

# Parametric study of two-stage refilled friction stir spot welding



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## ABSTRACT

Two-stage refilled friction stir spot welding (TFSSW) is a novel refilling process, based on conventional FSSW. This process is done in two steps and with two independent tools, conventional and refilling tool. In this paper, TFSSW is studied, using Al 1100 sheets which were 2 mm in thickness, to evaluate effect of welding parameters on joint strength. Tool rotational speed is the most important parameter that affects welding strength followed by refilling tool shoulder diameter. Application of lower tool rotational speed and bigger refilling tool shoulder diameter leads to stronger joints. Dwell time is the negligible parameter, because it has almost no effect on joint strength. Welding parameters for strongest joint, with 6.96 kN tensile shear strength, were tool rotational speed of 1000 rpm, conventional tool plunge depth of 3.8 mm, total dwell time of 6 s and refilling tool shoulder diameter of 14 mm.

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## 1. Introduction

To achieve higher fuel efficiency, using light weight metals, especially aluminum alloys, has been increased in automotive industry. Common welding process for automotive industry is resistance welding which is so costly for aluminum sheets due to hard surface film of aluminum oxide and high heat conductivity of aluminum sheets [1]. Friction stir welding is a solid-state welding process that is convenient for welding of aluminum alloys. Friction stir spot welding is a variant of main procedure which was invented by Mazda corporation and Kawasaki heavy industries [2]. This process uses a non-consumable rotary tool which is harder than sheet material. For welding, sheets should be fixed while they are overlapped. Firstly, tool penetrates in upper sheet. Tool rotation results temperature rising and with pressure of vertical movement of tool, joining takes place. Schematic illustration of friction stir spot welding is represented in Fig. 1(a)–(c).

Many researchers studied FSW and FSSW from different points of view. Effect of welding parameters on mechanical performance and microstructure of welded specimens [3–6], optimization of process parameters [7,8], effect of tool geometry on welding performance [9–11], failure analyzes [12] and numerical investigations [13–15] are some of studied fields.

Taysom et al. developed models for the application of model predictive control to FSW and assed temperature prediction capabilities in simulation [16]. Evans et al. introduced Two-sided friction stir riveting by extrusion which can be considered as a variant of

FSSW. They reported that this process secularly joints the dissimilar materials together [17]. Hoyos et al. stated that FSW offers important advantages in term of hydrogen content when it is compared to conventional fusion welding processes [18]. Zafar et al. studied effect of tool rotational speed on mechanical and thermal properties of friction stir welded Nylon 6 plates which were 16 mm in thickness [19].

The most important defect of FSSW is the keyhole. Keyhole is crated because welding tool has a pin, see Fig. 1(c). “It is believed that corrosion could take place preferentially at the keyhole because rainwater remains in the hole, where body paint barely reaches the bottom”, Uematsu et al. said [20].

There are four refilling FSSW procedures in the literature. First one uses a tool with retractable pin [20]. Second one uses a tool with movable pin and sleeve [21]. The time of welding in these methods are very shorter than other refilling procedures and using a single tool makes them suitable for industrial robots. In the later type, because of creating a space for extruded materials, thinning of upper sheet is minimized. But fabrication of welding tool is so costly, for these two methods, and implementing of these tools needs a special machine which should be able to handle independent linear and rotational movements. grooved shoulder pinless tool [22] and using a filler plate [23] are other refilling methods. Pinless tool that was introduced by Tozaki et al. can properly cover surface of nugget. Using a single tool, with simple design and manufacturing process, and performing the welding on milling machine are advantages of this type of refilling procedure. But there is no focus on this method because of inefficient stirring process and poor strength of joints [22]. Filler plate type is also a creative type of refilling with simple process and approximately zero thinning of

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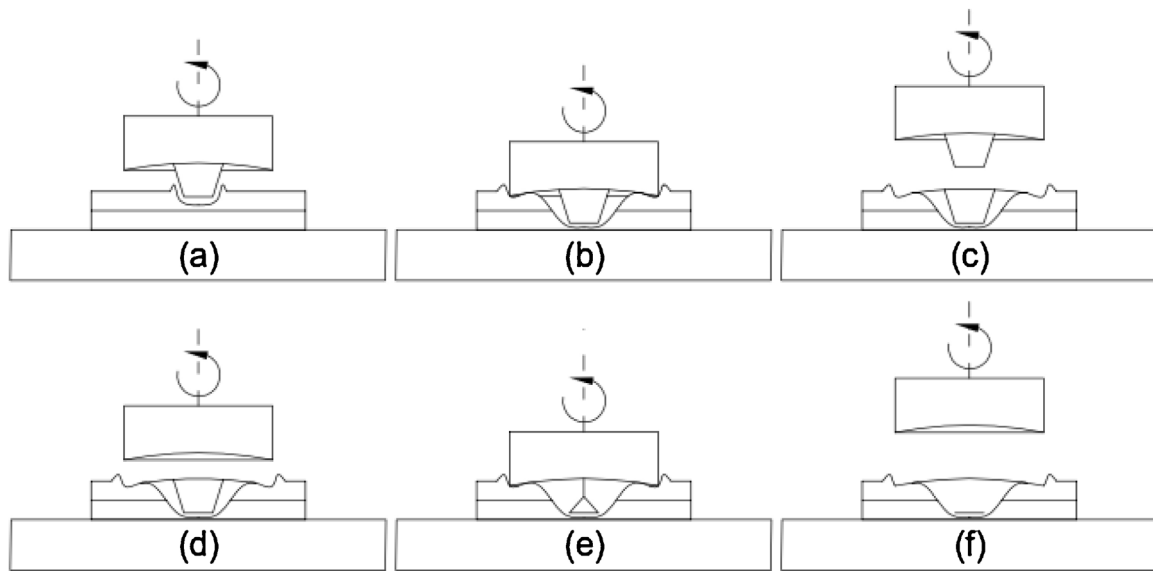


Fig. 1. Two-stage refilled FSSW process. (a)–(c) first step (conventional FSSW) and (d)–(f) second step (refilling process).

sheets. But it consumes considerable time and the joint should be treated in both sides [23].

Two-stage refilling friction stir spot welding which was introduced by author [24] is a cost effective method for refilling FSSW and can be applied with a FSW adopted universal milling machine. In this process there is two steps and each step uses an independent tool. First step is conducted by conventional FSSW tool and second step uses a pinless tool to refill the nugget. The schematic illustration of refilling procedure is presented in Fig. 1. Experimental tests have confirmed refilling action of two-stage refilling FSSW (TFSSW). Also tool replacing makes TFSSW a time-consuming process, compared to other refilling technics which use single tool, but simplicity of process and equipment, low cost of this operation, proper joining and high strength of welded samples are advantages that make it compatible with other methods. This process is lower in cost compared to single tool refilling processes because tools are simple in this method, with no internal movement. In the other hand this process can be done on simple milling machine and no special machine is needed.

## 2. Experiments

In this study, two-stage refilling friction stir spot welding (TFSSW) is studied parametrically to evaluate effect of welding parameters on joint strength. TFSSW is a cost-effective method compared to other refilling processes because it can be performed on a universal milling machine with two independent simple tools and in two separate steps: welding and refilling. The first step is just like conventional FSSW, same process and same tool. As second step, refilling tool, i.e. a tool without pin, refills the keyhole which was created by conventional tool pin in the first step. Fig. 1, illustrates TFSSW process, schematically. As it mentioned above, First step is typical friction stir spot welding with three phases: plunging, stirring and drawing out, see Fig. 1(a)–(c). After conventional FSSW, the conventional tool should be replaced with a pinless tool for refilling process. This step is conducted in three phases: refilling tool comes in contact with surface of nugget, rotation of refilling tool softens nugget material and makes their flow possible. Material flow refills the keyhole. At the end, refilling tool is drawn out; see Fig. 1(d)–(e). Also tool replacing makes TFSSW a time-consuming process compared to one-step refilling technics but simplicity of

Table 1

Conventional welding parameters and joint tensile properties. TN: test nomenclature, TRS: tool rotational speed, CTPD: conventional FSSW tool plunge depth, DT: dwell time, TSS: tensile shear strength DS: maximum displacement, JD: joint diameter.

| TN | TRS(rpm) | CTPD(mm) | DT(s) | TSS(kN) | DS( $\mu$ m) | JD(mm) |
|----|----------|----------|-------|---------|--------------|--------|
| 11 | 1000     | 3.7      | 3     | 5.20    | 590          | 9.89   |
| 12 | 1000     | 3.7      | 6     | 5.78    | 660          | 9.75   |
| 13 | 1000     | 3.8      | 3     | 6.11    | 820          | 10.52  |
| 14 | 1000     | 3.8      | 6     | 6.32    | 840          | 10.87  |
| 21 | 2000     | 3.7      | 3     | 4.14    | 650          | 8.45   |
| 22 | 2000     | 3.7      | 6     | 4.58    | 720          | 9.23   |
| 23 | 2000     | 3.8      | 3     | 4.87    | 810          | 8.84   |
| 24 | 2000     | 3.8      | 6     | 4.77    | 770          | 9.12   |

process and equipment and low cost of this operation make it compatible with other methods, especially for laboratory studies.

AA1100 aluminum sheet with thickness of two millimeters was used to perform tests. According to literature, tool rotational speed, tool plunge depth and dwell time are important FSSW parameters. Table 1, shows the nomenclature and parameter levels that were used for conventional FSSW. Based on our previous study [24], effect of tool rotational speed, conventional tool plunge depth, total welding dwell time and refilling tool shoulder diameter were studied. Tables 4–6, represent the nomenclature and parameter levels for welded specimens with TFSSW. For each configuration three specimens were tested. It should be noted that rotational speed and dwell time for conventional and refilling tool were equal.

Pin of welding tool plays an important role in friction stir welding and processing. The stirring process, material flow and strength of weld are highly dependent on geometry of tool pin. But there is a problem with it, too. In any type of friction stir welding processes, there is a keyhole on tool retracting point. For spot welding this problem is more critical. Because there is just one point that is welded and tool has no horizontal movement. In the other hand, spot welding is applied to body plans mostly, which usually are disposed to rain water. This results highly risk of corrosion for joints with a keyhole [20].

Tools were machined from H13 steel. They were hardened according to standard heat treatment procedure up to 54 HRC. Sajed et al. reported that screwed conic pin results highest strength [9]. So, this type of pin with minimum diameter of 3 mm was machined as conventional tool pin. Tozaki et al. concluded that taller pin leads

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