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To cite this article: Kareem Mohsen Raheef *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **928** 022121

IOP Conf. Series: Materials Science and Engineering **928** (2020) 022121 doi:10.1088/1757-899X/928/2/022121

Effect of revolution speed on the mechanical properties of dissimilar Aluminum alloy joined by friction stir spot welding

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ABSTRACT
Friction stir spot welding (FSSW) method was performed for welding of aluminum alloys AA6061-T6 with pure aluminum AA1100 sheets having thicknesses of 2.4 and 3 mm respectively. FSSW procedure was accomplished at varied tool rotational speeds (1000, 1600, and 2000 rpm). The dwell time was (2, 4, and 6 sec) and the geometry of the tool pin was threaded cylindrical pin with a cylindrical and straight shoulder.
The aluminum alloy AA6061-T6 sheet was overlapped on the pure aluminum AA1100 sheet. The tensile shear test was investigated for all specimens. It was deduced that the value of the maximum shear force is 1.95 kN. This value was obtained at the following welding factors: 2000 rpm spindle rotational speed, 4 sec dwell time and threaded cylindrical pin profile, the two other factors which were pin length and plunging time were kept as constant parameters through the tests at 3.2 mm and 40 sec respectively. It was also concluded that the fracture happens in the nugget zone mode at the highest lap-shear load.
KEYWORDS: friction stir spot welding; shear force; aluminum alloys

1. INTRODUCTION

Welding is the phenomenon of joining two objects in a significant manner. The friction stir welding (FSW) method was firstly used in 1991 by the UK based institute as a solid-state joining process. This technique was firstly used on aluminum alloys [1].

The friction stir spot welding (FSSW) method shown in Figure 1 looks like FSW. The rotating tool combined with a pin is used in both techniques. While the tool pin penetrates over a seam between two metal plates in the FSW, it holds in one spot in the case of the FSSW. Because of no consumable characteristics, the cost of the FSS joint is less than fasteners, such as clinch nuts or rivets [2].

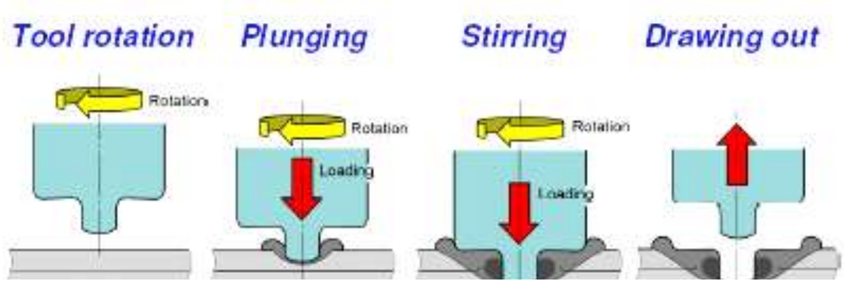

Figure 1. Schematic representation of FSSW process steps [3].

The hardened rotating tool shown in Figure 2 penetrates the workpiece being welded. Having reached the elected plunge depth position, the rotating tool is kept in it for a pre-set time which is sometimes indicated to as dwell period, which in other words can be defined as the duration of the time where the tool and the workpiece keep in contact during plunging, stirring, and drawing out stages. Thereafter, the rotating tool is withdrawn from the welded joint departing behind FSSW. Through the FSSW process, the penetration of the tool and the dwell period substantially set the plasticization of the material just around the pin, heat generation, weld geometry, and subsequently the welded joint properties [4; 5]. The tensile shear fracture load (TSFL) is influenced by the dwell time and the rotation speed of the tool and plunge depth [6].

Many advantages are attained by using this technique, such as welding of dissimilar materials and the metal which are hard to fusion weld, little distortion, simple in handling, and good mechanical properties [3].

However, some literature summary indicates that it is required to distinguish the influence of FSSW factors on the bonding performance [7; 9]. The current work transacts with the effectiveness of rotation speed and dwells time on the tensile shear strength. FSSW process is considered as an alternative method for electrical resistance welding (spot welding) and tungsten inert gas (TiG), and also instead of rivets used for joining thin sheets of similar and dissimilar metals.

Limited researches and few results have been published which investigate the FSSW of dissimilar aluminum alloys. Therefore, more researches on FSSW must be considered to optimize the FSSW process parameters for (Al6061-T6 and commercial pure aluminum alloy AA1100).

2. EXPERIMENTAL WORK

2.1. MATERIALS

Two commonly used materials (Aluminum alloy (AA6061-T6) and aluminum alloy (AA 1100-H112)) sheets were chosen in this work as shown in Figure 3. The dimensions of the Aluminum alloy (AA6061-T6) sheet and the Aluminum alloy (AA1100-H112) sheet were 100 × 25 ×2.4 mm^3 and 100 × 25 ×3 mm^3, respectively, knowing that the former is the top sheet metal and the latter is the bottom sheet metal.

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All the welded workpieces consisting of two sheets of 100×25 mm^2 (parallel to the direction of rotation) with 25× 25 mm^2 overlap area, were bonded in the middle center of this area. Figure 2 shows the tool used in this work. The chemical compositions for AA1100 and AA6061 alloys used in this work are listed in Table 1 and Table 2 respectively.

Figure 2. The tool used in this work.

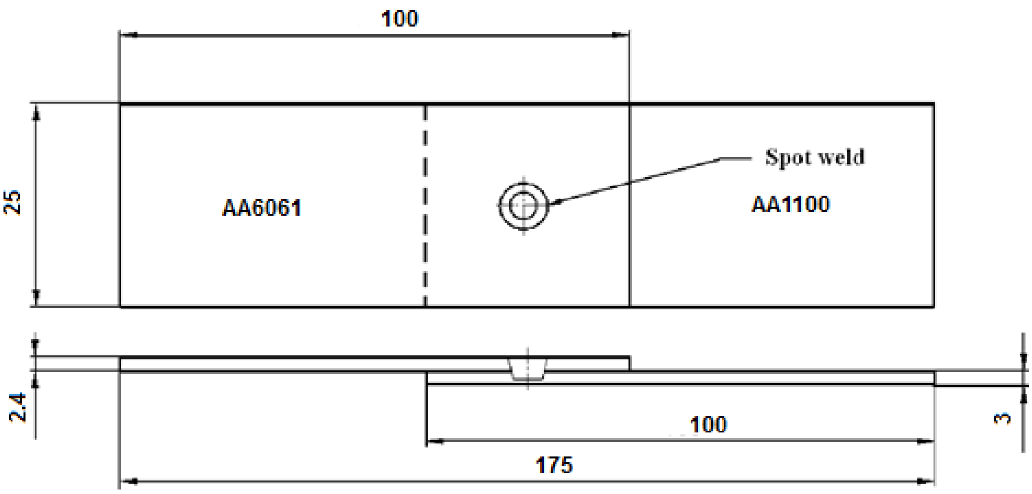

Figure 3. The sketch represents the spot-welded specimen dimensions.

Table 1. Chemical composition for the alloy AA1100-H112.

Element wt.%	Fe+Si		Cu	Mn	Mg	Cr	Ni	Zn	Ti	Others Each	Others Total	Al
Nominal (value)	0.95 Max		0.2 Max	0.05 Max	-	-	-	0.1 Max	-	0.05	0.15	Bal.
Measured (value)	0.153	0.593	0.154	0.003	Nil	0.0019	0.0016	0.006	0.003	Nil	0.007	Bal.

Table 2. Chemical composition for the alloy AA6061-T6, where T6 is the solution of heat treatment and artificial aging.

Element wt.%	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	Others Each	Others Total	Al
Nominal (value)	0.8 max	0.7 max	0.4 Max	0.15 Max	1.2 max	0.35 Max	0.05 Max	0.25 max	0.15 max	0.05 max	0.15 max	Bal.
Measured (value)	0. 539	0.532	0.303	0.092	0.921	0.209	0.0122	0.064	0.016	0.009	0.009	Bal.

2.2. FSS WELDING PROCESS

FSSW procedure was conducted by using a universal milling machine type (Φy251-Bulgaria) to fabricate the FSS specimens welded joints so that the AA6061-T6 sheet was the upper part placed over the pure AA1100-H112 which was the lower sheet. To develop the FSSW process, additional proper clamping fixture was used to get the required 1ap spot joints, as shown in Figure 4. The workpieces were of a 25x25 mm^2 overlap area. Through the FSS Welding, most of the heat energy used for joining was generated due to the friction that happened between the shoulder pin and the workpieces. The tool of 52 HRC hardness used in the welding process was manufactured from high-speed tool steel shaft (HSS). The tool pin profile which is (cylindrical threaded) was used to produce the bonding in this study.

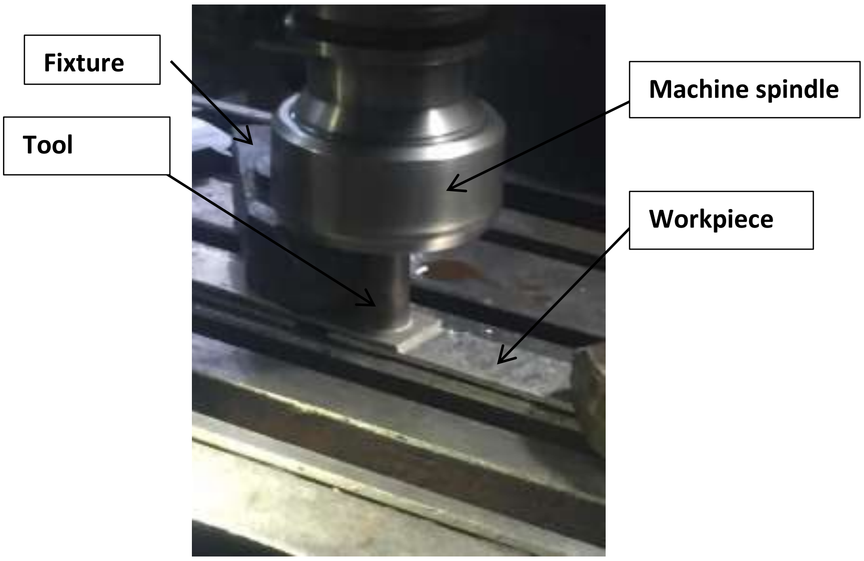

Figure 4. The workpiece as clamped to the milling machine bed.

3. TENSILE SHEAR TESTING

Tensile shear strength was executed on a spot-welded specimen having a length of 175 mm, a width of 25 mm, and a thickness of (2.4 and 3) mm. The welded specimens were examined on an Instron apparatus at 3 mm/min fixed crosshead speed with the highest load of 100 kN. For dissimilar metals (Al6061-T6 and pure Al1100), the friction spot-welded specimens were clamped using shims of two different thicknesses during the lap shear tensile test. This equals to that in the case of the spot-welded specimens. For each FSSW specimen and during the test, the maximum shear load was reported at the fracture point.

4. RESULTS AND DISCUSSION

4.1. TENSILE SHEAR FORCE TESTS

Tensile shear force (shear strength) is an important response property taken into consideration in the FSSW process because it describes the quality of spot-welded joints. Tensile shear tests for FSS samples were executed to estimate the shear strength of the FSSW joint. Table 3 explains the welding parameters and maximum shear force for all specimens welded by FSSW.

- Effect of dwell time on shear force
- Effect of rotation speed on shear force

The FSSW for (AA1100 to AA6061) was carried out at different conditions. Good results listed in Table 3, were obtained when the applied rotational speed is 2000 rpm. The first case was under 2000 rpm rotational speed, 2 sec dwell time, and 3.2 mm pin length. Accordingly, the maximum shear force recorded 1.82KN is considered a good result compared with the rest results. This behavior may be due to the lower dwell time, which is 2sec. In the second case which was under 2000 rpm speed and 4 sec, and at the same pin length 3.2 mm, it is noticed that the shear force increased to

1.95KN as shown in Figure 5 which represents a comparison between welding parameters and maximum shear force for the samples joined by FSSW. Figure 5 also shows that the maximum shear force increases until 4 sec and then reduces at 6 sec when the rotational speed increases. These results agree with that published by many researchers who have indicated that the tensile shear strength decreases by 16% when the dwell time increases from 5 to 10 sec [7].

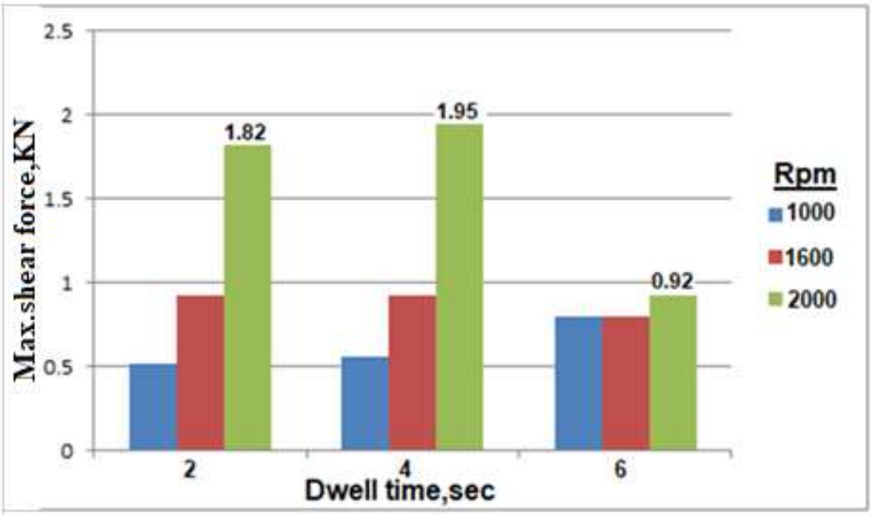

Figure 5. Comparison between bonding factors and maximum shear force test of samples joined by FSSW.

Table 3. FSSW of dissimilar alloys for AA1100 and AA 6061-T6 weld joints.

Alloys	Specimen no.	Rotation speed (rpm)	Dwell time (sec)	Maximum shear force (KN)
AA1100 & AA6061	1	1000	2	0.52
AA1100 & AA6061	2	1000	4	0.56
AA1100 & AA6061	3	1000	6	0.8
AA1100 & AA6061	4	1600	2	0.92

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AA1100 & AA6061	5	1600	4	0.94
AA1100 & AA6061	6	1600	6	0.82
AA1100 & AA6061	7	2000	2	1.82
AA1100 & AA6061	8	2000	4	1.95
AA1100 & AA6061	9	2000	6	0.92

In friction stir spot joints, there are three different fracture modes: nugget pull out fracture, interfacial shear fracture, upper sheet fracture, and lower sheet fracture [9]. Figure 6 explains the types of fracture modes of the tensile-shear specimens which were used in this test. It was concluded that the joint having nugget zone fracture has the highest strength which agrees with research published by the paper [10; 12]. For the nugget zone separation, two sheets were used to separate the partial bonding under load. As a consequence, fracture types depend on the area of the SZ [13].

Fracture mode	Lower sheet	Upper sheet
Upper and lower sheet fracture		
Nugget zone fracture		

Shear stress fracture		

Figure 6. Images of failure surfaces which is described by the failure mode of the test specimens.

CONCLUSIONS

The overall conclusions arising from the current work are as follows:

1- The tensile shear force of the joint obtained by using the FSSW method is greatly influenced by the speed of the rotating tool and dwell time.

2- The maximum shear force value obtained at 2000 rpm spindle rotational speed, 4 sec dwell time, and a threaded cylindrical pin profile is 1950 N.

3- The tensile shear force increases when the speed of the rotating tool increases in a limited domain of FSSW joints.

4- When the dwell time increases, the shear strength decreases.

5- Fracture happens at the nugget zone mode at the highest lap-shear load.

ACKNOWLEDGMENTS

The authors are grateful to the Mustansiriyah university (www.uomustansiriyah .edu.iq) for the use of their facilities in the laboratories of the college of engineering.

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