IOP Conf. Series: Materials Science and Engineering **377** (2018) 012012 doi:10.1088/1757-899X/377/1/012012

# Friction stir welding of thin aluminium alloy plates using milling machine: a basic compatibility study

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**Abstract**. The paper reports on the friction stir processing of aluminium alloy plates having a thickness of 2 mm using a reconfigurable vertical milling machine. In-house design and manufacturing of the tools were done using tool steel. A backing plate with fixture mechanism was designed for holding the plates in the vice of the machine. The tool was rotated using the milling machine at different speed ranging from 710 to 1400 rpm under a transverse constant speed of 80 mm/min. The average hardness and tensile strength of the produced weld joints were further analyzed for different tool rotational speeds. An optimum rpm of the spindle was found out for defect free joints.

## 1. Introduction

Friction stir welding is comparatively a recent welding technique developed by The Welding Institute (TWI), Cambridge, UK in the year 1991. As compared to the conventional welding methods, FSW consumes considerably less energy and since, no cover gas or flux is used, it is considered as the energy efficient and environment friendly method of metal joining [1]. The underlying principle of friction stir welding is based upon the concept of generation of heat due to friction. In this process, a non-consumable rotating tool is plunged into the joint by a vertical force and the tool is forced to travel along the joint line as shown in figure 1. The tool is made of two parts i.e., a shoulder which mainly heats the plate by friction and probe (pin) which stirs the material to avoid hole and to make the join compact. The generated heat results in plastic diffusion of the material at the joint resulting in welding.

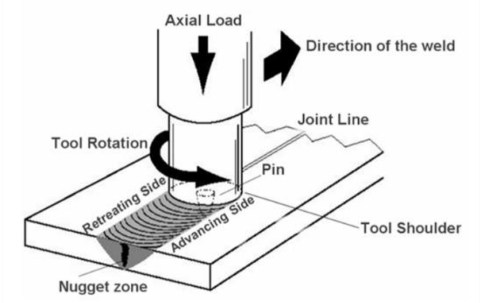


**Figure 1.** Schematic of FSW process by using a rotating tool which traverses in the direction of joined edges of plates adopted from [2].

Although this process of joining severs the purpose of academic research beautifully, but the need of costly machineries limits its accessibility in reaching the shop floors with lesser capital. This problem

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can be resolved to some extent by using vertical milling machine with some modifications of fixtures and using specifically designed tool. Minton and Mynors [3] were first among the researchers who have documented the investigation, whether a conventional milling machine is capable of producing friction stir welded joints. They tried production of welds of same thickness from 6.3 mm and 4.6 mm 6082T6 aluminium sheets. The results demonstrated that a conventional milling machine is highly capable of performing FSW and using a relatively stout tool to join 6.3 mm thick 6082-T6 aluminium, reasonable weld can be produced. Although while joining 4.6 mm thick 6082-T6 aluminium, weld quality was lower compared to 6.3 mm thick aluminum sheet. Akinlabi *et. al.* [4] performed FSW for producing butt weld of 6084 - T6Aluminium Alloy (AA) and C1000 copper (Cu) sheets having dimension 600 mm x 220 mm x 3 mm. they were able to achieve an optimum joint strength of 74 %. Shaikh *et. al.* [5] used vertical milling machine to produce weld on commercial 6 mm thick HDPE sheet. They achieved 85% of base material ultimate tensile strength in plain HDPE welds and also composite welds were produced without loss of strength.

The friction welding studies with vertical milling machine were mostly conducted on thicker plates. In the present study we are focussing mainly on FSW of thin aluminium plates by considering its wide practical use. The dimensions of the 6081-T6 aluminium alloy sheets were 200 mm x 18 mm x 2 mm. We have designed the tool and the fixture in house for producing welded joints.

## 2. Experimental procedure

Experiments were performed on a variable speed bed type-milling machine with a robust solid cast bed, power feed on the x, y and z-axes and equipped with a 4 kW motor. The spindle speed on the milling machine can be varied from 70 to 4200 rpm. However, we conducted the experiment at three different spindle speed namely 710, 1000, 1400 rpm and the tool traversing speed was kept constant at 80 mm/min. A fixture was prepared in house for performing the welding. The fixture was clamped in the bench vice of the machine, which acts as the backing plate during welding. Aluminium sheets were bolted at the ends before welding. The complete experimental set up was as shown in figure 2.

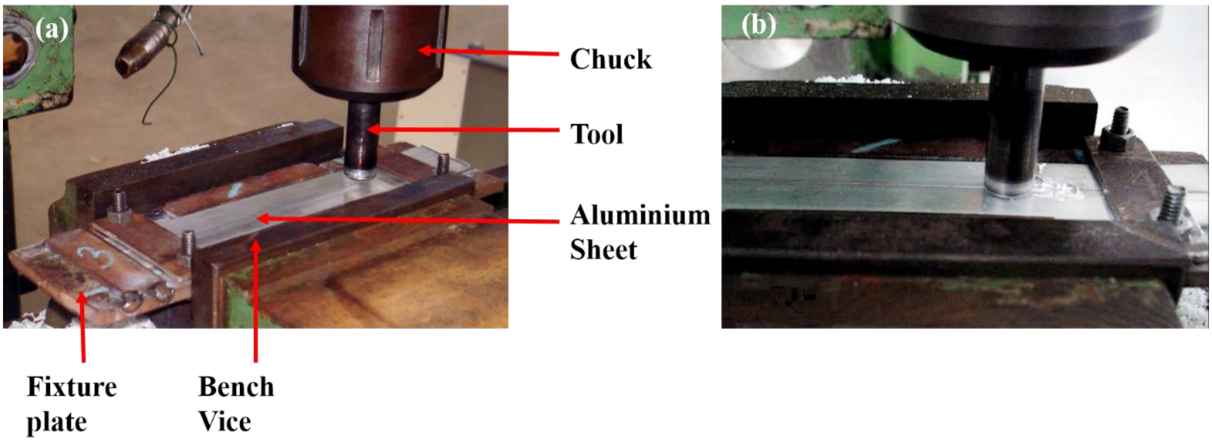


**Figure 2.** In house experimantal set up for FSW for the current experiments. Image (a) describes all the components. Image (b) shows FSW in operating condition.

### 2.1. Tool and fixture description

The tool used for FSW was made of 20MnCr5 steel and was fabricated in the lathe machine using carbide cutting tool. The diameter of the shoulder was 14 mm and we compounded the shoulder with the body of the tool. The shoulder had a configuration of flat-ended smooth cylinder. The diameter and the length of the tool were 4 mm and 1.7 mm respectively. The probe also had a configuration of flat-ended smooth cylinder. The tool design was optimized by considering the sheet thickness and the pressure required for plunging the tool along the weld line during welding. Figure 3(a) and 3(b) can be referred for tool geometry.

Figure 3(c) shows the fixture plate geometry used in FSW. The material used for its fabrication was mild steel having thickness 5 mm so that it can be easily clamped in the vice of the milling machine. Apart from holding the aluminium sheet, the fixture plate also acted as backing material during welding.

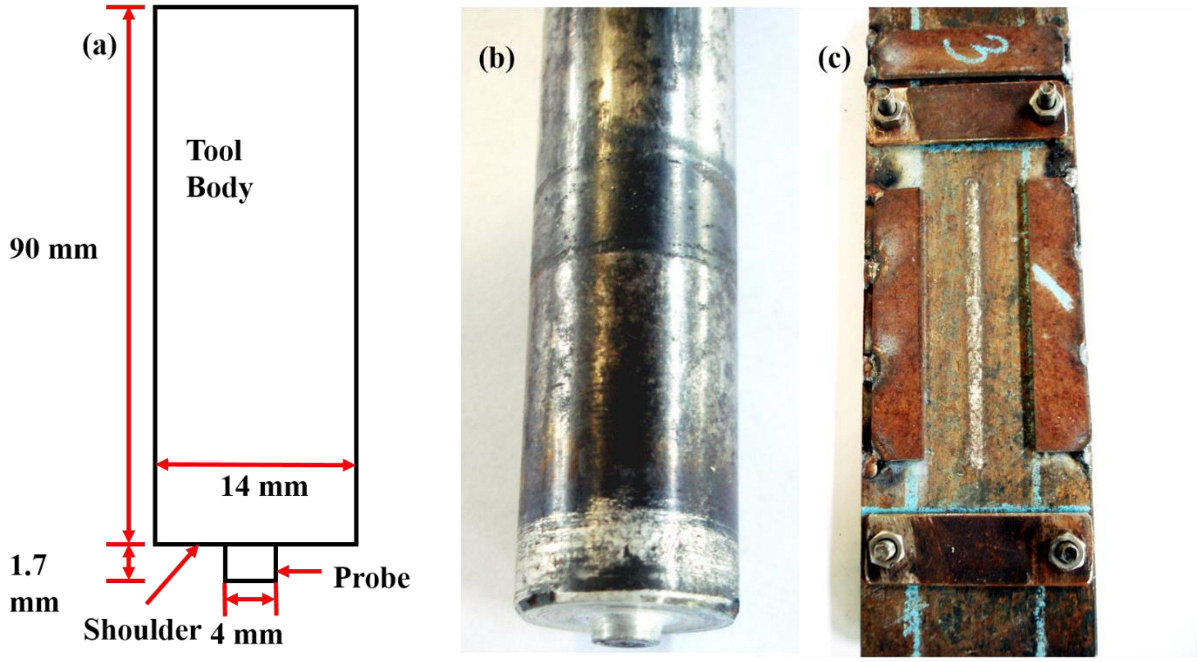


**Figure 3.** (a) Dimensions of the tool, (b) actual tool geometry and (c) fixture plate.

## 3. Results and Discussions

Figure 4 shows the surface appearance of the welded region for three different speeds namely 710 rpm, 1000 rpm and 1400 rpm. It can be seen from figure 4(a) that at 710 rpm the tool was not able to penetrate the sheet at the joint properly due to which rough welding took place. Although the welding was uneven, no cracks occurred in case of 710 rpm. Figure 4(b) shows the friction welded joint after welding at 1000 rpm. By looking at the figure, it can be deduced that the tool was able to properly penetrate the aluminium plate. As a result, onion ring pattern became visible as seen in the image. Minor cracks can be seen at the beginning of the penetration step. However, the welding is smooth which was absent in the previous case. If we further increase the welding speed to 1400 rpm, the tool was able to penetrate the plates properly as seen in figure 4(c). But due to the high rotational speed of the tool, high lateral force arises in the welding line and as a result the welding line between the aluminium sheets became wider, although it was clamped properly. Thus, continuous crack can be seen along the weld line because of non-availability of aluminium. The onion rings are clearly visible and wider. The above analysis points out that the welding region becomes wider as we continuously keep on increasing the welding speed. Also the size of the onion ring keeps on increasing along with increase in rotational speed. However, at 1000 rpm a defect free surface was achieved. Hence it can be inferred that there is always an optimum tool rotational speed for FSW of aluminium alloy plates in order to get defects free surface, depending upon the sheet geometry and tool probe diameter. In our case spindle speed of 1000 rpm at 80 mm/min constant speed can be concluded as the optimum speed.

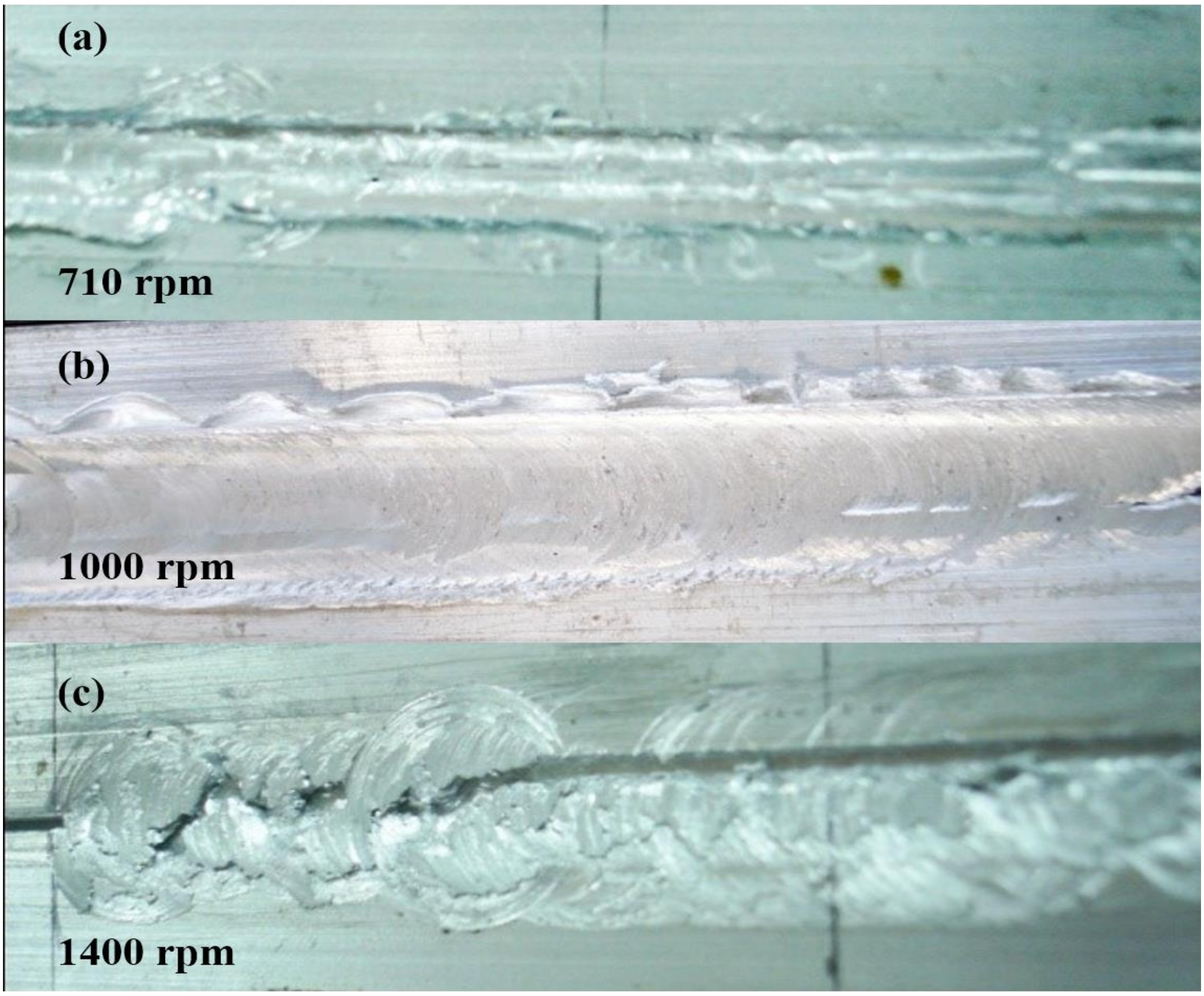


**Figure 4.** Surface appearance at different rpm of the spindle after FSW.

## 4. Tensile strength test

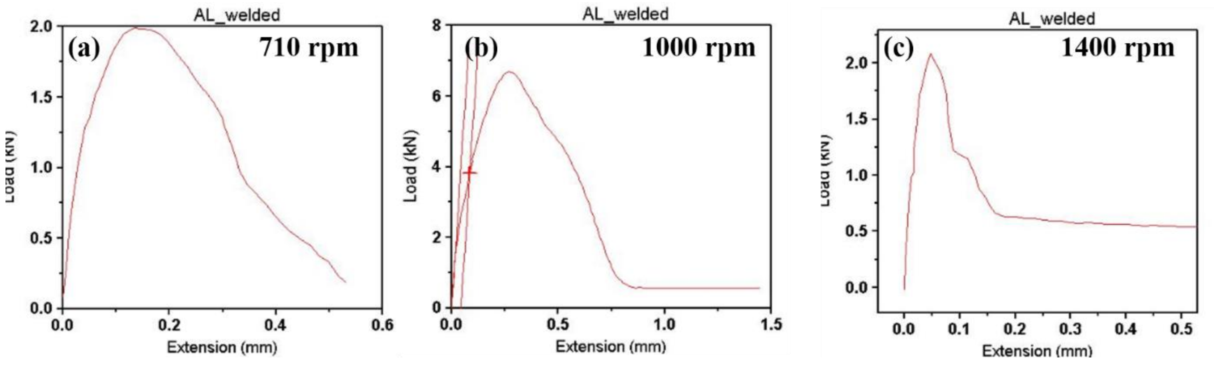


**Figure 5.** Load Vs extension graph for the transverse section of the friction stir welded region for different rpm.

Post welding, the samples were tested for their hardness and tensile strength. The tensile tests were carried out at Strength of Material Lab in IIT Guwahati using CLOSED LOOP SERVO-HYDRAULIC

DYNAMIC TESTING MACHINE (Model - INSTRON 8801, Max. capacity – 100 KN). The machine can perform tensile test, bend test, compression test, cyclic test etc. The tensile tests were carried out at room temperature (298 K) and humidity 78 % with a constant crosshead speed of 1mm/min. Figure 5 shows the load vs extension graph for the welding obtained at different rpm of the spindle. Table 1 shows some quantitative values obtained from the graphs shown in figure 5. The values in table 1 indicates that the weld obtained at 1000 rpm was able to take the maximum load i.e. 6.69 kN and also maximum extension was obtained for the same sample. Hence the tensile strength of the weld obtained at 1000 rpm is the highest, which is 66.89 MPa. The other two samples namely at 710 rpm and 1400 rpm has very less tensile strength compared to the sample obtained at 1000 rpm. This supports our previous claim in section 3 that the welding joint obtained in case of 1000 rpm is best among weld we have considered for the present experiment.

**Table 1.** Tensile test results of the welded sample.

| Tool Speed ( rpm) | Max Load (kN) | Max Extension ( mm) | Extension on max load (mm) | Max Tensile Stress (MPa) |
|---|---|---|---|---|
| **710** | 1.99 | 0.53 | 0.13 | 19.88 |
| **1000** | 6.69 | 1.45 | 0.27 | 66.89 |
| **1400** | 2.08 | 0.58 | 0.048 | 20.80 |

## 5. Hardness test

After the tensile strength test, Vickers micro-hardness tests were carried out on the welded samples as well as the parent material for a duration of 20 secs with a load of 4.9 N. The specification of the machine is: Model Name- MVH-II (Manufactured by – Omnitech). Indentation tool was a diamond pyramid with square base and having an angle of 136° ± 0.5 between opposite faces.

**Table 2.** Micro hardness test results of the parent material and welded sample.

| Tool Speed (rpm) | Sl No. | Load (N) | D1 (μm) | D2 (μm) | Hardness Value (H.V.) | Average Hardness Value (H.V.) |
|---|---|---|---|---|---|---|
| | 1. | 4.9 | 127.25 | 147.9 | 51.3 | |
| **PARENT** | 2. | 4.9 | 128.80 | 137.03 | 52.4 | 51.16 |
| **METAL** | 3. | 4.9 | 133.00 | 138.00 | 49.8 | |
| | 1. | 4.9 | 131.00 | 141.45 | 49.7 | |
| **710** | 2. | 4.9 | 114.25 | 126.00 | 63.5 | 58.00 |
| | 3. | 4.9 | 124.60 | 122.60 | 60.8 | |
| | 1. | 4.9 | 134.00 | 129.60 | 53.2 | |
| **1000** | 2. | 4.9 | 124.00 | 147.00 | 50.0 | 52.47 |
| | 3. | 4.9 | 131.85 | 129.60 | 54.2 | |
| | 1. | 4.9 | 125.20 | 139.10 | 53.0 | |
| **1400** | 2. | 4.9 | 127.00 | 141.00 | 51.0 | 51.33 |
| | 3. | 4.9 | 140.60 | 133.10 | 50.0 | |

Table 2 shows that all the welded joints were having hardness more than that of the parent material. This can be interpreted in terms of grain size [6] in the welded region. Due to FSW the grain size of the parent metal decreases, which results in increased hardness for all the welded joints. It is noteworthy that the average hardness increases remarkably at 710 rpm. However, at 710 rpm, the welding was not proper since the tool couldn’t penetrate completely along the weld line. Out of the two samples at 1000 rpm and 1400 rpm, where welding was perfect, the sample at 1000 rpm found to have more hardness and hence the weld obtained in this case is strongest among all the samples we considered. The average hardness values at different rpm are plotted in the graph shown in figure 6 below. The red dotted straight line in the graph indicates the hardness of the parent material measured initially

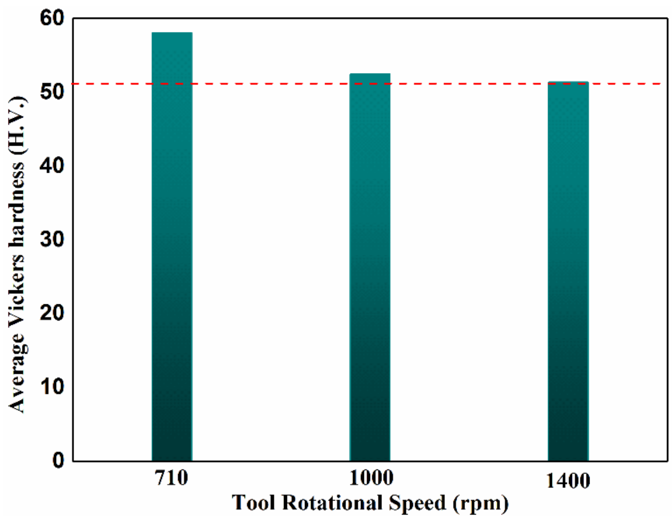


**Figure 6.** Graph plotted between average Vickers micro-hardness Vs tool rotational speed (rpm). Broken line represents average micro-hardness of the base metal alloy.

## 6. Conclusion

A vertical milling machine can successfully perform the friction stir welding of thin aluminium sheets. Welding joints obtained for different rpm of the spindle were tested for tensile and hardness test. All the strength tests infer that the weld obtained at 1000 rpm is having the highest quality of weld obtained from present experimental set up, tool and fixture geometry. The present experiments are the part of the preliminary study done by the author and can be extended further by manufacturing of robust tools and fixture, which will help to achieve precise welding of thin aluminium alloy sheets. One of the prime factors that can be considered for achieving excellent quality weld is to preheat the workpiece. Another important observation made during the study is the vibration of the tool due to its eccentricity and transfer of this vibration to workpiece during welding. The vibration of the work piece can be absorbed by using fixture of grey cast iron instead of mild steel. The vibration of the tool due to eccentricity can be minimized by choosing an efficient design of the collect holding the tool and also by optimizing the length of the tool body to be inserted within the collet. Extension of the present work will primarily focus on resolving the above issues in order to achieve god quality weld.

## Acknowledgements

The author would like to thank Dr. (professor) U. S. Dixit of Mechanical engineering department of IIT Guwahati for his immense support during the project. For all the manufacturing facility and experimental facility, author is very much thankful to the central workshop facility of IIT Guwahati.

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