Surface profilometry of laser welded Nimonic 263 sheets

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1. Introduction

Nimonic 263 is a nickel based superalloy, thermo-mechanically treated, and designed for uses in gas turbine, combustion chamber, casing, liner, exhaust ducting, bearing housing and many others [1].

Laser treatments induce the changes in the microstructure of superalloys [2, 3] with the aim to improve the mechanical properties of the material.

Laser welding process, owing to its inherently narrow HAT, offers potentional solution for producing no cracks welded joints in nickel based superalloys [4]. Laser welding is a high energy-density, low heat-input process with specific advantages over conventional fusion welding processes. These include high welding speed, narrow heat affected zone, low distortion, ease of automation, single-pass thick section capability and enhanced design flexibility. One of the many features of laser welding is the capability to weld without filler materials (autogenous welding) and it offers distinct advantages [5].

The principle of laser shock peening (LSP) is to use a high intensity laser and suitable overlays to generate high pressure shock waves on the surface of the workpiece.

The transient shock waves induce microstructure changes near the surface and cause high density of dislocations to be formed. The combined effect of the microstructure changes and dislocation entanglement contribute to an increase in the mechanical properties near the surface. Laser shock peening improves fatigue, corrosion and wearing resistance of metals through mechanical effect produced by shock waves. [6].

The microstructure of the material is closely associated with surface topography that is the surface characteristics. Macroscopically it is called the roughness. To characterize the profile defines the basic parameters of roughness, which is used as a measure of the surface deviations.

The interaction with laser beams can ameliorate the microhardness of many materials.

Recently, many studies are devoted to microstructure changes and mechanical properties of laser beam welded superalloys [7 - 10], as well as to laser shock peening process of various materials [11 - 14]. However, there are been limited studies about surface topography of laser welded superalloy, and laser shock peened nickel base superalloy. In this paper, profilometry of laser welded Nimonic 263 samples is analyzed and discussed. The welded joints are subjected to laser shock peening process and profilometry of obtained surface is investigated. The microhardness tests by Vickers are performed.

2. Experiment

Experiment was carried out on nickel based superalloy Nimonic 263 sheets.

According to literature recommendation [15, 16] and our experience [17] samples were cold rolled, and heat treated in two stages: 1) solid solution at 1150°C/1h and air cooling and 2) precipitation treated at 800°C/8h and air cooling.

Chemical composition was determined by gravimetrical analysis and is listed in Table 1.

Table1. Chemical composition of NIMONIC 263

El	C	Si	Mn	Al	Co	Cr	Cu	Fe	Mo	Ti	Ni
%	0.06	0.3	0.5	0.5	20	20	0.1	0.5	5.9	2.2	bal

Dimension of samples were 50x50x0.7mm. Nimonic 263 sheets were welded by pulsed Nd:YAG laser type HTS Mobile LS-P160 (OR Laser), without filler material. Laser specifications are listed in Table 2.

The samples are coated with an absorptive and protective layer (black paint), placed in the container filled with distilled water (a transparent layer) and exposed to pulsed laser beam ($Nd3^+$:YAG, wavelength 532 nm, pulse energy 37 mJ, and duration 10 ns). Protective overlay is used for two reasons: (1) to absorb the incident thermal energy, expand and transfer the shock wave to the metal target and (2) to protect the metal target from the heat influence of the incident. The implementation of the transparent layer increases the plasma pressure by a trapping-like effect on the plasma expansion.

Table 2. Specification of $ND3^+$: YAG Laser - Type HTS mobile LS-P160

Laser parameter	Parameter range
Max. mean laser power	160W
Pulse peak power	7.5 kW
Max. pulse energy	80 J
Pulse duration	0.2 - 20 ms
Pulse frequency	1.0 - 20 Hz
Focal diameter	0.2 - 2.0 mm

Detailed investigation of microstructural changes are performed by optical microscope – model KEYENCE VH-Z100, scanning electron microscopes (SEM) with energy-dispersive spectroscopy (EDS) – models: JOEL JSM-5800 and JEOL JSM-6460LV. Surface morphology changes of the irradiated samples are determined by Talystep profilometer. Average roughness, average maximum roughness valley depth, average maximum roughness peak height and skewness, are calculated using Gwyddion computer software [20]. The microhardness is performed by Vickers, by semiautomatic tester – Hauser 249A.

3. Result and discussion

Characterization of surface topography on specific features of mechanical workpieces with complex geometries presents a significant challenge. In this paper, the following characteristics are calculated and discussed: the average roughness, the average maximum profile valley depth, the average maximum profile peak height and skewness.

The fluctuations of a profile are commonly described by its average roughness. The average roughness is calculated according to standards: ASME B46.1-1995, ASME B46.1-1985, ISO 4287-1997, ISO 4287/1-1997. It presents the arithmetical mean deviation. The average deviation of all points roughness profile from a mean line over the evaluation length is calculated as follows [17]:

$$R_a = \frac{1}{N}\sum_{j=1}^{N} | r_j | \qquad (1)$$

The Average maximum profile valley depth (R_{vm}) is calculated using standards: ISO 4287-1997.

It is the mean valley depth based on one peak per sampling length. The single deepest valley is found in five sampling lengths (m = 5) and then averaged [17]

$$R_{vm} = \frac{1}{m}\sum_{i=1}^{m} R_{vi} \qquad (2)$$

The average maximum profile peak height (R_{pm}) is based on standards: ISO 4287-1997.

It presents the mean peak height based on one peak per sampling length. The single highest peak is found in five sampling lengths (m = 5) and then averaged [17]:

$$R_{pm} = \frac{1}{m}\sum_{i=1}^{m} R_{pi} \qquad (3)$$

The skewness (Rsk) is calculated according to standards: ISO 4287-1997.

Skewness is a parameter that describes the shape of the ADF (the amplitude distribution function). Skewness is a simple measure of the asymmetry of the ADF, or, equivalently, it measures the symmetry of the variation of a profile about its mean line [17]:

$$R_{sk} = \frac{1}{NR_q^3}\sum_{j=1}^{N} r_j^3 \qquad (4)$$

Figure 1 presents laser welded joint of Nimonic 263 sheets, thickness of 0.7mm, welded without filler material. The parameters of laser welding process are: pulse energy – 48J, pulse duration – 6.0ms and pulse frequency – 5.5Hz. The figure is taken by scanning electron microscope, and shows no cracks.

The profilometry is done on base material (Figure 2), in heat affected zone (Figure 3) and along the weld seam (Figure 4).

Calculated characteristics of the base material obtained by Gwyddion computer software are: average roughness 1.287 µm, average maximum roughness valley depth 3.766 µm , average maximum roughness peak height 3.317 µm, skewness |0.163|.

Calculated characteristics of the weld seam obtained by Gwyddion computer software are: average roughness 0.738 µm, average maximum roughness valley depth 3.182 µm , average maximum roughness peak height 2.829 µm, skewness |0.209|.

Calculated characteristics of the heat affected zone obtained by Gwyddion computer software are:average roughness 1.325 µm, average maximum roughness valley depth 4.211 µm, average maximum roughness peak height 4.408 µm, skewness |0.103|.

Analysing stated results it can be noticed that laser welding process decreases the avarege roughness of material. It is interesting that the roughess of weld seam is lower than base

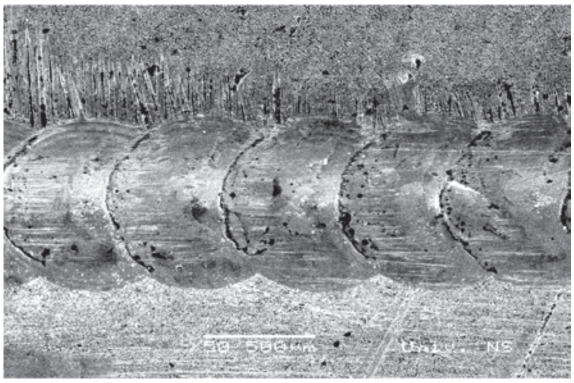

Figure 1. Laser welded joint – laser process parameters: pulse energy 48J, pulse duration 6.0ms, frequency 5.5 Hz [10]

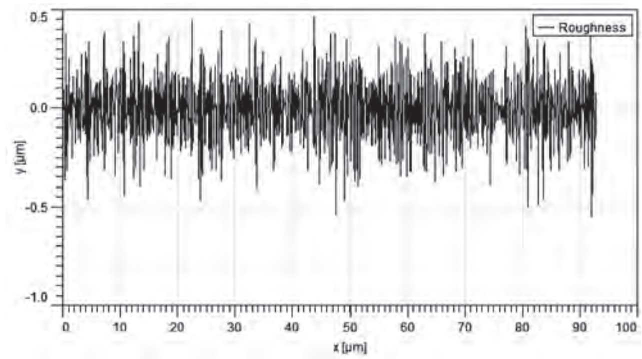

Figure 2. Roughness of the Nimonic 263 sample – base metal

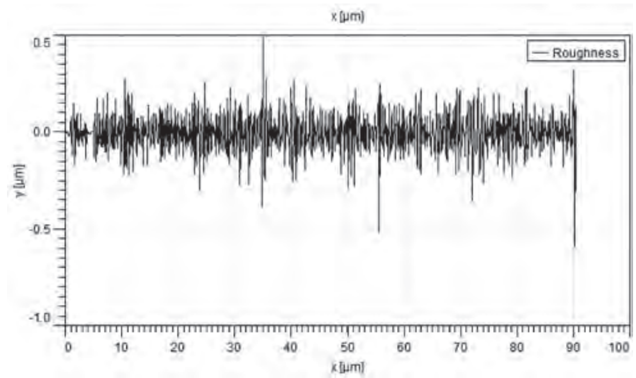

Figure 3. Roughness of the welded Nimonic 263 joint: pulse energy 48J, pulse duration 6.0ms, pulse frequency 5.5 Hz

material while the roughness of heat affected zone is higher than roughness of base material. The same is observed regarding to the average maximum roughness valley depth and average maximum roughness peak height.

Figure 5 presents laser welded joint of Nimonic 263 sheets presented in Figure 1, after applied laser shock peening The parameters of laser shock peening process are: wavelength 532 nm, pulse energy 37 mJ, and duration 10 ns. The figure is taken by scanning electron microscope, and shows no cracks.

The profilometry is done on base material (Figure 6), in heat affected zone (Figure 7) and along the weld seam (Figure 8).

Calculated characteristics of the laser shock peened Nimonic 263 material obtained by Gwyddion computer software are: average roughness 0.313 μm, average maximum roughness valley depth 1.096 μm , average maximum roughness peak height 1.055 μm, skewness |0.235|.

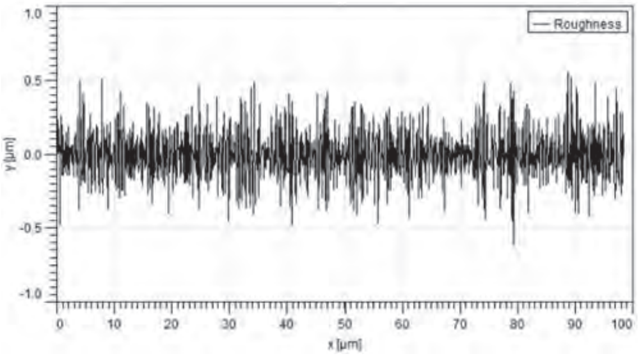

Figure 4. Roughness of HAZ of Nimonic 263 joint: pulse energy 48J, pulse duration 6.0ms, pulse frequency 5.5 Hz

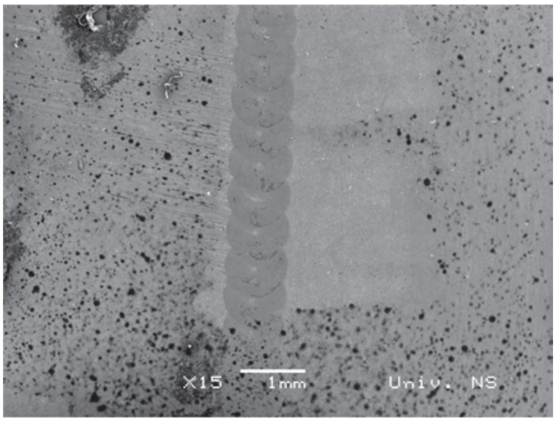

Figure 5. Laser shock peening of welded Nimonic 263 joint

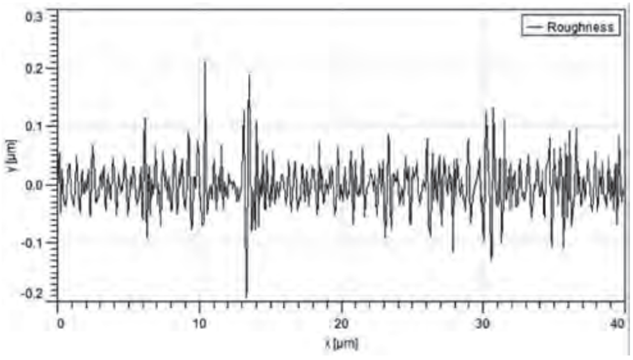

Figure 6. Roughess of Nimonic 263 sample after laser shock peening process

Calculated characteristics of HAT of Nimonic 263 material after laser shock peening process, obtained by Gwyddion computer software are: average roughness 0.344 μm, average maximum roughness valley depth 1.043 μm , average maximum roughness peak height 0.908 μm, skewness |0.450|.

Calculated characteristics of weld seam of Nimonic 263 sheets after laser shock peening process, obtained by Gwyddion computer software are: average roughness 0.245 μm, average maximum roughness valley depth 0.558 μm , average maximum roughness peak height 0.673 μm, skewness |0.445 |.

Presented results show that laser shock peening process decreses the avarege roughess of material. There is a little diference between the surface characteristics of base material and weld joint, but roughness sighificly decreses in all cases when LSP process is applied. The same is noticed for the average maximum roughness valley depth and average maximum roughness peak height as well.

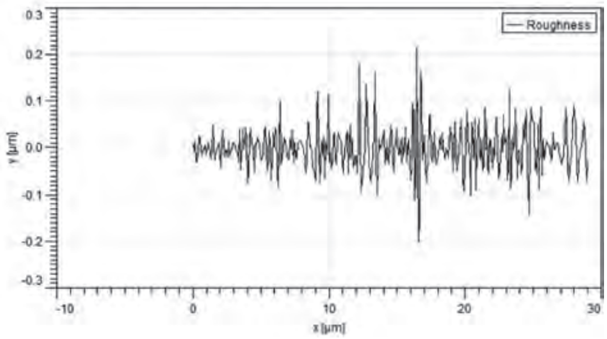

Figure 7. Roughess of heat affected zone of Nimonic 263 weld joint after laser shock peening process

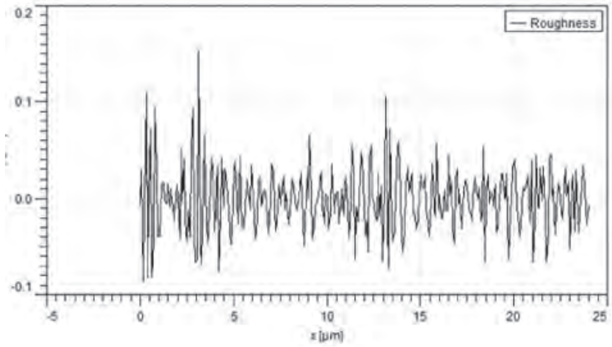

Figure 8. Roughess of weld seam after laser shock peening process

Figure 9. shows results of microhardness testing performed by Vickers. The results show that both laser welding and laser shock peening increase the microhardness of material. The higher values are obtained by laser welding process. It seems that laser shock peening after laser welding has no any influence on microhardness of material.

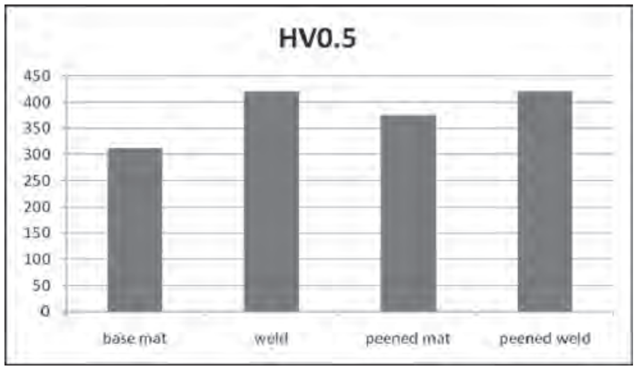

Figure 9. Microhardness by Vickers of base material, of weld seam and after laser shock peening

4. Conclusion

In this paper surface profilometry of welded joint and laser peened weld seam are discussed. The weld joint, obtained by optimal process parameters, used in this experiment, are crack-free. The results obtained in this investigation suggest that the laser beam interaction with material decreases average roughness of material, as well as average maximum roughness valley depth and average maximum roughness peak height. Also, the results show that laser shock peening process produces lower roughess of material than laser welding process. The microhardness of material increases after laser beam action, although the higher values are obtained by laser welding than by laser shock peening process.

References

[1]. Murthy G.V.S., Ghosh S., Das M., Das G. and Ghosh R.N., "Correlation between ultrasonic velocity and indentation-based mechanical properties with microstructure in Nimonic 263," Mater. Sci. Eng., Vol A 488, p.p. 398–405, 2008.

[2]. Reed. R. "The Superalloys, Fundaentals and Applications. USA: Cambridge University Press, New York, 2006.

[3]. Singh P.N. and Vakil Singh, "Influence of ageing treatment on work hardening behavior of Ni-base superalloy", Scripta Materialia, Vol. 34, No. 12, pp. 1861-1865, 1996.

[4]. Dubey A. Kr. and Yadava V., "Experimental study of Nd:YAG laser beam machining—An overview", J. Mat. Proc. Tech. 195 15, 2008.

[5]. Sun Z. and Ion J.C., "Laser welding of dissimilar metal combinations", J. Mater. Sci., vol. 30, p.p. 4205–4214, 1995.

[6]. Petronic S., PhD thesis, Faculty of Mechanical Engineering, University of Belgrade, Belgrade, 2010.

[7]. Yeni C. and Kocak M., "Fracture toughness analysis of laser-beam-welded superalloys Inconel 718 and 625", Fatique and fracture of Engineering Materials and Structure, vol. 29, No.7, p.p. 546-557, 2006.

[8]. Sun Z. and Kuo M., "Bridging the joint gap with wire feed laser welding", J. Mater. Process. Technol., vol. 87, p.p. 213–222, 1999.

[9]. Ojo O.A., Ding R.G. and Chaturvedi M.C.,"Heat affected zone microfissuring in a laser beam welded directionally solidified Ni3Al-base alloy", Scr. Mater., Vol. 54, p.p. 2131–2136, 2006.

[10]. Petronic S., Milosavljevic A., Sedmak A., Grujic B. and Colic K., "Microstructural changes in laser welded joint of Nimonic 263 alloy", Proceedings of 4th Int Conf Innovative Technologies Joining Advanced Materials, Timisoara, Romania, 2010, pp 207-212.

[11]. Peyre P., Berthe L., Scherpereel X., Fabbro R. and Bartnicki E., "Experimental study of laser-driven shock waves in stainless steels" Appl. Phy. 84, p.p. 5985 - 5993, 1998

[12]. Hu, Y., Gong, C., Yao, Z.and Hu, J. "Investigation on the non-homogeneity of residual stress field induced by laser shock peening", Surface & Coatings Technology 203, 3503-3509.

[13]. Warren, A.W., Guo, Y.B., Chen, S.C. (2008). Massive parallel laser shock peening: Simulation, analysis, and validation. International Journal of Fatigue, 30, p.p. 188-197, 2009.

[14]. Metal Handbook tenth edition – Vol 1 & Vol 2, Properties and Selection: Iron, Steel, and High- Perf. Alloys, 2005 (ASMI, Materials Park, Ohio)

[15]. Zhao J. C., Ravikumar V. and Beltran A. M., "Phase precipitation and phase stability in Nimonic 263", Metallur. Mater. Trans. A, vol. 32, p.p. 1271-1282.

[16]. Petronic S. and Milosavljevic A. "Heat treatment effect on multicomponent nickel alloys structure", FME Transaction, vol.35, p.p. 189-194, 2007.

[17]. http://gwyddion.net

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