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# STRUCTURAL PROPERTIES OF SIMILAR AND DISSIMILAR ALUMINUM ALLOY JOINTS BY FSW

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## ABSTRACT

The present study aims to predict the mechanical properties of similar and dissimilar aluminium alloy friction stir Welded joints. The present research also addresses the challenges in joining aluminium alloys Al5083 and Al6061 of 5mm thickness at varying process parameters. A total number of 24 joints have been fabricated with a set of eight joints each for Al6061(similar), Al5083(similar) and a combination of Al5083 x Al6061(dissimilar alloy) as per the experimental plan by Taguchi technique using L8 orthogonal array. The dimensions of the plates are chosen in such a way that the weld length is fixed to 150 mm. The tensile strength and the micro hardness of the welded joints as well as micro structures have been examined. Taguchi technique has been utilized to study the optimized value of the process parameters. The process parameters for joining these have been identified as rotational speeds at 1000 and 1600 rpm, traverse speed 40 and 160mm/min and axial force of 2.5 and 3.5kn.

## INTRODUCTION

Friction Stir Welding (FSW) is a fairly new type of joining process invented by TWI [1] in the year 1991. The studies on FSW are extensively used in many manufacturing applications and engineering as well. FSW has been proven to be an effective method to weld wrought aluminium alloys. Joining of metals by FSW results in less distortion, plastic deformation and less residual stresses [2-8].The process is operated below the melting temperatures[1] compared to conventional welding methods. A self- rotating tool with a pin at the bottom generates frictional heat which leads to metal deformation and this stirring action plasticizes the material to form a joint. The direction of rotating tool and weld direction are similar and travel along the weld path allowing plates to weld. The tool rotation and weld direction which are similar on one side are called "Advancing side" and opposite on the other called "Retreating side". This peculiar behavior of the weld makes this joint asymmetric when compared to conventional welds, which does not affect the heat affected zones. The physical phenomenon of the process helps one to identify the influence of process parameters on strength of the weld joint, among those factors are the tool rotational speed, traverse speed and axial force which are taken into consideration [9]. Hence, in the present study these parameters have been identified as the major influencing factors on the tensile strength and micro hardness. The earlier research studies on FSW of joining of similar and dissimilar metals by varying process parameters to identify change in mechanical properties of weldments can be seen in [10-15]. Studies on the effect of process parameters by using mathematical tools either by Taguchi or Response Surface Methodology can be seen in [9, 17-24]. In all the studies reported earlier one can find optimized values of process parameters either for similar or dissimilar alloy joints. Hence there is a necessity to study the same on joining similar, dissimilar alloys by FSW. With this motive, the present research has been carried out to study the tensile strength, micro hardness and the effect of the process parameters on the same for similar (Al5083,Al6061) and dissimilar (Al5083 x Al6061) aluminium alloy joints.

## EXPERIMENTATION

The friction stir welded joints of similar and dissimilar Al5083 and Al6061 were fabricated using NC friction stir welding machine of 5T. A total of 24 joints were fabricated as per the Taguchi's design plan. The chemical composition and the mechanical properties of the selected materials are given in table 1, table 2. The identified process parameters for the present investigation are given in table 3.

**Table 1 Chemical Composition of Al 5083 and Al 6061 alloys[16]**

| AL5083 | | AL6061 | |
|---|---|---|---|
| Componen t | Wt. % | Componen t | Wt. % |
| Al | 92.4 - 95.6 | Al | 95.8 - 98.6 |
| Cr | 0.05 - 0.25 | Cr | 0.04 - 0.35 |
| Cu | Max 0.1 | Cu | 0.15 - 0.4 |
| Fe | Max 0.4 | Fe | Max 0.7 |
| Mg | 4 - 4.9 | Mg | 0.8 - 1.2 |
| Mn | 0.4 - 1 | Mn | Max 0.15 |
| Other, each | Max 0.05 | Other, each | Max 0.05 |
| Other, total | Max 0.15 | Other, total | Max 0.15 |
| Si | Max 0.4 | Si | 0.4 - 0.8 |
| Ti | Max 0.15 | Ti | Max 0.15 |
| Zn | Max 0.25 | Zn | Max 0.25 |

**Table 2 Mechanical Properties of Al 5083 and Al6061 alloys[16]**

| Al5083 | | Al6061 | |
|---|---|---|---|
| Yield Strength | 228 MPa | Yield Strength | 276 MPa |
| Ultimate Tensile Strength | 317 MPa | Ultimate Tensile Strength | 310 MPa |
| Elongation | 16 % | Elongation | 12% |
| Hardness(Vickers) | 96 | Hardness(Vickers) | 107 |

**Table 3 Process Parameters[ 9]**

| Parameter | Level 1 | Level 2 |
|---|---|---|
| Tool Rotational Speed (rpm) | 1000 | 1600 |
| Traverse Speed (mm/min) | 40 | 160 |
| Axial Force (kN) | 2.5 | 3.5 |

A high carbon steel of 20 mm in diameter, shoulder diameter of 12 mm and a cylindrical pin of diameter of 5 mm is used in fabricating the joints. The schematic diagram and fabricated joint are shown in Fig. 1a and Fig. 1b.

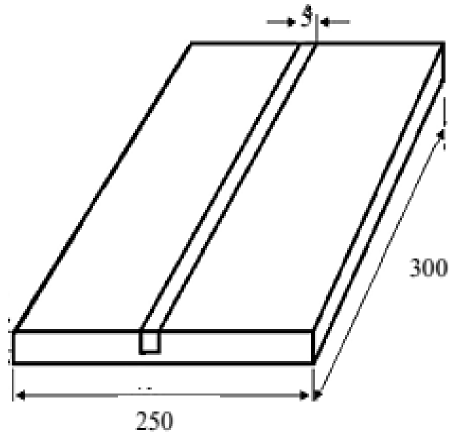


**Figure 1a Schematic Diagram FSW joint**

**Figure 1b Joint Fabricated by FSW**

The test specimens for tensile[25] and micro hardness which are shown in Fig. 2a and Fig. 2b, were extracted by using a Mitsubishi EDM wire cut machine.

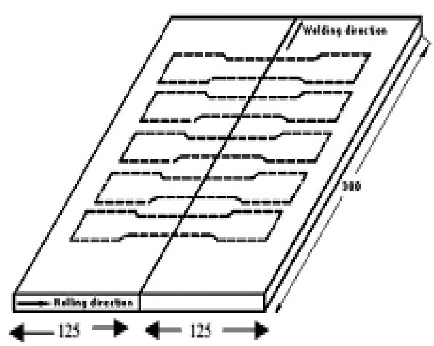


**Figure 2a Schematic Diagram Samples of FSW Joint**

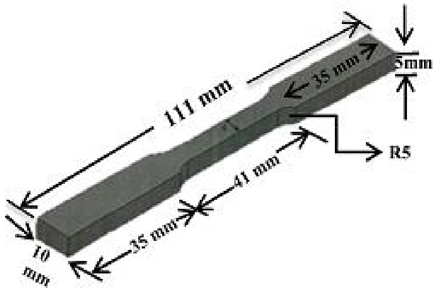


Figure 2b Tensile Specimen of FSW Joint

The tensile and micro hardness tests were done by using Instron tester and Wilson computerized hardness tester. From each fabricated plate 5 samples were extracted for micro-hardness (2 samples) and tensile test (3 samples). A row of indentation tests have been carried out on the two samples moving by a distance of 0.1mm from the weld zone. As per the design plan a set 24 experiments were carried out with 3 samples each for the tensile test and the average value of the three is considered as the strength of the joint. Similarly a set of 24 experiments for micro hardness with 2 samples each have been considered using the average. The results obtained from the tensile test and the micro hardness is given in Fig. 3a, Fig.3b, Fig. 3c….. Fig. 3f.

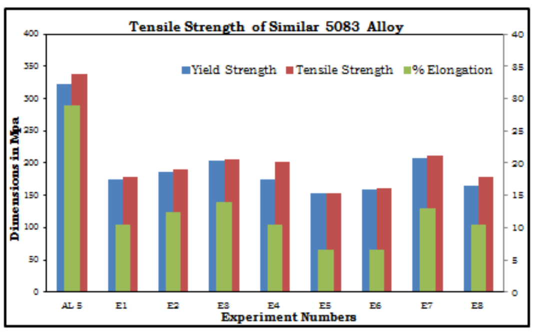


**Figure 3a Tensile Test Results of the fabricated Al 5083 FSW Joints**

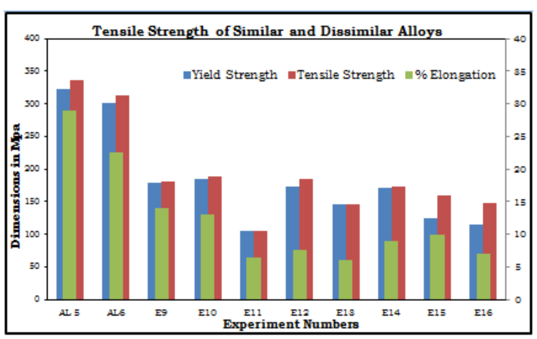


**Figure 3b Tensile Test Results of the fabricated Al 5083 x Al 6061 FSW Joints**

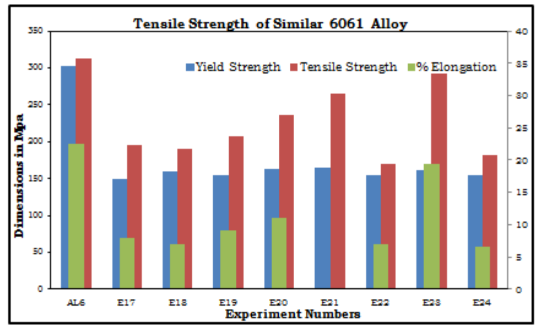


**Figure 3c Tensile Test Results of the fabricated AL 6061 FSW Joints**

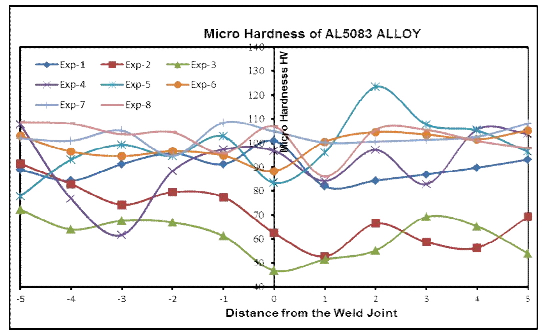


**Figure 3d Micro Hardness of the fabricated Al5083 FSW Joints**

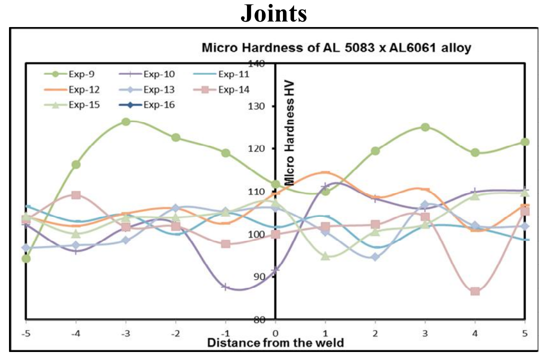


**Figure 3e Micro Hardness of the fabricated Al5083 x Al6061 FSW Joints**

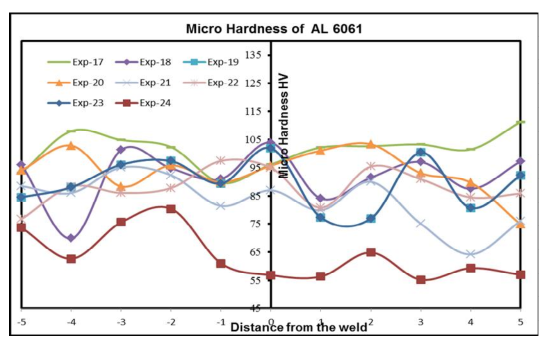


**Figure 3f Micro Hardness of the fabricated Al6061 FSW Joints**

## MICRO-STRUCTURAL EXAMINATION

The fabricated joints have been examined using an optical microscope to check for the defects. The Weck's reagent has been used as the etching agent and the sample has been kept for about 5-10 minutes. The main aim of this examination is to verify the joining of the dissimilar alloys. The interface of the welded region is shown in Fig 4.

**Fig 4 Microstructure of weld interface at 100x**

## OPTIMIZATION

The process parameters are optimized by choosing an L8 orthogonal array in Taguchi's technique [26]. The process parameters taken into consideration at two levels are rotational speed, traverse speed and axial force. The chosen parameters are 1000 and 1600 rpm, 40 and 160mm/min, 2.5kN and 3.5kN. The optimization of these parameters has been carried out three different times by Qualitek4 software to predict the response of the influencing parameters. The array containing the design plan is given in Table 4.

**Table 4 Experimental Design**

| | Metal | Advancing Side | Retreating Side | Tool Rotational Speed in rpm | Traverse Speed in mm/min | Axial Force in kN |
|---|---|---|---|---|---|---|
| Exp No 1 | Similar | A5083 | A5083 | 1000 | 40 | 2.5 |
| Exp No 2 | Similar | A5083 | A5083 | 1000 | 40 | 3.5 |
| Exp No 3 | Similar | A5083 | A5083 | 1000 | 160 | 2.5 |
| Exp No 4 | Similar | A5083 | A5083 | 1000 | 160 | 3.5 |
| Exp No 5 | Similar | A5083 | A5083 | 1600 | 40 | 2.5 |
| Exp No 6 | Similar | A5083 | A5083 | 1600 | 40 | 3.5 |
| Exp No 7 | Similar | A5083 | A5083 | 1600 | 160 | 2.5 |
| Exp No 8 | Similar | A5083 | A5083 | 1600 | 160 | 3.5 |
| Exp No 9 | Dissimilar | A5083 | A6061 | 1000 | 40 | 2.5 |
| Exp No 10 | Dissimilar | A5083 | A6061 | 1000 | 40 | 3.5 |
| Exp No 11 | Dissimilar | A5083 | A6061 | 1000 | 160 | 2.5 |
| Exp No 12 | Dissimilar | A5083 | A6061 | 1000 | 160 | 3.5 |
| Exp No 13 | Dissimilar | A5083 | A6061 | 1600 | 40 | 2.5 |
| Exp No 14 | Dissimilar | A5083 | A6061 | 1600 | 40 | 3.5 |
| Exp No 15 | Dissimilar | A5083 | A6061 | 1600 | 160 | 2.5 |
| Exp No 16 | Dissimilar | A6061 | A6061 | 1600 | 160 | 3.5 |
| Exp No 17 | Similar | A6061 | A6061 | 1000 | 40 | 2.5 |
| Exp No 18 | Similar | A6061 | A6061 | 1000 | 40 | 3.5 |
| Exp No 19 | Similar | A6061 | A6061 | 1000 | 160 | 2.5 |
| Exp No 20 | Similar | A6061 | A6061 | 1000 | 160 | 3.5 |
| Exp No 21 | Similar | A6061 | A6061 | 1600 | 40 | 2.5 |
| Exp No 22 | Similar | A6061 | A6061 | 1600 | 40 | 3.5 |
| Exp No 23 | Similar | A6061 | A6061 | 1600 | 160 | 2.5 |
| Exp No 24 | Similar | A6061 | A6061 | 1600 | 160 | 3.5 |

The tensile strengths and micro hardness results, given as input for each sample of Al5083 are shown in Table. 5a. and Table 5b.

**Table 5a Results of the Tensile strength for Al5083**

| | Sample 1 | Sample 2 | Sample 3 |
|---|---|---|---|
| Trial 1 | 179 | 172 | 169 |
| Trial 2 | 190 | 196 | 188 |
| Trial 3 | 206 | 200 | 208 |
| Trial 4 | 202 | 199 | 196 |
| Trial 5 | 153 | 151 | 150 |
| Trial 6 | 161 | 160 | 156 |
| Trial 7 | 211 | 208 | 207 |
| Trial 8 | 178 | 176 | 169 |

**Table 5b Results of the micro hardness for Al5083**

| | Sample 1 | Sample 2 | Sample 3 |
|---|---|---|---|
| Trial 1 | 100.3 | 112.4 | 90.06 |
| Trial 2 | 52.05 | 53.61 | 81.76 |
| Trial 3 | 72.89 | 33.75 | 33.52 |
| Trial 4 | 103.9 | 99.42 | 86.93 |
| Trial 5 | 97.16 | 66.33 | 86.46 |
| Trial 6 | 94.17 | 93.91 | 76.84 |
| Trial 7 | 103 | 107.3 | 103.9 |
| Trial 8 | 102.1 | 100.2 | 97.8 |

Similar set of results for the Al5083 x Al6061 and Al6061 fabricated FSW Joints have been given as input for the Qualitek4 software. The result obtained from the analysis is given in Fig. 5a, Fig. 5b….. and Fig. 5f.

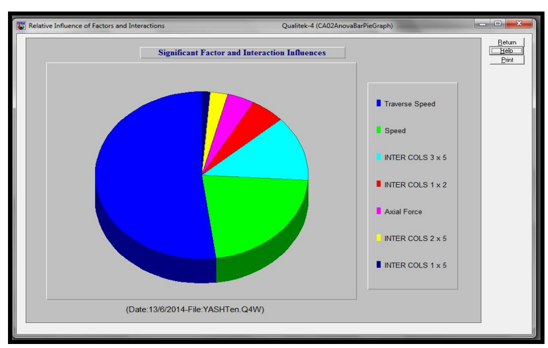


**Figure 5a. Relative Influence of Factors on Tensile strength for Al5083**

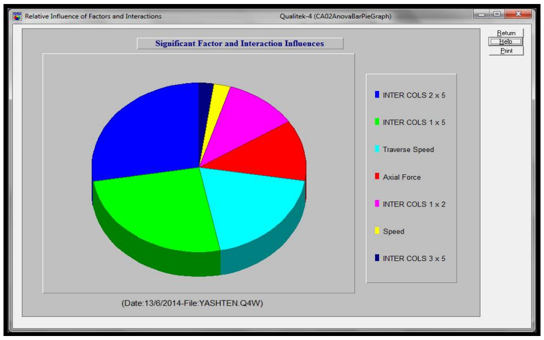


**Figure 5b. Relative Influence of Factors on Tensile strength for Al5083 x Al6061**

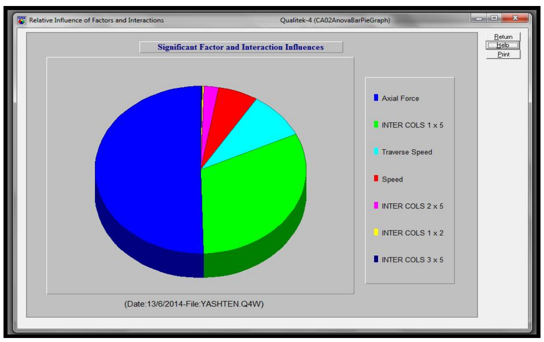


**Figure 5c. Relative Influence of Factors on Tensile strength for Al6061**

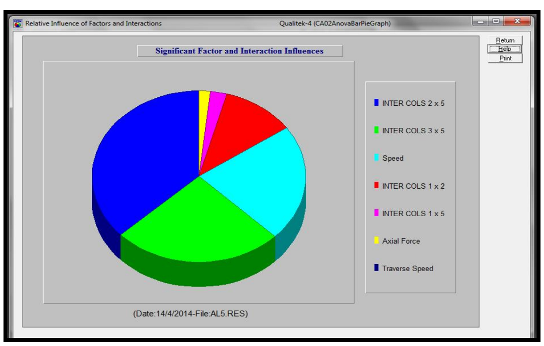


**Figure 5d. Relative Influence of Factors on Micro Hardness for Al5083**

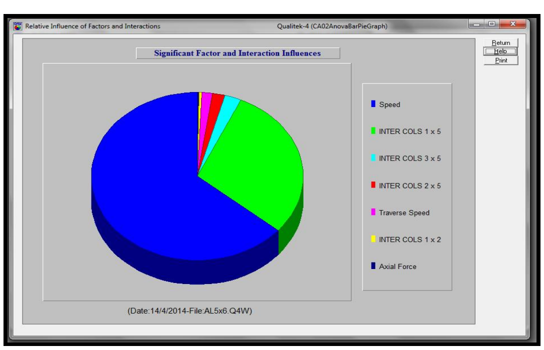


**Figure 5e. Relative Influence of Factors on Micro Hardness for Al5083 x Al6061**

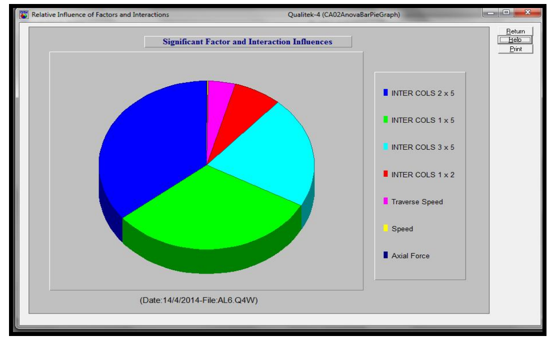


**Figure 5f. Relative Influence of Factors on Micro Hardness for Al6061**

## DISCUSSION

Experimental investigation states, by increased rotational speed, axial force and keeping weld speed constant there is a increase in tensile behavior and change in hardness values, and decrease in the same values when there is a increase in weld speed by keeping other parameters constant. Tensile strength increases due to change in axial force and insufficient frictional heat. If the weld speeds are high it reflects in poor heat generation and plastic flow of material. This is the reason for weak interface at the joint. High weld speed with low heat generation is not suitable for better joints, because the joints thus obtained have less strength and are low in metallurgical transformations. From the results obtained by the Taguchi Technique using Qulaitek4 software while welding either Al5083 or Al6061 alloys the influence of speed, traverse speed and axial force is observed as the most influencing parameter. However, the most influencing parameter in joining dissimilar alloys is observed as the rotational speeds. The influence of the other factors one over the other is seen in all the cases. Hence, there exists a necessity to further study on the influence of process parameters by choosing higher levels.

## CONCLUISIONS

In the present investigation joining of Al5083, Al6061 and Al5083 x Al6061 has been achieved successfully. The tensile strength and micro hardness for the welded samples have been studied. The microstructural examination has been carried out to check the efficiency of the produced joint. An optimization tool Qualitek4 has been employed to study the influence of the process parameters on joining the similar and dissimilar alloys.

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