INVESTIGATIONS INTO THE EFFECTS OF SPOT WELDING ON THIN SHEET OF SUPERALLOYS HASTELLOY X AND HAYNES 230®

MŁYNARCZYK Piotr, SPADŁO Sławomir, DEPCZYŃSKI Wojciech

Kielce University of Technology, Poland, EU
piotrm@tu.kielce.pl, sspadlo@tu.kielce.pl, wdep@tu.kielce.pl

Abstract

In the paper there are presented preliminary results of microwelding thin sheet of superalloys Hastelloy X and Haynes 230®. The studies determined the basic parameters of microwelding superalloys thin sheet. In this paper, welding connections of examined superalloys free from cracking was obtained and its microstructural growth characteristic was investigated. Welding of thin metal sheet was made by resistive pulse microwelding with use of a SST WS 7000s device. The study focused on the leading investigated parameters such as microhardness and the obtained weld microstructure observation. Microhardness measurements of the joints were taken using Matsuzawa Vickers MX 100 type with applied load 100 g (0.98 N). The joints were examined using metallographic microscope Nikon Eclipse MA200. The survey indicates that although many studies have been performed, there is still a considerable need to further examine how to obtain satisfying quality joint, using micro welding between the thin sheet from superalloy Hastelloy X and Haynes 230®.

Keywords: Microwelding, surface engineering, microstructure, microhardness

1. INTRODUCTION

Microwelding resistive-pulse technique [1-4] 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) [5], laser cutting [6, 7], Electrical Discharge Machining (EDM) [8-11], hybrid machining [12] or nonconventional welding processes [13-16] and opposite to the "conventional" group turning, milling, grinding, drilling etc. 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 [17-19]. 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 [19, 20].

The paper is focused on microwelding effects as a "non-conventional" machining methods of superalloys, having wide application in aerospace and energy industry. The aim of research is to study the effects of spot welding on thin sheet superalloys (Hastelloy X and Haynes 230®).

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 [21]

Parameter	**Characteristics**
Supply	~220V/50Hz
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)

The spot welding of thin sheet of superalloys Hastelloy X and Haynes 230® were obtained used following parameters:

- the applied welding amperage in the range of 50-70% of the power device (max. 7000 A);
- welding time 10 ms;
- form of impulse: wire-ribbon;
- duty cycle: multi impulse welding cycle.

In this work were studied the nickel-chromium-molybdenum alloy Hastelloy X and the nickel-chromium-tungsten alloy Haynes 230®, produced by Haynes International whose compositions are given, respectively, in **Table 2** and **Table 3**. Both alloys were delivered by thin rolled sheet form. Before the welding process thin sheets was degreased and oxides were removed with sandpaper.

Table 2 Composition (in wt.%) of Hastelloy X [22]

	Ni	**Cr**	**Fe**	**Mo**	**Co**	**W**	**C**	**Mn**	**Si**	**B**
Min.	47.0	22.0	18.0	9.0	1.5	0.6	0.10	1.0	1.0	0.008

Table 3 Composition (in wt.%) of Haynes 230® [23]

	Ni	**Cr**	**W**	**Mo**	**Co**	**Al**	**La**	**Mn**	**C**	**Si**
Min.	47.0	20.0	13.0	1.0	-	0.20	0.005	0.3	0.05	0.25

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 thin sheet joint were cut across the weld and mounted in resin. After proper polishing and electrolytically etching in oxalic acid (2%), the weld structure was subjected to observation. Different zones of different microstructures characterize welded samples: base metals (BM), heat affected zones (HAZ), and fusion zone (FZ). HAZ has an average width in the range of several µm, which is typical of the welding techniques used. The samples show a larger FZ width in the sheet closer to the pulse source. Instead, HAZ has a small width in both joined sheets. 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.

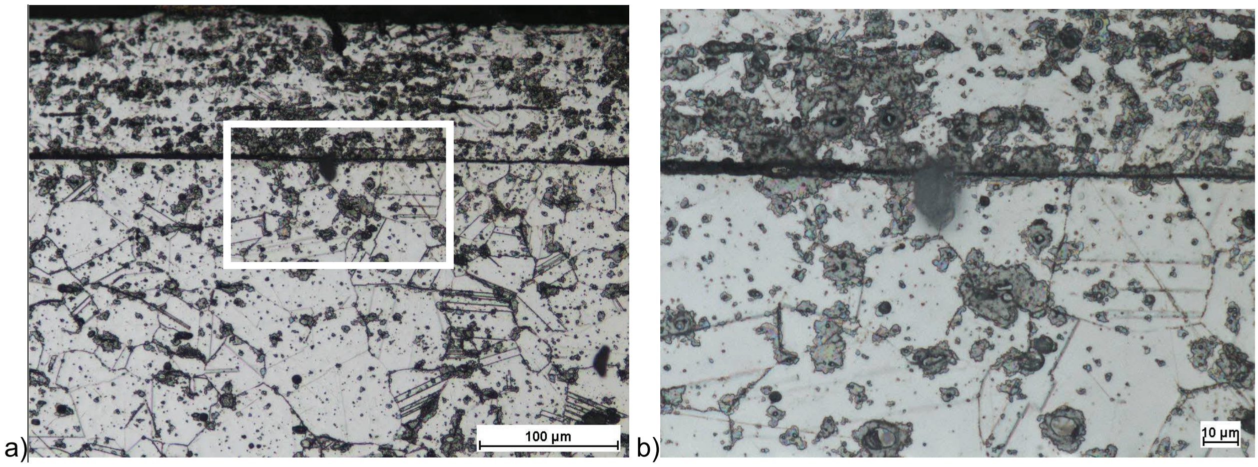

Figure 1 Microphotography of weld structure; welding amperage 50%

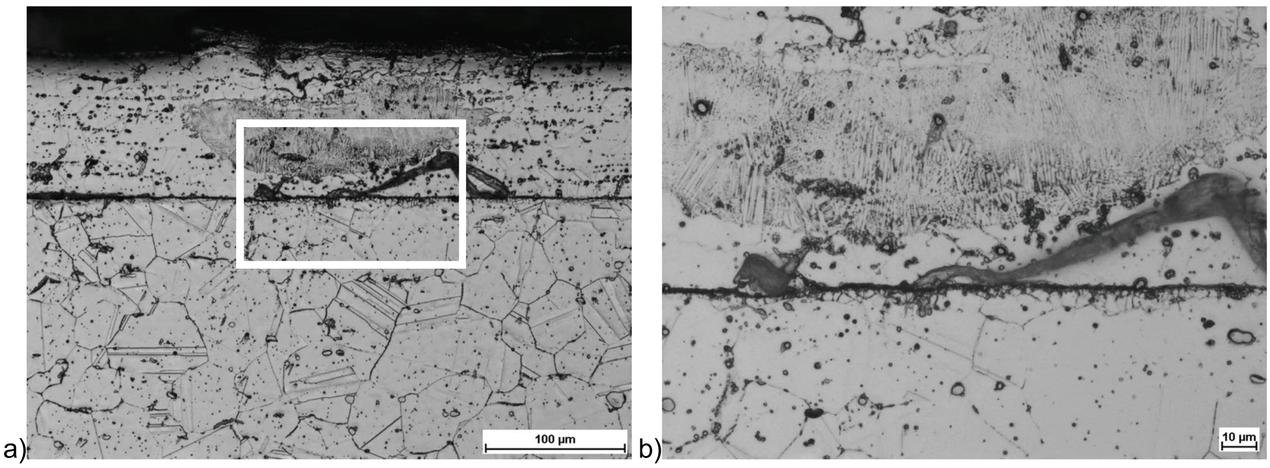

Figure 2 Microphotography of weld structure; welding amperage 60%

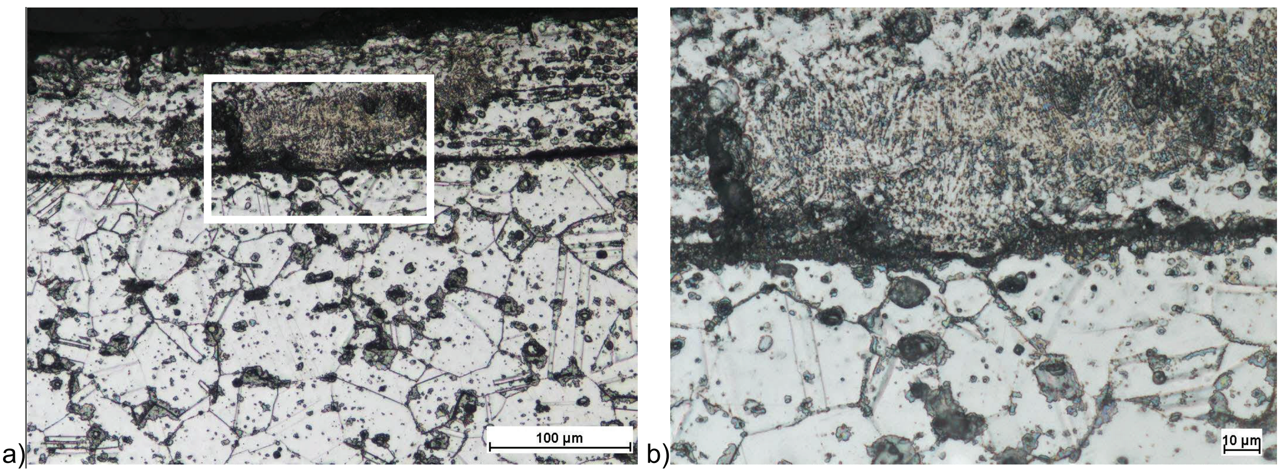

Figure 3 Microphotography of weld structure; welding amperage 70%

4. MICROHARDNESS OF MICROWELDED JOINTS

Microhardness tests were carried out by using a Vickers indenter, with an applied load of 0.98 N for 15 s. For investigation there was used Matsuzawa Vickers microhardness MX 100 type.

5. RESULTS AND DISCUSSION

Figure 1 shows an examples of the micrographs etched cut cross-sections of welded joints at 50% amperage. Because of the low welding parameters, no melted zone was achieved. Connections are typical for spot welding. **Figure 2** shows an example of OM micrographs etched cut cross-sections of welded joints at 60% amperage. The observed connection is similar to that obtained with lower parameters. However, the zone with clearly visible column crystals was noticed. This zone didn't reach the connection zone. Only the connection obtained at 70% amperage for the used device, allowed the connection to be melted, **Figure 3**. Different zones of different microstructures characterize the welded sample: base material (BM), heat affected zone (HAZ), and fusion zone (FZ). HAZ has an average width of several μm, typical for used welding techniques [24, 25, 26]. Generally in the examined samples, a larger FZ width is observed in the sheet closer to the pulses source (see upper section in the figures). Instead, HAZ has almost the same width in the top and bottom. FZ is characterized by a small column-shaped grain in the test weld. The upper sheet has been melted down. In the middle zone of FZ there are tiny uniform grains. Microhardness measurements show that in the place where the it should be the smallest due to the longest heat transfer, the maximum value has been achieved. The "soft" weld microstructure can be explained by slower cooling rate in the welding material, caused by the special geometry of the microweld. Similar phenomena were observed for other welded materials using the described method [27, 28, 29]. On the surface of the top sheet at the contact point - connection between the upper and lower plate separates the greatest increase of heat due to electrical pulses flow. In fact, during welding, the heat remains trapped inside the weld, and then for a longer time it gives a higher temperature, with reduced cooling rate on the microwelded material. The hardness values varied depending on the position in the coupling area. This is due to the change of the structure of the materials when exposed to an electric pulse during welding. The hardness of BZ was 232 - 295 HV FZ was 267-360 HV. The measurement of hardness in the HAZ was not possible because of its small width. In all types of structures in FZ, the hardness of the microstructure increases as a result of more difficult microstructures caused by melting, followed by rapid cooling during welding, and which have been observed in previous metallurgical investigations. In some of the analyzed samples, the microhardness seemed to increase toward the center of FZ, and decreasing at the edges. There were no fractures in FZ or HAZ - but such cracks are often reported by other researchers using other welding techniques such as Laser Beam Welding or TIG welding [30, 31].

6. CONCLUSION

The paper presents the microstructural and mechanical characteristics of microweldet thin sheets of Haynes 230 and Hastalloy X. Welded samples were tested with a linear welding bead. The characteristics were based on metallographic observations, and microhardness measurements. The main findings of this study can be summarized as follows:

- the proper microstructure connection was obtained with sufficiently high power parameters.
- the microhardenal profiles in all tested joints confirmed an increase in hardness in the weld zone and superheated zone.
- no cracks were found in the area of the weld and heat affected zones.

This means that the total joint strength is controlled by the strength of the base metal (BM), which is consistent with full penetration welding zone characterized by higher microhardness (and therefore higher static strength) comparing to the base metal. The aim of work to research the effects of spot welding on thin sheet superalloys (Hastelloy X and Haynes 230®) was achieved.

REFERENCES

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

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

[3] DEPCZYŃSKI, W., MŁYNARCZYK, P., SPADŁO, S., ZIACH, E., HEPNER, P. The selected properties of porous layers formed by pulse microwelding technique. In *METAL 2015: 24rd Anniversary International Conference on Metallurgy and Materials*, Ostrava: TANGER, 2015, pp. 1087-1092.

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

[5] KRAJCARZ, D. Comparison Metal Water Jet Cutting with Laser and Plasma Cutting. In *24th DAAAM International Symposium on Intelligent Manufacturing and Automation*, 2013, Book Series: Procedia Engineering, 2014, Vol. 69, pp. 838-843.

[6] MUCHA, Z., WIDLASZEWSKI, J, KURP, P. et al. Mechanically-assisted laser forming of thin beams. In *Laser Technology 2016: Progress and Applications of Lasers,* Book Series: Proceedings of SPIE, 2016, vol. 10159, Article Number: 101590U.

[7] NAPADLEK, W. The impact of the output stereometry and absorbent coating on the efficiency of ablative laser texturing of iron alloy 100CrMnSi6-4. *Materials Testing*, 2015, vol. 57, no. 10, pp. 920-924.

[8] SPADŁO, S., KOZAK, J., MŁYNARCZYK, P. Mathematical modelling of the electrical discharge mechanical alloying process. In *Proceedings of the Seventeenth CIRP Conference on Electro Physical and Chemical Machining (ISEM)*, 2013, vol. 6, pp. 422-426.

[9] MŁYNARCZYK, P., SPADŁO, S. The Analysis of the Effects Formation Iron - Tungsten Carbide Layer on Aluminum Alloy by Electrical Discharge Alloying Process. In *METAL 2016: 25th Anniversary International Conference on Metallurgy and Materials*, Ostrava: TANGER, 2016, pp. 1109-1114

[10] SPADŁO S., DEPCZYŃSKI W., MŁYNARCZYK P. Selected properties of high velocity oxy liquid fuel (hvolf) - sprayed nanocrystalline wc-co infralloy(tm) s7412 coatings modified by high energy electric pulse, METALURGIJA Volume: 56 Issue: 3-4 Pages: 412-414 Published: JUL 2017

[11] ONISZCZUK, D., ŚWIERCZ, R. An investigation into the impact of electrical pulse character on surface texture in the EDM and WEDM process. *Advances in Manufacturing Science and Technology*, 2012, vol. 36, no. 3, pp. 43-53.

[12] SPADŁO, S., MŁYNARCZYK, P. Analysis of the mechanical interactions of the filament brush electrode on the formation of the surface roughness. In *METAL 2016: 25th Anniversary International Conference on Metallurgy and Materials*, Ostrava: TANGER, 2016, pp. 1169-1174.

[13] KRAJEWSKI, A., WŁOSIŃSKI, W., CHMIELEWSKI, T., KOŁODZIEJCZAK, P. Ultrasonic-vibration assisted arc-welding of aluminum alloys. *Bulletin of the Polish Academy of Sciences: Technical Sciences*, 2013, vol. 60, no. 4, pp. 841-852.

[14] CHMIELEWSKI, T., GOLAŃSKI, D., WŁOSIŃSKI, W. Metallization of ceramic materials based on the kinetic energy of detonation waves. *Bulletin of the Polish Academy of Sciences Technical Sciences*, 2015, vol. 63, no. 2, pp. 449-456.

[15] CHMIELEWSKI, T., GOLAŃSKI, D. New method of in-situ fabrication of protective coatings based on Fe-Al intermetallic compounds. Proceedings of the Institution of Mechanical Engineers, Part B, *Journal of Engineering Manufacture*, 2011, vol. 225, no. 4, pp. 611-616.

[16] MATUSZEWSKI, M., KAŁACZYŃSKI, T., ŁUKASIEWICZ, M., MUSIAŁ, J. Surface geometric structure after various treatments and wear process. *The International Scientific Journal Problems of Tribology*, 2013, no. 1, pp. 75-80.

[17] NABEEL, A., CHUNG, H. Alternating current-gas metal arc welding for application to thin sheets. *Journal of Materials Processing Technology*, 2014, vol. 214, pp. 1828-1837.

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

[19] SHAKIL, M., TARIQ, N. H., AHMAD, M., CHOUDHARY, M. A., AKHTER, J. I., 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.

[20] PRASADA, K. S., RAO, C. S., 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.

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

[22] *HASTELLOY X alloy Information*. http://www.haynesintl.com.

[23] *HAYNES® 230® alloy Information*. http://www.haynesintl.com.

[24] GRANEIX, J., BEGUIN, J.-D., PARDHEILLAN, F., ALEXIS, J., MASRI, T. Weldability of the superalloys Haynes 188 and Hastelloy X by Nd:YAG. In *MATEC Web of Conferences*, 2014, No. 14, 13006, DOI: 10.1051/matecconf/20141413006.

[25] QIAN, S., HONG-SHUANG, D., JUN-CHEN, L., 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.

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

[27] 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, vol. 12, pp. 31-44, DOI 10.1007/s11043-008-9049-6.

[28] BULUT COSKUN, M., SERDAR, A., 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.

[29] CAIAZZO, F., ALFIERI, V., SERGI, V., SCHIPANI, A., CINQUE, S. Dissimilar autogenous disk-laser welding of Haynes 188 and Inconel 718 superalloys for aerospace applications. *Int. J. Adv. Manuf. Technol.*, DOI 10.1007/s00170-013-4979-9.

[30] BAGHJARI, S. H., GHAINI, F. M., SHAHVERDI, H. R., EBRAHIMNIA, M., MAPELLI, C., BARELLA, S. Characteristics of electrospark deposition of a nickel-based alloy on 410 stainless steel for purpose of facilitating dissimilar metal welding by laser. *Int. J. Adv. Manuf. Technol.*, DOI 10.1007/s00170-016-8668-3.

[31] DAVID, S. A., SIEFERT, J. A., FENG, Z. Welding and weldability of candidate ferritic alloys for future advanced ultrasupercritical fossil power plants. *Science and Technology of Welding & Joining*, 2016, DOI: 10.1080/13621718.2016.1143708.