Characterization of Frictional Stir Welding for two dissimilar materials and Influence of Ageing on their Mechanical Properties

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Abstract: *The objective of the present study is to examine the influence of ageing on mechanical properties of two dissimilar materials welded together by friction stir welding (FSW) process. The study was accomplished by altering the rotational and traverse speeds of samples. Dissimilar welding of AA5083 and AA6082 samples, aged at 140ºC and 180ºC respectively, was accomplished at 600 RPM and 900 RPM of rotational speeds and 45 mm/min and 90 mm/min of traverse speeds respectively. The tensile test reveals that the properties of AA 6082 increase with an increase in the temperature of ageing. But, these properties were poorer as compared to the parent material. This might be due to the formation of fine precipitates. The ultimate tensile strength and % elongation of the dissimilar weld samples increase with increasing traverse speed. As the ageing temperature increases, the % elongation decreases drastically. But, the weld strength increases even at a low traverse speed. The hardness of the weld zone decreases for the parent material and increases for the aged samples with an increase in the rotational and traverse speed. For a dissimilar weld of AA5083 and AA6082, aged at 180ºC, the optimum rotational speed and traverse speed are found to be 900 RPM and 45 mm/min respectively.*

Keywords: *Frictional Stir Welding (FSW), Dissimilar Welding, Ageing, Fractography.*

I. INTRODUCTION

Friction stir welding (FSW) is a welding process which utilizes a non-consumable rotating tool, invented mainly to avoid solidification related problems such as oxidation, shrinkage and porosity. Welding of aluminium by the arc welding methods would eventually accelerate to poorer properties due to inevitable defects [1]. A rotating tool is plunged into the work piece. When translating it along the weld line, it generates the heat by friction at the tool surface. The microstructure and the mechanical properties of the welded joint mainly depend on the material flow behaviour and the thermal cycle. These characteristics are highly influenced by welding parameters such as welding speed, rotation rate, and the pin/shoulder geometry [2,3]. AA5083 is a non heat treatable Al-Mg alloy with good corrosion resistance property, while AA6082 is an age hardening Al-Mg-Si alloy which forms Mg_2Si precipitates. Both alloys exhibit higher strength to weight ratio, good ductility, and good corrosion resistance [4-6]. Dissimilar welding of these two materials brings the joint properties of both materials, which makes the most desirable combination specially required in various military applications like light combat aircraft (LCA), light combat vehicle (LCV), future main battle tank (FMBT), bridge layer tank (BLT), armoured ambulance, submarine torpedo, etc. [7].

Many researchers have deliberate the dissimilar welding of aluminium alloys, particularly concentrating on the evolution of microstructure and texture, tool pin profile and material flow during FSW [7-14]. Steuwer et al. [11] has examined the influence of process parameters on residual stress in dissimilar frictional stir welding of AA5083–AA6082. It was described that the residual stresses are predominately affected by the rotational speed of the welding tool when compared to the traverse speed. The residual stress on the AA5083 side is higher as compared to the AA6082 side. Donatus et al. [14] investigated the flow patterns in friction stir welds of AA5083 and AA6082 alloys. It was stated that slower traverse welding speeds delivers a better mixture of materials in the weld zones as compared to the higher traverse welding speed. Between the tool shoulder and the tool pin domain, the material pull is highest from the retreating side to advancing side. Threaded pin profiled tool demonstrates superior performance as compared to the tapered pin profiled tool. It is due to the formation of fine and uniformly distributed precipitates, circular onion rings and smaller grain [7].

Need of the study

Many researchers have published reviews on friction stir welding and handling, the tools employed, Friction stir processing, and on aluminium alloys. To the best of our cognition, no review is focusing on friction stir welding of two dissimilar aluminium materials for different grades and also the influence of ageing on their attributes. Therefore, this paper critically reviewed the current published literature by concentrating on the recent work completed on friction stir welding. The rest of the paper focuses on an exertion which was made to join the heat treatable (AA6082) aged at different ageing temperatures with a non-heat treatable (AA5083) aluminium alloys and also the influence of welding parameters on their properties.

II. MATERIALS AND METHODS

Aluminium plates of series AA6082 and AA5083 are taken for the experimental procedure of required dimensions (100mm x 60mm x 6mm). The schematic arrangement [15] of FSW process for dissimilar joints used in this study is presented in Figure1.

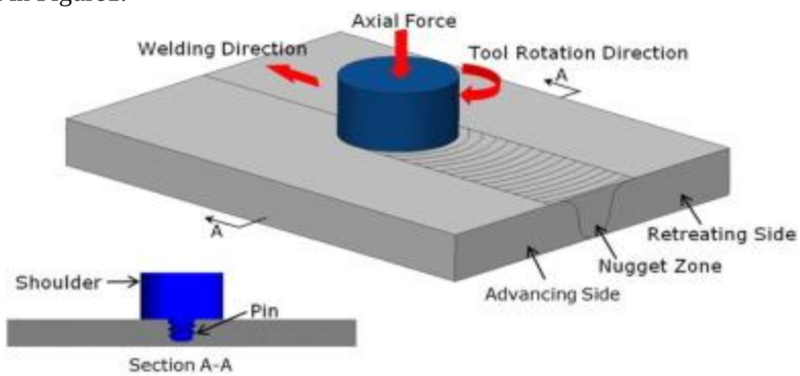


Figure1: Frictional stir welding process set-up

AA6082 alloy has been solutionized at 540ºC for 90 minutes and then subjected to ageing temperatures at 140ºC and 180ºC for 8 hrs. FSW of various combinations of AA5083 and AA6082 has been accomplished at different rotational speed and traverse speeds as shown in Table 1. Microstructural analysis has been done by using Field Emission Scanning Electron Microscopy (FESEM). FESEM was fitted out with an energy dispersive X-ray spectroscopy (EDS) tool to identify the elements available in the material. XRD peaks were obtained using XRD machine. Tensile specimens were prepared perpendicular to the weld line according to the ASTM E8 standard. All the tensile tests were conducted on the Zwick/Roell Z100 tensile machine under position controlled at 0.5 mm/min. Hardness values were determined by using Brinell hardness testing machine with 10 mm dia ball indenter.

Table1: Different combinations of dissimilar welding

Sample combination	5083 and 6082 (Parent)		5083 and 6082 (aged at 140ºC for 8 hrs)		5083 and 6082 (aged at 180ºC for 8 hrs)	
Rotational Speed	600 rpm	900 rpm	600 rpm	900 rpm	600 rpm	900 rpm
Traverse Speed	45 mm/min and 90 mm/min	45 mm/min and 90 mm/min	45 mm/min and 90 mm/min	45 mm/min and 90 mm/min	45 mm/min and 90 mm/min	45 mm/min and 90 mm/min

III. RESULTS AND DISCUSSION

Hardness Test

The hardness test values of the parent alloys and the dissimilar welds of various combinations in the weld stir zone are shown in Table2 and Table3.

Table 2: Values of Brinell hardness test performed at different ageing conditions

Sample conditions	Brinell hardness number
5083 (Parent)	44.15
6082 (Parent)	48.67
6082 aged at 140ºC	28.46
6082 aged at 180ºC	36.91

Table4 clearly indicates that the hardness value of 6082 alloy is superior to 5083 alloy but the 6082 aged samples show lower values. However, the hardness of the 6082 aged at 180ºC shows a higher value than the 6082 sample aged at 140ºC. As the ageing temperature is increased the hardness value increases and as the ageing time increases the hardness values might further increase and reach the value either same or higher than the parent sample. The hardness values of these samples show a similar trend as that of the UTS values. From Table5, the hardness values at the weld stir zone show an increasing trend as the rotational and traverse speed increases. The hardness value of 5083 and 6082 show a reverse behaviour of low hardness value for 900 rpm when compared with 600 rpm. For a constant rotational speed of 600 rpm, as the traverse speed increases the hardness value increased for different combinations of dissimilar welding. The hardness value of 5083 and 6082 aged at 180ºC is approaching a close value to that of the parent materials welding of 5083 and 6082 at 600 rpm and 90mm/min.

Table 3: Values of Brinell hardness test performed in the weld stir zone

Sample combinations	Rotational speed (rpm)	Traverse speed (mm/min)	Hardness in the weld stir zone
5083 (Parent) and 6082 (Parent)	600	45	42.17
		90	47.09
	900	45	37.23
		90	36.69
5083 (Parent) and 6082 aged at 140ºC for 8 hrs	600	45	44.56
		90	39.34
	900	45	48.95
		90	52.95
5083 (Parent) and 6082 aged at 180ºC for 8 hrs	600	45	37.01
		90	44.41
	900	45	48.30
		90	49.03

Tensile Test

The tensile test determines the ability of a material to withstand loads before elongation. Table 4 shows the tensile test values for AA5083 and AA6082.

Table 4: Tensile strength of AA5083 and AA6082 in different conditions

Samples	UTS (MPa)	UTS Elongation (%)	Fracture Strength (MPa)	Fracture Elongation (%)
5083 (Parent)	305.01	19.01	253.19	27.15
6082 (Parent)	341.34	34.10	286.51	45.67
6082 aged at 140ºC	264.74	39.07	225.19	49.10
6082 aged at 180ºC	316.32	29.08	270.82	40.11

From Table4, it is clear that the strength (UTS) and % elongation of AA6082 alloy is superior to AA5083 alloy. The age hardening process is the prominent strengthening mechanism for aluminium alloys, but contrary results were obtained showing a lower strength value which can be attributed to the formation of fine and very low amount of precipitates due to low ageing temperature and ageing time. Thereby, it signifies that optimum ageing time and temperature would lead to superior properties else the properties would be inferior to parent material. As the ageing temperature is increased and the ageing time is kept constant, the strength of the alloy has increased but the elongation has decreased.

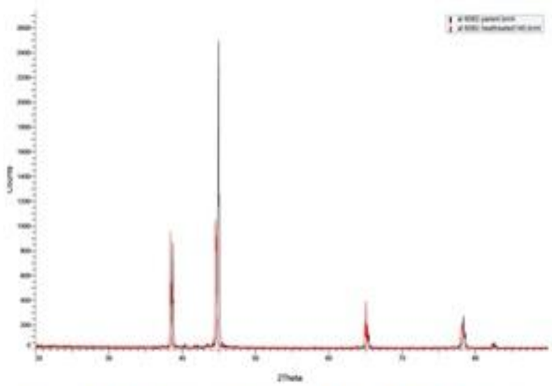
Table 5: Tensile strength of dissimilar welds of different combination

Sample combinations	Rotational speed (rpm)	Traverse speed (mm/min)	UTS (MPa)	UTS Elongation (%)
5083 (Parent) and 6082 (Parent)	900	45	176.12	12.01
5083 (Parent) and 6082 (Parent)	900	90	190.34	11.95
5083 (Parent) and 6082 aged at 140ºC for 8 hrs	900	90	149.14	06.05
5083 (Parent) and 6082 aged at 180ºC for 8 hrs	900	45	167.10	07.91

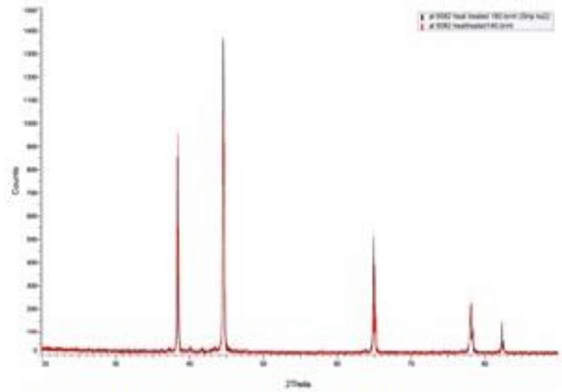
Table5 shows the tensile strength of the 5083 and 6082 dissimilar welded samples. As the traverse speed increases for a given rotational speed, the UTS increases but the elongation at UTS remains the same. It was described that at a constant rotation rate, when the welding speed increases from 50 to 150mm/min, UTS also increases up to 100mm/min and then decreases, but the elongation always decreases. When both parent alloys were welded together, the weld strength is obtained 62.4% of the AA5083 alloy. When AA5083 is welded with 6082 aged, has lower weld strength as compared to 6082 parent materials. Better UTS values were obtained even for a low traverse speed for aged dissimilar welded samples. The fracture of these samples has occurred at the weld zone which shows the significance of lower strength at weld zone when compared with parent zone.

XRD

The XRD patterns of 6082 and 6082 aged show a peak shift as evident in Fig. 2. There is no peak shift observed in Fig. 3. It can be said that the peak shift in aged sample might be due to the beginning of the formation of the precipitates. The XRD patterns of 6082 aged at 140ºC and 180ºC show a similar nature and coherency.



a. XRD Patterns of 6082 and 6082 aged samples

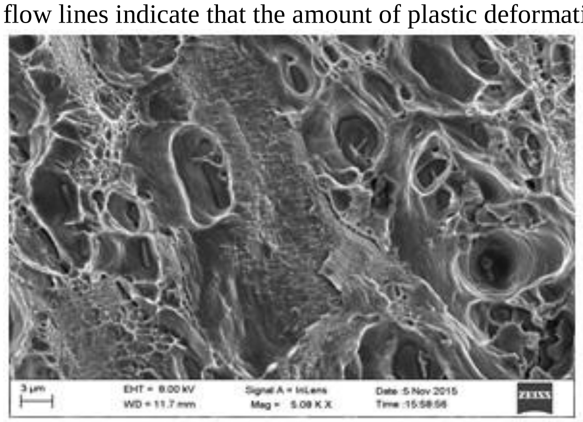


b. XRD Patterns of 6082 aged at 140°C and 180°C

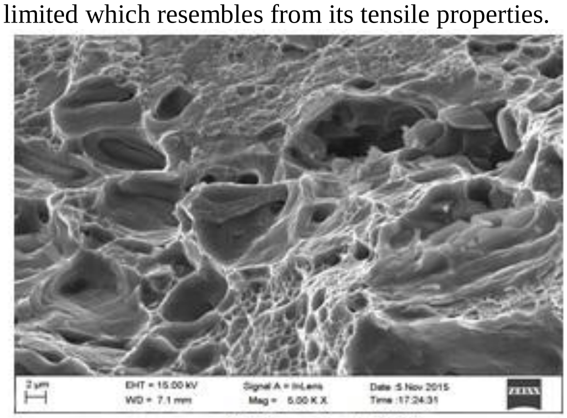
Figure2: Field Emission Scanning Electron Microscopy (FESEM)

Fractography

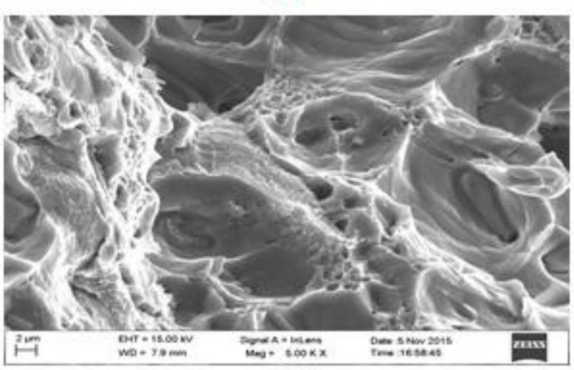
The fracture surface of 5083, 6082 and 6082 aged samples show a similar kind of ductile fracture as shown in Fig. 3. 6082 and 6082 aged alloy show more of flow lines which is an indication of plastic deformation and more dimples indicating the ductile fracture. 5083 alloy shows more dimples indicating the ductile fracture but very few flow lines indicate that the amount of plastic deformation is limited which resembles from its tensile properties.



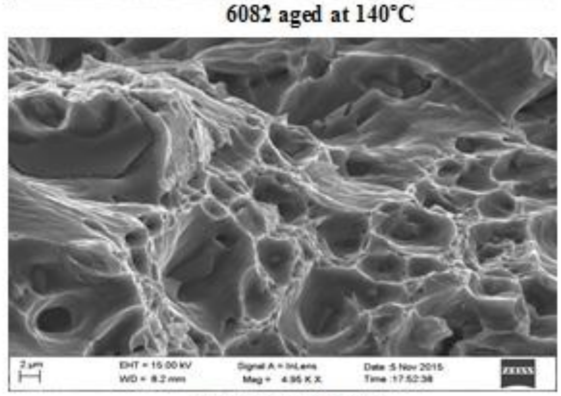
5083



6082 aged at 140°C



6082



6082 aged at 180°C

Figure3: Fractrography of samples before ageing and after ageing

IV. CONCLUSION AND FUTURE RESEARCH

The UTS and elongation of 6082 are superior than 5083 alloy but the aged samples show lower values. Almost 62.4% of UTS is obtained in welded samples for high rotational and traverse speeds. The optimum rotational speed and traverse speed are found to be 900 rpm and 45 mm/min respectively for a dissimilar weld of AA5083 and AA6082 aged at 180ºC. As ageing temperature increases, the UTS values also increases and it is expected that longer ageing times would yield higher tensile properties than the parent samples properties. The hardness values in the weld stir zone are in close proximity with the parent metal for high rotational and traverse speeds. Fracture surfaces reveal the formation of dimples indicating the ductile fracture.

Research on friction stir welding between two different grades of aluminium has not yet been comprehensively examined; much of the work has been concentrated on welds categorizations and study of the ageing effect on properties. Thus, a strong need in developing the industrial applications of FSW between various dissimilar materials in the manufacturing sector for the enhancement of the manufactures.

In summary, the characterization of friction stir welding of two dissimilar aluminium materials for different grades has been successfully conducted. This will supply a comprehensive insight for the existing and also furnish the current state of research on FSW between AA5083 and AA6082 in order to occupy the gaps with new research advances and estimates. Furthermore, new studies on FSW between dissimilar materials like aluminium, copper, titanium, Magnesium, steel, etc with respect to the process optimization and selection of cost effective FSW tools to make sound welds still needs to be built up.

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V. REFERENCES

[1] *Flores O V, Kennedy C, Murr L, Brown D, Pappu S, Nowak B M, et al., "Microstructural issues in a friction-stir-welded aluminum alloy", Scripta Materialia, Vol. 38, 1998, pp 703–708.*

[2] *Mahmoud TS, Gaafer AM, Khalifa TA, "Effect of tool rotational and welding speeds on microstructural of friction stir welded A319 cast Al alloy", Materials Science and Technology, Vol. 24, 2008, pp 553–559.*

[3] *Nandan R, Deb Roy T, Bhadeshia HKDH, "Recent advances in friction stir welding process, weldment structure and properties", Progress in Materials Science, Vol. 53, 2008, pp 980–1023.*

[4] *Perez-Bergquist Sara J, Rusty Gray III GT, Ellen K Cerreta, Carl P Trujillo, Alex Perez-Bergquist, "The dynamic and quasi-static mechanical response of three aluminum armor alloys: 5059, 5083and7039", Materials Science and Engineering A, Vol. 528, 2011, pp 8733-8741.*

[5] *Katsas S, Nikolaou J, Papadimitriou G, "Microstructural changes accompanying repair welding in 5xxx aluminium alloys and their effect on the mechanical properties", Materials and Design, Vol. 27, 2006, pp 968-975.*

[6] *Kumbhar NT, Bhanumurthy K, "Friction stir welding of Al 6061 alloy", Asian Journal of Experimenal Sciences, Vol. 22(2), 2008, pp 63-64.*

[7] *Ilangovan M, Rajendraboopathy S, Balasubramanian V, "Effect of tool pin profile on microstructure and tensile properties of friction stir welded dissimilar AA6061-AA5086 aluminium alloy joints", Defence Technology, Vol. 11, 2015, pp 174-184.*

[8] *R. Fonda, K. Knipling, J. Bingert, "Microstructural evolution ahead of the tool in aluminum friction stir welds", Scripta Materialia, Vol. 58, 2007, pp 343–348.*

[9] *S. Xu, X. Deng, "A study of texture patterns in friction stir welds", Acta Materialia, Vol. 56, 2008, pp 1326–1341.*

[10] *S. H. Kang, H. H. Han, K. H. Oh, J.-H. Cho, C. G. Lee, S. J. Kim, "Investigation of the material flow and texture evolution in friction-stir welded aluminum alloy", Metals and Materials International, Vol. 15, 2009, pp 1027–1031.*

[11] *A. Steuwer, M.J. Peel, P.J. Withers, "Dissimilar friction stir welds in AA5083–AA6082: the effect of process parameters on residual stress", Materials Science and Engineering A, Vol. 441, 2006, pp 187–196.*

[12] *S. H. Kang, H. S. Chung, H. N. Han, K. H. Oh, C. G. Lee, S. J. Kim, "Relationship between formability and microstructure of al alloy sheet locally modified by friction stir processing", Scripta Materialia, Vol. 57, 2007, pp 17–20.*

[13] *E. A. El-Danaf, M. M. El-Rayes, "Microstructure and mechanical properties of friction stir welded 6082 AA in as welded and post weld heat treated conditions", Materials and Design, Vol. 46, 2013, pp 561–572.*

[14] *U. Donatus, G.E. Thompson, X. Zhou, J. Wang, K. Beamish, "Flow patterns in friction stir welds of AA5083 and AA6082 alloys", Materials and Design, Vol. 83, 2015, pp 203–213.*