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Research Article

Experimental Investigation of Mechanical Properties on Friction Stir Welding of Dissimilar Aluminum Alloys

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Abstract

Friction stir welding (FSW) has been the most attracting solid state welding process as it serves numerous advantages like good mechanical, metallurgical properties etc. Non weldable alluminium alloys like 5XXX, 7XXX series can be joined easy using this process. In this present study, experiments were successfully performed to evaluate mechanical properties of FSW on dissimilar alluminium alloys i.e. AA 5083 to AA1100. Tensile strength and micro hardness for different process parameters are reported. It was noticed that in FSW of this combination of dissimilar alloy with tool made of H-13 tool steel, friction is the major contributor for the heat generation. It was seen that tool rotational speed and traverse speed have significant effect on tensile strength of FSW.

Keywords: *FSW, solid state welding, mechanical properties, cylindrical pin profile, tapered cylindrical pin tool, AA1100, AA5083, micro hardness.*

1. Introduction

Friction stir welding (FSW), which was developed by The Welding Institute (TWI) in 1991 (Thomas, et al, 1991), which produces welds using stir, penetrate and traverse actions of a specially fabricated tool. The phenomenon of this process is material in the work piece plasticizes due to the high frictional contact between the rotating, traversing tool and a stationery work piece. This process eliminates almost all the drawbacks associated in the conventional welding techniques and also offers many advantages like unchanged metallurgical properties, ease and environmental friendly process etc. The working principle of this process is shown in Fig. 1.

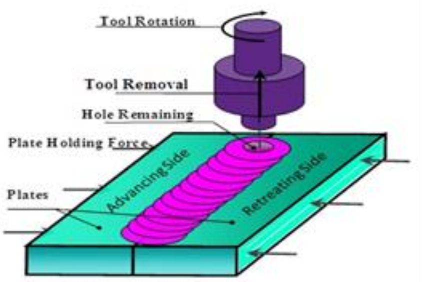

Fig. 1FSW Process

FSW tool has two parts i.e. tool pin and shoulder diameter, the size and geometry of these two has significant effect on the final weld quality. Tool rotational speed, Tool traversing speed, Tool tilt and plunge depth are the other important parameters which greatly influence the mechanical properties of the final FSW weldment.

Many materials have been joined by FSW process, aluminum is the most commonly welded. Research has been performed on similar and dissimilar alluminium welds (Li et al, 1999)(Reynolds, et al, 2000) (Heinz et al, 2000) (Nicholas and Thomas, 1998) (Reynolds et al, 2000) (Norman et al, 2000) (Rhodes et al, 1997) (Sutton et al, 2002). Mechanical properties of similar and dissimilar friction stir welded joints are discussed in this section. Dissimilar aluminum alloys AA2024-T4 and AA7075-T6 have been taken into account (Barcellona et al, 2006). The joint strength has been tested through tensile tests and microhardness tests. Post welding heat treatments can improve the material mechanical characteristics and overall can increase the joints resistance. Al 1080 alloy materials have been welded using FSW process (Boz and Kurt, 2004).

The influence of stirrer design on the welding process have been investigated. (Chao et al, 2001) studied the dynamic, compressive stress strain curves of AA2024-T3 and AA7075- T7351 aluminum alloys welded by the friction stir welding process and found that yield stress of the weld metal to below that of the base metal. Friction Stir Welding is mainly used to join similar materials; few publications have been reported on FSW of dissimilar materials (Shigematsu et al, 2003) (Lee et al, 2003) (Wert, 2003) (Karlsson et al, 2001) (Nandan et al, 2007). Recently, there has been increasing interest in FSW of higher temperature materials such as stainless steels,

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similar efforts have been reported (Kumar and Kailas, 2010) (Park et al, 2010) (Chen and Lin, 2010).

The necessity to produce dissimilar material welding is to minimise the weight of an aircraft/ships/automobiles with same metallurgical and mechanical properties. FSW process promisingly fulfils this requirement. Alluminium AA5083 is widely applicable in marine industry for ship building and AA1100 is a commercially available alluminium alloy which is used for almost all industrial applications. The aim of the present study is to investigate the optimum process parameters and mechanical properties of dissimilar friction stir butt welds of AA5083 and AA1100.

2. Experimental Details

Two dissimilar alluminium alloy AA5083 and AA1100 test samples of size 200mm long, 100mm wide and 6mm thick plates were welded with the below referred FSW tools shown in Figure.3. Specifications of milling machine used for FSW experimentation are vertical type milling machine, Motor capacity: 7.5 HP, Rotational Speeds: 50-1500RPM, Traversing Speeds: 22-555mm/min. The tool was rigidly fixed on an arbor. The workpiece edges are machined in order to obtain a neat square butt and clamped to the machine bed without any root gap. The clamping of workpieces was done such that the movement of workpieces restricted in all degrees of freedom to with stand mainly plunging and translational forces of the tool. The butting line of two workpieces was seen to match exactly with the center of the tool pin. After tool plunging on the butted plate and visually ensuring full contact of the tool shoulder with the plate surface, the bed horizontal movement was switched on and continued up to the end. A typical FSW setup is shown in Fig. 2.

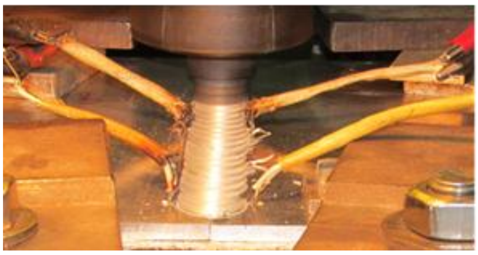

Fig. 2 FSW setup

Fig. 3 FSW tools fabricated

Two types of FSW tools have been used in this work one is of straight cylindrical pin tool and another is tapered cylindrical tool. The FSW tools were fabricated using H13-Tool steel materials, the shoulder diameter of cylindrical tool is 20mm, pin length and diameter is 5.7, 2.5mm respectively. Whereas the pin dimensions of tapered cylindrical tool are length 5.7 and 8, 4mm diameter.

Many trail run experiments have performed to find out the optimum process parameters for welding the above said dissimilar materials. Design of experiments has performed by using Taguchi technique to find out the number experiments are shown in Table. 1.

3.Results and Discussions

3.1 Vickers Micro Hardness Test

Hardness measurements were taken on cross-sections perpendicular to the welding direction. Welding was carried out using two types of FSW tools with varying process parameters as shown in Table 1. Fig .4 shows the micro hardness testing machine.

Fig. 4 Vickers micro hardness testing machine

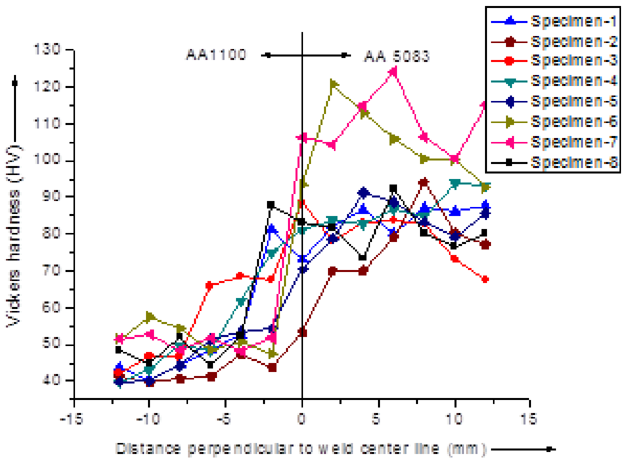

Fig. 5 Vickers micro hardness for eight different FSW samples

Test samples for the hardness measurement were taken from two groups of welded samples. The first group consists of test pieces welded using cylindrical tool and the second group of samples welded with tapered

Table 1 Different process parameters used for dissimilar FSW of AA1100 and AA5083

Exp. No	Material Type	Tool Type	Tool Rotational Speed(rpm)	Welding Speed (mm/min)	Position of workpiece & tool rotational direction
1	AA1100-AA5083	20C	1000	56	Adv. AA5083, CW
2	AA1100-AA5083	20C	1000	80	Adv.AA5083, CW
3	AA1100-AA5083	20C	1400	56	Adv. AA5083, CW
4	AA1100-AA5083	20C	1400	80	Adv. AA5083, CW
5	AA1100-AA5083	20T	1000	56	Adv.AA5083, CW
6	AA1100-AA5083	20T	1000	80	Adv.AA5083, CW
7	AA1100-AA5083	20T	1400	56	Adv.AA5083, CW
8	AA1100-AA5083	20T	1400	80	Adv.AA5083, CW

cylindrical pin tool. The hardness at the different zones of the test samples was measured. At a particular location on the weld zone five number of hardness reading have been noted and the average of these readings was taken. The indentation load for the hardness measurement was kept at 500 gf. The variation of hardness for all the eight test samples is shown in Fig. 5.

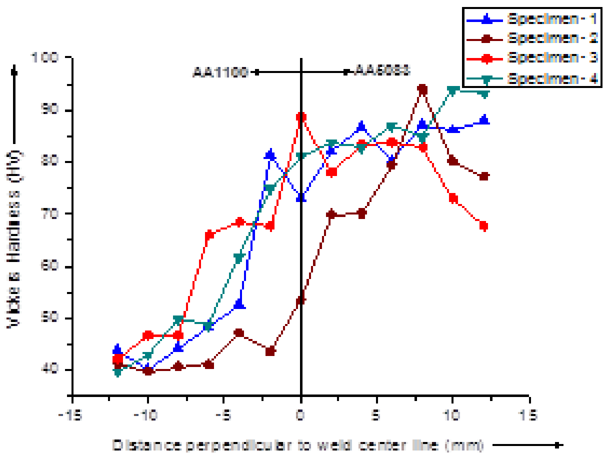

Fig. 6 Vickers micro hardness for the specimens welded by cylindrical pin tool

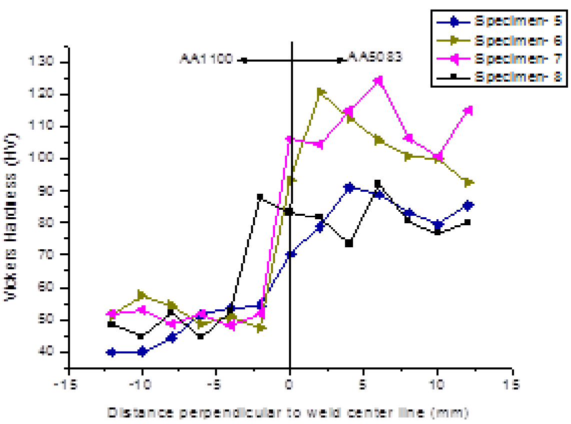

Fig. 7 Vickers micro hardness for the specimens welded by Tapered cylindrical pin tool

It was observed that from Fig.5 a huge variation of hardness were found from centre of weld zone to away from the weld zone on both sides. It was seen that in the centre of weld line the hardness values are average of both the parent material because in this region intermixing of both the material taken place. Hardness values for the samples 7 and 6 are higher than others. The Hardness values for the specimens 1 and 2 are comparatively lower.

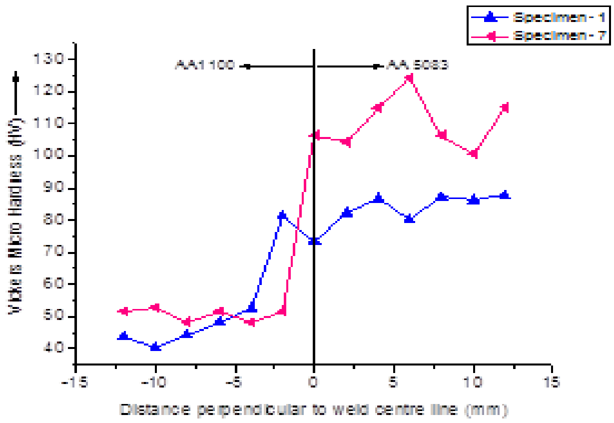

Fig. 8 Comparison of maximum and minimum hardness for the specimens welded by two different tool geometries with same process parameters

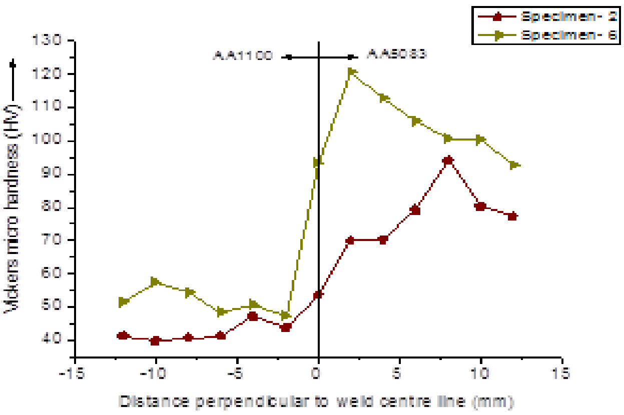

Fig. 9 Comparison of maximum and minimum hardness for the specimens welded by two different tool geometries with same process parameters

The variation of hardness values for the specimens welded by straight cylindrical tool pin profilehave shown in Figure 6 and the Hardness values for the specimens welded by the tapered pin profiles are shown in figure 7 Comparison of hardness for the specimens welded with same process parameters but with different FSW tools are shown below. Fig. 8 shows the comparison of maximum and minimum hardness for the specimens welded by two different tool geometries keeping the same welding conditions. Fig. 9 shows the hardness perpendicular to the weld centre lines for the specimens 6, 2 welded with different parameters by keeping the other parameters same.

Specimen 1, 2 are welded by the cylindrical tool pin and the specimens 6, 7 are welded by the tapered pin tool. From the Fig.8, Fig.9 it was observed that the magnitude of hardness was more in case of tapered cylindrical tool using same welding parameters.

3.2 Tensile Test

Instron-8801 tensile testing machine was used for tensile test shown in Figure 10. The specifications of this machine are closed loop servo hydraulic dynamic testing machine, maximum load capacity is 100KN, and actuator displacement is about 75mm and in full scale 150 +/- 5 mm.The tensile test specimens were taken perpendicular to the welding direction from the welded test samples.

Fig. 10 Instron-8801Universal testing machine

All tensile tests were performed at a constant crosshead displacement rate of 10mm/min using an Instron tensile testing machine. Some of the tested samples are shown in Fig. 11. Tests were performed to study the stress vs. strain characteristics for the specimens welded under the parameters shown in Table 1.

Fig. 11 Tested tensile samples

Engineering stress vs. strain curves have plotted for the all the eight samples welded under different welding conditions have shown in figure 12. In this result, specimens 1-4 have welded by the cylindrical pin tool and the specimens 5-8 was welded with the tool of tapered pin geometry. It is observed that the stress-strain plots of specimen 6, 7, 8 have enhanced nature compare to all others. The ultimate tensile strength for the specimens 5, 6, 7, 8 were 30% higher than the specimens 1,2,3,4.

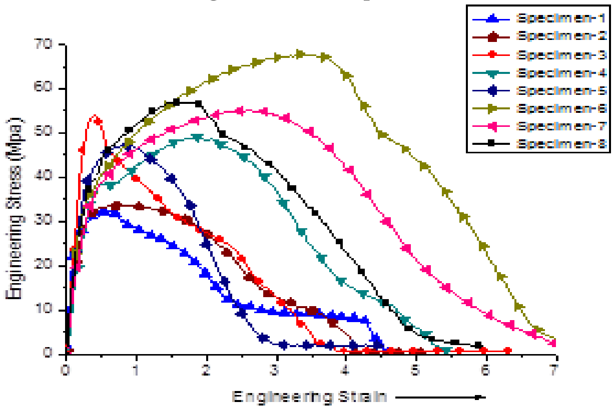

Fig. 12 Stress vs. Strain plot for eight samples welded by different process parameters

The stress vs. strain plots for the specimens 1-4 welded by the straight cylindrical pin tool and with varying tool rotational speed, tool traversing speeds are shown in the figure 13 and the stress vs. strain curves for the specimens 5-8 welded by tapered tool pin are shown in Figure 14.

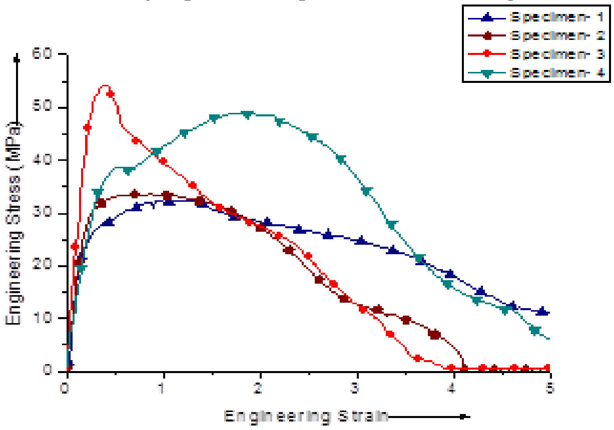

Fig. 13 Stress vs. Strain plot for the samples welded by cylindrical pin tool

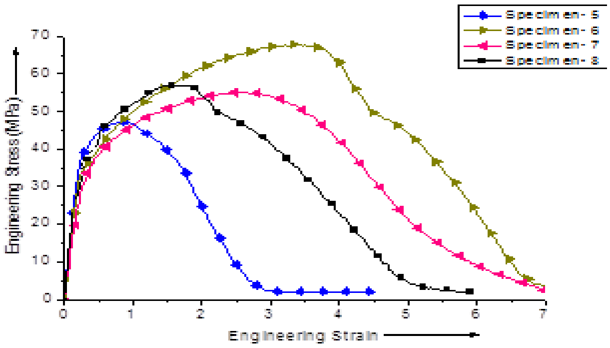

Fig. 14 Stress vs. Strain plot for the samples welded by Tapered cylindrical pin tool

By observing the plots of specimens 6,7,8, in the Fig. 14, the ultimate strength of these welded specimens are more compared to that of the specimens welded by cylindrical pin tools i.e., specimens 1-4. The specimens 5-8 exhibit superior properties than the specimens 1-4.Stress vs. strain comparisons for the specimens 7, 2 and 6, 1 are shown in Fig. 15 and Fig. 16. It is observed that significant variation in the stress vs. strain graphs for the specimens welded with different tool geometries keeping the same process parameters.

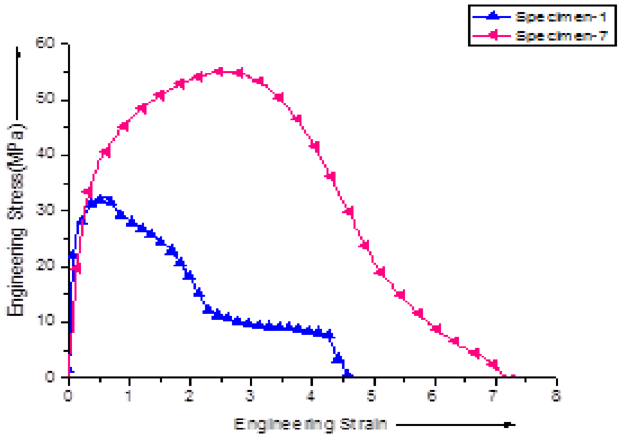

Fig. 15 Comparison of Stress vs. Strain plot for the samples 7 and 1 welded by two different FSW tools

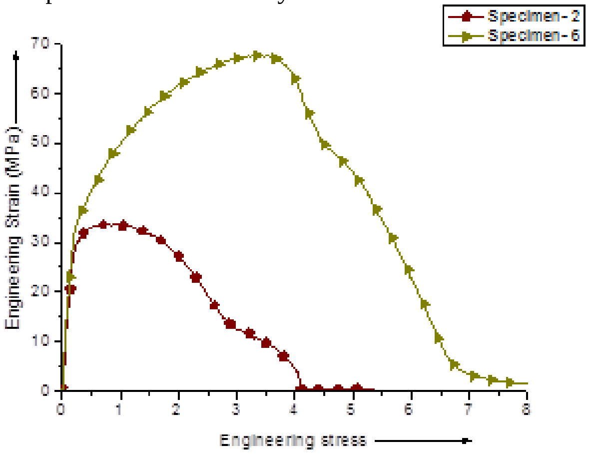

Fig. 16 Comparison of Stress vs. Strain plot for the samples 6 and 1 welded by two different FSW tool

Conclusions

A comparative study on effect of process parameter on weld quality using 2 different tool geometries was successfully done. From the above study the following important conclusions can be made.

1. Due to the FSW tool stirring effect the intermixing of two different alluminium material was observed. Because of this the hardness value becomes the average hardness values of both the parent materials i.e. AA5083 and AA1100.
2. Tool geometries have significant effect on weld quality of dissimilar material FSW. Both the hardness and tensile strength were higher in case of taper cylindrical tools with same process parameter.
3. Lower tool traverse speeds with higher rotational speeds gives the best tensile properties in dissimilar alloy friction stir weldments.
4. Tapered cylindrical pin geometries gives better weld quality and good mechanical properties in dissimilar alluminium friction stir welding.

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