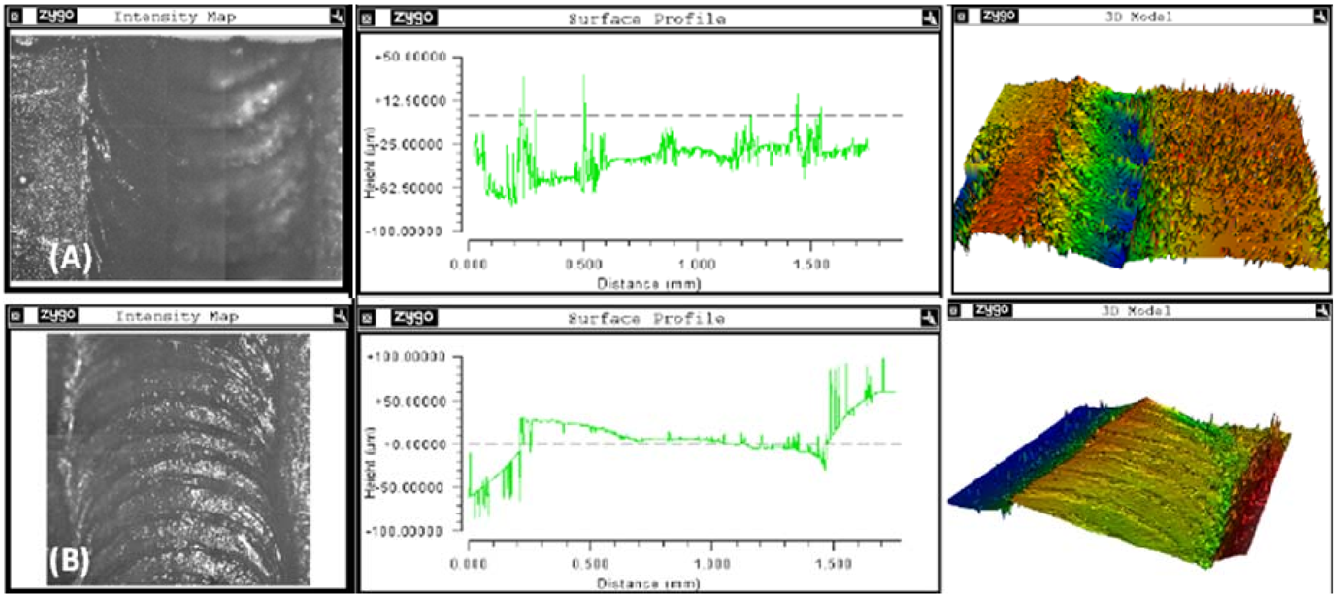

Figure 7. Micorgraphs, two-dimensional profile and 3D maps: (A) welded and (B) laser peened welded Nimonic 263 sheet.

CONCLUSION

In this paper, laser welding of Nimonic 263 sheets is analysed. Optimized parameters provided crack free weldments. All specimens fractured in the weld seam due to the welding process without filler material. Fracture surface is ductile, with dimples spherically shaped.

Mechanical and microstructural properties of welded joints are improved by laser shock peening post-welding treatment. Mechanical properties of peened weldments improved and roughness of peened welded joints has decreased. The microhardness in the weld seam after laser shock peening is higher compared to the weldment without laser shock peening after welding. Further research might include residual stress measurements and analysis, as well as investigation of the same process using different lasers and processing different materials.

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