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EXPERIMENTAL COMPARISON OF RESISTANCE SPOT WELDING AND FRICTION-STIR SPOT WELDING PROCESSES FOR THE EN AW 5005 ALUMINUM ALLOY

EKSPERIMENTALNA PRIMERJAVA ODPORNOSTI PROCESOV TOČKOVNEGA VARJENJA IN TOČKOVNEGA TORNEGA VARJENJA PRI ALUMINIJEVI ZLITINI EN AW 5005

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Friction-stir spot welding (FSSW) is a solid-state welding process suitable for the spot joining of lightweight low-melting-point materials. The process is performed by plunging a rotating pin that creates a connection between sheets in an overlap configuration by means of frictional heat and mechanical work. In this study the tensile-shear-strength and hardness variations in the weld regions are discussed. The results obtained are compared with those derived from the application of traditional resistance spot welding (RSW). The experimental results of the study show that FSSW can be an efficient alternate process to electrical resistance spot welding.

Keywords: aluminium alloys, friction stir welding, friction stir spot welding, resistance spot welding, tensile shear strength

Torno mešano točkovno varjenje (FSSW) je proces, ki se odvija v trdnem in je primeren za točkovno spajanje lahkih kovin z nizkim tališčem. Pri tem postopku se z vrtečim se trnom, s toploto trenja in z mehanskim delom ustvari povezava med pločevino in konfiguracijo prekritja. Študija obravnava variacije natezne strižne trdnosti in trdote v območjih zvara. Dosežene rezultate smo primerjali s tistimi, ki so bili doseženi s tradicionalnim uporovnim točkovnim varjenjem (RSW). Rezultati preizkusov kažejo, da je lahko FSSW učinkovit altrenativen proces za električno točkovno uporovno varjenje.

Ključne besede: aluminijeve zlitine, torno mešalno varjenje, torno mešalno točkovno varjenje, uporovno točkovno varjenje, natezna strižna trdnost

1 INTRODUCTION

Friction-Stir Spot Welding (FSSW) is a derivative of Friction-Stir Welding (FSW), and has been gaining momentum since the beginning of this decade. Unlike FSW, FSSW can be considered as a transient process due to its short cycle time (usually a few seconds). Friction-Stir Spot Welding (FSSW) is a novel variant of the "linear" FSW process; it creates a spot, lap-weld without any bulk melting[1]. As indicated in **Figure 1**, during FSSW, the tool penetration and the dwell period essentially determine the heat generation, the material plasticization around the pin, the weld geometry and therefore the mechanical properties of the welded joint[1].

This technique has the same advantages as FSW. The advantages of FSW over fusion welding processes are the ease of handling, the joining of dissimilar materials and materials that are difficult to fusion weld, the low distortion, the excellent mechanical properties and the little waste or pollution. Hence, we envisage applying the technique the for joining of lightweight materials in order to achieve high performance and the energy and cost savings of machines and structures[3].

The rapid development of applications of lightweight materials in the automotive industry is reflected in the increasing use of aluminum alloys[4]. Many components produced from these alloys, by stamping, casting, extrusion and forging, have to be joined as a part of the manufacturing processes.

Resistance welding is one of the oldest of the electrical welding processes in use by industry today. The weld is made by a combination of heat, pressure and time. Mild or low-carbon steel comprises the largest percentage of material welded with the resistance spot welding process. All low-carbon steels are readily weldable with the process if the proper equipment and procedures are used[5]. The resistance welding of aluminium is more difficult than steel because of the characteristics of aluminium. The electrical conductivity of

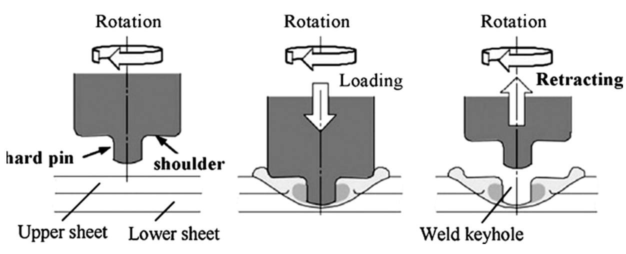

Figure 1: Schematic representation of FSSW process[2]
Slika 1: Shematičen prikaz procesa FSSW[2]

Table 1: Chemical and mechanical properties of the EN AW 5005 aluminum alloy[7]
Tabela 1: Kemična sestava v masnih deležih (*w*/%) in mehanske lastnosti aluminijeve zlitine EN AW 5005[7]

Chemical composition *w*/%	Fe	Si	Cu	Mn	Mg	Zn	Cr	Al
	0.45	0.3	0.05	0.15	0.5–1.1	0.2	0.1	Balance
Mechanical properties	Yield Strength (MPa)		Tensile strength (MPa)		Elongation (%)		Hardness (HV)	
	45		110		15		32	

aluminium is high, and welding machines must provide high currents and exact pressures in order to provide the heat necessary to melt the aluminium and produce a sound weld. A FSW of aluminium has several advantages over fusion-welding processes. Problems arising from the fusion welding of aluminium alloys, such as solidification cracking, liquation cracking and porosity, are eliminated with FSW, due to the solid-state nature of the process[6]. In this study, the hardness distribution and the tensile shear strength of RSW and FSSW welds in the EN AW 5005 aluminum alloy has been investigated based on our experimental results.

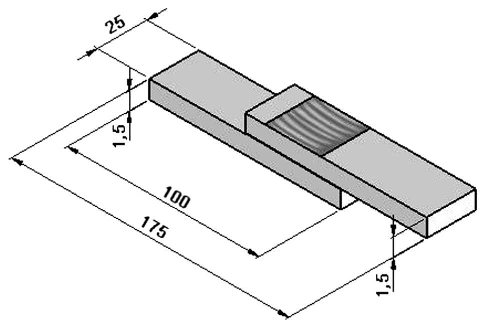

Figure 3: Dimensions of tensile shear test specimens
Slika 3: Dimenzije nateznih strižnih preizkušancev

2 EXPERIMENTAL DETAILS

2.1 Workpiece material

The EN AW 5005 aluminum alloy was used as a workpiece material with a thickness of 1.5 mm. The specimens were machined out in 100-mm lengths and 25-mm widths. The specimens were overlapped with an area of 25 mm × 25 mm. The composition and mechanical properties of the workpiece material are listed in **Table 1**. **Figure 2** (a) and (b) schematically shows the resistance spot and FSSW welding processes.

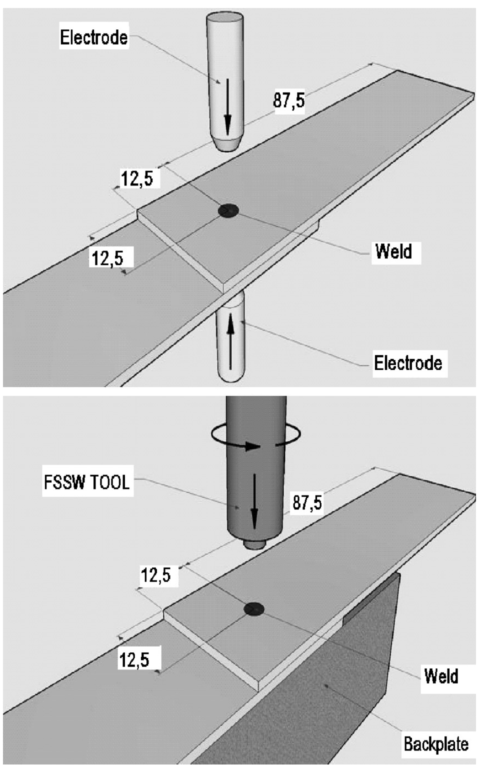

Figure2: Schematic representations of: (a) RSW process and (b) FSSW process
Slika 2: Shematičen prikaz: (a) proces RSW, (b) proces FSSW

The welded samples were loaded on an *INSTRON 8801* tensile testing machine with a load of 100 kN capacity. **Figure 3** shows the dimensions of the lap-shear specimen used to investigate the shear strength of the friction-stir spot weld and the resistance spot welds under shear loading conditions.

2.2 Tool Geometries and Welding Equipment

a) Resistance Spot Welding

Water-cooled copper is used as the electrode material. The electrode shape is flat-ended with a contact diameter of 4 mm. The experiments were performed on a resistance spot welding machine, which is a pneumatically operated, electronically current-and-timing controlled welding machine. The current values of the spot welding machine range from 5 kA to 50 kA. The pressure, applied through the pneumatic cylinder, can be controlled and adjusted according to the required value during the welding period. The applied pressure is measured and controlled with the help of a manometer, which is mounted on the valve section of the machine. The selected RSW parameters were taken as recommended in literature[8]. The parameters of the RSW were 2.5-kN electrode force, 30-kA welding current, holding time 10 periods, and welding time 7 periods. The experiments were performed by maintaining the type of

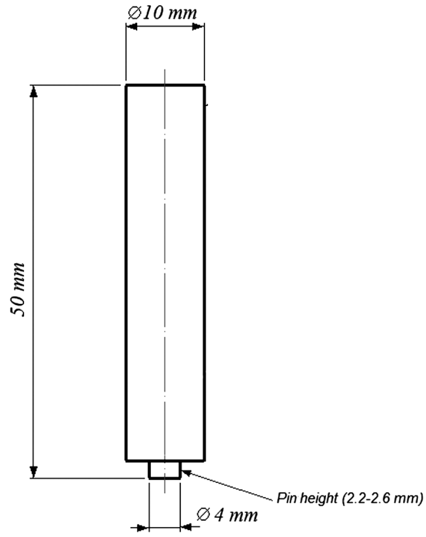

Figure 4: Tool geometry used in the FSSW process
Slika 4: Geometrija orodja, uporabljenega pri procesu FSSW

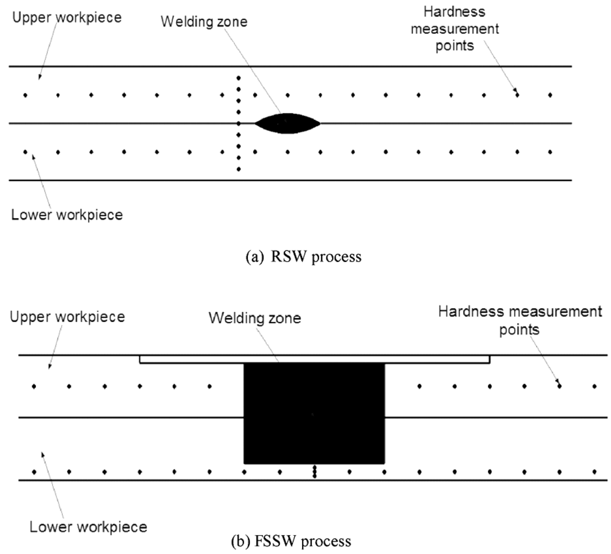

Figure 5: Hardness-measurement distribution
Slika 5: Porazdelitev izmerjenih trdot

electrode and tool materials, the water flow rate, the electrode nose geometry (flat ended) and the contact diameter constant, and then changing the other parameters.

b) Friction-Stir Spot Welding

AISI 1050 steel was used as the FSSW tool material. The tool was manufactured with the dimensions shown in Figure 4. The tool was hardened to 52 HRC before the welding applications. The pin height (*h*) was varied as 2.2 mm and 2.6 mm. The contact diameter of the tool was manufactured as 4 mm. The FSSW welding was performed on a CNC vertical milling machine.

In the FSSW process, parameter identification is still being investigated. In this study, the FSSW parameters were selected as given in **Table 2**.

Table 2: Welding parameters for the FSSW processes
Tabela 2: Varilni parametri za procese FSSW

Experiment No	Pin height (mm)	Tool rotation (r/min)	Welding time (s)	Tensile shear strength (MPa)
1	2.2	1500	5	70.27
2	2.2	1500	10	58.92
3	2.2	2000	5	70.86
4	2.2	2000	10	60.66
5	2.6	1500	5	68.21
6	2.6	1500	10	122.16
7	2.6	2000	5	102.70
8	2.6	2000	10	100.71

2.4 Microhardness

The hardness measurements were performed on a Vickers Microhardness Tester (HV_{50}). The measurements were taken at various points along the cross-section of the welded specimens. As shown in **Figure 5**, in order to eliminate the indentation effect, the readings were taken with 1-mm increments.

3 RESULTS AND DISCUSSION

3.1 Tensile Shear Strength

The maximum average tensile shear strength of the RSW and FSSW welded joints were 41.38 MPa and 122.16 MPa, respectively. The maximum tensile shear strength of the FSSW joint is 295 % higher than the RSW joint.

When experiments 3 and 7 were compared, it is clear that the tensile shear strength increased from 70.86 MPa to 102.70 MPa, as seen in **Figure 6**. The FSSW joints that were obtained with higher pin heights resulted in a higher tensile shear strength. These results can be explained by the larger volume of bonded materials as the pin height increases. Increasing the pin height has a positive effect on the tensile shear strength. These results

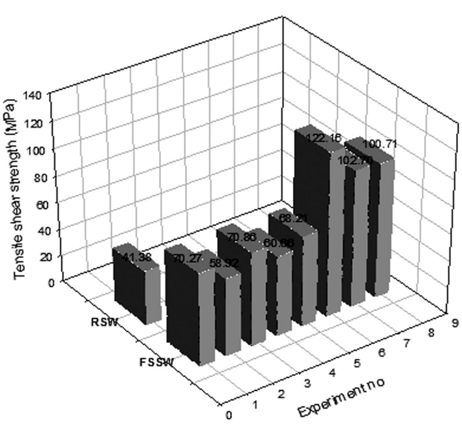

Figure 6: Comparison of the tensile shear strength of the RSW and FSSW welded joints
Slika 6: Primerjava natezne strižne trdnosti zvarov RSW in FSSW

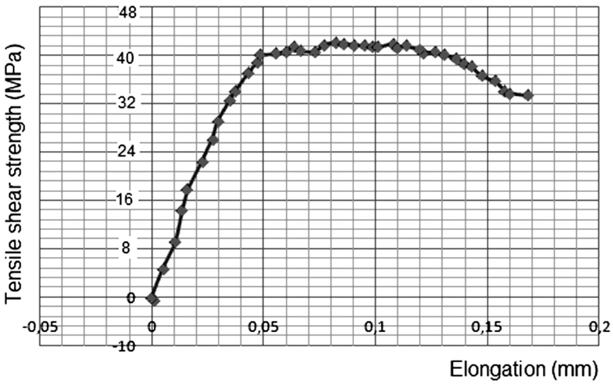

Figure 7: Tensile shear strength of RSW joints (Electrode force, 2.5 kN; welding current, 30 kA; holding time, 10 cycles; welding time, 7 cycles)

Slika 7: Natezna strižna trdnost zvarov RSW (sila elektrode 2,5 kN, varilni tok 30 kA, čas držanja 10 ciklov, čas varjenja 7 ciklov)

show that the stirring effect and the refined structure improve the mechanical properties of the FSSW joints. The tensile shear strengths of the FSSW joints reduced when the welding time increased from 5 s to 10 s. The experiments 1–2, 3–4, 7–8 verify this result. This situation can be explained by the statement of Kalpakjian et al.[9], i.e., there is a relation between the temperature, the time and the strength.

The graphical results of the tensile shear strength of the RSW and FSSW welded joints are given in **Figure 7** and **Figure 8**, respectively. The results of the tensile shear tests show that a 304 % improvement can be obtained with the FSSW process when compared with the RSW. The tensile strength of the FSSW joint is stronger than that of the RSW This strength improvement can be explained by the structure obtained with the FSSW process. The studies in the literature report that the microstructure of the FSSW is a refined structure, while the RSW welds have a cast structure[1,3]. The stirring effect and the refined structure improve the mechanical properties of the FSSW joint.

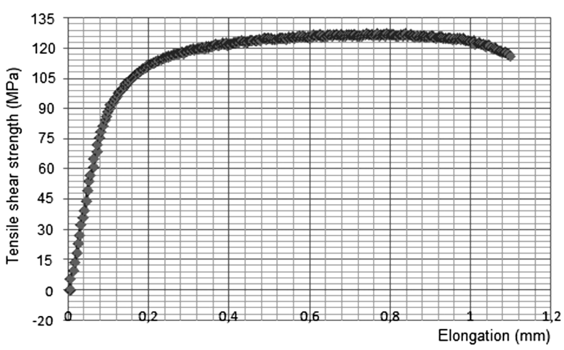

Figure 8: Tensile shear strength of FSSW joints (pin height, 2.6 mm; tool rotation, 1500 r/min; welding time, 10 s)

Slika 8: Natezna strižna trdnost zvarov FSSW (višina trna 2,6 mm, hitrost vrtenja trna 1500 r/min, čas varjenja 10 s)

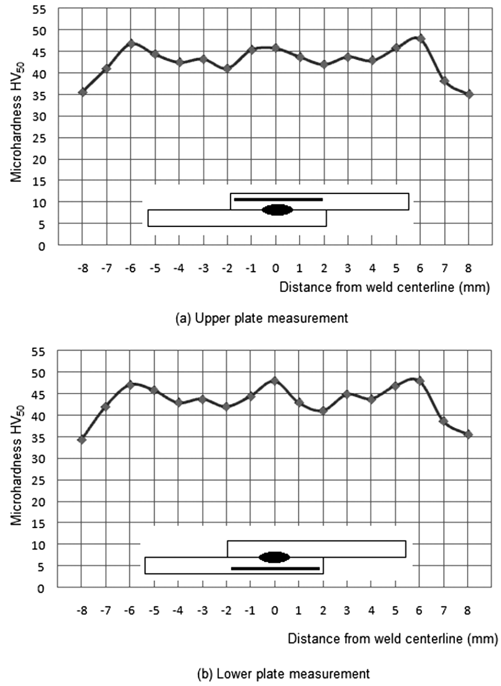

Figure 9: Microhardness distribution of RSW welded joints

Slika 9: Porazdelitev mikrotrdote v zvarih RSW

3.2 Microhardness

The microhardness of the base plates was measured to be 32 HV_{50}. The microhardnesses of the RSW and FSSW welded joints are given in **Figure 9** (a. upper

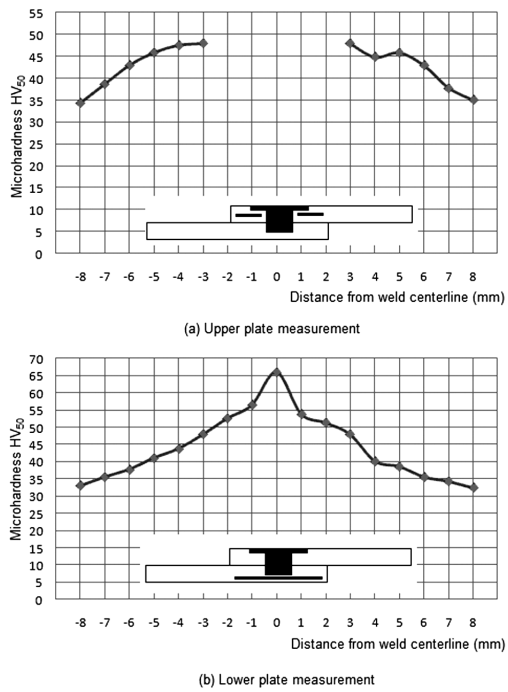

Figure 10: Microhardness distribution of FSSW welded joint (sample 6)

Slika 10: Porazdelitev trdote v zvaru FSSW (vzorec 6) plate, b. bottom plate) and **10** (a. upper plate, b. bottom plate). The hardness of both of the RSW and FSSW were higher than the un-welded material. Plastic deformation during the joining processes increased the hardness of the welds, as seen in **Figure 9 and 10**. The average microhardnesses of the RSW and FSSW were 42 HV_{50} and 45 HV_{50}.

The hardness of the weld nugget was measured as 47 HV_{50} for the RSW. The hardness value of the upper and lower plates of the FSSW were measured as 48 HV_{50} and 65 HV_{50}, as seen in **Figure 9**. The reason for obtaining higher hardness value on the lower plate of the FSSW welded joints can be explained by the higher plastic deformation due to the higher pin-plunge distance. The increase in the hardness of the plates can be explained by the plastic deformation during the welding process. From the **Figure 10**, it is clear that there is more plastic deformation in the FSSW process than in the RSW process. The plastic deformation of the materials results in an increase in the strength and hardness[9].

4 CONCLUSIONS

In this work the mechanical properties of the friction-stir spot-welded overlap connections of the EN AW 5005 aluminum alloy material were investigated and compared with resistance spot welding. It can be concluded from this study that:

- Pin-height, tool-rotation and welding-time parameters affect the tensile shear strength of the FSSW joints,
- Pin height is the major factor that affects the tensile shear strength in the FSSW process. The welding time and tool rotation are the second and third, respectively, in the FSSW process,
- The tensile shear strengths of the FSSW welded joints are higher than those of the RSW welded joints,
- Tool rotation and welding time give better results when larger pin heights are used.
- Higher plastic deformation is obtained in the welding zone of the FSSW process than the RSW process,
- The hardness increase in the FSSW process is higher than in the RSW process,
- FSSW can be a more efficient alternate process the electrical RSW process.

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