THE IMPACT OF PROCESS VARIABLES ON THE CONNECTION PARAMETERS DURING PULSE MICRO-WELDING OF THE H800 SUPERALLOY

Wojciech DEPCZYŃSKI [1], Robert JASIONOWSKI [2], Piotr MŁYNARCZYK [3]

[1]*Kielce University of Technology, Poland, EU, wdep@tu.kielce.pl*
[2]*Martime University of Szczecin, Poland, EU, r.jasionowski@am.szczecin.pl*
[3] *Kielce University of Technology, Poland, EU, piotrm@tu.kielce.pl*

Abstract

The paper presents, the impact of process variables on connection parameters during micro-welding of H800 superalloy. The research discusses the apparatus and features, including the advantages of the welding procedure. The process variables determining the influence of pulse micro-welding method on the metallographic structure of welds of thin superalloys were given. The process uses a thin sheet of H800 superalloy welded on a C22 alloy substrate. During the experiment, welded joints of tested superalloys were obtained and the characteristics of their microstructure were examined. Welding of thin sheet was made by means of resistive pulse welding using the SST WS 7000s device. The focus was on the leading tested parameters, such as microhardness and observation of the weld microstructure. The aim of experiment was to check the regeneration possibility of heat and mechanically loaded machine parts made of superalloys.

Keywords: Microwelding, surface engineering, microstructure, microhardness

1. INTRODUCTION

The high replacement costs of aircraft gas turbine blades and vanes have created a fast-growing, highly-specialized segment of the gas turbine repair industry. Gas turbine blades experience dimensional and metallurgical degradation during engine operation [1,2]. Dimensional degradation derives from wear, nicks, dents, hot corrosion and, in the case of coated blades, stripping and recoating as in repair. Metallurgical degradation derives from fatigue and high-temperature creep. Some degradation, depending on location and extent, is amenable to "repair"; the definition of repair being rather broad [3,4]. Microwelding resistive-pulse technique [5-8] is a thermo-electric process in which heat is generated at the interface of the parts to be joined by passing an electrical current through the parts for a precisely controlled time and under a controlled pressure also called force. The microwelding is often included in the "non-traditional" or "non-conventional" group of machining methods together with processes such as electrochemical machining (ECM), water jet cutting (AWJ) [9], laser cutting [10], Electrical Discharge Machining (EDM) [11-14] and opposite to the "conventional" group turning, milling, grinding, drilling etc. Welding is used to repair cracks but filler materials have their own limits (welding repair limits) based on the mechanical stresses (centrifugal stresses and gas fl ow stream load) to withstand. There are different types of welding: G as tungsten arc welding (GTAW) or tungsten inert gas (TIG) welding; plasma and microplasma transferred arc welding (PTAW); laser welding (LBW) (LPW) (LFW); electron-beam welding (EBW). Microwelding is used where due to the small size of the deposition areas conventional welding techniques are excluded of use. Microwelding resistive-pulse technique allows for a significant increase in scope of repairs arising comparing to traditional methods of regeneration [15-17]. Nowadays, achieved by modern equipment for microwelding current voltage parameters indicate the possibility of producing connections of elements made of Ni-based called superalloys. In the available literature, the authors frequently shall take the study of superalloys thin sheet connections made by various microwelding methods [18-21]. Paper is focused on microwelding effects as "non-conventional" manufacturing methods. The aim of the research is to study the effects of spot welding thin sheet of H800 superalloy welded on a C22 alloy substrate. The aim of experiment was to check the regeneration possibility of heat and mechanically loaded machine parts made of superalloys. These are materials that are widely used in the aerospace and energy industries.

2. EQUIPMENT AND MATERIAL

The spot welding were made using the device to microwelding WS 7000 S from SST France & Vision Lasertechnik. This machine welding generates pulses with an average frequency of 5000 Hz. The welding parameters are summarized in **Table** 1.

Table 1 Microwelder SST WS 7000s - Characteristics

Parameter	**Characteristics**
Supply	~220 V / 50 Hz / 60 Hz
Type of Converter	Medium frequency 5 kHz
Maximum Welding Power	10 kW
No Load Voltage U20	3.6 V
Type of Control	Current Regulation
Welding Time	1 - 250 ms
Current Accuracy	8 A
Maximum Impulse Speed	16
Maximum Welding Capacity	1 / 0.3
Adjustable Parameters	- Welding Amperage in % - Welding Time in MS - Single Impulse / Multi Impulse Welding Cycle - Form of Impulse (Powder / Wire - Sheet)

A thick tape 150 µm was made from Inconel 800 by cold rolling, and spot welded on the sample from Chronin C 22 (cuboid shape). The spot welding of thin sheet of superalloys Chronin C 22 and Inconel 800 were obtained used following parameters:

- the applied welding amperage in the range of 70%-90 % of the power device (max. 7000 A);
- welding time 10 ms;
- form of impulse: wire-ribbon;
- duty cycle: multi impulse welding cycle.

The alloys studied are the Chronin C 22 and Inconel 800, whose compositions are given, respectively, in **Table 2.**

Table 2 Composition (in wt.%) of Chronin and Inconel 800

Alloy	**Ni**	**Fe**	**Cu**	**S**	**Si**	**Mn**	**Cr**	**Co**	**Mo**	**Ti**	**Al**	**V**	**W**	**Mg**
Chronin C22	56.82	4.09	-	0.001	0.048	0.31	21.48	0.03	13.78	-	-	0.018	3.20	-
Inconel 800	74.1	8.95	0.0005	0.001	0.28	0.20	15.96	0.021	-	0.200	0.22	--	-	0.006

3. WELD MICROSTRUCTURE

To illustrate structures of the joints we used the metallographic microscope Nikon Eclipse MA200 with the image analysis system NIS 4.20. During the preparation process for the joint were samples cut across the weld and mounted in resin. After proper polishing and etching the weld structure was subjected to observation.

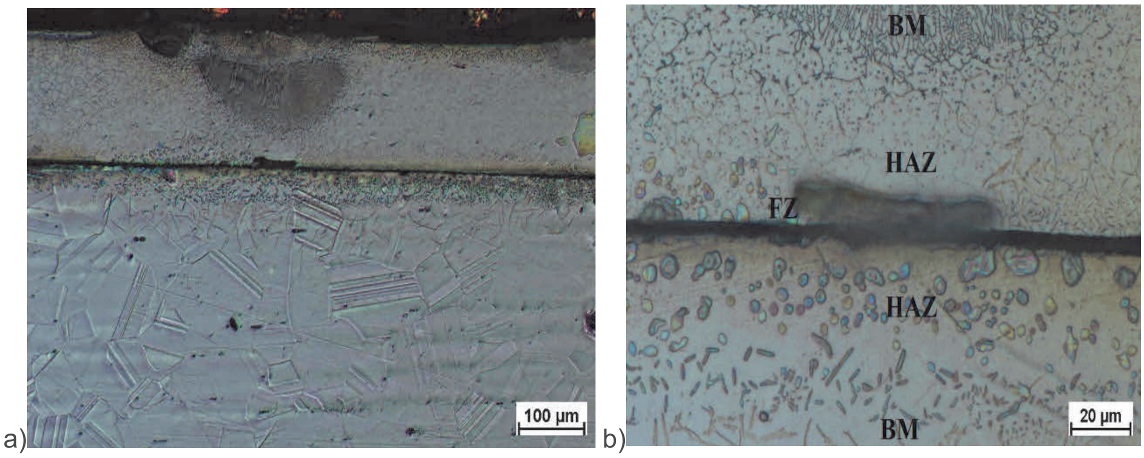

Figure 1 Microphotography of weld structure; welding amperage70%

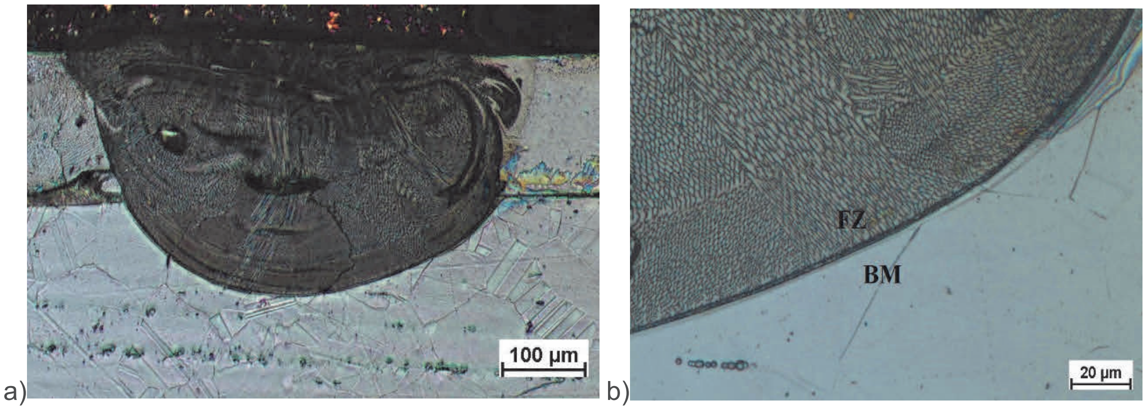

Figure 2 Microphotography of weld structure; welding amperage 80%

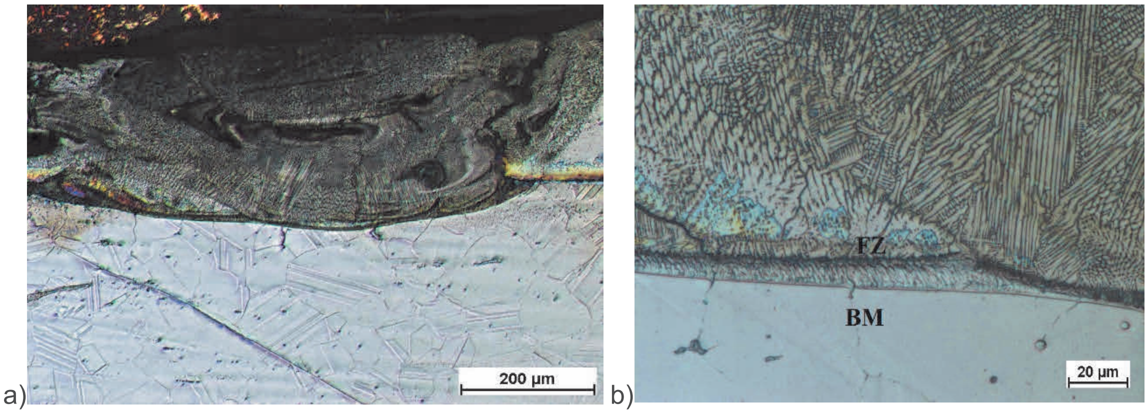

Figure 3 Microphotography of weld structure; welding amperage 90%

4. MICROHARDNESS OF MICROWELDED JOINTS

Microhardness tests were carried out by using a Vickers indenter, with an applied load of 100 g (0.98 N) for 15 s. For investigation there was used Matsuzawa Vickers microhardness MX 100 type. There was applied load 100 g (0.98 N). The tests were performed on the cross-section of the weld. Measurements include material zones of the Fusion zone (FZ) and Heat affected zone (HAZ).

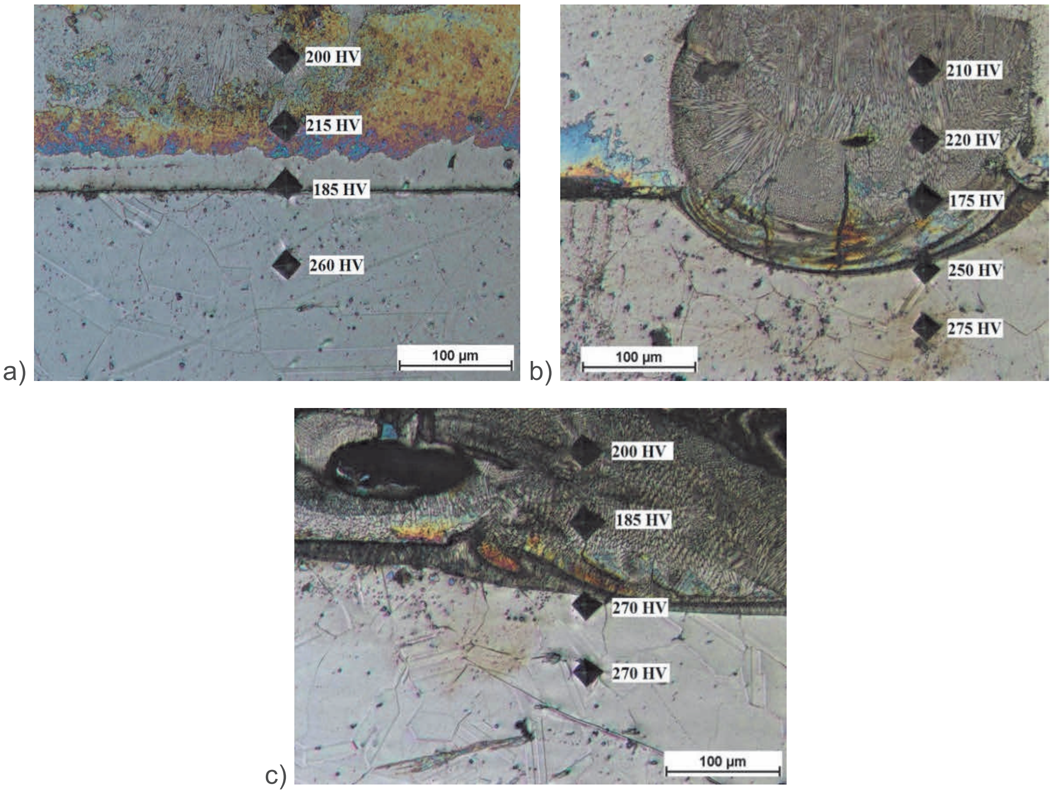

Figure 4 Microphotography of weld structure with intender view and microhardnes mark; welding amperage a) 70% b) 80% c) 90% of power

5. RESULTS AND DISCUSSION

Material selection is a key factor in gas turbine performance and lifecycle cost because it has a central influence in the maintenance of the gas turbine. Further, the operation of a gas turbine does result in gas path degradation that impacts lifecycle costs and eventually design, manufacture, material choice and maintenance. A component repair programme that minimizes maintenance costs and maximizes equipment availability can be instituted to meet or improve lifecycle cost. This chapter presents the key factors influencing the need for maintenance and the choices available. **Figures 1** to **3** show examples of optical micrographs of the etched cross-section for welded joints with linear weld geometry. **Figures** also show various zones with different microstructures characterize the welded specimen: base metal (BM), heat-affected zone (HAZ) and fusion zone (FZ). All examined specimens showed that there was no re-melting through the two microwelded elements, with an average penetration width of about 0,04 mm bottom elements (i.e. around half the thickness of joined sheets). The HAZ has an average width ranging from a few µm, which is characteristic for used techniques of welding [18, 19]. In our specimens, a larger width FZ is generally observed in the sheet closer to the impulse source (see top part in the **Figures**). Instead, the HAZ has almost the same width in both upper and lower sheet.

In all welded joints examined, the FZ is characterized by small columnar-shaped grains. The upper sheet there was re-melted through. In the middle fusion zone there are tiny equiaxed grains. Meanwhile in place where the microhardness should appear the lowest because of longest way of heat transfer, the microhardness value has reached maximum. The ‘‘softer’’ microstructure of welds could be explained by a slower cooling rate in weld material, caused by the particular geometry of the microweld. On the surface of upper sheet at contact point - the joint between upper and lower sheet, separates highest heat development due to the flow of electrical impulses. In fact, during welding the heat remains entrapped inside the joint and then gives higher temperatures during long time, with reduced cooling rate on the microwelded material. A similar phenomenon is observed regularly during the tests of connections of thin sheets from superalloys, as well as during the welding of regeneration layers made of superalloys into elements with larger cross-sections. The microhardness distribution (see **Figure 4**) in the cross section of microweld is relatively balanced and does not exceed 70 $HV_{0.1}$. It was expected that at the centre of the microwelded zone will be the lowest hardness values are shown generally depending on the position in the weld area as a result of different microstructures. The hardness of FZ ranged in values 175-280 HV, and BZ ranged in values 220-280 HV, respectively to the place of measurement. In all joint types, an increase of micro-hardness is observed in FZ, due to harder microstructures that are caused by melting and subsequent rapid cooling during welding, and which have already been observed in previous metallurgical studies. In some of analyzed specimens, the micro-hardness appear to increase towards the center of FZ, while decrease at the edges.

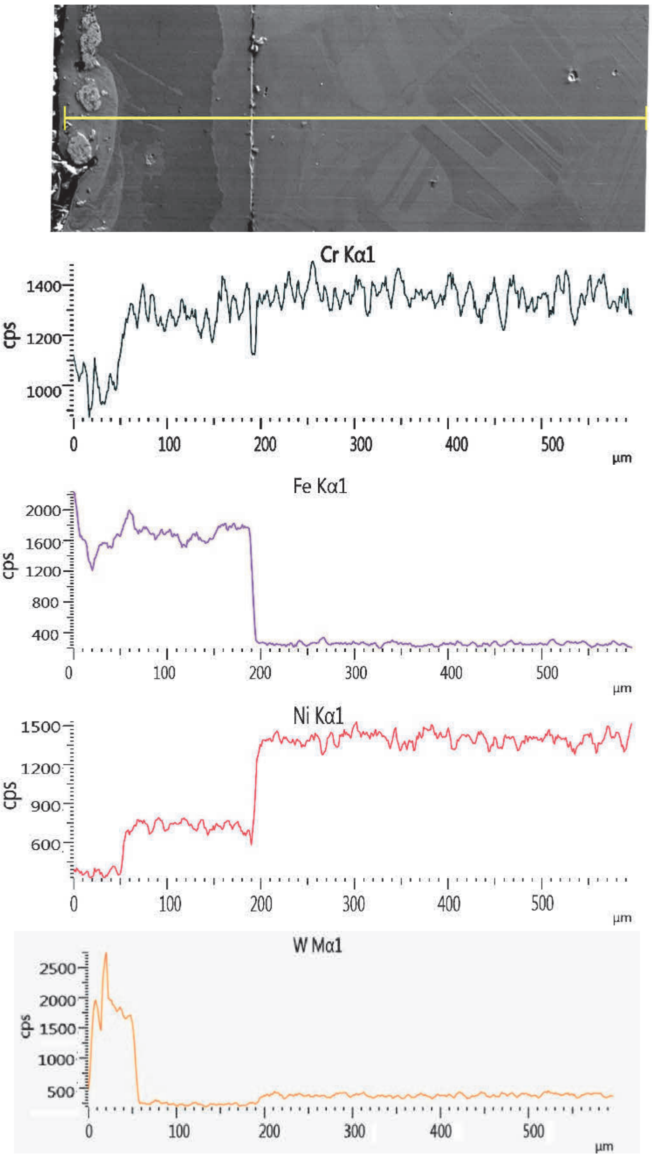

Figure 5 X-ray line scan of the superficial layer after microwelding process using a 90% of power

SEM examination was performed using a JEOL JSM 7100F microscope with microprobe Oxford EDS X-series - **Figure 5**. The results showed that there is a possibility of obtaining the joint between C22 substrate and superalloy H800. It was important to that did not occur significant diffusion of C22 in the direction of superalloy H800. As a result of EDS analysis, there was no diffusion of elements C22 in the direction of superalloy H800.

During the welding process has taken place, diffusion of other elements in the direction of Fe in the direction of H800. Additional studies are required to determine the effects of these phenomena on the properties of the alloy H800 at the maximum operating temperatures. It should be added that the diffusion zone is very small. Other chemical analysis carried out at a greater distance from the weld not showed elements diffusion.

6. CONCLUSION

The article presents the impact of process changes on the parameters of the connection in the pulse micro-welding of the H800 superalloy. The microstructural and mechanical characterization of thin layers deposited from superalloys by microwelding was investigated. Welded samples with a linear weld bead were observed. The changes in the welding pulse power affected the characteristics of microhardness and the geometry of the joint. Welding morphologies were characterized by dynamic temperature changes that accompany micro-welding processes, using millisecond high-frequency electrical impulses. The most important effect of the research is the increase of microhardness in the WZ weld zone, which is higher than in other zones. Heat affected zone is very small and difficult to observe. This means that the total strength of the joint is controlled by the strength of base metal which is compatible with the area of full penetration welding characterized by higher microhardness (and therefore higher static strength) compared to base metal. The applied welding technology enables the repair of minor damage to components constructed on the basis of super alloys, such as gas turbine blades, centrifugal pumps and devices for controlling the flow of turbulent fluids working under cavitation conditions. All connections proved to be stable in the 70-90% range of amperage. Considering the microstructure observation, 80% of amperage seemed to be most effective for creating of regeneration layer.

REFERENCES

[1] ÁLVAREZ TEJEDOR, T. *‘Gas turbine materials selection, life management and performance improvement’. Power Plant Life Management and Performance Improvement*. Edited by J. E. Oakey, Cranfield University, UK, Woodhead Publishing Series in Energy. 2011. no. 23.

[2] HENDERSON, M. B., ARRELL, D., LARSSON, R., HEOBEL, M. and MARCHANT, G. Nickel based superalloy welding practices for Industrial gas turbine applications.pp. 13-21. Published Online: 04 Dec 2013, doi.org/10.1179/136217104225017099.

[3] HENDERSON, M. B., ARRELL, D., HEOBEL, M., LARSSON, R. and MARCHANT, G. Nickel-Based Superalloy Welding practices for industrial gas turbine applications. *Science and Technology of Welding and Joining*. 2004. vol. 9, no. 1, pp. 13-21.

[4] BI, G., GASSER, A., WISSENBACH, K. DRENKER, A. and POPRAWE, R. Characterization of the process control for the direct laser metallic powder deposition. *Surface & Coatings Technology*.2006. vol. 201, no. 6, pp. 2676-2683.

[5] DOBRANSZKY, J. *The microwelding technologies and their applications*, Budapest 2004.

[6] RUSZAJ, A. *Nonconventional methods of machining machine elements and tools*. IOS Krakow. 1999.

[7] MŁYNARCZYK, P., SPADŁO, S., DEPCZYŃSKI, W. Investigations into the effects of spot welding on thin sheet of superalloys Hastelloy x and Haynes 230 (r). In *METAL 2017: 26th International Conference on Metallurgy and Materials*. Ostrava: TANGER, 2017, pp. 1881-1886.

[8] MŁYNARCZYK, P., SPADŁO, S., DEPCZYŃSKI, W., ŚLIWA, E., STRZĘBSKI, P. The selected properties of the connection superalloy Haynes h 230 (r) using microwelding. In *METAL 2015: 24rd International Conference on Metallurgy and Materials*. Ostrava: TANGER, 2015, pp. 792-797.

[9] HLAVAC, L. M., KRAJCARZ, D., HLAVACOVA, I. M., SPADŁO S. Precision comparison of analytical and statistical-regression models for AWJ cutting. *Precision Engineering-Journal of the International Societies for Precision Engineering and Nanotechnology*, 2017, vol. 50, pp. 148-159. DOI: 10.1016/j.precisioneng.2017.05.002.

[10] QIAN, S., HONG-SHUANG, D., JUN-CHEN, L. and XIAO-NAN, W. Effect of pulse frequency on microstructure and properties of welded joints for dual phase steel by pulsed laser welding. *Materials and Design*. 2016. vol. 105, pp. 201-211.

[11] SPADŁO, S., MŁYNARCZYK, P., DEPCZYŃSKI, W. Investigation of the selected properties of superficial layer alloying with the tungsten electrodes. In *METAL 2015: 24rd International Conference on Metallurgy and Materials*. Ostrava: TANGER, 2015, pp. 863-867.

[12] ŚWIERCZ, R., ONISZCZUK-ŚWIERCZ, D. Experimental investigation of surface layer properties of high thermal conductivity tool steel after electrical discharge machining. *METALS*, vol. 7, Issue: 12, Article Number: 550, Published: DEC 2017.

[13] GHOLAMI SHIRI, S., SARANI, A., ELMI HOSSEINI, S.R. and ROUDINI, G. Diffusion in FSW joints by inserting the metallic foils. *J. Mater. Sci. Technol*. 2013.vol. 29, no. 11, pp. 1091-1095.

[14] SHAKIL, M., TARIQ, N.H., AHMAD, M., CHOUDHARY, M.A., AKHTER,J.I. and BABU,S.S. Effect of ultrasonic welding parameters on microstructure and mechanical properties of dissimilar joints. *Materials and Design*. 2014. vol. 55, pp. 263-273.

[15] PRASADA, K.S., RAO, C.S. and RAO, D.N. Effect of welding current mode on weld quality characteristics of pulsed current micro plasma arc welded AISI 304L sheets*. Applied Mechanics and Materials*. 2014. vols. 465-466, pp. 1209-1213.

[16] SPADŁO, S., MŁYNARCZYK, P., DEPCZYŃSKI, W., SKOWRON, E., MIJAS, R. Research on the influence of electron beam welding of titanium alloy microstructure connection. In *METAL 2017: 26th International Conference on Metallurgy and Materials*. Ostrava: TANGER, 2017, pp. 1939-1944.

[17] MCDANIELS, R.L., CHEN, L., STEWARD, R, LIAW, P.K.et al. The strain-controlled fatigue behavior and modelling of Haynes® HASTELLOY® C-2000® superalloy. *Materials Science and Engineering A*. 2011. vol. 528, pp. 3952-3960.

[18] LEE, S.Y., LU, Y.L., LIAW, P.K.et al. High-temperature tensile-hold crack-growth behavior of HASTELLOY® X alloy compared to HAYNES® 188 and HAYNES® 230® alloys. *Mech. Time-Depend Mater*. 2008. no. 12, pp. 31-44. DOI 10.1007/s11043-008-9049-6.

[19] BULUT COSKUN, M., SERDAR AKSOY and MAHMUT, F. Friction and wear characteristics of Haynes 25, 188, and 214 superalloys against Hastelloy X up to 540 °C.*Tribol. Lett*. 2012. vol. 45, pp. 497-503. DOI: 10.1007/s11249-011-9912-5.

[20] GRANEIX, J., BEGUIN, J. D., PARDHEILLAN, F. et al. Weldability of the superalloys Haynes 188 and Hastelloy X by Nd:YAG. In *MATEC Web of Conferences.* 2014. no. 14, article no. 13006. DOI: 10.1051/matecconf/20141413006.

[21] *Operating Instructions for microwelding WSS 7000S.*