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Effect of Rotational Speed, and Dwell Time on the Mechanical Properties and Microstructure of Dissimilar AA5754 and AA7075-T651 Aluminum Sheet Alloys by Friction Stir Spot Welding

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In the current study, the effects of dwell time and rotation speed on the mechanical properties and microstructure of friction stir spot welded joints of dissimilar aluminum sheet alloys were investigated. Aluminum AA5754 and AA7075-T651 alloys were selected as the work piece. The joint quality, microstructural evolution and mechanical behavior of the welded regions were considerably affected by the welding parameters. The results obtained that rotation speed and dwell time play an important role on welding quality of aluminum sheet. The microstructure images showed the dwell time and rotation speed has great effects on pin penetration and hook deformation. Maximum tensile shear load 806.3 N was produced at 1000 rpm and 2 s dwell time, while the tensile shear load reduced around 25 % with longer dwell time 5 s and high rotation speed 1400 rpm. Moreover, the welding joint microhardness was improved by the decrease of dwell time and increase of rotation speed.

Keywords: friction stir spot welding, aluminum alloy, lap joint, welding parameters.

1. INTRODUCTION

In recent years, weights saving materials are getting significance importance in automotive industry and the application of lightweight material like (aluminum alloys) for vehicles can help to reduce cost and enhanced fuel efficiency. Aluminum and its alloys are very attractive candidate because of their high strength to weight ratios [1]. Welding of aluminum alloys is important for structural construction and aircraft fabrications. The applications of dissimilar materials joints are increasing due to their appropriate mechanical properties and many more advantages which can provide good cost reduction. In addition to this, there are certain joining methods, which are being identified as hard challenge to weld dissimilar alloys [2]. Currently, resistance spot welding (RSW) is the most frequent applied joining technique which in automotive industry, which can use for low carbon high strength coated steel. On the other hand, in case of aluminum alloy sheet the RSW is full of shortcomings including cracks and porosity [3]. A revolutionary solid state joining method is invented by The Welding Institute (TWI) is Friction Stir Welding (FSW), and it is an efficient method for joining material that are poorly welded by fusion welding[4].Ultrasonic welding is one of a solid phase joining technique, which has lower energy consumption than resistance spot welding and friction stir spot welding. Due to the problem of sticking phenomenon between the horn and the top sheet could be solved by using a buffer sheet or metal foil as interlayer [5, 6]. FSSW is a type of FSW and it has solid state nature of weld process. It is an emerging welding technique that utilized on particular spot weld thin sheets of metals [7, 8]. This unique method inspired many researchers to use it to join materials with different mechanical properties, chemical compositions and structures [9]. The basic advancement of FSSW was achieved by Mazda, Norsk Hydro Company, Kawasaki Heavy Industries, Ltd and Sumitomo Light Metal Industries, Ltd. In 2003, Mazda started FSSW in rear door panel assembly of RX-8 [10]. Many researchers demonstrated great interest in FSSW owing to its advantages including low distortion, ease of handling, excellent mechanical properties, neat working environment and low cost. Certain designed of cylindrical tool used in FSSW with various ends, geometries and probe pins plunged into upper sheets. A downward force is applied when certain rotating tool contact the upper surface with the help of backing tool under the lower sheet for supporting downward force. Meanwhile, fractional heat is generated at constant rotation speed for a specified time, due to fractional heat material become softened and deform plastically; according to tool specification and a solid bond will generate between lower and upper sheet surface. Finally, the tool is exerted from sheet surface [11]. Pan [12], reported that FSSW process is dependent on process parameters which include the tool plunge depth, dwell time, and rotational speed. These three parameters are of the greatest importance in FSSW. For load bearing components, weld strength is crucial for FSSW, joint strength was greatly influenced by process parameters and tool geometry. In addition, a key factor that affect the heat generation and material flow is the geometry of tool, such as diameter of shoulder, length [7]. Badarinarayan, Shi et al. [13], express tool geometry effect on the static strength and formation of hook which obtained that the geometry of probe have

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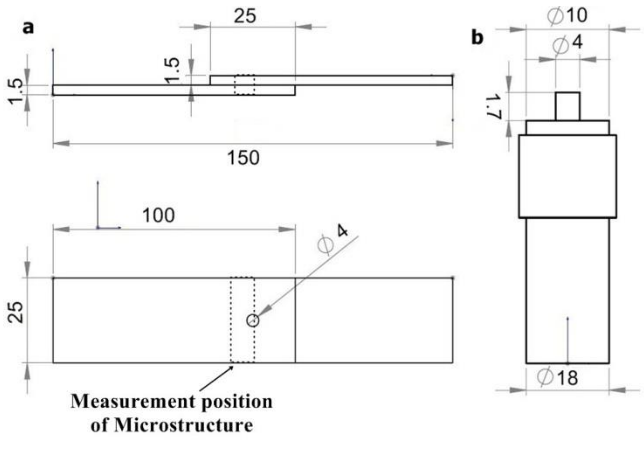
significant effects on the formation of hook. In addition, weld joint strength is also under the effect of process parameters. Piccini and Svoboda [14] explore the effects of penetration depth and tool geometry during the FSSW of AA5052-LCS (low carbon steel) joints.

Kim, Ahn et al. [1] studied the effects of tool geometry and process parameters on mechanical characteristics of FSSW dissimilar aluminum alloys. Bozkurt and Bilici [3], showed that welding parameters played key roles in determination of weld strength. Yazdi, Beidokhti et al. [15] evaluated the FSSW strength of 6061-T6 aluminum alloy sheets by probes(with pin lengths of 2 – 3 mm) and pinless tools (with L-shaped and scroll grooves) they obtained that the highest average tensile-shear strength for welds performed using pinless tools, which due to higher areas of bonded surfaces formed by pinless tool. Labus Zlatanovic, Balos et al. [16] investigated the effects of FSSW parameters including rotation speed on multiple sheets of A5754 alloys by pinless convex tool. They reported that the adopted strain rate (tool rotational speed) directly affected joined part microstructure. Bozzi, Helbert-Etter et al. [2], emphasize the importance of parameters like, shoulder penetration, plunge depth, and tool rotational speed to understand the microstructure and strength of weld. Piccini and Svoboda [17] explored the influence of the length and penetration depth of the pin of welding tool during FSSW of overlap joint of AA6063 with galvanized low-carbon steel. Rostamiyan, Seidanloo et al. [18], demonstrates that tool rotational speed increment increases heat input and temperature. Fereiduni, Movahedi et al. [19], investigate the effects of dwell time and rotational speed on the microstructure of joint interface and tensile shear strength of FSSW Al 5083 with St-12 steel alloy. In the present study, the aluminum alloy AA5754 and AA7075-T651, which are widely used in industries, were lap-welded using FSSW. The influences of the main welding parameters, including dwell time and tool rotation speed on the mechanical properties and microstructure of the joints were investigated.

2. EXPERIMENTAL

The aluminum AA5754 and AA7075-T651 plates with size of 100 × 25 × 1.5 mm (Fig. 1 a) were adopted in this work.



a b

Fig. 1. Schematic diagram: a – lap joint; b – FSSW tool, mm

Table 1 lists the compositions of the AA7075-T651 and AA5754 aluminum alloys, respectively. Both faying surfaces were rinsed with warm water and cleaned using alcohol to remove contaminants that can produce metal oxides. The upper and lower composition of specimen with same thickness of 1.5 mm assembled as AA5754/AA7075-T651. The process of FSSW involves basically three steps: plunging, stirring and drawing out (Fig. 2). The plates were positioned below and in the middle of FSSW tool pin after adjusting the vertical milling machine settings.

Table 1. Chemical composition of AA7075-T651 and AA5754 aluminum alloys, wt.%

Alloy	Al	Zn	Mg	Si	Mn	Cr	Cu	Fe
AA7075-T651	Bal.	5.72	2.63	0.08	0.05	0.19	1.55	0.19
AA5754	Bal.	0.19	2.66	0.31	0.42	0.15	0.01	0.4

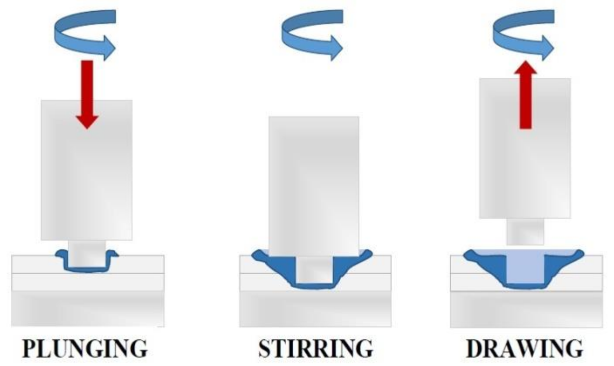


Fig. 2. Illustration of FSSW process

The tool was made with high strength H13 mild steel tool in the dimensions of 10 mm of shoulder diameter with 4 mm of cylinder pin diameter, and 1.7 mm length (Fig. 1 b). Welding parameters were completely randomized using Minitab 18.1 software. Design of experiment full factorial design, including two quantitative levels (dwell time and rotation speed), were carefully selected for this joining process (Table 2).

Table 2. Two-level 2k full factorial design

Sample no.	Stdorder	Runorder	A	B	Rotational speed, rpm	Dwell time, s
1	3	4	–1	–1	1000	2
2	2	2	–1	1	1000	5
3	4	1	1	–1	1400	2
4	1	3	1	1	1400	5

Welded plate tensile shear load was measured by using a universal tensile test machine (INSTRON-5582). Three specimens were prepared for each parameter. The specimens were mounted between the machine's jaws and the load rate was set at 3 mm/min for all runs. The microhardness values of welded metals for this experiment were measured using Vickers test with Vickers hardness of 0.5, force of 4.903 N, and dwell time of 10 s. Several indents were made along a 10 mm distance within the joint's cross-section from the center of weld to investigate hardness profile pattern at different weld regions. The cross sections of metallographic specimens were cut from the middle of welding joint zone. The specimens were ground, polished and etched using Keller's etchant. Optical microscope and Scanning electron microscopy coupled (SEM) was carried out using JEOL JSM-6400 were utilized to inspect welding joint cross-sections.

3. RESULTS AND DISCUSSION

3.1. Microstructure analysis

The microstructural examination provides important information on joint metallurgy. Hook formation, nugget/SZ size, and actual weld depth (top sheet thinning) are geometrical features observable through the cross sectional images. The scanning electron microscopy (SEM) image can be seen in Fig. 3. A metallurgical bonding between lower and upper sheets can be easily observed around the penetrating pin (Fig. 3 a). As tool penetrated at high rotational speed material around the pin penetrate into lower sheet and a strong metallic bonding appear between lower and upper sheets (Fig. 3 b). Geometry of the weld demonstrates the mixing phenomena. Aluminum AA5754 is penetrating into the AA7075-T651.

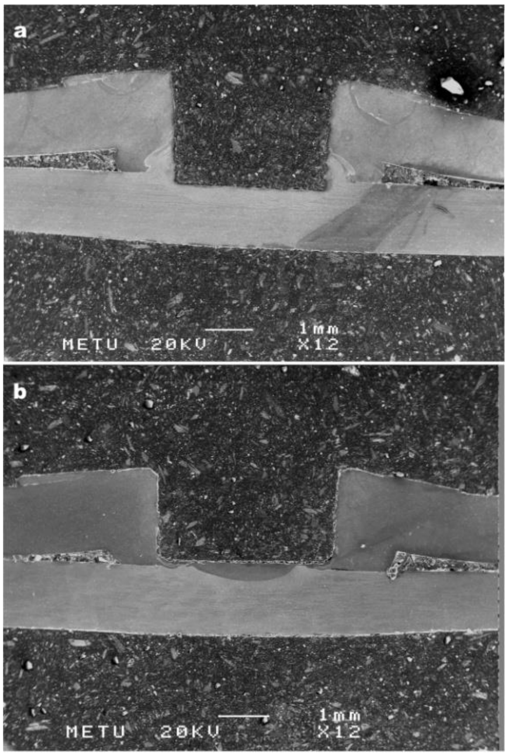


Fig. 3. Cross-section of the welding zone: a – sample 1 at 1000 rpm and 2 s dwell time; b – sample 4 at 1400 rpm and 5 s dwell time

The indentation profiles reflect the general shape of the pin probe profile; the tool has unthreaded flat probe. Bottom of probe profile is flat [20, 21]. The heated and softened upper sheet material pushed down around the probe pin of the tool into lower sheet. The heated and softened material of the upper sheet moved outward and upward because of probe pin indentation. Tool shoulder indentation gave rise in the radial expansion of the upper sheet along the outer circumference of the indentation of tool shoulder. Because of tool indentation inside the upper sheet with rotation speed of 1400 rpm, material becomes soft and begins to bend around the circumference of the tool. In addition, due to the indentation of the tool at higher rpm a hook defect tends to curve top end wards on the external end of the nugget zone [22 – 24].

3.2.Microhardness

Fig. 4 shows the hardness values for the Vickers hardness distributions of the welding joint zone made at two different welding conditions of dwell time of 2 and 5 seconds and speed of 1000 and 1400 rpm. The hardness values of thermomechanical affected zone (TAMZ) were higher than those of the stir zone (SZ) around 11 – 23 %, which can be because of grain size increase in the former [7, 25].

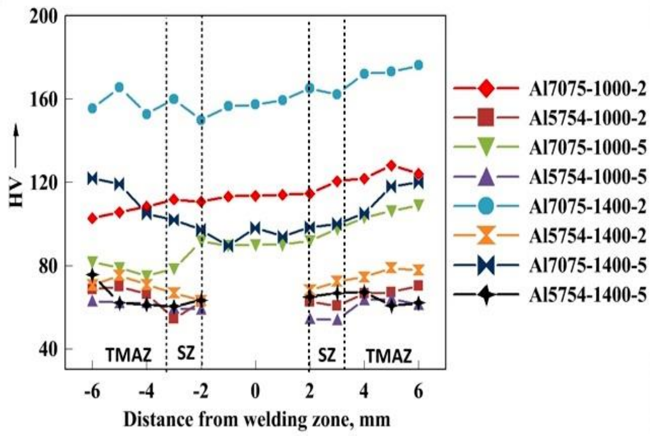


Fig. 4. Hardness as a function of tool rotational speed and dwell time

Moreover, the rotation speed and dwell time also significantly affected the hardness values. At lower dwell time of 2 s and higher rotation speed of 1400 rpm the hardness value of Al 7075-T651 side increased compare to longer dwell time of 5 s. Similar result were found at lower rotation speed 1000 rpm dwell time of 2 s, the hardness value of Al 7075-T651 side is higher than the longer dwell time of 5 s. In the aluminum Al 5754 sample subjected to rotation speed 1400 rpm had higher hardness than the sample subjected to rotation speed 1000 rpm. The one of the reason of this increased hardness is thermomechanical influence of shoulder on interface [26, 27]. In addition, the increment in dwell time makes material region soften and wider which decrease hardness [28, 29].

3.3. Tensile shear load

Tensile shear load test was performed to determine the performance of the welded dissimilar aluminum Al 5754/Al 7075-T651 joint at various welding parameters. Tensile shear load values were varied by manipulating the welding parameters in terms of dwell time and rotation speed as shown in Fig. 5. Tensile shear load of welded joint with rotational speed 1400 rpm and 1000 rpm at a longer dwell time 5 s decreased by 34 % (600.9 N)and 27 % (634.5 N) respectively compare to welded joint with shorter dwell time and low rotation speed. While the maximum tensile shear load produced at 1000 rpm and 2 s dwell time was 806.3 N. The maximum load might due to low heat generation which produced by lower rotation speed 1000 rpm, which is related to the high performance of weld. On the other hand, high rotation speed produce high input which leads to rise the grain size that decrease the strength of the joint [24].

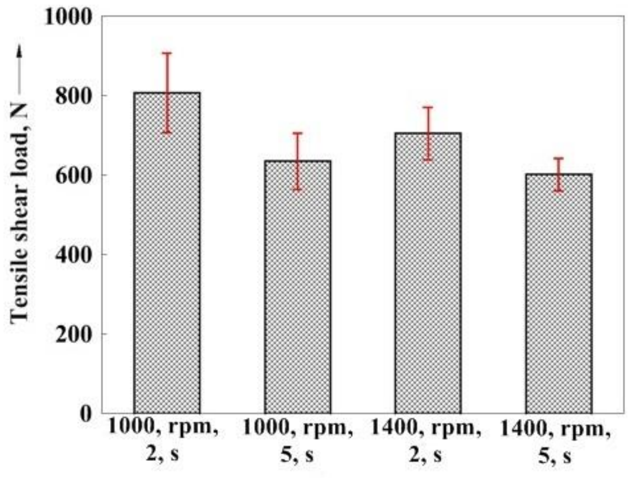


Fig. 5. Variation in tensile shear load of FSSW joint as a function of tool rotational speed and dwell time

It had reported that the increment in dwell time can enhance the nugget thickness; in all this process dwell time is of great importance in attaining a nugget with larger size [28 – 30]. Moreover, it had reported that at low dwelling time the hook plays a key role in FSSW failure [30]. Low rotation speed and dwell time lead to refine the grain of upper sheet especially at SZ. it became clear that long dwell time and high rotational speed results in higher heat input and more extensive stirring during FSSW, which develops the SZ [2].

4. CONCLUSIONS

In the present work, dissimilar aluminum Al 5754/Al 7075-T651 alloys were successfully joined by friction stir spot welding process. The influences of welding parameters such as dwell time and rotation speed were studied. From the experimental results, the following conclusions were drawn:

1. The microstructure images showed the parameters of dwell time and rotation speed affect hook geometry. In addition, tool indentation inside the upper sheet with rotation speed of 1400 rpm, material become soft compare to lower speed 1000 rpm.
2. The hardness value was significantly affected by dwell time and rotation speed, especially in Al 7075-T651. 1000 rpm rotation speed and 2 s dwell time resulted in higher hardness value compared with other specimens. The dwell time has no significant effect compared with rotation speed in the Al 5754 side.
3. The maximum tensile shear load value obtained at 2 s dwell time and 1000 rpm was approximately 806 N. By contrast, the minimum load value was obtained at 1400 rpm and 5 s dwell time. This significant decrease may be due to excessive heat inputs, which expand heat effect zone.

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