EFFECT OF THE BRUSHING PROCESS ON THE STATE OF THE SURFACE LAYER OF BUTT JOINTS MADE OF USING THE FSW METHOD

Wpływ obróbki szczotkowaniem na stan warstwy wierzchniej spoiny wykonanej metodą FSW

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DOI: 10.15199/160.2020.3.4

Abstract: Friction stir welding (FSW) is one of the most modern methods of joining metals and their alloys in a solid state. This method is particularly suitable for joining the materials that are difficult to weld, such as steels and high-strength aluminum, copper and titanium alloys, as well as some nickel, zirconium and copper alloys. It makes it possible to use this method in the production of aviation structures while reducing the labour consumption, cost and weight, while maintaining comparable or higher strength parameters compared to classic methods. However, the face of weld made using the FSW method is often uneven and moreover, the welding process itself introduces tensile stresses in the surface layer, which reduces the fatigue strength of the joints. Brushing is one of the methods of removing the welding burrs. The study investigates the effect of brushing treatment on the selected properties of the surface layer of butt welds of 2024-T3 aluminum alloy. The research was carried out with the use of wire brushes and cutting brushes with ceramic fibers. The analysis of the obtained results showed that brushing with using a wire brush at a feed rate of 70 mm/min (variant 1) introduced the most favorable residual stresses, while brushing with a ceramic brush at a feed rate of 100 mm/min (variant 4) provided the lowest roughness parameters.

Keyword: brushing, Friction Stir Welding, aluminum alloy, brush ceramic tools

Streszczenie: Zgrzewanie tarciowe z przemieszaniem FSW (ang. Friction Stir Welding) jest jedną z najnowocześniejszych metod łączenia metali i ich stopów w stanie stałym. Metoda ta jest szczególnie przydatna do łączenia materiałów trudno spawalnych, jak na przykład stale i wysoko wytrzymałe stopy aluminium, miedzi i tytanu, a także niektóre stopy niklu, cyrkonu i miedzi. Daje to możliwość stosowania tej metody przy produkcji struktur lotniczych przy jednoczesnym obniżeniu pracochłonności, kosztów i ich ciężaru, zachowując porównywalne lub wyższe parametry wytrzymałościowe w porównaniu do metod klasycznych. Lico spoiny wykonanej metodą FSW jest jednak często nierówne a ponadto sam proces zgrzewania wprowadza rozciągające naprężenia własne w warstwie wierzchniej, co skutkuje obniżeniem wytrzymałości zmęczeniowej złączy. Jednym ze sposobów usunięcia zadziorów powstałych podczas zgrzewania jest obróbka szczotkowaniem. W pracy przeprowadzono badania wpływu obróbki szczotkowaniem na wybrane właściwości warstwy wierzchniej spoin blach ze stopu aluminium 2024-T3. Badania prowadzono z wykorzystaniem szczotek drucianych oraz szczotek tnących z włóknami ceramicznymi. Analiza uzyskanych wyników wykazała, że szczotkowanie szczotką drucianą przy posuwie 70 mm/min (wariant 1) wprowadza najkorzystniejsze naprężenia własne, natomiast szczotkowanie szczotką ceramiczną firmy Xebec przy posuwie 100 mm/min (wariant 4) powoduje zmniejszenie parametrów chropowatości.

Słowa kluczowe: szczotkowanie, zgrzewanie tarciowe z mieszaniem materiału, stopy aluminium, szczotkowe narzędzia ceramiczne

Introduction

In the aviation industry, the reduction of fuel consumption and exhaust emissions is an important aspect having an impact on the environment. One of the ways to achieve this goal is, among others, the reduction of the weight of the plane while maintaining very good strength properties of the material. The weight reduction can be achieved through the use of light metals or the use of appropriate joints, while reducing labour consumption, costs and their weight, while maintaining comparable or higher strength parameters compared to the classic methods. One of the most modern methods of joining metals and their alloys in a solid state (at temperatures lower than the melting point of the material to be joined) includes friction stir welding (FSW). This method is particularly useful for joining materials which, according to traditional technologies, are difficult to weld, such as steels and high-strength alloys of aluminum [3, 5, 7], copper and titanium [2], as well as some nickel, zirconium and copper alloys [4]. However, the face of weld made using the FSW method is often uneven and moreover, the welding process itself introduces tensile stresses [10,12, 14] in the surface layer, which results in a reduction of the fatigue strength of the joints. Brushing is one of the methods for removal of the welding burrs. This method applies removing the outer layer of the material with a rotating brush. Brushing is mainly used for burring, deburring and polishing operations. This treatment can be used to create a surface layer with appropriate physical and mechanical properties that differ from the properties of the material core or as a pretreatment the joining process [8]. The high availability and variety of brushes as tools is due to their good productivity, ease of implementation as manual or automatic surface finishing, and even distribution of cutting forces on the surface of the workpiece. As a result, it allows for a controlled removal material process, simple clamping the workpiece and a lower risk of damage to the machine tool and the workpiece [9]. Traditional tools used for surface finish work consist of steel or plastic fibres, their disadvantages are the permanent deformation of the fibres and quick wear, which in turn affects the surface quality [11]. The brushes made of ceramic material by Xebec are the alternative. They present innovative technology in the use of abrasive for surface treatment. Thanks to the unique Xebec technology, the abrasive in the form of fibres allows for a constant machining performance. The fibre abrasive is better than conventional abrasive because it does not tend to stick during treatment. Such a property of the brushes allows maintaining a constant cutting efficiency. One single fibre of the Xebec brushes has 1000 sanding edges. This property of abrasive brushes allows them to be used for precise deburring and polishing operations.

The surface condition of welded joints is crucial from the point of view of their operation. Residual stresses, the geometric surface structure or hardening of the surface layer often determine the strength properties of the weld. Therefore, it is important to analyze the state of surface layer the welded joints.

The study focuses on the analysis of the impact of brushing treatment on the state of residual stresses and the geometric surface structure of FSW welded joints made of 2024-T3 aluminum alloy. Additionally, the possibility of removing flashes, burrs resulting from the welding process with using different kinds of brushes was investigated.

Method

The paper presents the experimental studies the aim of which was to analyze the residual stresses and the geometrical surface structure of butt joints using the FSW method after brushing. The possibility of removing flashes and micro-inequalities resulting from welding with using two types of brushes: wire and with ceramic fibres was also examined. For the tests, the specimens made of aluminum alloy 2023 in state T3 were used. This type of aluminum is employed in the elements that require good strength to weight ratio. This alloy has a low corrosion resistance and low weldability, widely used in the production of aviation components. The welding process was carried out on a universal vertical milling machine JAFO FWF32J2. The FSW process was made with a tool rotational speed of 1300 rpm (n), feed rate of 50 mm/min (f) and depth of 1.7 mm (d). Two sheets of aluminum were fixed in special device and next butt-welded. The thickness of the welded sheets was 2 mm. In the next stage, the welded sheets on the same machine were brushed using two types of brushes: wire brush (Fig. 1a) and with ceramic fibres (by Xebec) (Fig. 1b). The research was carried out according to several variants presented in Table 1.

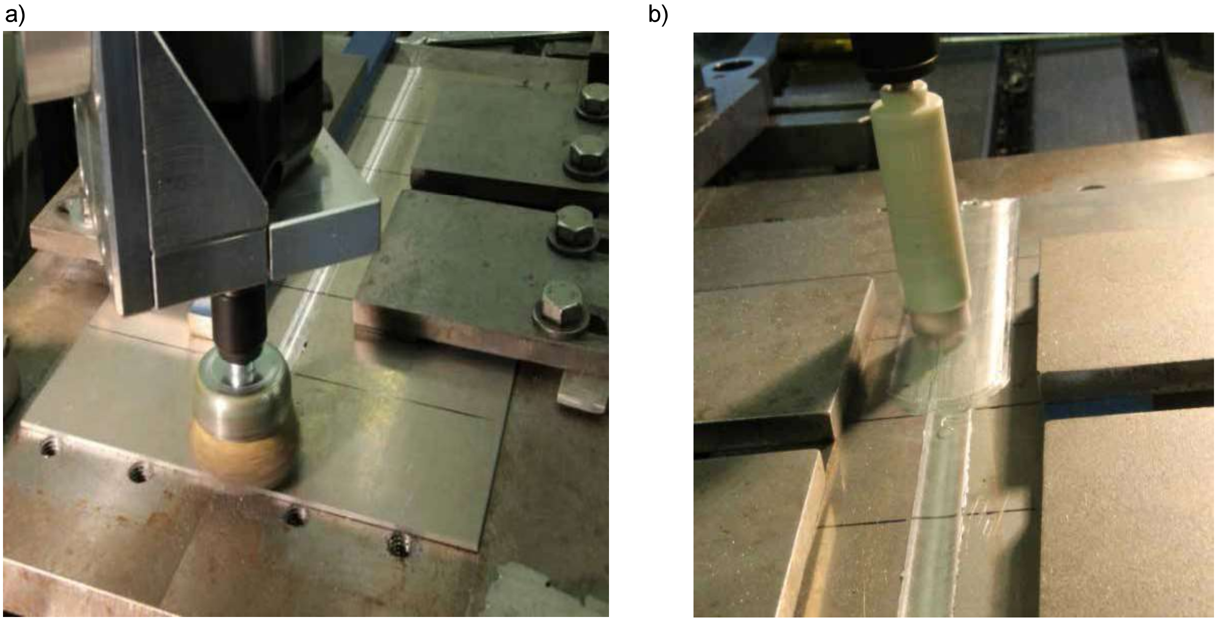

Fig. 1. Brushing with using of: wire brush (a) and brush with ceramic fibres (Xebec) (b)

Table 1. Variants used in the experiment

Variant	Parameters of process		Type of brush/treatment
	Feed rate f, mm/min	Rotational speed V, rpm	
1	70	10 000	Wire brush
2	100	10 000	Wire brush
3	100	10 000	Wire brush+ Xebec
4	100	10 000	Xebec
5	70	10 000	Xebec
6	-	-	Base (without treatment)

The residual stress was measured with the X-ray diffractometer Proto iXRD Combo and computer software XRD Win 2.0 by Proto Manufacturing. The research was carried out at the Department of Materials Science at Rzeszow University of Technology. This device enables measurements to be carried out directly on the tested element - it is a non-invasive test. To calculate the value of residual stresses in a given measuring point, the $\sin^2\Psi$ [1] method was used, which involves the use of symmetrical Bragg-Brentan diffraction. The Ψ-type goniometer allows obtaining appropriate inclinations of the diffraction vector by the angles Ψi in the plane perpendicular to the diffraction plane [13]. In this research was used a lamp with a chromium anode and a beam of CrKα characteristic radiation with a wavelength $\lambda = 2.291$ Å and a collimator diameter of 2 mm, an anode current of 4 mA and anode voltage of 20 kV. The stresses were determined for the constant values of the angle Ψ in the range from 25 ° to -25 °. The elastic deformations in the tested element were carried out for the diffraction line from the {311} family of planes at the angle $2\theta = 139.3$ °. The values of Poisson's ratio = 0.33 and Young's modulus E = 73.1 GPa were assumed in the measurements of residual stresses [6]. The residual stresses were measured on the specimen in the area of the weld at two points in the direction parallel and perpendicular to the direction of welding. The measurements were conducted for the variants after brushing and for the base surface after welding.

The study of the geometric surface structure was performed using the Taylor Hobson Talysurf CCI optical profilometer. The research included the measurements of roughness parameters, profilograms, 3D views. The surface roughness was analyzed according to the variants presented in Table 1.

Results and discussion

The presented three dimensional illustrations show that brushing with using ceramic fibres (Fig. 5 and Fig. 6) mostly removes traces of the tool used in the welding process (Fig. 7), which in effect reduces the surface roughness. For this type of brush, a decrease in the roughness parameter Ra in the range of 84 ÷ 89% (respectively variant 5 and 4) can be observed compared to the specimen without treatment (variant 6). A decreased trend can be also observed for the other amplitude parameters, for example: the Rz parameter, a decrease in the range of 76 ÷ 84% compared to variant 6. The lowest roughness was obtained for variant 4, where the feed rate was f = 100 mm/min. In turn, the largest in the case of brushing with wire brush according to variant 1, where f = 70 mm/min. For this variant, the value of the Ra parameter was 7.94 μm, which is comparable to the base variant (Ra = 8.01 μm). When comparing the roughness profiles, in the case of variant 1 (Fig. 2), we can notice a significant dimpling resulting from brushing with a using the wire brush, where the value of the parameter Rv = 27.4 μm, an increased by 34% in relation to the base surface (Fig. 7). This may be due to the properties of the welded material, which is aluminum. In all the analyzed cases, it can also be observed that the parameter describing the maximum profile peak height Rp decreased as compared to the base variant, in the range of 31 ÷ 91%, which proves that the use of brushes removes irregularities resulting from friction stir welding. The use of the Xebec brush after brushing with a wire brush (variant 3) also had a favorable effect on the roughness. In this case, the parameter Ra decreased about 35% compared to variant 2 (wire brush).

When analyzing the obtained results of roughness, the attention should be paid to the technological parameters of the brushing process. In the experiment, the variable parameter was the feed rate, adopted at two levels: 70 mm/min and 100 mm/min. Both in the case of brushing with wire brush and ceramic brush, the roughness decreases with increasing feed rate (variant 2 and 4). Summing up, it can be stated that properly selected technological parameters of the brushing process, both in the case of using wire and ceramic brushes, reduce the roughness surface of the welded joints.

In turn, the reduction of roughness has a favorable effect on the quality of the welded joints. Brushing removed flashes, notches and micro-inequalities formed during welding (Fig. 8), which could be a source of crack propagation and consequently, reduce the fatigue strength of the joint.

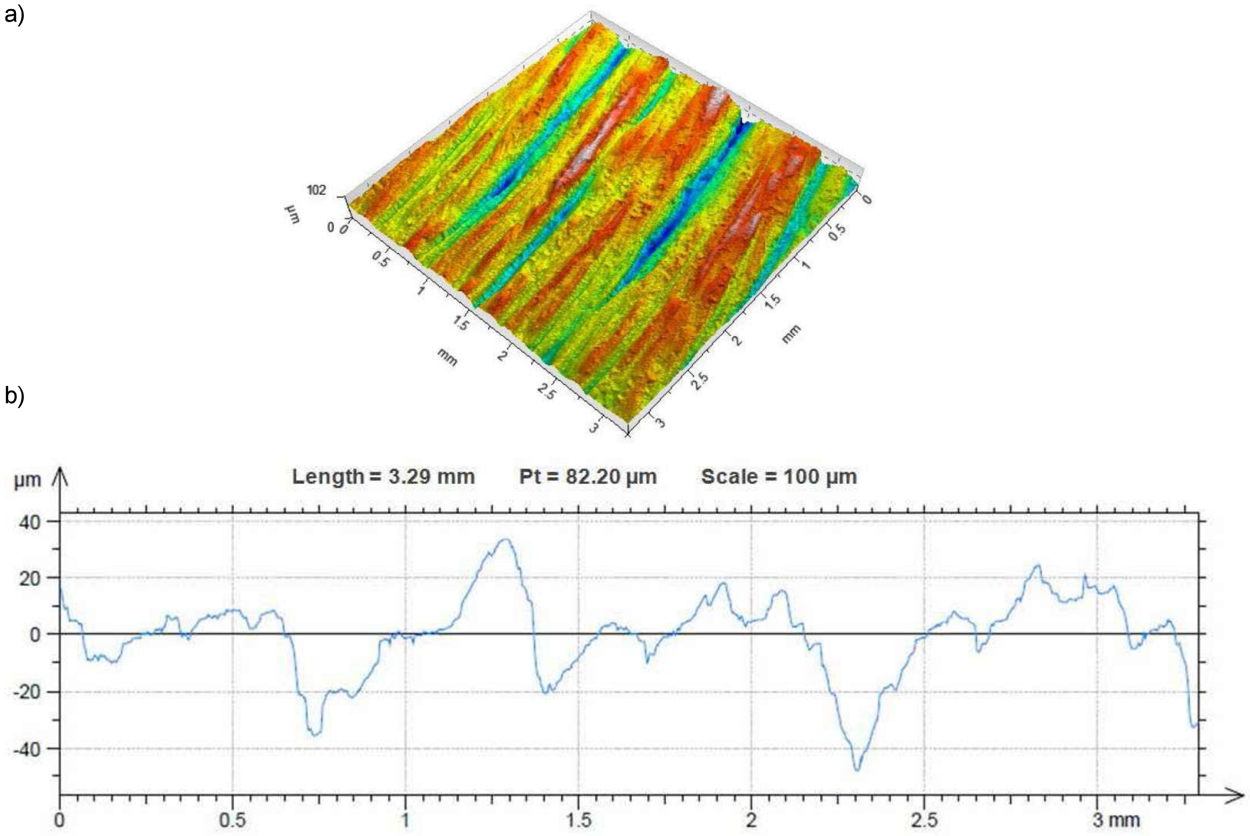

Fig. 2. Three dimensional illustration (a) and surface profilogram (b) of the specimen with brushing, variant 1

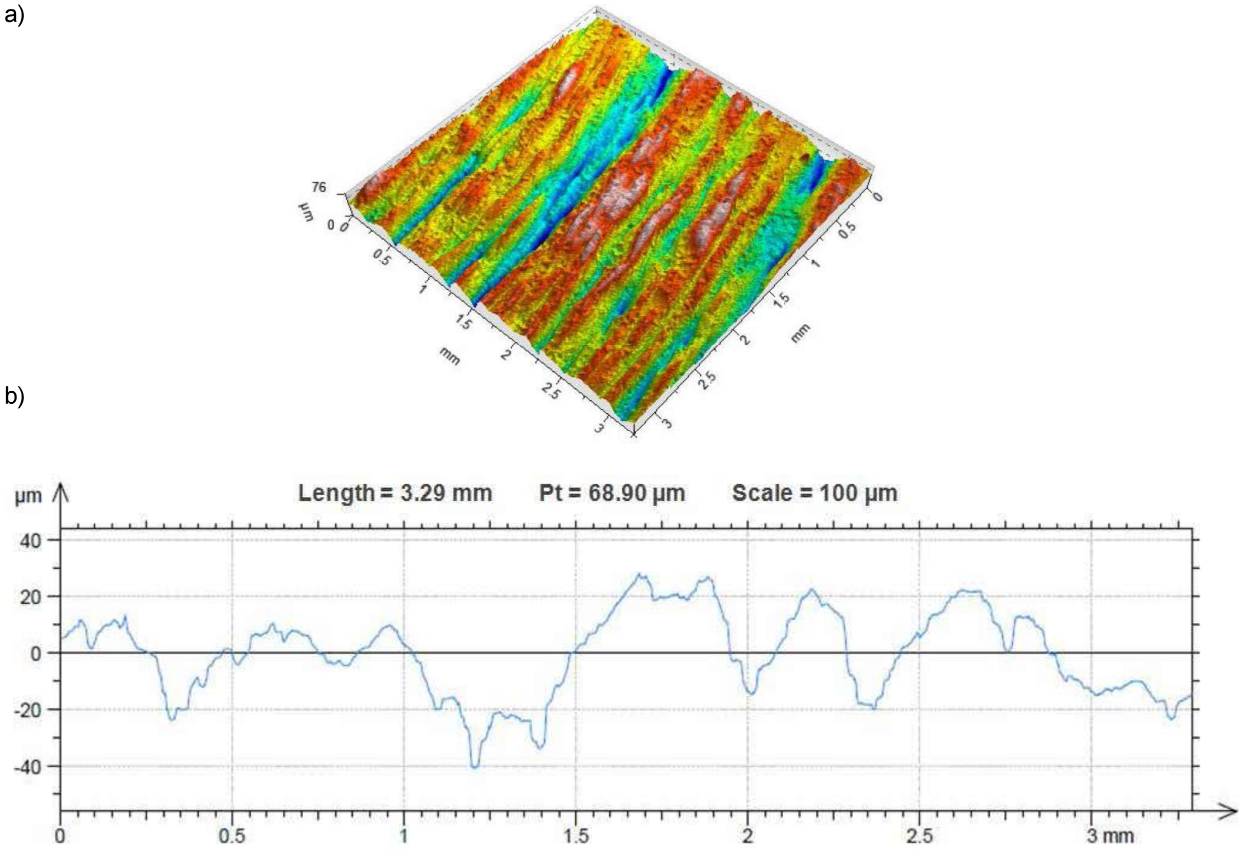

Fig. 3. Three dimensional illustration (a) and surface profilogram (b) of the specimen with brushing, variant 2

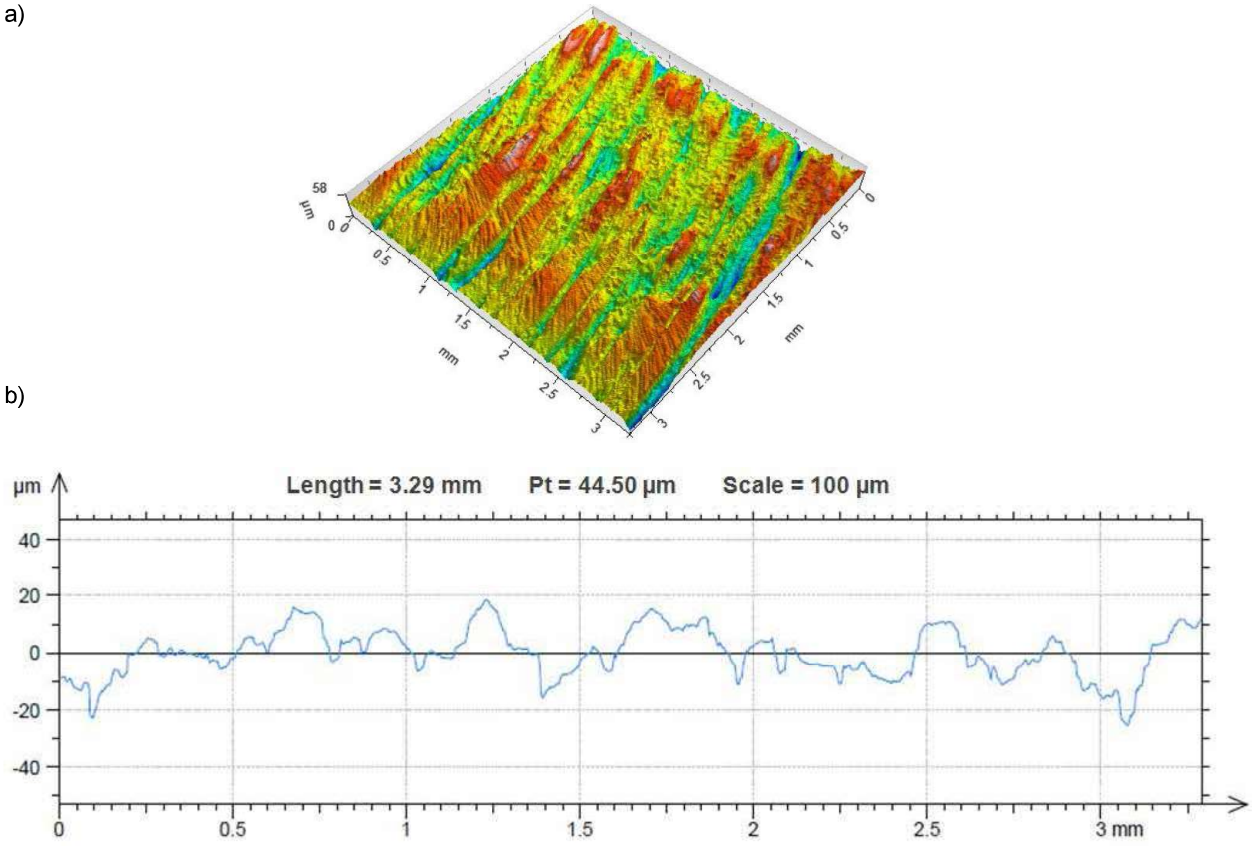

Fig. 4. Three dimensional illustration (a) and surface profilogram (b) of the specimen with brushing, variant 3

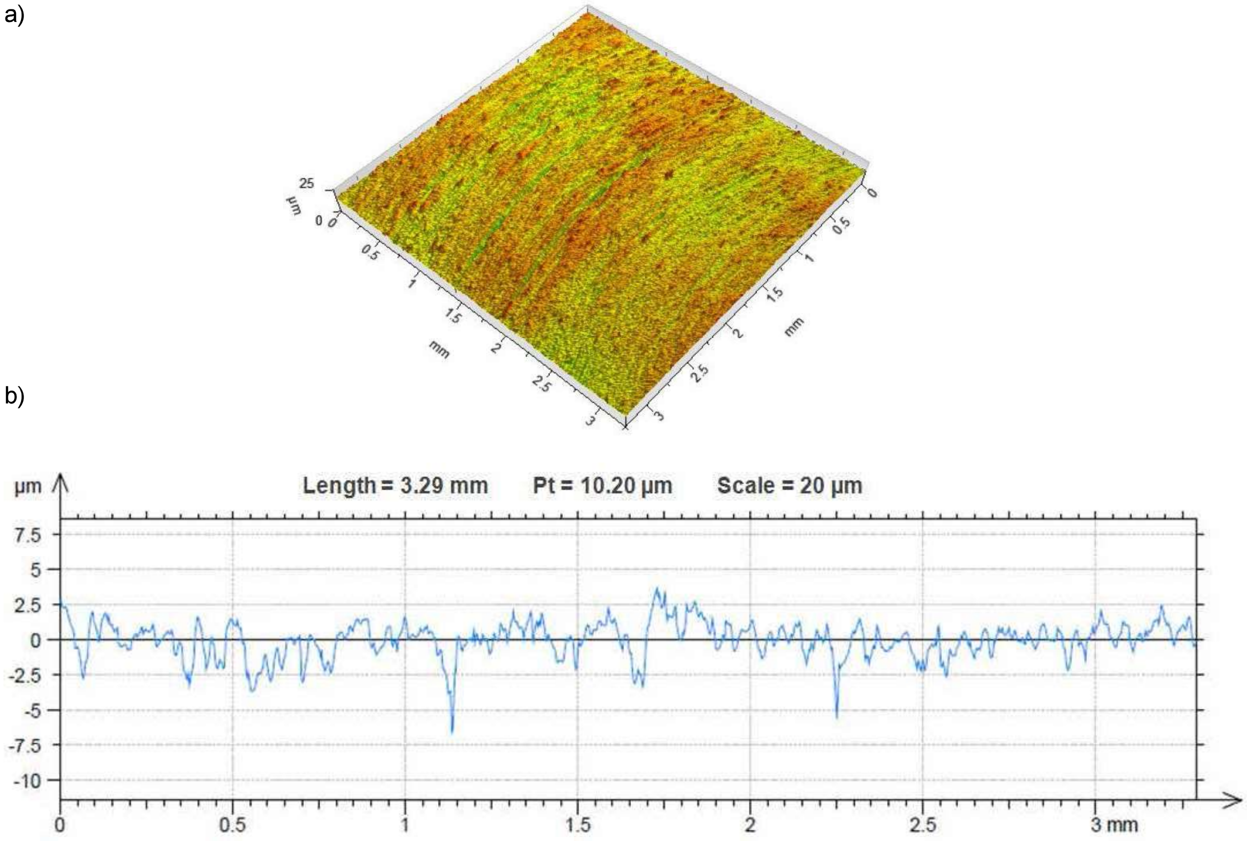

Fig. 5. Three dimensional illustration (a) and surface profilogram (b) of the specimen with brushing, variant 4

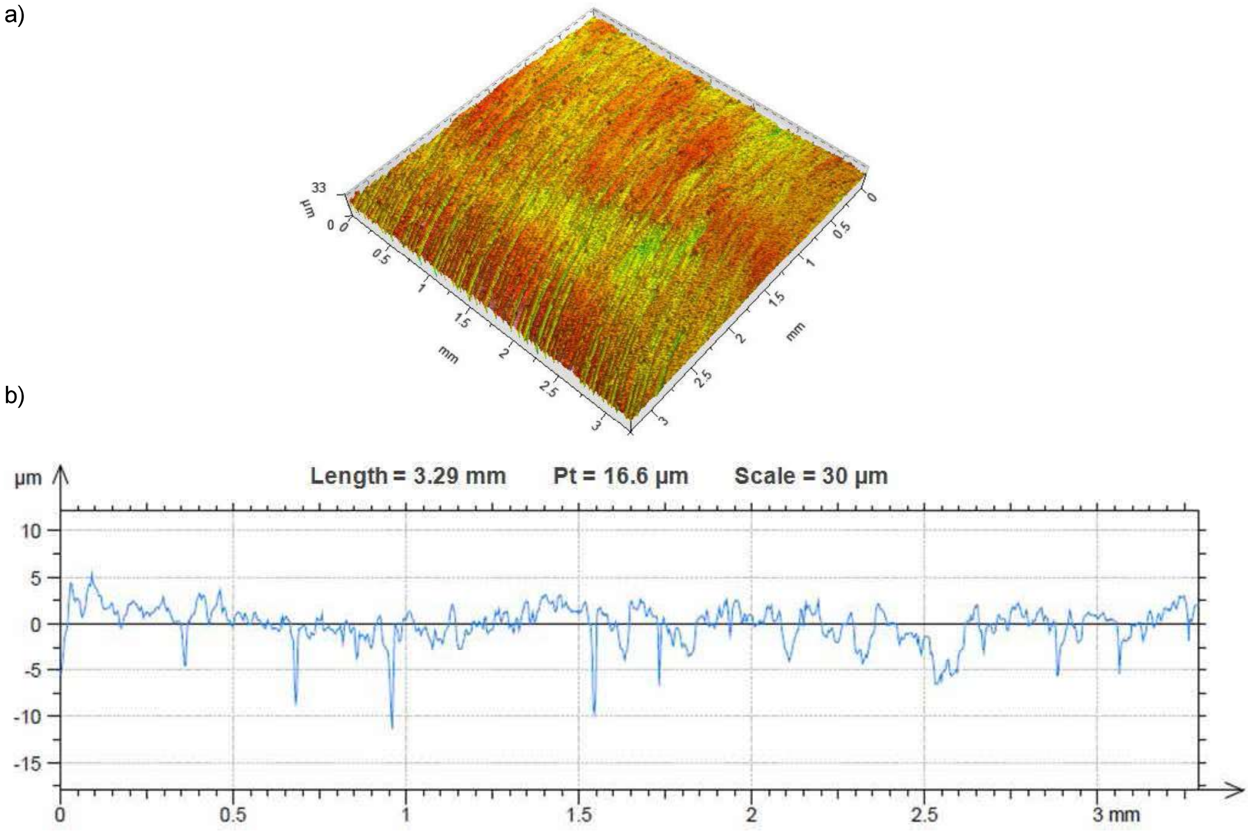

Fig. 6. Three dimensional illustration (a) and surface profilogram (b) of the specimen with brushing, variant 5

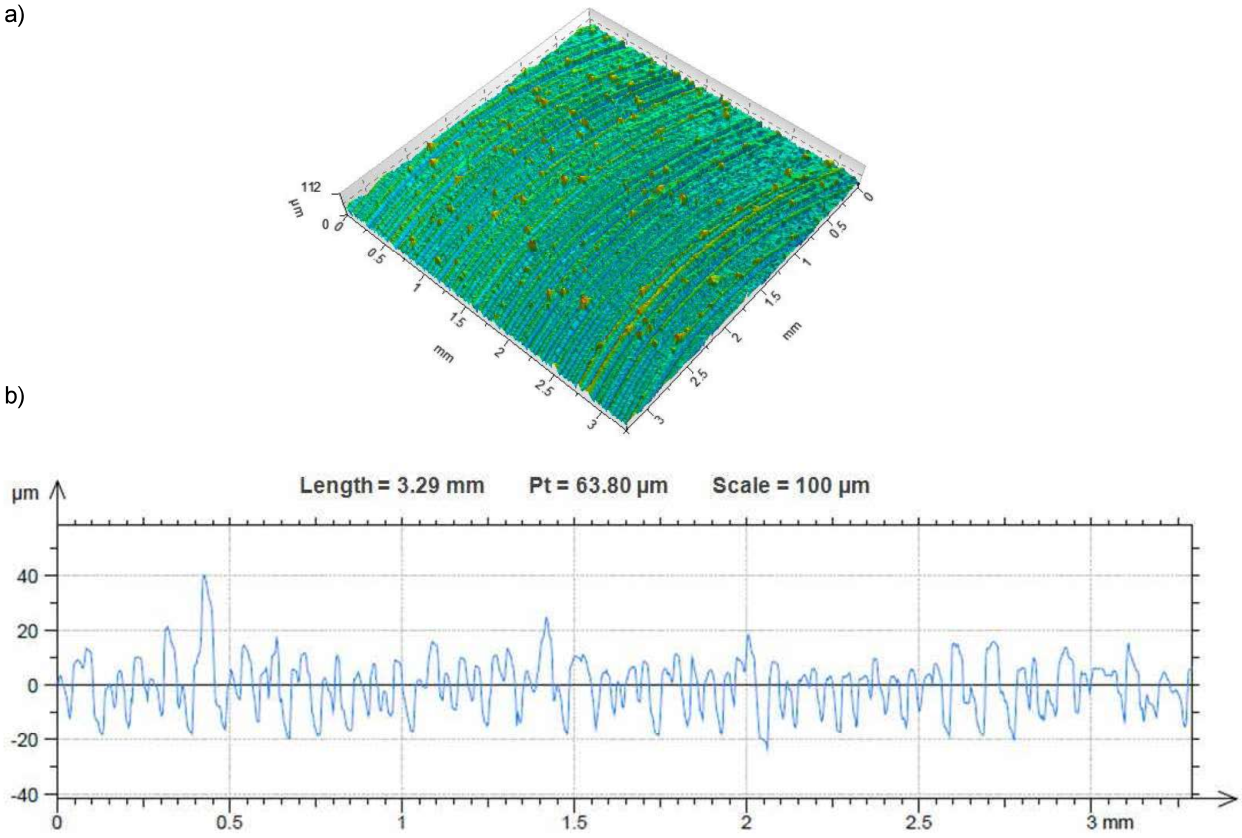

Fig. 7. Three dimensional illustration (a) and surface profilogram (b) of the specimen with welding, variant 6

Table 2. Surface roughness parameters after treatment according to adopted variants

Variant	Rp, µm	Rv, µm	Rz, µm	Rc, µm	Rt, µm	Ra, µm	Rq, µm
1	18.2	27.4	45.6	30	57.3	7.94	10.4
2	14.4	23	37.4	23.4	40.3	7.41	8.93
3	12.3	11.9	24.2	14.8	31.4	4.68	5.83
4	2.4	5.19	7.59	2.71	9.34	0.906	1.18
5	2.95	8.45	11.4	4.12	13.6	1.26	1.78
6	26.5	20.5	47	23.2	59	8.01	9.84

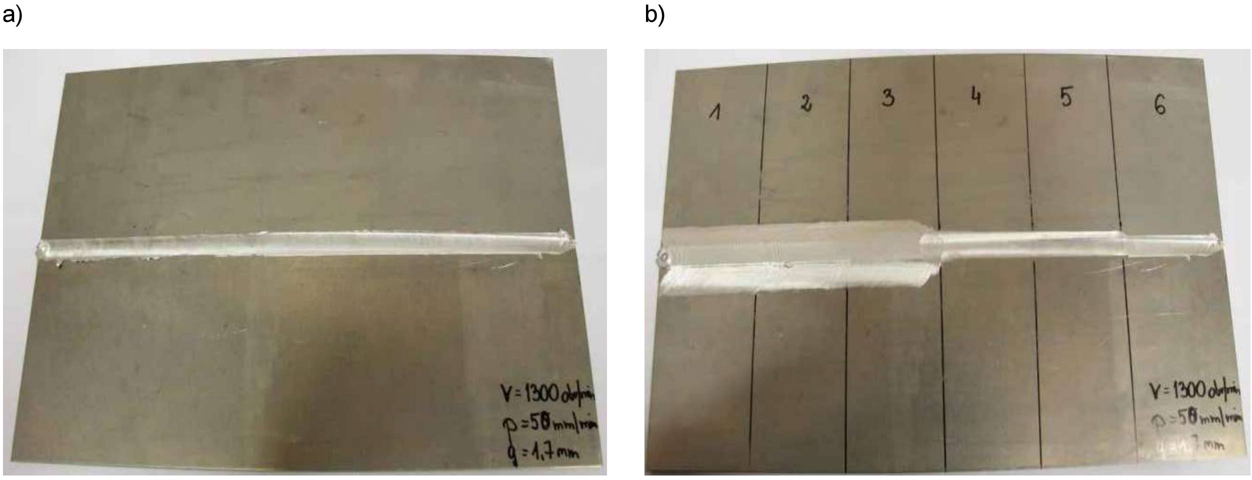

Fig. 8. The view of welded specimen before (a) and after brushing (b)

The residual stress research showed that brushing with a wire brush introduced compressive residual stresses in both directions. Taking into account the measurement error in the range of +/- 4 MPa, it can be concluded that, in the case of using the wire brush, the direction of stress measurement does not significantly affects the stress value. This type of brush introduces the highest compressive stresses in the direction perpendicular to the welded joint, which are σ_x = -104 MPa and σy = -98 MPa (variant 1), which is almost a 4-fold increase in stresses in the direction perpendicular and 2-fold in the direction parallel compared to the surface after welding (variant 6). Brushing according to variant 3, where two types of brushes were used, also introduced favorable compressive stresses reaching the value of σ_x = -70 MPa and σ_y = -67 MPa. In this case, when taking into account the measurement error, which was +/- 3 MPa, it can be concluded, that the direction of measurement did not significantly affect the stress value. A significant difference can be observed between the values of stresses measured in different directions in the case of brushing with the using of Xebec brush for variants 4 and 5. In the direction parallel, occurred the compressive stresses, reached the values of σ_y = -20 MPa and σ_y = -28 MPa, respectively. In turn, in the direction perpendicular occurred the tensile stresses in the range of σ_x = 10 ÷ 27 MPa. A similar relationship can be also observed after friction stir welding specimen. When analyzing the obtained test results, it can be concluded that brushing with using the wire brush, with the feed rate was f = 70 mm/min is most favorable from the point of view of residual stresses.

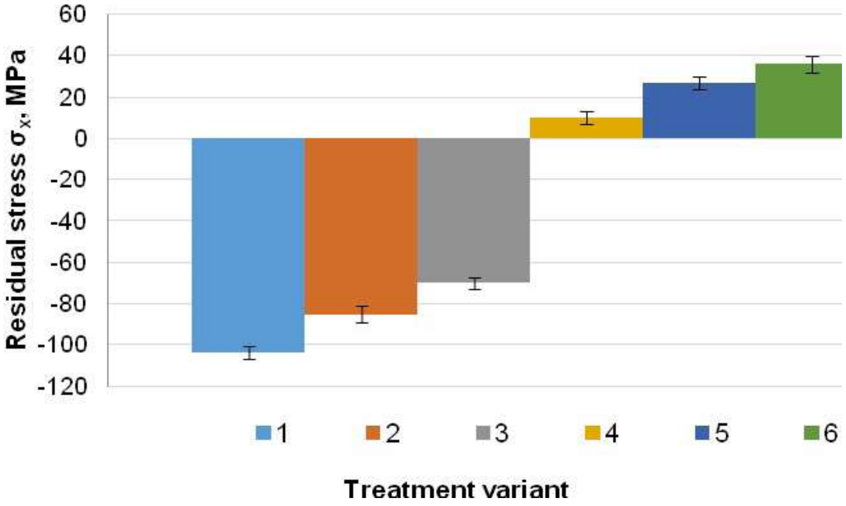

Fig. 9. Effect of treatment variant on the value of residual stresses in the perpendicular direction to the welding direction

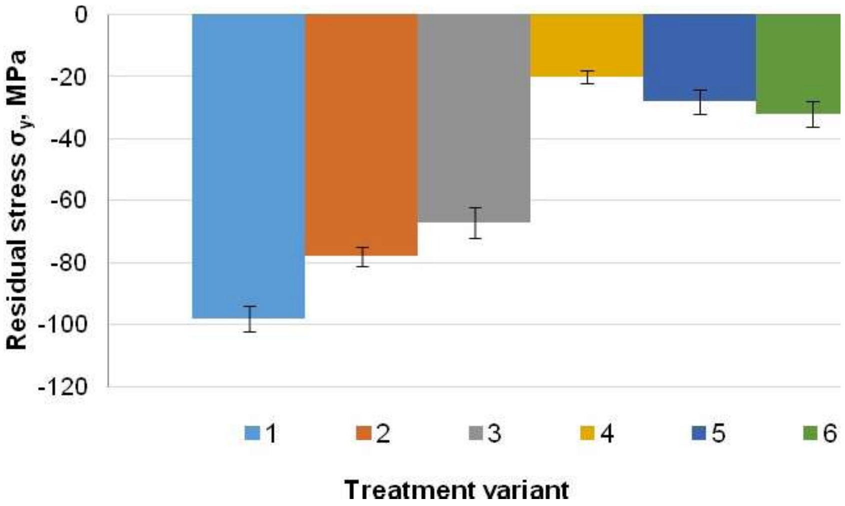

Fig. 10. Effect of treatment variant on the value of residual stresses in the parallel direction to the welding direction

Conclusions

Based on the investigation of the effect of the brushing treatment as a method to improve the condition of surface layer after welding in aluminum 2024-T3, the following conclusions can be made:

- The lowest roughness was obtained for the surface after brushing with the brush by Xebec, where the feed rate value was 100 mm/min (a decrease of 89% compared to the base specimen).
- Brushing with using two types of brushes, in the first step with wire brush and then with ceramic fibres (variant 3), resulted in a decrease in roughness by 42%, from Ra = 8.01 μm for the base specimen to Ra = 4.68 μm. In this case, there were also obtained the beneficial compressive stresses with the values of σ_x = -70 MPa and σ_y = -67 MPa.
- The use of wire brush had a positive effect on the state of stresses in the surface layer of welded joints, for brushing according to variant 1, compressive stresses reached the value of σ_x = -104 MPa and σy = -98 MPa.
- Brush with ceramic fibres can be used to remove micro-inequalities, burrs or flashes resulted during FSW process.
- When taking into account the obtained measurement results of the residual stress, the further stage of the research should include carrying out the fatigue tests of the welded joints after brushing.

References

[1] Bonarski J. 2013. Measurement and use of the texture-stress microstructure characteristics in materials diagnostics. Cracow: Institute of Metallurgy and Materials Science of the Polish Academy of Sciences.

[2] Buffa G., Fratini L., Micari F. 2012. "Mechanical and microstructural properties prediction by artificial neural networks in FSW processes of dual phase titanium alloys". Journal of Manufacturing Processes 14(3): 289-296. https://doi.org/10.1016/j.jmapro.2011.10.007

[3] Cao J. Y.,Wang M., Kong L., Zhao H.X., Chai P. 2017. "Microstructure, texture and mechanical properties during refill friction stir spot welding of 6061-T6 alloy". Materials Characterization 128:54–62. https://doi.org/10.1016/j.matchar.2017.03.023

[4] Khodaverdizadeh H., Mahmoudi A., Heidarzadeh A., Nazari E. 2012. "Effect of friction stir welding (FSW) parameters on strain hardening behavior of pure copper joints". Materials & Design 35: 330-334. https://doi.org/10.1016/j.matdes.2011.09.058

[5] Kluz R., Bucior M., Kubit A. 2019. "Identifying optimal Friction Stir Welding process parameters for 2024 Al alloy butt joint". Advances in Science and Technology-Research Journal 13(4): 48-53. https://doi.org/10.12913/22998624/110740

[6] Kłysz S. 2015. Basics of strength of materials. Warsaw: Technical Institute of Air Forces.

[7] Kubit A., Bucior M., Wydrzyński D., Trzepieciński T., Pytel M. 2018. „Failure mechanisms of refill friction stir spot welded 7075-T6 aluminium alloy single-lap joints". Int J Adv Manuf Technol 94:4479–4491. https://doi.org/10.1007/s00170-017-1176-2

[8] Matuszak J., Zaleski K. 2009. "Effect of technological parameters brushing steel S235JR roughness of the machined surface and the mass of material removed". W Zastosowanie informatyki w inżynierii produkcji, 69-80. Lubelskie Towarzystwo Naukowe. http://bc.pollub.pl/Content/567/PDF/zastosowania.pdf#page=69

[9] Matuszak J., Zaleski K. 2016. Deburring after milling aluminum and magnesium alloys. Lublin: Politechnika Lubelska. http://bc.pollub.pl/Content/12904/PDF/usuwanie.pdf

[10] Prime M., Gnäupel-Herold T., Baumann J., Lederich R., Bowden D., Sebring R. 2006. "Residual stress measurements in a thick, dissimilar aluminum alloy friction stir weld". Acta Materialia 54(15): 4013-4021. https://doi.org/10.1016/j.actamat.2006.04.034

[11] Sałaciński T., Pająk P. 2015. "Ceramic tools for surface finish deburring and polishing operations." Mechanik 10: 762-765. https://www.researchgate.net/publication/282834174_Ceramic_tools_for_surface_finish_deburring_and_polishing_operations

[12] Shen Z., Chen Y., Hou J.S.C., Yang X., Gerlich A.P. 2015. "Influence of processing parameters on microstructure and mechanical performance of refill friction stir spot welded 7075-T6 aluminium alloy". Sci Technol Weld Join 20:48–57. https://doi.org/10.1179/1362171814Y.0000000253

[13] Skrzypek S. 2002. New possibilities of measuring macro stress of materials using X-ray diffraction in the geometry of a constant angle of incidence. Cracow: AGH.

[14] Yang H.G., Yang H.J. 2013. "Experimental investigation on refill friction stir spot welding process of aluminum alloys". Appl Mech Mater 345:243–246. https://doi.org/10.4028/www.scientific.net/AMM.345.243

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