THE SELECTED PROPERTIES OF THE CONNECTION SUPERALLOY HAYNES H 230® USING MICROWELDING

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Abstract

The article presents preliminary results of microwelding thin sheet occurred of superalloy H 230®. There were shown the possibilities of combining thin metal sheet using resistive pulse microwelding. The joints were made using a device to microwelding SST WS 7000s. For characterizing of the obtained weld tests properties there were examined mechanical properties like: measuring the microhardness, stretching test and microstructure observation. Microhardness measurements of the joints and base material where taken using *Matsuzawa Vickers MX 100* type with applied load 100G (0,98 N). Stretching test where made on Zwick/Roell Z100 machine with applied load 10kN. To observe mentioned joints, metallographic microscope *Nikon Eclipse MA2000* was used. The studies determined the basic parameters of microwelding thin sheet of joint made and the quality of the weld. The results showed that there is a possibility of obtaining the satisfying quality joint using micro welding between the thin sheet from superalloy H 230®.

Keywords: microwelding, surface engineering, microstructure, microhardness

INTRODUCTION

Throughout the world there are conducted intensive research, concentrated on developing techniques based on creation and processing of materials by an electric discharge. Primary factor determining technology development is availability of power devices for the purpose of generating electrical impulses with the assumed course and sufficient current-voltage parameters [1,2,3,4]. The exploitation of electrical impulses takes important place also in the joining elements technique – like microwelding.

Janos Dobranszky defines microwelding as: "all these welded joints, which are proper for joint thin sheet metals and wires build-in with thickness or diameter less than 0,5 mm, or cross-section is no greater than 0,5 x 0,5 mm" [3]. Microwelding is used for reparation and regeneration of foundry molds as a joining technique in jewelry and electronics industry, and even aerospace. Microwelding is also applicable wherever you need a very precise welds made of small dimensions. Therefore, microwelding is used where due to the small size of the deposition areas conventional welding techniques are excluded of use. This allows for the formation of the deposited layers thickness greater by an order of magnitude, comparing to the ESD technique [5,6,7,8,9]. Microwelding resistive-pulse technique allows for a significant increase in scope of repairs arising comparing to traditional methods of regeneration [10,11,12]. Nowadays, achieved by modern equipment for microwelding current voltage parameters indicate the possibility of producing connections of elements made of Ni-based called superalloys. One of mentioned superalloys applied in technique is Haynes H 230®. In the available literature, the authors frequently shall take the study of Superalloys thin sheet connections made by various microwelding methods [11,12,13].

To obtain precise and clean welds on very small and thin components, these techniques may not be sufficient. At this time the resistive pulse microwelding is not very popular method of joining and repairing of such elements. This method allows for welding most known metals and their alloys so seems to be unique and versatile. Reports on literature confirm, that the method has been investigated at all kinds of stainless steel, titanium, platinum, gold, silver and many others.[9,12] High power pulse focused at one point in a split second melt metal while allowing for cooling distal portion. Pulse microwelder is a great alternative to expensive laser equipment in industries such as prosthetics, jewellery and many more.

1. MATERIALS AND EXPERIMENTAL PROCEDURE

In the paper microstructure and mechanical properties of resistive-pulse microwelded lap joints are investigated. Microstructure is characterized by metallurgical analysis and micro-hardness measurements. Mechanical behavior is studied by tension tests, which provide the tensile strength, longitudinal deformation, as well as typical failure mechanisms.

1.1. Base materials and lap microwelded joints

Haynes H230 is a nickel-chromium alloy with tungsten and molybdenum additions. This alloy has excellent oxidation resistance (1150°C) and superior strength at high temperature, outstanding resistance to oxidizing environments up to 1150°C for prolonged exposures, resistance to nitriding environments, and excellent long-term thermal stability. Haynes H230 also provide excellent service in clean and moderately-dirty environment. It is readily fabricated and formed. Haynes H230 is also mark by lower thermal expansion characteristics than most alloys, and a pronounced resistance to grain coarsening with prolonged exposure to high-temperatures. [14]

Table 1 Composition (in wt%) of the base material. [14]

	Ni	Cr	W	Mo	Co	Al	La	Mn	C	Si	Ph	S	B	Ti	Cu	Fe
MIN	47.00	20.00	13.00	1.00	-	0.20	0.005	0.30	0.05	0.25	-	-	-	-	-	-
MAX	65.00	24.00	15.00	3.00	5.00	0.50	0.005	1.00	0.15	0.75	0.03	0.015	0.015	0.10	0.50	3.00

Haynes 230 alloy has also excellent forming and welding characteristics. The alloy can be welded by a variety of techniques, including Gas Tungsten-Arc (TIG), Gas Metal-Arc (MIG) Shielded Metal-Arc (coated electrodes), and resistance welding techniques. The welds 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 application of welding time ranges from 0,1 ms to 99 ms with increments of 1, 5 or 10 ms. Welding-current value generated reaches 11 900 A at a voltage of +/- 5 V. The device allows you to use electrodes silver-tungsten - non-magnetic diameters from 2,5 to 8 mm and magnetic electrodes with diameters of 2,5 and 4,5 mm. Magnetic electrodes shall apply to ferromagnetic powder surfacing [15]. The welding parameters are summarized in Table 2. No post-weld heat treatment was applied after welding.

Table 2 Microwelder SST WS 7000s – Characteristics [15]

Parameter	**Characteristics**
Supply	1~220V/50Hz/60Hz
Type of Converter	Medium frequency 5kHz
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

Parameter	Characteristics
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 laser-welded lap joints were obtained by welding two overlapping thin sheets with a Microwelder. The microwelding SST WS 7000s machine where used to join thin sheet from superalloy H 230®. The following parameters were used:

- the applied welding amperage in the range of 40-60% of the power device (max. 7000 A);
- used for the welding time in the range of 6 ms to 20 ms;
- selected form of impulse: powder and wire-ribbon;
- duty cycle: multi impulse welding cycle.

1.2. Weld microstructure

To illustrate structures of joints there was used the optical microscopy. The microscope Nikon MA 200 Eclipse with the image analysis system NIS 4.20 for metallographic specimens testing was used. During the preparation process for the joint were cut across the weld and mounted in resin. After proper polishing and etching the weld structure was subjected to observation.

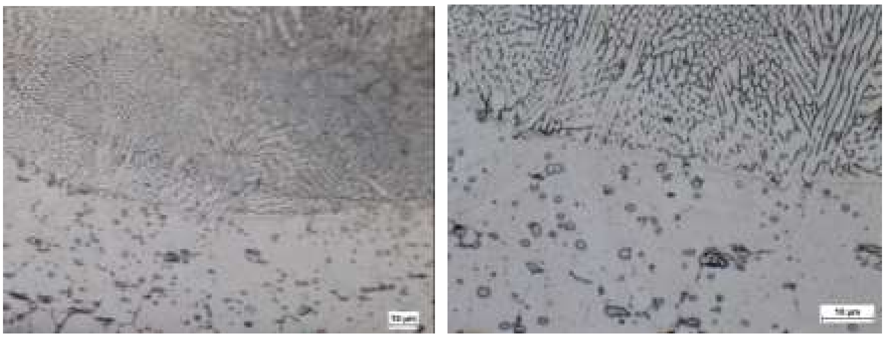
A  B

Fig. 1 Microphotography of weld structure; magnification A) x500 B) x1000

1.3. Microhardness of microwelded joints

Microhardness tests were carried out by using a Vickers indenter, with an applied load of 100G(0,98 N) for 15 s. The indentations were positioned at regular intervals in the transverse direction across the weld zone, from the fusion zone up to the base metal. Microhardness values were measured at the center of both the upper and lower sheets of microwelded lap joints. For investigation there was used Matsuzawa Vickers microhardness MX 100 type. There was applied load 100G(0,98 N). Results are shown in the figure 2.

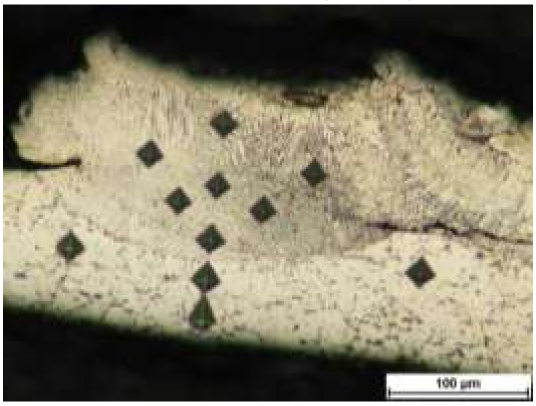


Fig. 2 Imprints on the indenter on the joint cross-section.

1.4. Tensile tests

Tensile tests of base metal sheets were performed according to the standard EN ISO 6892-1 [16] for tension testing of metallic materials. Steel sheets were shaped by mechanical cutting into dog-bone shaped specimens, with a width of 14 mm and a gauge length of 50 mm, see figure 3.

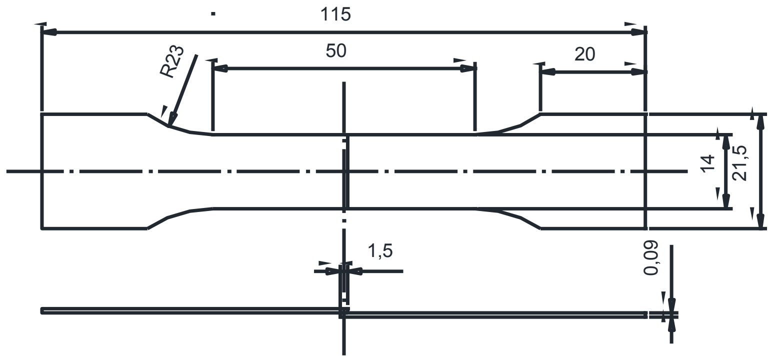


Fig. 3 Tensile specimen according to specification; all dimensions in millimeters

The specimens of base metal sheets were intentionally designed to have identical dimensions of lap joints with linear weld, see figure 4, to allow a comparison of load-displacement curves. Tensile tests of base metal were carried out using a electromechanical Zwick/Roell Z100 testing machine, with a 10 kN load cell. The cross-head speed was 0,1 mm/min, in the elastic range, and the plastic range of the tensile curve. Tensile tests of microwelded lap joints were carried out on a Zwick/Roell Z100 testing, under displacement control mode, with a speed of 1 mm/min. Tensile tests were replicated for each microwelded sample in configuration listed below table 3.

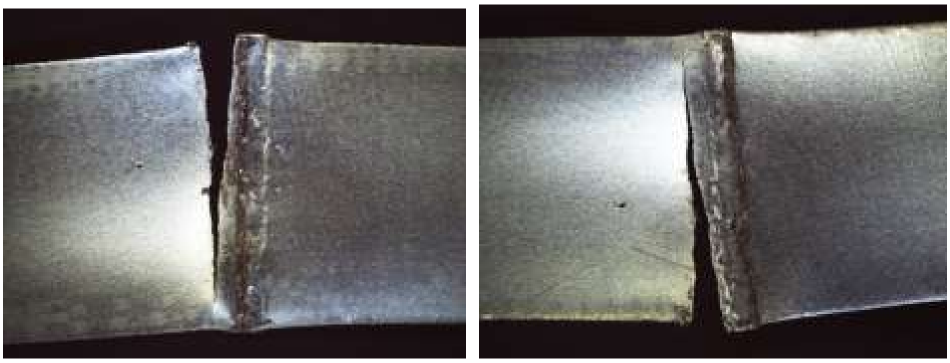


Fig. 4 Macrophotography of the fracturing joint on sample No 5

2. RESULTS AND DISCUSSION

2.1. Metallurgical observations

The figure 5 shows examples of optical micrographs of the etched cross-section for welded joints with both linear weld geometry. Different 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 remelting 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).

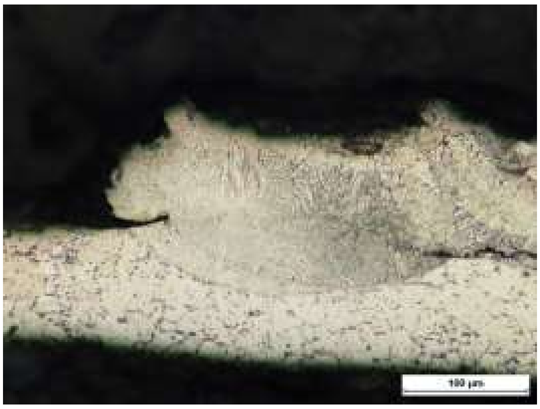


Fig. 5 Optical micrographs of the etched cross-section for welded joints

The HAZ has an average width ranging from a few µm, which is characteristic for used techniques of welding [10,11,12]. 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.

2.2. Microhardness tests

The microhardness distribution in the cross section of microweld is relatively balanced and does not exceed 70 µHV 100. It was expected that at the center of the microweld zone will be the lowest hardness.

The micro-hardness profiles are plotted in figure 6 with values for both upper and lower sheet in welded specimen. 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 330–402 HV, and BZ ranged in values 288–295 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.

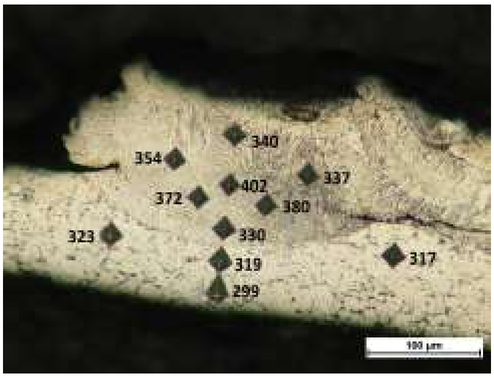


Fig. 6 The micro-hardness distribution

Where it was attributed to a self-annealing effect occurred by many microwelds impulses at the edge of re-melted zone, due to a reduced fast cooling compared to metal, while higher cooling rates characterized the center of weld zone [17].

This remark could explain why this hardness decay has mostly been observed in the top sheet that is closer to impulse source, where higher temperatures are observed [17]. The width of hardness profile in FZ is generally higher in the sheet connect zone, compared to bottom one and upper one, due to a larger FZ caused by the higher impedance on this zone as mentioned above.

This particular trend can be correlated to the different width of weld zone, which is influenced by the position and thickness of welded sheets. In particular, a larger FZ characterizes the top sheet directly exposed to impulse source influence (see also micrographs in figures.5.). Furthermore, a larger thickness of "cold" for bottom sheets also promotes a faster cooling during welding. and thus harder microstructures. A rapid decrease of hardness occurs within the HAZ around the FZ. This decrease, although not very pronounced, can easily be detected, especially for the lower sheet in that is no-directly exposed to the impulse source. This lower hardness values, observed in the HAZ, characterize the ‘‘softer’’ microstructures that are induced by the lower cooling rate promoted by further heating by next impulses during pulse-microwelding process as discussed in the previous section.

2.3. Tensile tests

Tensile tests: strength, deformation and failure mode Typical stress–strain curves for base metal steels are shown in figure 7. HAYNES 230 exhibit high-ductility behavior, with investigated joining no 5 having the largest elongation at failure (Figure 7).

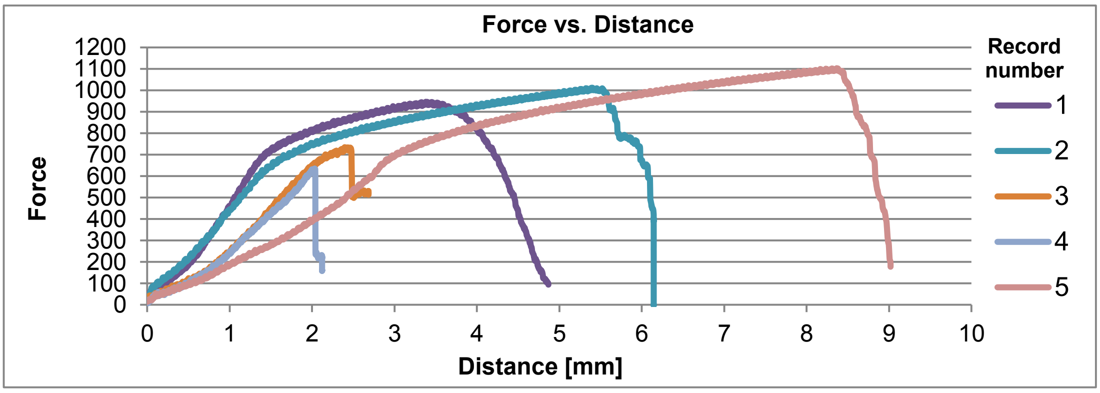


Fig. 7 Load–displacement curves of microwelded lap joints

Conversely, the 4 joining shows, as expected, the highest strength compared to 1 material. The load–displacement curves of microwelded lap joints are shown in figure6. All plots also show for comparison the tensile test curve for Haynes 230, together with a tensile curve (colorized line). A summary of experimental results is also given in Table 3.

Table 3 A summary of experimental results.

Number	R_m [MPa]	F_{max} [kN]	A_{gt} [%]	a_0 [mm]	b_0 [mm]	S_0 [mm^2]
1	753	0,95	5,7	0,09	14	1,26
2	801	1,01	9,0	0,09	14	1,26
3	587	0,74	4,0	0,09	14	1,26
4	507	0,64	3,4	0,09	14	1,26
5	880	1,11	13,9	0,09	14	1,26

For each tested specimen, the table gives the maximum load, the deformation at a fracture. The maximum load per unit sheet width is also calculated. In all welded joints, the fracture was occurred at BM, in some distance away from the weld. This confirms that a full penetrated bead, characterized by an increased microhardness and thus by increased yield strength compared to base metal, is the strongest part of the welded specimen. As expected, welded specimens no 3 failed at the weakest joint (3), while specimens No 4 failed in the highest parameters of welding. Some samples of fractured specimens are given in figure 5. Experimental results confirm that the strength of tested microwelded specimens is controlled by base metal. However, a direct comparison with the tensile curve for base metals is possible. As shown in figures 6, all tested welded joints showed a failure of high ductility values, still lower than base metal. Similarly to strength, also the elongation of welded specimens cannot be directly compared to base metal. This can be explained by the overlap length of 1 mm in welded joints, which reduces the active gauge length to approximately one half of total sheet length. The sheet in the welded joint then behaves with a reduced gauge length, compared to the sheet used in base metal tensile test. It can be concluded that the overlap configuration of lap joints reduces the deformation capability of the specimen under shear loading, compared to a homogeneous metal sheet with identical width and length. But to obtain a combination of such thin elements it is necessary. During the tests, the weld bead rotates as the applied displacement increases, due to the offset of the applied load. The rotation angle is influenced by the weld geometry and by the thickness of welded sheets as well. Although for so thin sheet it has less meaning [17].

CONCLUSIONS

This paper presented a microstructural and mechanical characterization of microwelded lap joints in thin Haynes 230 sheets. Welded specimens with linear weld bead were studied. Characterisation was based on metallurgical observations, micro-hardness measurements and tensile tests, which gave information on the ultimate tensile strength and fracture mode of welded specimens. The main findings of this study can be summarised as follows:

a) micro-hardness profiles in all tested joints confirmed an increment of hardness in the weld zone and heat-affected zone.
b) all tested specimens fractured in the base metal, far away from the weld zone.

This means that the overall joint strength is controlled by base metal strength, which is consistent with a full penetrated weld zone characterised by higher micro-hardness (and hence higher static strength) compared to base metal.

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