An Investigation of Mechanical Properties and Temperature Distribution of Micro Friction Stir Welded Aluminium 5052 Thin Sheets

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Abstract

Welding of thin sheets is complicated process even after the development of modern joining processes. Friction stir welding (FSW) is a promising joining technology especially developed for welding of aluminium and its alloys but extended its application to Copper, Magnesium, Titanium, Steel and so on. The objective of this study is to investigate the capability of FSW for joining thin sheets having thickness less than 1 mm (Micro FSW). Aluminium 5052 alloys are widely used for aerospace, marine, heat exchangers and for general sheet metal work. In this study 0.9 mm thick AA 5052 thin sheets are joined by FSW in butt configuration using aluminium backing plate. Micro FSW tool was fabricated with 0.9 mm pin diameter and 6 mm shoulder diameter. Successful welds were obtained at a constant rotational velocity of 3000 rpm and three traverse velocities of 60, 75 and 90 mm/minutes respectively. The temperature distribution across the weld line was measured with six K-Type thermocouples and tool temperature was measured with an infrared camera. The temperature measurement during welding indicated that heat loss from the workpiece is severe because of high surface area to volume ratio of thin sheets. Tensile test and hardness test was also investigated. The joint possess good tensile properties and more than 70 % joint efficiency is obtained for all samples. The results show that hardness of workpiece increases with increase in welding speed and tensile strength decreases with increase in welding speed.

Keywords: Micro Friction Stir Welding, Aluminium Backup plate, Mechanical properties of FSW joints

1. INTRODUCTION

Micro FSW (μFSW) is the adaptation of FSW of sheets having thicknesses less than 1 mm. Welding of sub size aluminium sheet is very difficult due to its high surface area to volume ratio and material properties of aluminium. Therefore fusion welding processes are not suitable for welding thin aluminium alloy sheets. FSW [1] is originally invented in the year 1991 by The Welding Institute (TWI) as a new technology of joining materials using the frictional heat. In FSW, a specially designed non-consumable tool having a shoulder and pin rotates and plunge in to the sheets to be joined. Then the tool traverses along the weld line. Due to the combined action of rotation and translation, frictional heating will take place which soften the metal to be welded. The moving tool stirs the material in a distinctive flow pattern and forges the material in the vicinity of the pin together. The resulting solid state bond joins the two pieces into one which is solely made of parent materials [2-3].

The joining using micro FSW is difficult to achieve due to the increased heat loss from the workpiece. Usually mild steel backup plates are used for performing micro FSW. Many researchers replaced the conventional steel backup plates (as it has high thermal conductivity) with a ceramic backup plate. Since the thermal conductivity of ceramic plates is very low, heat loss through the backup plate can be reduced. However the usage of ceramic backup plate has some practical limitation in the industrial aspect. Sattari et.al.[4] uses a heat resistant backing plate for joining 0.8 mm thick AA 5083 sheets. They considered three rotational speeds (ω) 600, 900, 1115 rpm and two feeds (v) 32, 60 mm/min. Mechanical properties show that yield stress of all samples are below the base metal and by increasing in speed ratio (w/v) the average of micro hardness was decreased and tensile strength increased.

Dissimilar Micro FSW of AA 5052 H32 to AA 6061 T6 was carried out by Doley et.al. [5] at constant rotational speed of 1500 rpm and two tool traverse speeds of 63 mm/min and 98 mm/min. Results shows that weld produced at 63 mm/min speed gives more ductility than the weld produced at 98 mm/min. Since Micro FSW is relatively new development, significant work has been done to date with interesting research findings being reported. Sithole et. Al. [6] comprehensively reviewed the developments in μFSW to date. The focus of the paper is to summaries the problems peculiar to μFSW due to downscaling to the micro scale and other practical considerations. Papaefthymiou et.al. [7] evaluated the applicability of micro-friction stir welding to wrought titan zinc alloy sheets and then to improve the structural integrity of such joints.

Welding of thin aluminium sheet is very difficult due to its high surface area to volume ratio and material properties of aluminium such as high thermal expansion coefficient, high heat transfer, specific heat and high electrical transfer [4-7]. The present research works uses aluminium backup plates, which is considered as the most ideal condition. However the heat loss through the aluminium backup plate is obviously higher, since the conductivity of aluminium is very high. This can be overcome by increasing the heat generation from the tool. Thus in the present research work, a higher value of rotational velocity of the tool (3000 rpm) is used. Since the heat generation increases with increase in tool rotational velocity, heat loss through the aluminium backing plate can be compensated by using high rotational velocity of the tool.

2. MATERIAL, TOOL AND FIXTURES

Aluminium 5052 alloys are widely used for aerospace, marine, heat exchangers and for general sheet metal work. A 0.9 mm thick AA 5052 sheets are welded together by a micro FSW tool made by H13 tool steel having 6 mm shoulder diameter, 0.9 mm pin diameter and 0.85 mm pin height. The chemical composition of aluminium 5052 is tabulated in Table 1. The tool is fabricated by using a conventional precision turning machine. The precision turning operation was performed at 750

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Table 1
Nominal composition of AA 5052 alloy (in weight %)

AA5052	Mg	Si	Fe	Cr	Mn	Ti	Zn	Al
	0.15	0.25	0.20	0.10	0.02	0.01	0.01	Bal

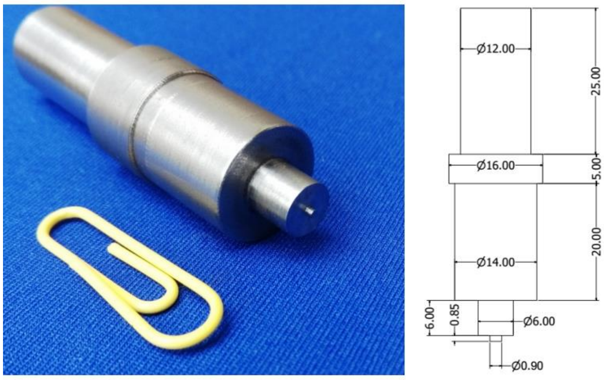

Fig. 1. Micro FSW Tool (All dimensions are in mm)

to 1200 rpm and manual feed in sub millimeters. The dimension and surface quality of the tools is verified with Insize Digital Microscope. The tool geometry that was used for the present study is shown in fig 1.

The weld coupons were cut from the AA 5052 sheet along the rolling direction using power shearing machine. The sheared edges were deburred and top surface of the coupons were cleaned using fine grade emery paper. Three holes having diameter 1.0 mm and depth 0.45 mm were drilled on the top surface of each coupons for making provision for thermocouple beads. Each thermocouple bead is separated by 10 mm and the nearest thermocouple was also 10 mm from the weld center. The layout of the thermocouples is shown in fig 2.

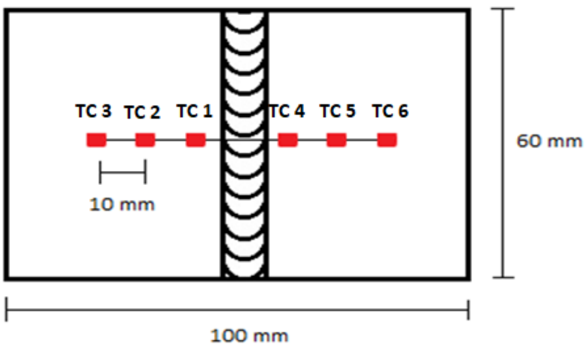

Fig. 2. Layout of Thermocouples

A high precision fixture for holding workpiece is essential for performing micro FSW. The sheets should be aligned very accurately and without any deflection at the top surface. The deflection of the sheet leads to variation plunge depth, resulting in the formation of excessive flash and thinning of sheets. The fixture consists of a mild steel block having a cavity to accommodate the workpiece, a backing plates and top clamps. Acrylic sheets of 6 mm thickness were used for top clamping. Thus the heat loss from the workpiece through the clamping can be reduced. Aluminium 5052 sheets of thickness 2 mm is used as backing plate.

In micro FSW, placing the thermocouple in position and making proper clamping of the workpiece is a difficult task because of the low thickness of the sheet. In the present research work a specially designed top clamp made by acrylic material is used. These top clamp design can hold three thermocouples in position and clamp the workpiece properly. Therefore after every set of welding, replacing the welded coupons and refixing it and thermocouple is an easy task. The fixture and top clamping are shown in fig. 3.

3. EXPERIMENTAL PROCEDURES

Micro FSW is performed on a Tiger Tech TR 203-2 light duty CNC router equipped with Weihong N105G2 CNC controller. The metal fixture is fixed on the table and its alignment is dialed using a Mitutoyo dial gauge. Weld coupons (60x50x0.9 mm) were carefully clamped along with 6 K-type thermocouples on the fixture using the dedicated top clamps without any misalignment with 2 mm AA 5052 as backing plate. A constant rotational velocity of 3000 rpm is used throughout the experiment. Three Welding feed 60 mm/min, 75 mm/min and 90 mm/min is used. Transient temperature data of the workpiece were recorded with National Instruments 8 Channel Data Acquisition System. The temperature of the tool was recorded with Fluke Ti-400 IR Fusion thermal imager.

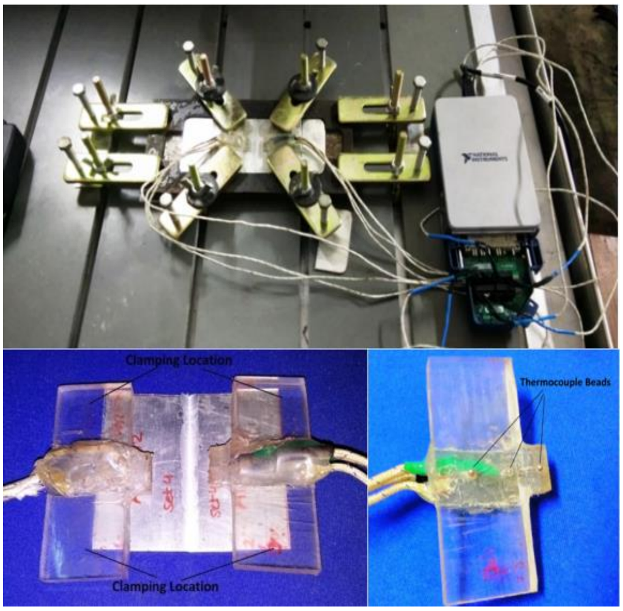

Fig. 3. Fixture and top clamping

Fig. 4. Complete Experimental Setup

Tensile test samples were prepared from the weld coupons as per ASTM-E8 standard. Tensile specimens were cut perpendicular to the welding direction. Tensile testing was carried out on a Shimadsu AG-X Plus Universal Testing Machine (UTM) of 10 kN capacity with testing speed 0.5 mm/min. Vickers Hardness was measured using MATSUZAWA VMT-X hardness tester as per ASTM E384-11 standard. Hardness was measured on the polished top surface with a load of 2 kgf and dwell time of 10 s at different points on both sides of NZ with 3 mm intervals on base metal and 0.5 mm intervals on welded region.

4. RESULTS AND DISCUSSIONS

Heat loss from the work piece is a major problem in micro friction stir welding because of the high surface area to volume ratio of the thin sheet. In addition to that because of the high thermal conductivity of aluminium alloy heat will dissipated very rapidly. A portion of the heat is carried away by the tool. To overcome all these heat losses most of the researchers are using backing plate having low thermal conductivity like mild steel or ceramic materials. In the present research the backing plate material is same as weld material, for compensating the heat loss through the backing plate, moderately high rotational velocity of the tool is used (3000 rpm).

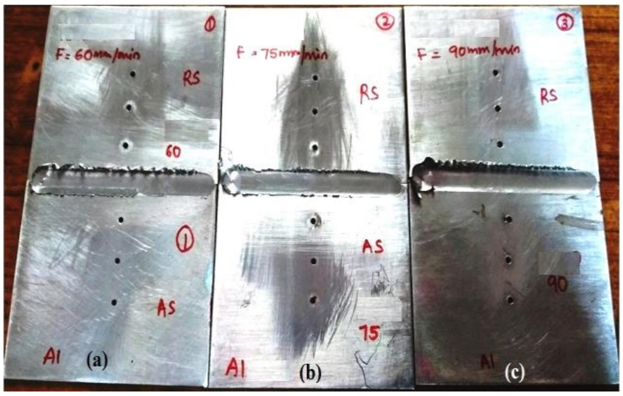

Fig. 5. Welded samples at 3000 rpm and various feed rates- (a) 60 mm/min, (b) 75 mm/min, (c) 90

Successful weld were produced at constant rotational velocity of 3000 rpm and welding speed of 60 mm/min, 75 mm/min and 90 mm/min as shown in fig. 5. A slight flash formation was observed at 90 mm/min due to the extreme heating of the workpiece and excessive plunging of the tool in to the workpiece. The maximum temperature of the workpiece and tool is listed in table 2. The temperature results shows that maximum temperature is observed at 60 mm/min feed and when feed rate increases the temperature decreases.

The temperature data of workpiece shows that heat loss from the workpiece through the aluminium back up plate is very high. But the high rotational speed of tool creates sufficient heat for producing friction stir welding. Due to the high heat dissipation rate of thin aluminium sheet together with highly conductive aluminium backing plate reduces the overall temperature of the workpiece.

Hardness profile across the weld line shown in fig. 6 indicates that there is not much reduction in hardness of the welded region. In literatures a typical 'W' profile is usually observed as the hardness distribution across the weld line. Lowest hardness is usually observed in the heat affected zone (HAZ) and thermo mechanically affected zone (TMAZ). But in the present study there is no appreciable reduction in hardness. This is due to the fact high thermal conductivity of aluminium backing plate carry away the heat from the work piece quickly and finer grains may be formed in the welded region. It is observed that the average hardness of the workpiece increases with increase in feed rate. This is due to the fact that, when feed rate increases heat input decreases which results in the formation of fine grains at higher feed rates.

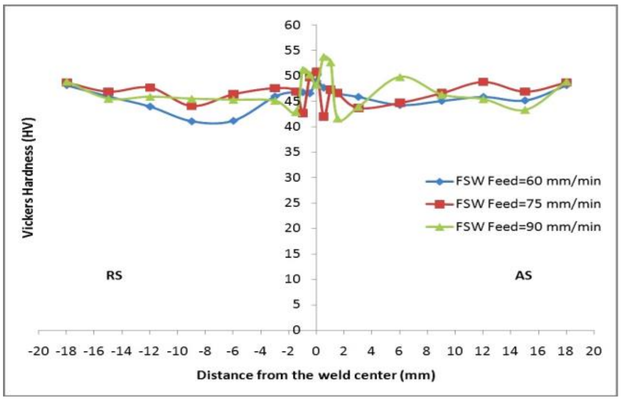

Fig. 6. Hardness profile of weld sample

The engineering stress strain diagram of welded samples and parent metal is shown in fig.7. It is observed that tensile strength and percentage elongation of the welded specimen decreases with increase in feed rate. Maximum tensile strength achieved is 193.78 N/mm^2 at 60 mm/min feed rate which is 88.5% strength of parent metal. Minimum tensile strength is 155.48 N/mm^2 at 90 mm/min feed rate which is 71 % of strength of the parent metal. The reason for the higher tensile strength at lower feed rate is temperature development during welding. At low feed rate temperature development is maximum and the yield strength of the material reduces drastically during welding, which enhances the stirring appreciably. Thus at lower feed rates, tensile strength increases. The same trend is applicable for percentage elongation also. In all the samples failures take place near to the joint. All the above results show good agreement with the work done by sattari et.al. [4]

Table 2
Maximum temperature recorded at various feed rates

RPM	Feed (mm/min)	Max Temp. (Advancing Side) (Degree Celsius)			Max Temp. (Retreating Side) (Degree Celsius)			Max Temp. on the Tool (Degree Celsius)
		TC1	TC2	TC3	TC4	TC5	TC6	
3000	60	79.18	91.78	151.35	131.88	80.43	73.24	317.9
3000	75	77.06	80.37	142.61	125.08	79.88	68.79	298.4
3000	90	71.60	75.16	130.88	120.91	74.45	65.90	265.8

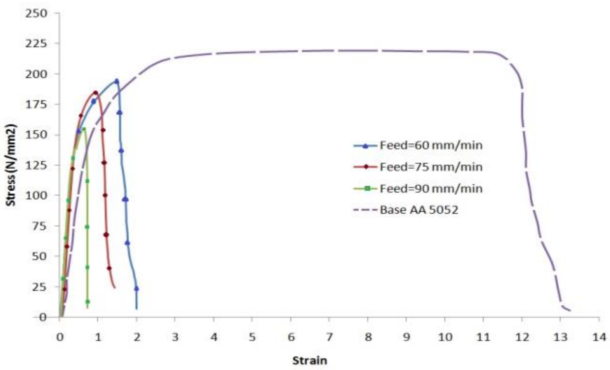

Fig.7 Stress strain diagram of welded samples and base

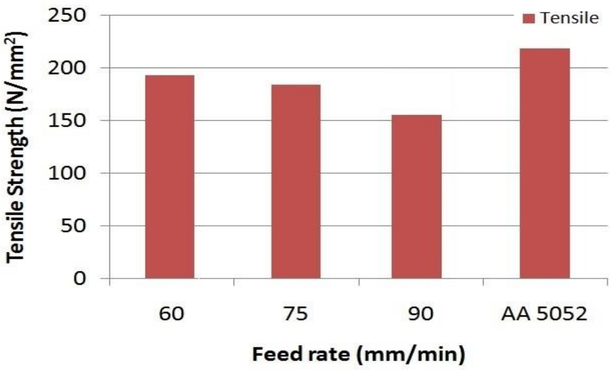

Fig.9 Tensile strength of welded samples at various feed rates and base metal

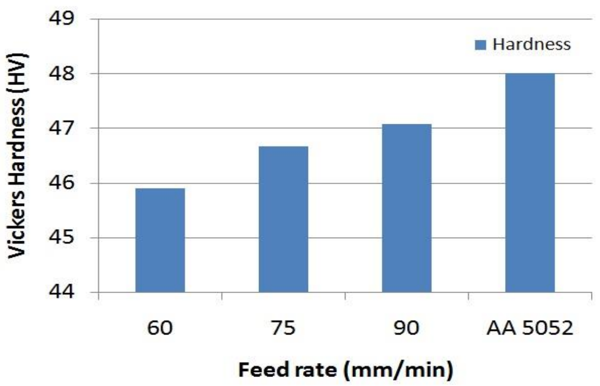

Fig.8 Average hardness of welded samples at various feed rates and base metal

5. CONCLUSIONS

Micro FSW is the adaptation of friction stir welding of sheets having thickness 1 mm or less. In this research work micro friction stir welding of 0.9 mm thick AA 5052 is conducted at a constant rotational speed of 3000 rpm and three different welding speed 60 mm/min, 75 mm/min and 90 mm/min respectively with aluminium backing plate. The temperature distribution of work piece has been measured with 6 K-type thermocouples and that of tool is measured by an IR fusion camera. Results show that heat loss from the workpiece through the backing plate and tool is severe due to the high surface area to volume ratio of the work piece and high thermal conductivity of aluminium backing plate. However successful welds are obtained at all feed rates. Hardness distribution across the weld line shows that there not much reduction in the average hardness of the work piece. This is due to the fact that fine grains are formed at lower temperature. The joint possess good tensile properties and more than 70 % joint efficiency is obtained for all samples. The results show that hardness of workpiece increases with increase in welding speed and tensile strength decreases with increase in welding speed.

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