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THE INFLUENCE OF THE BURNISHING PROCESS ON THE HARDNESS AND SURFACE ROUGHNESS OF ALUMINIUM WELDED JOINTS

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Abstract: The article presents the effect of burnishing on the surface roughness and hardness of the EN AW-6060 aluminum alloy after welding. The samples prepared were welded using the 141-TIG method, and then the surfaces to be burnished were prepared in the turning process to remove the weld face and run-out of the workpiece. After the turning process, the process of surface plastic treatment by roller burnishing began. Then, measurements of surface hardness and selected surface roughness parameters were performed. The analysis of the test results showed an increase in the hardness of the surface layer and an improvement in the surface roughness parameters Ra and Rt.

Keywords: aluminum alloys, aluminum welding, treatment by burnishing, surface roughness, strengthening of the surface layer.

1. INTRODUCTION

Burnishing involves applying pressure to the surface of the workpiece with a smooth and hard burnishing element, which is the working part of the burnishing tool, or hitting the surface with burnishing elements. Most burnishing elements are the shape of a ball, a cylinder, a cone, a solid composed of a cylinder and a cone, a segment of a sphere, or a segment of a torus. The burnishing process causes changes in the geometric structure of the surface and plastic deformation of the material of the surface layer of the workpiece [Przybylski 1987].

The fatigue resistance of welded joints made of steel and aluminum is lower compared to the native material. The cause is the notch effect produced by the weld bead, the change in the microstructure (metallic notch) and the possible presence of residual tensile stresses in the weld root. Therefore, many post-weld treatment methods have been developed and approved in recent decades to increase the fatigue resistance of welded joints, for example high-frequency mechanical shock [Marquis and Barsoum 2016; Schubnell and Farajian 2022].

However, the main focus of previous work in this field was to apply post-weld machining of welded joints made of structural steel (typically steel grades range from S235 to S960). In the case of welded joints made of aluminum alloys, the authors' recommendation [Haagensen and Maddox 2013] includes the grinding and needle hammering process, and this also applies to welded joints made of aluminum alloys 5000 and 6000. There is still relatively little literature or data available regarding mechanical post-processing of aluminum alloys. However, some previous studies focus on the use of shot peening for post-treatment of aluminum welds made of 5000 alloys [Wohlfahrt, Nitschke-Pagel and Zinn 1996; Sidhom et al. 2005].

Burnishing is a widely used industrial process of mechanical surface treatment featuring a high degree of automation, used to modify hardness, roughness and residual stresses and to structure the surface. Industrial applications include journals, crankshafts, steering knuckles, engine valves, spindles, threaded bolts, bearings and gears for the automotive, aerospace and railway industries [Schulze et al. 2016]. Juijerm et al. conducted extensive fatigue tests on deep-rolled and burnished samples made of 5000 and 6000 alloys [Juijerm et al. 2004]. These studies have shown that working hardening (increase in dislocation density) can inhibit or delay the initiation of surface fatigue cracks as well as the growth of fatigue cracks, provided that the working hardening state near the surface is stable during cyclic loading.

On the other hand, Schubnell and Farajian (2022) in their tests of welded joints made of EN AW 5083 aluminum alloy achieved a significant reduction in roughness and an increase in hardness at the weld root by applying the diamond ball burnishing process to the joints. However, it should be mentioned that further research must be carried out to optimise the process parameters for this new method of post-weld treatment of welded joints.

2. RESEARCH METHODOLOGY

The preliminary research is aimed at determining the effect of burnishing of EN AW-6060 aluminum alloy pipes on the improvement of the quality of the treated surface with simultaneous strengthening of the surface layer of the welded joint. All measurements of the tested sample, after finishing turning and burnishing, were carried out under production conditions for one sample mounting on a conventional machine tool. Surface roughness and hardness measurements were made using portable measuring devices.

The tests used aluminum pipes with an external diameter of 50 mm, which were welded using the 141-TIG method (argon gas 4.5).

The parameters for the welding process are presented in Table 1.

Table 2 shows the chemical composition and mechanical properties of the filler metal.

Table 1. Welding process parameters

Welding process	**141 TIG**
Joint type	BW (Butt weld)
Welding position	PA (Flat position)
Base material	6060 AlMgSi 0.5
Dimension of testing sample	L = 200 mm ø60
Filler material	ø3.2 mm OK Tigrod 5656
Arc Voltage U [V]	-
Welding Current I [A]	170 – Bead I for the penetration 120 – Bead II for the face
Gas flow rate [l/Min.]	9

Table 2. Chemical composition and mechanical properties of the filler metal

Additional material name	Al	Si	Mg	Fe	Mn	**Mechanical properties**			
						Rm [MPa]	Re [MPa]	A_5 [%]	**AlMg5** **ø 3.2 mm**
OK Tigrod 5356	95	<0.25	5.0	<0.40	<0.20	≥240	≥110	≥17	

The preliminary and finishing turning process was carried out on a conventional TUC 50 x 1000 lathe shown in Figure 1. The sample tested was mounted in a three-jaw chuck, and the cutting process was carried out using a replaceable cutting plate CCGT09T302-DL from DURACARB. The first and second passes of the turning tool in the turning process were intended to remove the weld face and runout of the workpiece. The next pass was a finishing one, which was performed with the following cutting parameters: cutting speed Vc = 170 m/Min., feed f = 0.08 mm/rev and cutting depth ap = 0.5 mm. The turning process was carried out using a cooling and lubricating liquid.

The chuckle-workpiece-tool view is shown in Figure 2.

Fig. 1. TUC 50 x 1000 machine used in the tests

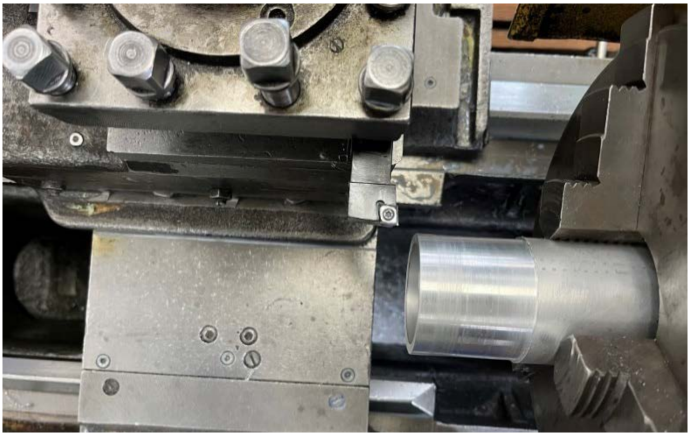

Fig. 2. View of the sample after the turning process

The burnishing process was also carried out on a TUC 50 x 1000 lathe, using an SRMD burnisher from Yamato. The view of the burnishing tool mounted in the tool post and the sample after the turning process are shown in Figure 3.

The burnishing parameters were selected based on process documentation and own research [Charchalis, Starosta and Labuda 2010; Labuda and Khudoley 2016]. The parameters used in the plastic forming of the surface were: burnishing force Fn = 1.1 kN, feed fn = 0.08 mm/rev and burnishing speed Vn = 52 m/Min. The burnishing speed and feed values were selected taking into account the setting capabilities of the lathe. Machine oil was used to perform the burnishing process.

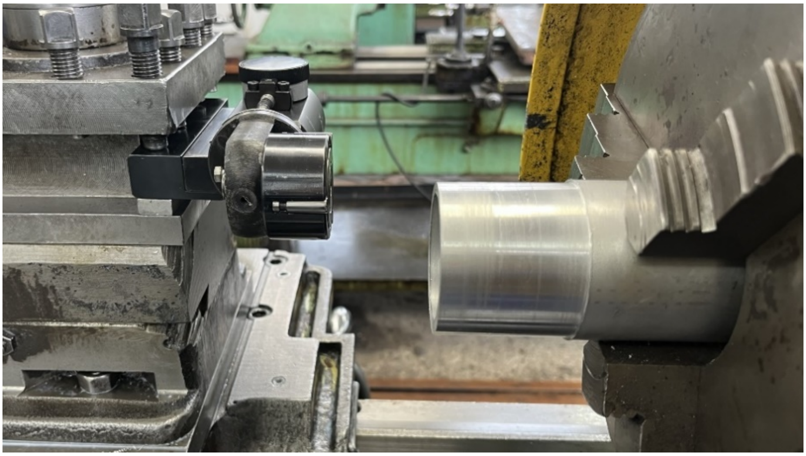

Fig. 3. View of the pressing tool and specimen on the TUC 50 x 1000 lathe

An important role before measuring roughness is played by a preliminary check of the directionality of the profile structure, which is characteristic of particular types of surface treatment, and by a visual assessment of the surface condition, which makes it possible to determine the elementary section. The directionality was adopted along the turning axis so that the tested surface corresponded to the maximum values of the parameters Ra (arithmetic mean of the roughness profile ordinates) and Rt (total height of the roughness profile). The measurement direction was perpendicular to the direction of the irregularities.

The measurement of the selected surface roughness parameters was performed with a Waveline W5-Set profilometer from JENOPTIK (Fig. 4). The value of the elementary section lr for the roughness measurements was 0.8 mm; for the measuring section, it was ln = 4.0 mm. A measurement speed of Vt = 0.5 mm/s was set during the tests.

Fig. 4. Waveline W5-Set profilometer

In order to determine the effect of the treatment by burnishing on the strengthening of the surface layer, the relative surface hardening index Su [%] was determined. The surface hardness measurements were made using an alphaDUR II ultrasonic hardness tester, which is shown in Figure 5.

Fig. 5. AlphaDUR II ultrasonic hardness tester

3. RESEARCH RESULTS

In order to control and determine changes in the surface roughness and hardness of the tested welded joint, three measurement points were placed on the pipe circumference at 120° intervals. In each of these places, an area was marked where measurements were taken.

Figure 6 shows example measurement areas for Point 3.

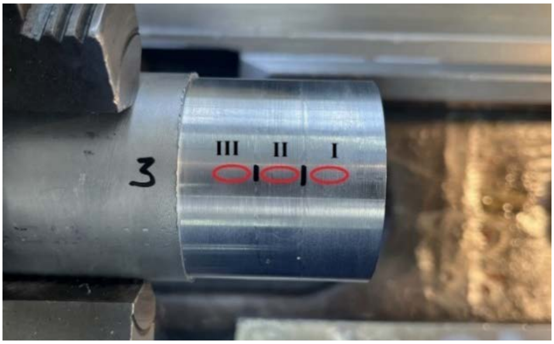

Fig. 6. View of the test Point No. 3 for the test piece

The measurement tables include markings for individual zones according to the following areas:

I – Native material before the weld,

II – Joint,

III – Native material behind the joint.

Five measurements of hardness and surface roughness were made at each measurement location after the finishing turning and after the surface plastic treatment process. Three measurements were included in the basic statistical analysis because extreme values were discarded.

Table 3 presents the results of the basic statistical analysis of the Ra parameter along with the roughness reduction index KRa, which determines the ratio of the Ra value obtained after the finishing turning to the value after the treatment by burnishing.

Table 3. Results of basic statistical analysis of Ra parameter and KRa index

Measurement area	**Basic statistical analysis**	**Ra [µm]**		**KRa [-]**
		After turning	**After burnishing**	
I	Mean value	1.803	0.767	2.4
	Standard dev.	0.113	0.116	
	Standard error	0.038	0.039	
	Min.	1.672	0.572	
	Max.	2.062	0.897	
II	Mean value	1.871	0.095	19.7
	Standard dev.	0.173	0.026	
	Standard error	0.058	0.009	
	Min.	1.545	0.053	
	Max.	2.051	0.131	
III	Mean value	1.912	0.081	23.7
	Standard dev.	0.133	0.016	
	Standard error	0.044	0.005	
	Min.	1.745	0.057	
	Max.	2.139	0.111	

Figure 7 shows a graphical interpretation of the effect of the treatment concerned on the change in the average value of the Ra for the individual measurement zones.

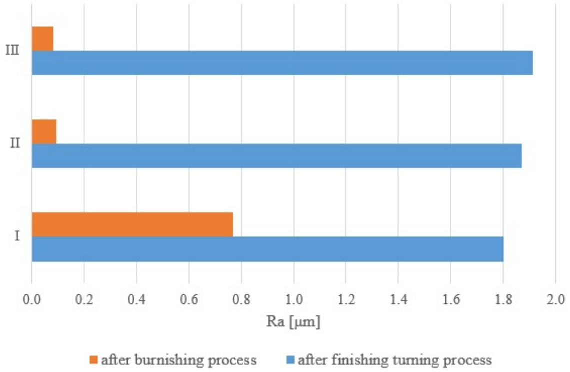

Fig. 7. Effect of burnishing on the change in Ra [μm];
Orange = Before, Blue = After

Table 4 presents the results of the basic statistical analysis of the Rt parameter and the reduction index of the total roughness height KRt, while Figure 8 shows their graphical interpretation.

Table 4. Results of the basic statistical analysis of the Rt parameter and the KRt index

Measurement area	Basic statistical analysis	Rt [µm]		KRt [-]
		After turning	After burnishing	
I	Mean value	11.234	8.861	1.3
	Standard dev.	1.550	1.512	
	Standard error	0.517	0.504	
	Min.	9.043	6.939	
	Max.	13.864	10.498	
II	Mean value	12.238	1.169	10.5
	Standard dev.	1.285	0.372	
	Standard error	0.428	0.124	
	Min.	10.832	0.658	
	Max.	14.966	1.756	
III	Mean value	11.937	0.953	12.5
	Standard dev.	0.869	0.285	
	Standard error	0.290	0.095	
	Min.	10.251	0.552	
	Max.	12.910	1.456	

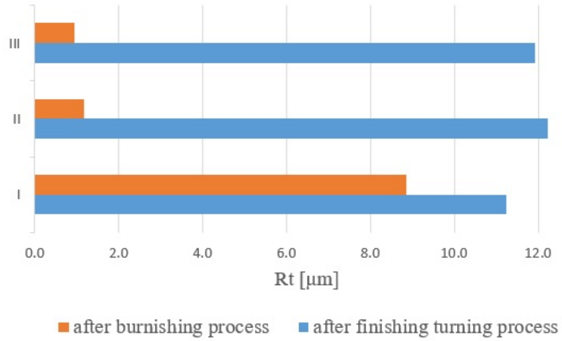

Fig. 8. Effect of burnishing on the change in Rt [µm];
Orange = Before, Blue = After

Measurements of the surface roughness parameters Ra and Rt show that the surface plastic treatment has a beneficial effect on quality of the machined surface. The highest values of the coefficients KRa = 23.7 µm and KRt = 12.5 µm were obtained for measurement zone III (the native material behind the joint). The initial burnishing parameter values used also allowed for a nearly 20-fold reduction in the surface roughness parameter Ra and more than a 10-fold reduction in the Rt parameter for measurements made in the weld area. The lowest values of the coefficients KRa = 2.5 and Rt = 1.3 were obtained on the surface of the native material before the weld.

Figure 9 shows a view of the sample surface after the burnishing process. Peeling of the surface layer occurred in the zone of the native material before the weld, which was probably due to insufficient lubrication of the burnishing roller with machine oil. Moreover, the applied burnishing force of 1.1 kN may have been too high. Another reason may be the fact that, in the first stage of the burnishing process, the burnishing roller eliminated the play in the MCWT system (machine-chuck-workpiece-tool), and the workpiece was not supported.

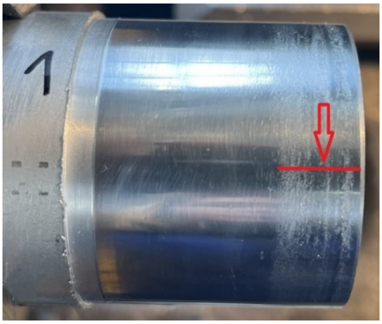

Fig. 9. View of the sample surface after burnishing

Table 5 presents the results of the basic statistical analysis for surface hardness measurements after the finishing turning and burnishing, taking into account the surface hardening factor Su.

Table 5. Results of basic statistical analysis of surface hardness measurement and Su index

Measurement area	Basic statistical analysis	Surface hardness HV		Su [%]
		After turning	After burnishing	
I	Mean value	42.9	54.1	26.2
	Standard dev.	6.1	9.6	
	Standard error	2.0	3.2	
	Min.	34	43	
	Max.	52	74	
II	Mean value	52.6	57.7	9.7
	Standard dev.	4.8	4.5	
	Standard error	1.6	1.5	
	Min.	47	52	
	Max.	63	64	
III	Mean value	38.7	45.7	18.1
	Standard dev.	5.2	6.0	
	Standard error	1.7	2.0	
	Min.	33	38	
	Max.	48	52	

Figure 10 shows a graphical interpretation of the effect of the burnishing treatment on the change in the surface hardness of the tested sample.

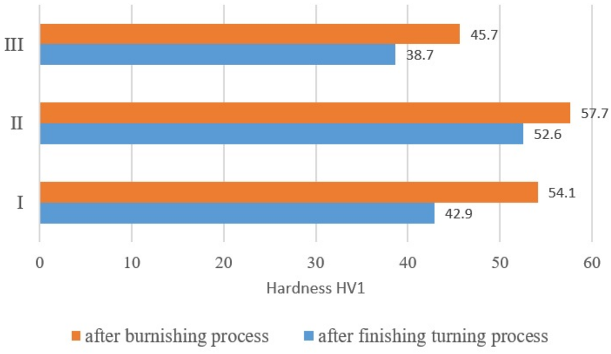

Fig. 10. Effect of the burnishing on the change in surface hardness;
Orange = After burnishing, Blue = After final turning

The burnishing of the welded joint resulted in a 26.2% increase in the hardness of the native material before the weld; after the weld, its hardness increased by 18.1%, and within the weld it increased by 9.7%.

4. CONCLUSIONS

The preliminary tests performed have shown that the burnishing treatment makes it possible to obtain surfaces with Ra parameter values below 0.1 μm for the native material and the weld. At the same time, it can reduce the value of the Rt parameter by smoothing peaks of surface irregularities. The use of the surface plastic processing also brought benefits by strengthening the surface layer of the pipe and the weld. Burnishing the welded joint resulted in an increase in the hardness of the native material before the weld by 26.2%, 18.1% increase after the weld and a 9.7% increase within the weld.

The tests have demonstrated the need to mount the samples tested in a three-jaw chuck with a support, such as a revolving centre, and to ensure adequate lubrication during the process. Therefore, further tests of the burnishing process on welded joints will be performed on a sample mounted in centres with a burnishing force of 1 kN.

The burnishing tool causes plastic deformation of the tops of surface irregularities during the burnishing process. Therefore, reducing the values of the surface roughness parameters analysed while strengthening the surface layer should have a positive impact on selected properties of the welded joint tested. After this, tests of corrosion resistance, contact fatigue resistance and stress distribution tests in the surface layer are planned.

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