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THE IMPACT OF MICROSTRUCTURAL NON-CONFORMITIES ON MICROHARDNESS OF EN AW 5754 ALUMINIUM ALLOY WELDED JOINTS MADE WITH THE USE OF THE TIG METHOD

Wpływ nieprawdłowości mikrostrukturalnych na mikrotwardość połączeń spawanych wykonanych ze stopu aluminium EN AW 5754 przy użyciu metody TIG

***Abstract**: The article presents the impact of welding non-conformities on microhardness of EN AW 5754 aluminium alloy welded joints made with the use of the TIG method. The results of microhardness tests of welded samples made with various process parameters. The impact of the welding non-conformities disclosed with the use of a tomographic method on the welded joint microhardness were analysed. The studies showed a strong link between the participation of welding non-conformities, welding process parameters and microhardness of welds.*

Keywords: aluminium alloy, weld, microstructure, non-conformities, microhardness

***Streszczenie**: Niniejszy artykuł opisuje wpływ nieprawidłowości spawalniczych na mikrotwardość połączeń spawanych wykonanych ze stopu aluminium EN AW 5754 przy użyciu metody TIG. Wyniki badań mikrotwardości próbek spawanych wykonano za pomocą różnych parametrów procesu. Dokonano analizy wpływu niezgodności spawalniczych ujawnionych przy użyciu metody tomograficznej na mikrotwardość połączeń spawanych. Badania ukazały silne powiązanie pomiędzy obecnością nieprawidłowości spawalniczych, parametrami procesu spawalniczego oraz mikrotwardością spoin.*

Słowa kluczowe: stop aluminium, spoina, mikrostruktura, nieprawidłowości, mikro-twardość

1. Introduction

During operation of a machine, malfunctions and damage to elements made with the use of a welding method appear; they result from the impact of the external environment, ageing and wear processes [10, 11]. Moreover, the weld non-conformities arising as a result of incorrect selection of process parameters and execution errors associated with failure to comply with welding procedure requirements, contribute to their formation. The second group of factors causing damage to the elements with welded joints are mechanical and thermal loads of different value and nature [1, 4, 9]. They occur as both static and dynamic loads. A static load is constant or changes very slowly over time in terms of value, direction and point of application. Static forces induce deflections caused by constant load of the structure. However, the dynamic loads are characterised by variable and sometimes rapid action of external or inertia forces generated as a result of mass acceleration [2, 12]. In order to ensure safe and reliable operation of welded structures, it is necessary to satisfy numerous process requirements. The studies on the impact of the microstructural non-conformities of the EN AW 5754 aluminium alloy weld, made with the use of the TIG method TIG (tungsten inert gas, i.e. a method of welding with a non-consumable tungsten electrode shielded with inert gases), on the weld microhardness were undertaken. Five sets of samples with the names of SPI to SPV containing seven samples in sets were adopted for tests. In each set, the welding technology parameters were changed in accordance with table 1. After the welding process completion, the samples were tested for the participation of microstructural defects and welding non-conformities. The tests were implemented with the use of computed tomography [3, 5, 12, 13]. The test results of samples and acceptable values of the welding nonconformities expressed in PN-L-01426 [6] and PN-ISO 5817 [7] standards were presented in table 2. Unacceptable values were marked in red.

Table 1

Welding parameters in particular sets of Samples

	SP JOINTS	CURRENT [A]/ BALANCE	AC CURRENT FREQUENCY [Hz]/ TUNGSTEN ELECTRODE TYPE	SHIELDING GAS FLOW ARGON [l/min]	WELDING SPEED [m/min] Min-max	FILLER METAL Grade/ diameter [mm]
DIRECTION OF CHANGES ↓	SPI	130/-25	90/WP20	13	0,044÷0,060	AlMg3 / 2,4
	SPII	130/-25	90/WP20	20	0,035÷0,050	AlMg3 / 2,4
	SPIII	130/-10	90/WP20	14	0,050÷0,060	AlMg5 / 2,4
	SPIV	140/-10	90/WP20	14	0,030÷0,070	AlMg5 / 2,4
	SPV	140/-10	90/WP20	20	0,01÷0,015	AlMg5 / 2,4

Table 2

Welding non-conformities expressed in accordance with the PN-L-01426 [6] and PN-ISO 5817 [7] standards

TYPES OF NON-CONFORMITIES IN INDIVIDUAL WELDS	SPI			SPII			SPIII			SPIV			SPV		
	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3
DIMENSIONS OF GAS PORES – NON-CONFORMITY LENGTH L [mm]															
ROUND 1	1	---	1	0.5	---	---	0.7	0.5	---	0.7	1.2	1.2	0.1	0.3	---
ELONGATED 2	---	1.5	---	---	---	---	---	---	0.7	---	---	0.12	---	---	---
PORE CHAIN/DEFECT LENGTH[mm] 3	---	---	---	---	---	---	1.6	---	---	---	---	---	---	---	---
SOLID INCLUSIONS 4	1	2	1.2	2	2	---	25	2	7	---	10	---	---	---	---
NO JOINT PENETRATION 5	30	2	---	30	30	30	15	---	30	---	30	---	---	---	---
WELDING NON-CONFORMITIES RELATED TO SHAPE															
UNDERCUT/DEPTH [mm] 6	0	0	0	0	0	0.2	0	0	0	0	0	0	0	0	0
EXCESSIVE CROWN REINFORCEMENT – PN-ISO 5817 CRITERIA h max [mm] 7	1.5	0.5	0.3	0.7	1.5	0.5	2.3	1.5	2.5	1.2	1.0	1.5	1	1	1
LEAKAGE FROM THE WELD ROOT - PN-ISO 5817 CRITERIA h max [mm] 8	1.5	2.5	2.5	0.5	1.0	2.0	----	1.5	2.0	2.0	----	1.5	1.8	2	1.5
OFFSET [%] Z 9	12	12	12	----	----	20	25	8	25	----	12	12	---	---	---

2. Microhardness test of welded joints

The microhardness tests of welded joints were carried out by applying the Vickers method with the use of the Innovatest microhardness tester (fig. 1). The hardness measurements were carried out in cross sections of the welded joints in accordance with the Polish standard requirements [8]. The 0.98N penetrator load was applied within 10s. For particular welds, 20 measurements for the path 1 with 80 measurements for the paths 2 and 3 (every 750 µm) in the characteristic areas, including the weld, heat-affected zone (particularly including the fusion line) and the base material.

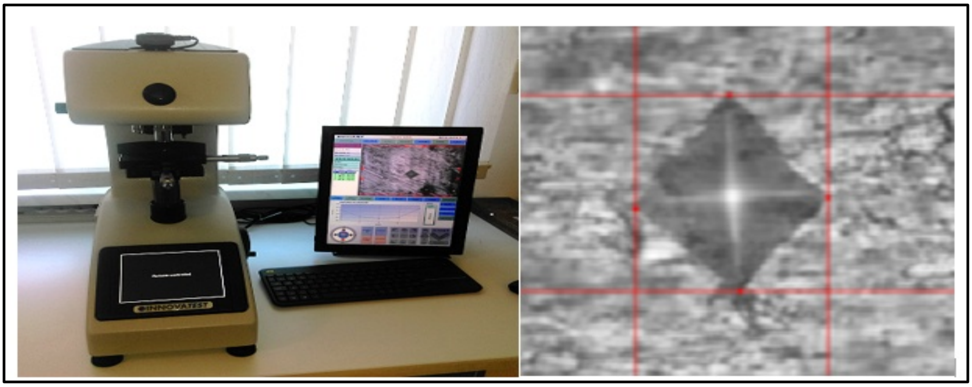

Fig. 1. General view of the Innovatest microhardness tester and the Vicker penetrator imprint

The microhardness measurements for the selected welded joints were carried out along the paths 1, 2 and 3 schematically shown in figure 2. The measurement was carried out on five samples for each type of the weld, taking the results as average values.

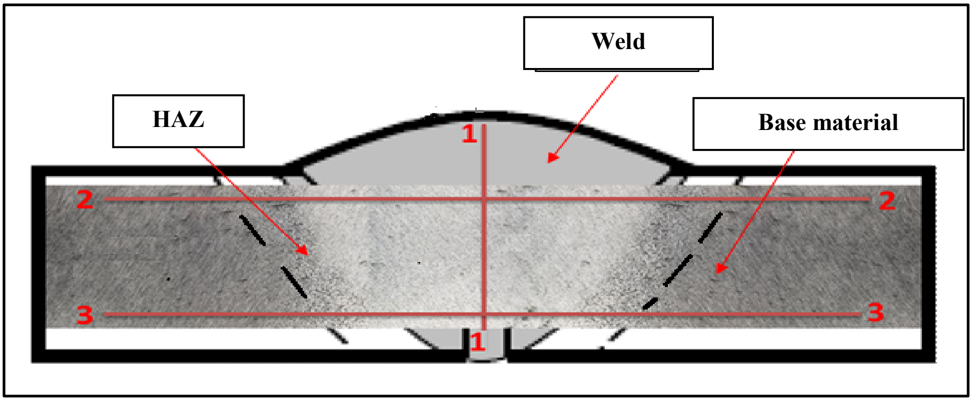

Fig. 2. Microhardness measurement paths of welded joints, HAZ – heat affected zone

3. Microhardness test results with the use of the Vickers method

The microhardness test results of welds applying the Vickers method with the use of the Innovatest microhardness tester were presented in table 3.

Table 3

Summary of the microhardness measurement results along the path 1 from the crown to the weld root and along the paths 2 and 3 from the weld through the heat-affected zone (HAZ) to the base material.

Weld symbol	Measurement path	Average hardness value HV0.1		
		Path 1	Weld	Heat-affected zone
SP I	2	83.3	82.4	81.2
	3		81.6	80.9
SP II	2	83.9	83.4	82.2
	3		82.1	82.7
SP III	2	101.7	99.7	88.4
	3		97.8	91.5
SP IV	2	108.2	108.3	102.4
	3		106.0	101.2
SP V	2	109.3	107.4	103.7
	3		108.8	102.2

On the basis of the measurement results (fig. 3), it was found that the base material microhardness oscillates around 83.4÷88.5 HV0.1. The HV0.1. record means that the hardness test was carried out with a load of the diamond penetrator (shaped like a pyramid with a tip angle of 136°) with the force of 9.81 N. As a result of the carried-out measurements on the cross section of samples, the microhardness distribution was obtained in the characteristic areas of the welded joint. The hardness test results for the SP1 – SPII welds confirmed a slightly higher value of the HV0.1 parameter in the weld area, however, in the heat-affected zone, the hardness values were slightly lower and similar to the base material in terms of parameters. Such slight differences may result from the use of the same grade of aluminium alloy both for the weld and for the base material, as well as too little supplied heat during welding, which would confirm the lack of penetration in these joints. The analysis of the hardness test results of the SPIII÷SPIV welded joints showed that the highest value of the HV0.1 parameter is characteristic of the weld, and then the heat-affected zone, and the base material has the lowest value. The achievement of such an effect is probably associated with the use of another weld grade (AlMg5) than the base material because the AlMg5 weld grade is characterised by higher strength parameters. A base material and filler metal (AlMg3 and AlMg5) mixture with intermediate strength properties for these alloys was formed in the penetration zone. The achievement of full penetration for the SPIII - SPV joints could result in the situation that in the heat-affected zone, as a result of two various aluminium alloy grades, the HV0.1 parameters lower than the weld, and higher than the base material, were obtained. In addition, the observed hardness increases in particular zones of joints for all tested welds results from a decreasing amount of welding non-conformities owing to the introducing changes in the welding process. On the basis of the measurement results, it was confirmed that the SPIII – SPV joints are characterised by the highest hardness value for the tested areas. In these joints, there are no significant welding non-conformities. However, the SPI and SPII joints, in which a number of internal and external non-conformities was revealed, are characterised by the lowest hardness.

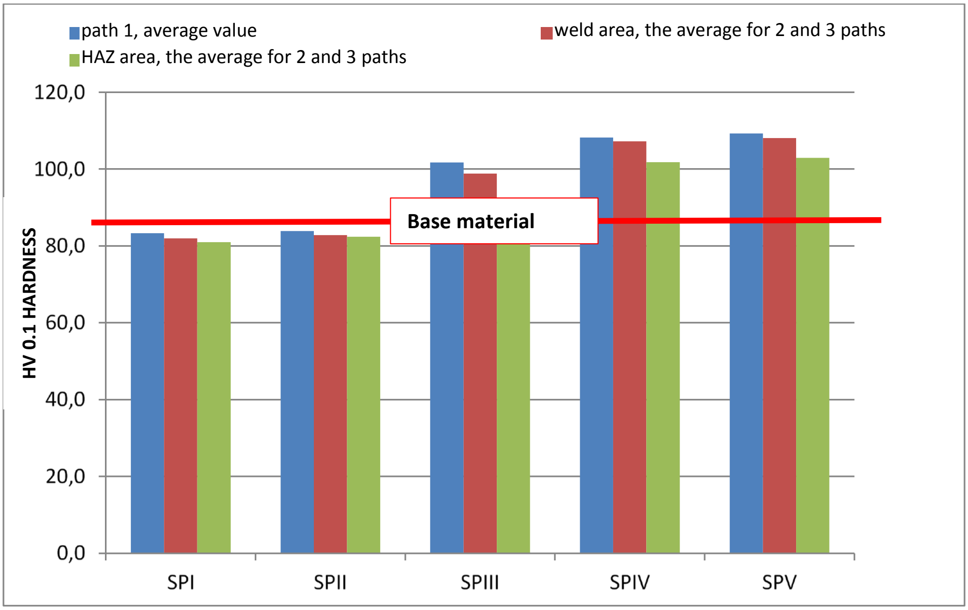

Fig. 3. Hardness distribution for the SPI÷SPV welded joints in relation to the base material

In order to deepen the analysis of the non-conformity impact on the weld quality, the non-conformity participation in the weld volume was assessed. In order to assess the non-conformity participation in the weld, the Un coefficient that is the quotient of the sum of non-conformities (gas pores, solid inclusions and no penetration expressed by the estimated area of non-conformities for individual samples of the SPI – SPV joints and the weld volume estimated with the use of a displacement method) was adopted. Absolute dimensionless quantities were adopted for assessment. The calculated value of the Un coefficient was included in table 4. However, figure 4 presents the dependence of the HV0.1 path 1 weld hardness results (fig. 2) on the Un coefficient value.

$$\mathbf{Un = \Sigma Pn/Vs} \tag{1}$$

Where: ΣPn – sum of non-conformities (gas pores, solid inclusions and no penetration expressed by the estimated area of non-conformities for individual samples of the SPI÷SPV joints),

Vs – weld volume.

Table 4

Estimation of the non-conformity participation in the weld and the Un coefficient value

TYPES OF NON-CONFORMITIES IN INDIVIDUAL WELDS	SPI			SPII			SPIII			SPIV			SPV		
	Pr.1	Pr.2	Pr.3	Pr.1	Pr.2	Pr.3	Pr.1	Pr.2	Pr.3	Pr.1	Pr.2	Pr.3	Pr. 1	Pr. 2	Pr. 3
NON-CONFORMITY AREA P [mm²]															
ROUND 1	0,3	---	0,3	0,3	---	---	0,13	0,3	---	0,3	0,8	0,5	0,1	0,3	---
ELONGATED 2	---	---	---	---	---	---	---	---	0,12	---	---	0,1	---	---	---
SOLID INCLUSIONS 3	0,4	0,5	1,2	1	1	---	10	0,8	6	---	3,5	---	---	---	---
NO PENETRATION 4	80	5	---	90	90	60	15	---	15	---	15	---	---	---	---
NON-CONFORMITIES [mm²]	80,7	5,5	1,5	91,3	91	60	25,6	1,1	21,1	0,3	19,3	0,6	0,1	0,3	0
Vs weld volume and Un coefficient value															
Vs weld volume [cm³]	1,69	2,15	1,69	1,72	1,69	1,74	2,04	2,10	2,15	2,02	1,98	2,15	2,10	2,02	2,12
THE PARTICIPATION OF NON-CONFORMITIES IN THE WELD **Un=ΣPn/Vs**	47,7	2,6	0,89	53,1	53,8	34,5	12,5	0,5	9,8	0,15	9,8	0,28	0.05	0,15	0
AVERAGE VALUE	51			141,4			22,8			10,23			0,2		

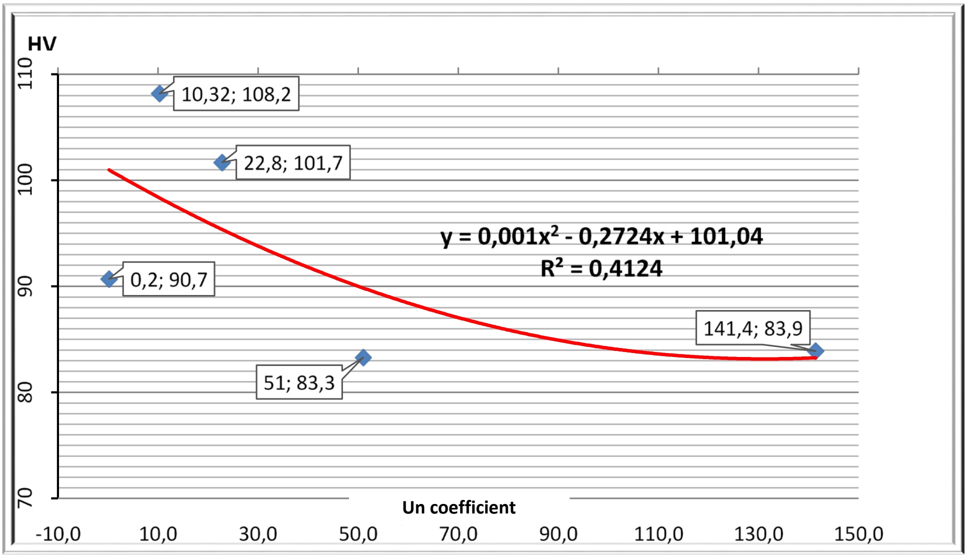

Fig. 4. The dependence of the HV0.1 path 1 weld hardness results (fig. 2) on the Un coefficient value (participation of non-conformities in the weld volume according to table 4)

4. Conclusions

The microhardness test results of the welded joints made with the use of the TIG method confirm the impact of the welding non-conformities on its value. The parameters used in order to make the SPIII - SPV welds allowed to obtain the best quality butt joints. The biggest negative participation of the welding non-conformities was found in the SP and SPII welds, which contributed to lower microhardness values. The lack of penetration and solid inclusions occurring in the weld microstructure (table 4) turned out to be the most important impact on the microhardness value of the tested joints. In addition, it was observed that the weld shape non-conformities in the SPI and SPII also had an impact on the microhardness value.

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