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EFFECTS OF PROCESS PARAMETERS ON TENSILE SHEAR STRENGTH OF FRICTION STIR SPOT WELDED ALUMINIUM ALLOY (EN AW 5005)

WPŁYW PARAMETRÓW PROCESU WYTWARZANIA NA WYTRZYMAŁOŚĆ NA ŚCINANIE ZGRZEWANEGO TARCIOWO STOPU ALUMINIUM (EN AW 5005)

Aluminium and its alloys have been used in automotive technology since the first model of the car. The need for aluminium material is getting increased for weight reduction, improved fuel economy and vehicle performance. The amount of the aluminium used in a car is mainly related with joining processes of aluminium alloy. This can be achieved by developing the welding techniques for aluminium alloys. The purpose of this study was to determine the effects of friction stir spot welding parameters on tensile shear strength of friction stir spot welded lap joint EN AW 5005 Aluminium alloy. The variable parameters were tool rotation (rpm), dwell time (s) and the tool pin height (mm). Tensile shear test results indicated that the weld performance was significantly affected by the tool rotation, dwell time and the tool pin height. The results of the study indicates that there are optimum process parameters which give the highest tensile shear strength.

Keywords: Friction stir spot welding, FSSW, Friction stir welding, welding, aluminium

Aluminium i jego stopy są stosowane w produkcji samochodów od pierwszego modelu. Zapotrzebowanie na aluminium rośnie z powodu dążenia do zmniejszenia masy własnej pojazdu, zmniejszenia zużycia paliwa i poprawy osiągów pojazdu. Ilość aluminium stosowanego w samochodzie jest głównie związana z procesem łączenia stopów aluminium. To może być osiągnięte poprzez rozwój technik spawalniczych dla atopów aluminium. Celem tej pracy było określenie wpływu parametrów zgrzewania tarciowego FSW, na wytrzymałość na ścinanie zakładkowych złączy ze stopu aluminium EN AW 5005. Zmiennymi parametrami były prędkość obrotowa narzędzia (obr/min), czas (s) i wysokość trzpienia (mm). Wyniki testów ścinania wskazują, że jakość złącza jest istotnie uzależniona od prędkości obrotowej narzędzia, czasu i wysokości trzpienia.

Wyniki tej pracy wskazują, że istnieją optymalne parametry zgrzewania tarciowego FSW, które dają najwyższą wytrzymałość na ścinanie.

1. Introduction

Friction stir spot welding (FSSW) is an ideal competent process for aluminium welding comparing to conventional resistance spot welding (RSW). FSSW is a derivative of friction stir welding (FSW) process. FSSW is a single spot joining process, in which a solid-state joining is made between adjacent materials at overlap configuration [1]. Friction spot joining has four steps depicted in Figure 1a. First, the tool is positioned perpendicular to the work surface, and it starts to rotate. Next, the tool is pushed against the surface of the top sheet. Friction heats the materials, and the pin enters the softened metal. After the pin has plunged completely into the workpiece, the tool continues to spin and apply pressure for a set length of time. The materials around the pin are stirred together, and the lapped plates are metallurgically unified. At that point, the tool is extracted from the sheets [2]. The geometries of the FSSW joint is schematically shown in Figure 1b. The FSSW can be considered for many of the applications presently performed with traditional resistance spot welding, riveting, or mechanical clinching [3].
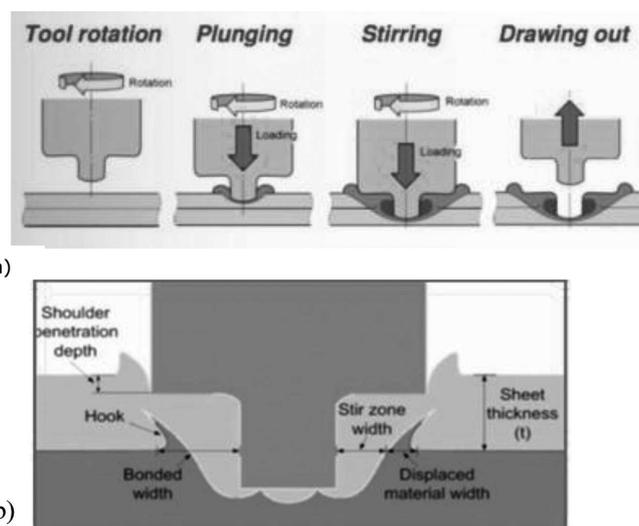

Fig. 1. a) FSSW process [3], b) Schematic illustration of Joint geometry of FSSW [4]

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Joint geometry of FSSW can be more efficient (significant energy and cost savings) alternate process to electric resistance spot welding [5]. The FSSW has some distinct potential advantages on aluminium over other welding processes such as RSW, MIG-Spot as well as performing better than mechanical joining techniques. The FSSW tends to have much lower operating costs due to improved energy efficiency and a virtual lack of a consumable. Additionally, the FSSW equipment requires significantly less surrounding infrastructure. That is, FSSW requires no water, no compressed air, nor complex electrical transforming equipment [6].

However, the literature review indicate, there is a need to identify the effect of FSSW parameters on the weld performance [7,8]. This study deals with the effects of tool rotation, dwell time and the pin height on the tensile shear strength.

2. Experimental Procedure

Commercially available Aluminium alloy plates (EN AW 5005) with a thickness of 1.5 mm were used to fabricate the joints. The chemical and mechanical composition of studied material is given in Table 1

TABLE 1

Chemical and mechanical properties of EN AW 5005 aluminum alloy

Chemical composition %	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	

Samples for shear tensile test were machined out in the dimension of 100×25×1,5 mm. Specimens were lap positioned with an 25 mm×25 mm overlap area (Figure 2).
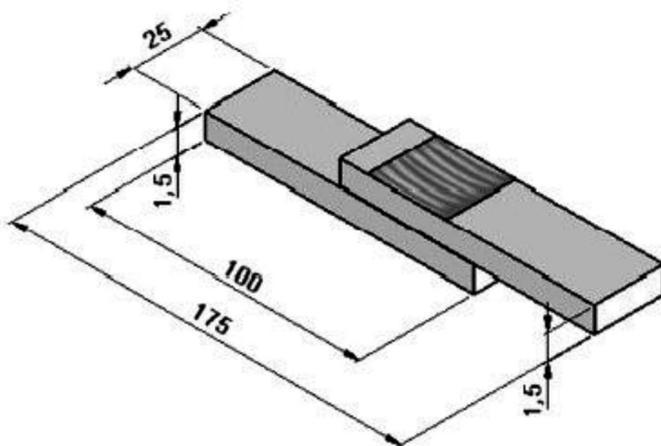

Fig. 2. Dimensions of FSSW lap specimens

The AISI 1050 steel was used as the FSSW tool material. The tool was manufactured with the dimensions shown in Figure 3. The tool was hardened to 52 HRC before the welding applications. Pin height (h) was varied from 2.2 to 2.6 mm. The diameter of the tool pin was 4 mm.
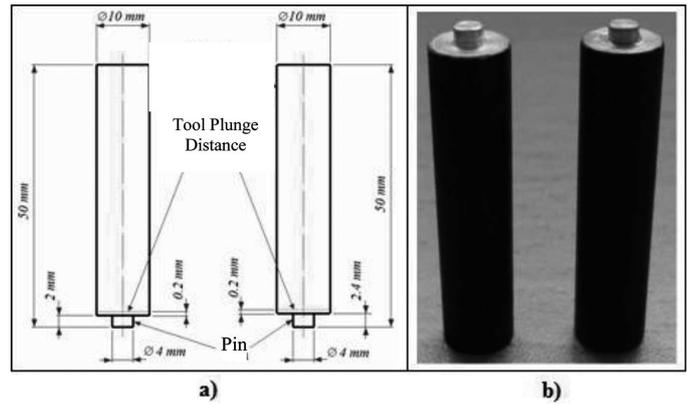

Fig. 3. a) Dimensions and b) photography image of tools used for FSSW application

The FSSW welding was performed on a vertical milling machine. Prepared samples were joined with FSSW using different tool rotation speeds, dwell time and tool pin heights. The process parameters are given in Table 2. 4 sample pair were joined for each of the parameter set. Average of shear tensile test results of 4 samples were used to evaluate the performance of joints. Prepared specimens were joined with FSSW process as illustrated in Figure 4.

TABLE 2

FSSW parameters

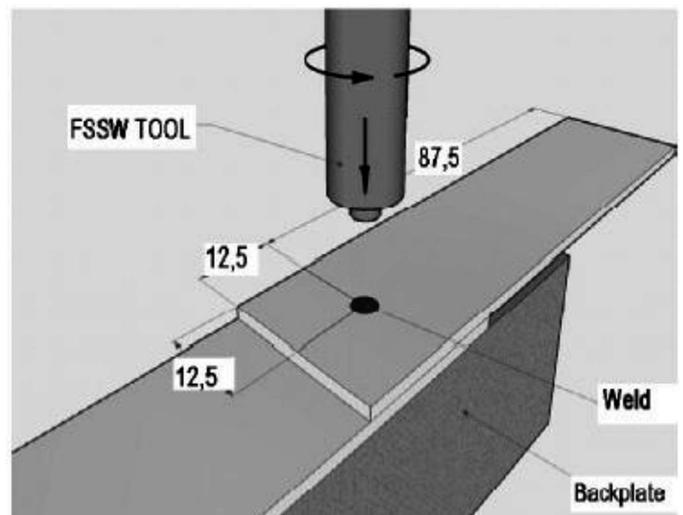| Sample group	Pin height (mm)	Tool rotation (rpm)	Dwell time (s)	Number of welded samples
First sample group	2.2	1500	5	4
	2.2	1500	10	4
Second sample group	2.2	2000	5	4
	2.2	2000	10	4
Third sample group	2.6	2000	5	4
	2.6	2000	10	4

Fig. 4. Schematic illustration of FSSW

3. Results and Discussion

Tool rotation for First samples selected as 1500 rpm, tool pin height 2.2 mm and dwell time 5 s and 10 s. Tensile shear strength results of first group test samples are given in Figure 5. The higher shear strength value exhibited the sample welded with 5 s than 10 s dwell time. The increasing in the dwell time from 5 s to 10 s reduced the tensile shear strength by 16%. Tool rotation for second samples was selected as 2000 rpm, tool pin height 2.2 mm and dwell time 5 s and 10 s.
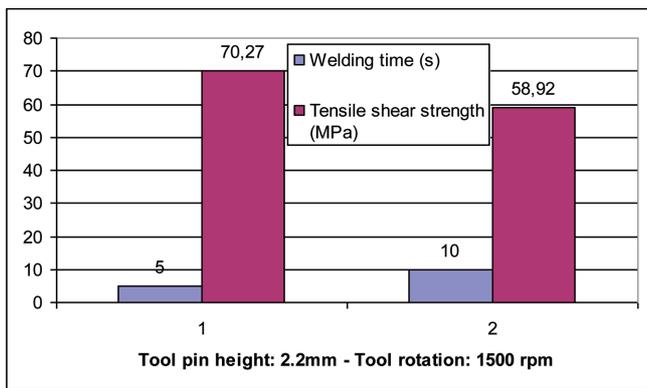

Fig. 6. Welding parameters and shear tensile test results of second samples joined with FSSW

Fig. 5. Welding parameters and shear tensile test results of first samples joined with FSSW

Fig. 7. Welding parameters and shear tensile test results of second samples joined with FSSW

FSSW parameters of second samples and Tensile shear test results are given in Figure 6. Increasing the dwell time from 5 s to 10 s reduced the tensile shear strength by 14%. The results of second samples set showed that the dwell time effect on the tensile shear strength is similar. Tensile shear strength reduction can be attributed to higher heat input due to a longer thermal cycle. Third samples set were used to investigate the tool pin height effect on tensile shear strength. Tool rotation for third samples was selected as 2000 rpm, tool pin height 2.6 mm and dwell time 5 s and 10 s. The tensile shear test result of 5 s dwell time was higher than that of 10 s sample as seen in Figure 7. The increasing in the dwell time from 5 s to 10 s reduced the tensile shear strength of third samples by 2%. The reduction in the tensile shear strength can be explained with the microstructure changes due to heat generation at stirring location. Jonckheere et. al [9] stated that high tool rotating speeds also give hot welds. Hot welding parameters lead to low ultimate forces. Kulekci et al. stated that excessive heat input during FSW negatively affects the mechanical properties of joints [10]. Barlas and Ozsarac [11] reported similar welding strength reduction for joining AlMg3 alloy by friction stir butt welding process. The results of their study reveals that heat effected zone (HAZ) and weld nugget zone (WNZ) have more coarse grains when 1100 rpm used than that of 900 rpm. The increasing of the grain size in HAZ and WNZ might be attributed to a longer thermal cycle due to higher heat input for the tool rotation speed of 1100 rpm than that of 900 rpm [8].
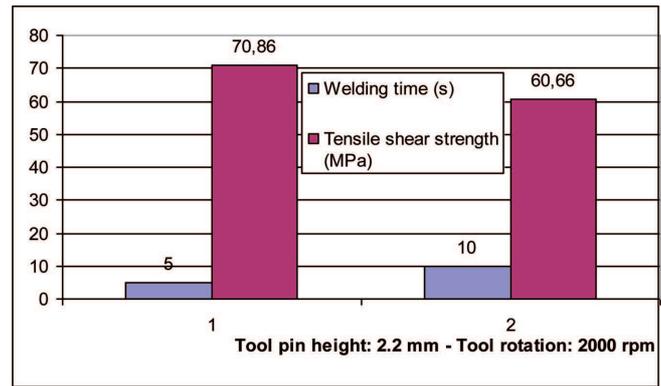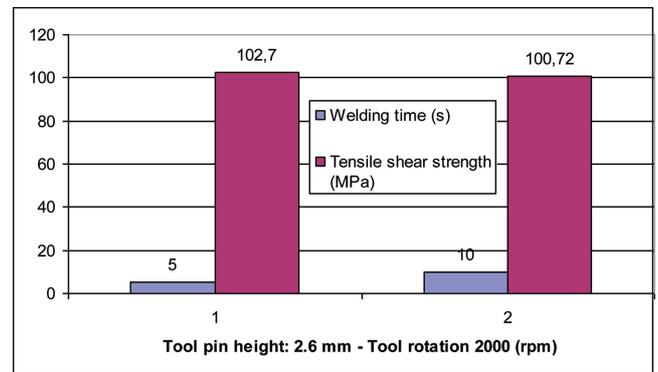
Tensile shear test results of third samples set are higher than first and second sets. The increase in tensile shear strength of third samples set is over % 29. The higher shear tensile strength of third samples set can be attributed to the higher pin tool height. Yuan et. Al [12] showed that in their study the plunge depth profoundly influenced lap-shear separation loads. Comparing the data given in Figure 5,6 and 7 shows that the effect of tool pin height parameter on tensile shear strength is grater than dwelling time and tool rotation. The results of the study indicates that should be an optimum tool pin height which gives the highest tensile shear strength. Additional studies are needed to identify optimum parameters for the FSSW process.

4. Conclusion

From the results given above, the following conclusions can be drawn:
- The tensile shear strength of FSSW significantly affected by tool rotation, dwell time and the tool pin height.
- The increase in tool rotation increases the tensile shear strength in a limited range of FSSW joints.
- The increase in dwell time reduces the tensile shear strength.
- Excessive heat input due to longer thermal cycle FSSW reduces tensile shear strength of FSSW joints due to changes in microstructure at stirring location.
- The increase in the tool pin height increases the tensile shear strength.

224

- Effect of tool pin height parameter on the tensile shear strength is grater than dwelling time and tool rotation.
- There is an optimum tool pin height which gives the highest tensile shear strength.

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