



24th COBEM - 2017



24th ABCM International Congress of Mechanical Engineering  
December 3-8, 2017, Curitiba, PR, Brazil

COBEM-2017- 0658

## STUDY ON THE EFFECTS OF WELDING PARAMETERS ON FORCE AND TEMPERATURE DURING FRICTION STIR SPOT WELDING OF AA6060-T5

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**Abstract.** *The FSSW is a well-known technology used to obtain joints in overlap configuration. It was developed by Mazda Motors Corporation in partnership with Kawasaki Motors Corporation in 2001. The weld is performed by a rotating tool, composed of two cylindrical geometric features named pin and shoulder. The tool plunges into the sheets, in overlap configuration, at a given rotational speed until the shoulder reaches a defined depth in the upper sheet. In this study, FSSW joints of AA6060-T5 in sheets 3,2 mm thick were produced to assess the effect of welding parameters on plunge force, temperature and joint strength. Three levels of rotational speed and dwell time were defined using a DOE factorial complete analysis that led to a L9 orthogonal matrix. For each welding configuration four samples were produced, one for microstructural assessment and three for mechanical tests. The results showed that the dwell time proved to be a determining factor in the strength of the welded joint. Temperature and plunge force are strongly affected by the welding parameters and their assessment give important insight into the welding development.*

**Keywords:** *welding, FSSW, DOE, temperature, plunge force.*

### 1. INTRODUCTION

Mazda Motor Corporation proposed the Friction Stir Spot Welding (FSSW) in partnership with Kawasaki Motors Corporation in 2001 (Mazda media release, 2003). The FSSW is a welding technology suited for spot joint of metal sheets without bulk melting. The base of FSSW technology is on the Friction Stir Welding (FSW), which the main difference between the technologies is the absence of tool translation in the FSSW (Su, *et al.*, 2006).

The process produces a spot weld by plunging a rotating tool onto the sheets in overlap configuration. The tool is composed of two main elements: a pin and a shoulder. The pin plunges onto the sheets and is the most responsible for the material flow, while the shoulder produces heat and exerts pressure on the top of the weld. As shown in Fig 1, there are 3 stages in the FSSW, between stages 2 and 3 might have a period called Dwell Time (s).

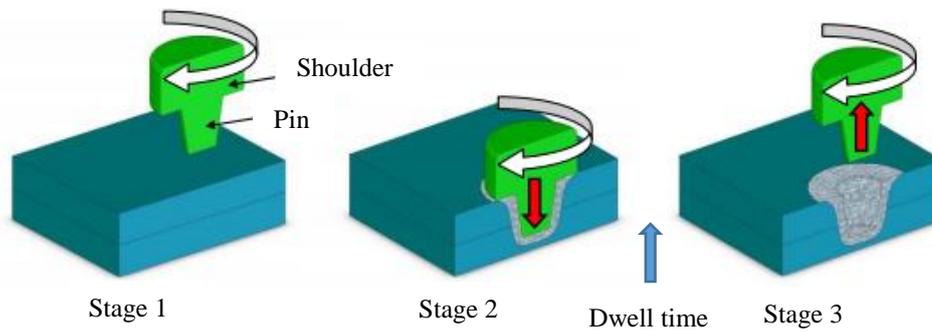


Figure 1 - Process Stages

One of the major characteristics of the FSSW is the ability to produce welds in the solid state, in other words, the joints are formed with no melting of the sheets, which leads to enhanced mechanical properties when compared to conventional welding. Other advantages are minimum thermal distortion, no need of surface preparations and no generation of fumes, been an environment friendly process.

Since the FSSW is a relatively new technology, studies are still necessary to understand all the mechanisms associated to the joint formation, correlation between welding parameters and joint properties, types of defects, etc.

This work aims the investigation on the effects the welding parameters have on temperature, plunge force and joint strength of FSSW joint of aluminum alloy 6060-T5.

## 2. METHODOLOGY

Welded joints in overlap configuration were produced using the FSSW process in sheets of AA6060-T5 3,2mm thick. The joints were produced in the form of shear tensile samples as shown in Fig 2a. A schematic drawing of the tool used is shown in Fig 2b. The welding was performed using a ROMI D800 machine. The joint properties depends on the different process parameters, in this work two different processing parameters were investigated: Rotation Speed (rpm) and Dwell Time (s). Figure 2c shows the welding setup.

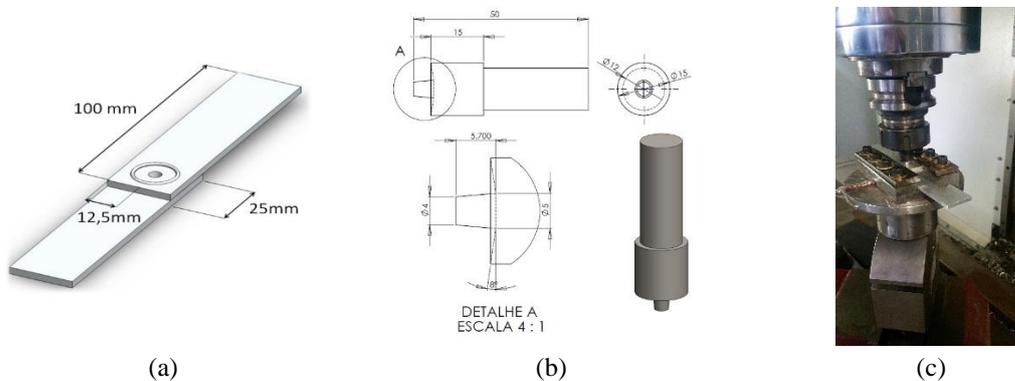


Figure 2 – (a) Test samples, (b) welding tool and (c) welding setup.

To determine the welding parameters combinations, a Design of Experiments (DOE) analysis was applied by a complete factorial  $3^2$ . Two welding variables were investigated, rotational speed and dwell time, each having three different levels, leading to the 9 combinations shown in Table 1.

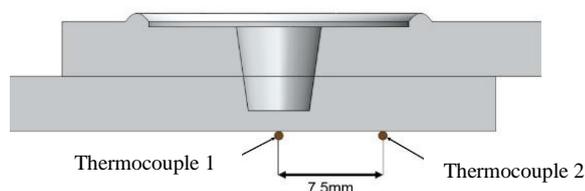


Figure 3 – Thermocouples setup.

Table 1- Welding combinations (L9 orthogonal array).

Welding combinations	Rotational speed (RPM)	Dwell time (s)
1	1500	0
2	1500	2
3	1500	4
4	2000	0
5	2000	2
6	2000	4
7	2500	0
8	2500	2
9	2500	4

For each welding combination were produced five samples, four for mechanical tests and one for metallographic assessment. While the samples were being produced, plunge force and temperature could be measured by a Spider 8 (HBM) acquisition system, using a load cell of 100kN capacity and two type J thermocouple, respectively. The joint strength was evaluated by means of shear tensile tests (0,5mm/min loading speed). For macrograph evaluation was used standard metallographic process, using as etchant the solution 100HCL, 100 HNO<sub>3</sub>, 100H<sub>2</sub>O and 25HF

### 3. RESULTS AND DISCUSSION

#### 3.1 Macrograph and Joint Strength:

The macrograph of the cross section of a welded joint is shown in Figure 4a. It is visible the mark left by the welding tool and the stir zone. Figure 4b shows the shear tensile results. As can be observed, the best joints, in terms of shear strength, are those produced with 1500rpm with dwell time of 2s and 4s. The Dwell Time is the most effective parameter on the joint strength, increasing the joint strength for all the rotational speeds investigated.

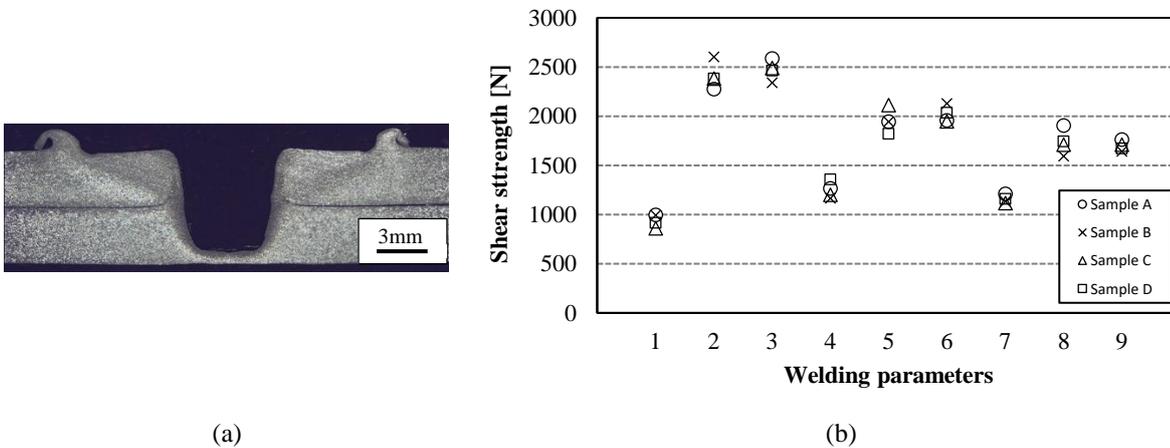


Figure 4 – (a) Cross section macrograph of a welded joint and (b) shear strength.

Table 2 shows the Analysis of Variance table indicating the contribution each welding parameter has on the joint strength.

Table 2 - ANOVA table for the contribution of welding parameters on joint strength.

	DOF	Seq SS	Contribution [%]
<b>Rotational Speed</b>	1	253749	10,89
<b>Dwell Time</b>	1	1344567	57,69
<b>Error</b>	5	489452	21,00
<b>Total</b>	8	2330493	100

As can be seen, the Dwell Time is responsible for almost 60% of gain of joint strength. Also worth noting is the absence of gain on strength from 2s to 4s of dwell time. This is probably associated to the stick/slip phenomenon as have already been reported by other authors (Rosendo, 2009 and Aita, 2017).

### 3.2 Temperature and Plunge Force

Figure 5a shows the plunge force during welding and fig 5b shows the temperature evolution for the joints produced with 1500RPM/4s. A peak in the plunge force is observed in the moment the shoulder touches the upper sheet surface. From this point, during dwell time the plunge force decreases due to the heat being generated. As expected, the temperature rises rapidly during the plunging of the welding tool and then it drops exponentially until the complete cooling of the joint.

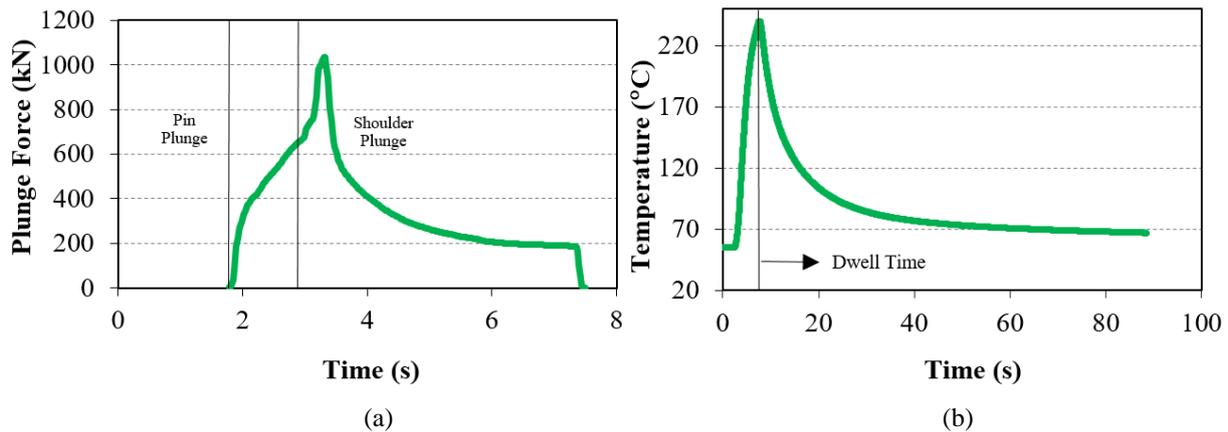


Figure 5 – (a) Plunge force and (b) temperature in thermocouple 1.

Figure 6a shows the maximum plunge force for each welding combination and Fig 6b shows the maximum temperature. As can be seen the plunge force was higher for the welds produced with 1500rpm and lower for 2000 and 2500RPM. This observation, together with the increase of temperature (Fig 6b), helps to explain the drop in joint strength for higher rotational speeds. As have been shown by other authors (Rosendo, 2009 and Aita, 2017), when the temperature reaches a critical value, the material softens and the contact condition between the welding tool and the material changes from a stick to slip condition. This causes the plunge force to drop for higher rotational speeds.

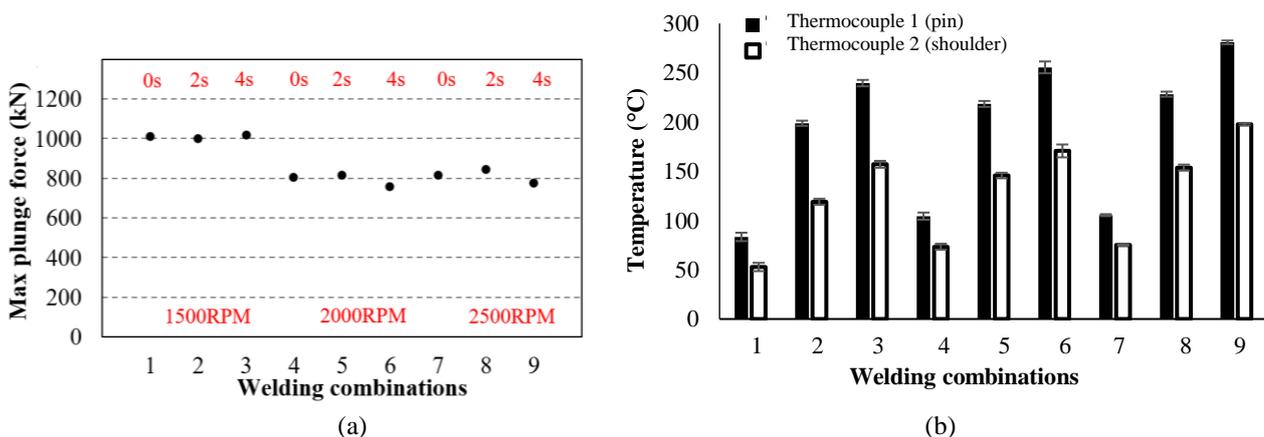


Figure 6 – (a) Maximum plunge force and (b) peak temperature for the welding combinations tested.

### 4. CONCLUSIONS

In this study, a combination of welding parameters in terms of rotational speed and dwell were determined by means of a DOE analysis. The effect of these welding parameters on plunge force and temperature of FSSW joints was investigated. The results indicated that the welding parameter of major importance on joint strength was dwell time followed by rotational speed. The welding parameters tested affected the plunge force and the temperature developed

during welding, which are important indications of the energy necessary to produce the joints. As expected, an increase in dwell time reduces both plunge force and temperature. It can be concluded:

- The Dwell Time is the parameter most important on the joint strength, affecting in almost 60% on its value.
- The Rotational Speed of 1500RPM led to the best welding results, but only if associated with Dwell Time.
- The discrepancy between the results of temperature and joint strength, suggests the occurrence of the phenomenon known as transition stick / slip for the rotations of 2000 and 2500RPM.

## 5. REFERENCES

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## 6. RESPONSIBILITY NOTICE

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