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# Influence of Welding Parameters on the Mechanical Properties of Dissimilar AA7075-AA6061 Friction Stir Welds

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***Abstract*: *Friction stir welding (FSW) of different Aluminium alloys and materials is becoming advancing essential as it enables to take the advantage of both the materials. In present study FSW of different AA7075-AA6061 is studied regarding to welding speed, rotational speed and tooling geometry. The friction stir weld joints were carried out according to Taguchi L9 orthogonal array. Three different tools with different probe profiles i.e. tapered cylinder, straight cylinder and square were fabricated for this study. Mechanical testing's likely tensile, impact; bending and hardness tests are performed to study the mechanical properties and nature of weld joints. A reduced polynomial equation of second order will be well implemented and developed using regression analysis. Furthermore Taguchi analysis will be performed in order to identify the optimized levels for obtaining good quality welds. In addition to above ANOVA is also performed to identify the most significant effective parameters among various process parameters.***

***Keywords: Aluminium alloys, ANOVA, Friction Stir Welding (FSW), Regression analysis, Tool Rotational speed, Welding Speed.***

## INTRODUCTION

In present days FSW is highly utilized technique for joining process, especially for some aluminium alloys. The welding of similar or dissimilar aluminium alloys can be easily done by using FSW process. The fundamental approach of FSW is easy and understandable.FSW is known as solid state welding technology where different materials are to be welded by means of a rotating tool which is non consumable in nature. It doesn't require an extra fillet material for joining process. A specially designed tool which is rotating and non consumable is used for performing FSW. This tool consists of tool pin and tool shoulder, in which the tool pins, must have specific profile and tool shoulder with a specific diameter. So by the rotation of tool, the tool pin causes a stirring action on the work pieces while performing FSW process. Once the tool pin tip touches the material surface, then automatically a heat is generated between the material upper surface and the shoulder. After some time the tool must be traversed along the line that is to be welded, so a continuous joint can be produced due to combined friction stirring of the tool pin and the frictional heat developed. The solid nature of friction stir welding mainly extends to several advantages than fusion and traditional welding methods. Issues such as cracking, redistribution, liquation cracking can be avoided during friction stir welding. Defects such as surface galling, voids, insufficient penetration will occur due to improper level of parameters that were selected for FSW. The FSW process mainly depends on some major factors that contributes a crucial part in welding process, these can be called as process parameters or welding parameters. The process parameters such like traverse speed, rotating speed and depth of penetration highly influences the properties of welding. The graphical presentation of FSW is shown in Fig 1.

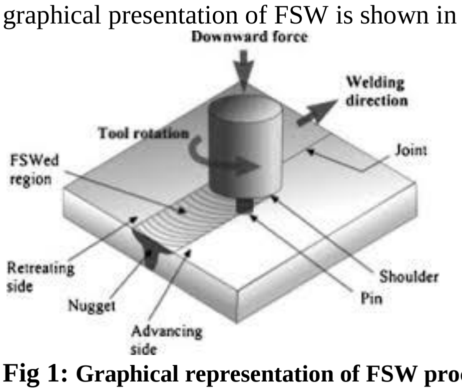


**Fig 1: Graphical representation of FSW process**

The strength for friction stir weld joint mainly depends on speed of spindle; angle placed, feed rate and depth of penetration. The speed can be adjusted accordingly for different parameters and the material that is being to be weld. Excessive spindle speed may cause more defects in welding, so by using correct and required welding speed for the materials may lead to improve the life of the tool and a better surface finish can be obtained. The feed rate is the traverse

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velocity in which the cutter is fed, that is advanced against the work piece; it can be represented in millimeters per revolution. Accordingly by referring various previous journals, this study aims to investigate the method for analyzing different mechanical tests for different aluminium alloys AA7075-AA6061 friction stir welds.

## II. LITERATURE REVIEW

***Thomas W.M et al, [1]***. He describes that by friction stir butt welding gives a wide range of work pieces to be attached by using a non consumable tool with lesser defects. ***Nandan et al, [2]*** Investigated and deals with its metallurgical parameters. The main focus of his study is on transfer of heat, generation of heat and flow of material plastic during welding. Study about the major understanding of the defect formation and shape and properties of the weld joints. ***Hasan et al, [3]***.Better friction stir welds can be produced by having an absolute draft of backing and clamping structure with improved choice of weld parameters. This works mainly provides simple design of plates and fixtures that are to be utilized in FSW of Aluminium Alloys. Different combinations of dissimilar aluminium alloys 7075-6061 were welded to inspect the design validity. ***Gopalsamy et al, [4]*** This investigation mainly deals with Taguchi and ANOVA i.e. analysis of variance and were performed to study the effective characteristics of machining inputs like speed , feed, depth of insertion while considering the life of tool and surface finish. The obtained results obtained by performing Taguchi analysis are close to ANOVA and most effective and influenced parameter is cutting speed. The regression equations were calculated for estimate of tool ware rate and surface roughness. ***Hasan et al, [5]*** Investigated about the study of dissimilar AA 7075-6061 with respect to rotating and axial forces, tool geometry and tool positioning angle by specialized method called RSM with complex design. Five different types of tools are used and fabricated a self designed clamping system and finally found that the tool which has threaded cone pin results in good weld with better tensile nature and study surface finish. ***Murr et al, [6]*** Summarizes the process of FSW over a period of more than a decade which involves 18 same materials of friction stir welding reference systems, and similarly 25 dissimilar materials which are clearly summarized. ***Mishra et al, [7]*** He stated that FSW is one among the many effective joining processes in a decade. The author mainly investigates the present form of improvement of FSW and FSP are employed. Particular importance has given to technique responsible for production of welds and effect of FSW parameters on final properties. ***Aval et al, [8]*** mainly investigated that weld strength and variations in hardness following welding mainly based on the heat absorbed per unit length. And the kinetics of natural aging in the welded pieces was seemed to be observable with in the 14 days from start, and slowly its effect decreases in higher aging durations. ***Silva et al, [9]*** Investigated the mechanical performance in terms of tensile and hardness testing by test results. The flow rate of material using stop action approach is also investigated to understand the important feature of mixing process and a nonstop rotational flow inside the threading has identified because of forming of cavity behind the pin. ***Jayaraman et al, [10]*** this study mainly discusses the use of Taguchi method design process for improving the tensile strength of aluminium alloy A319. For correlation of the tensile strength and process parameters a math model is generated by regression model. Accordingly by referring various previous journals, present work helps to develop the model for anticipating different mechanical tests for dissimilar AA7075-AA6061 friction stir welds and to perform Taguchi, Regression and ANOVA for obtaining better results.

## III. EXPERIMENTATION

### *A. Selection of materials*

Aluminium alloys of AA7075 Ad AA6061 were prefered for fabrication of dissimilar joints using FSW process. Some remarkable properties of aluminium are better strength, good thermal conductivity, less weight, electrical conductivity.

**Table I: chemical distribution (wt.%) of aluminium alloys**

| Alloy | Si | Fe | Cu | Mn | Mg | Cr | Zn | Ti | Al |
|---|---|---|---|---|---|---|---|---|---|
| AA7075 | 0.07 | 0.27 | 1.6 | 0.03 | 2.5 | 0.19 | 5.7 | 0.02 | Bal |
| AA6061 | 0.67 | 0.32 | 0.23 | 0.014 | 1.06 | 0.21 | 0.01 | 0.02 | Bal |

### *B. Preparation of work pieces*

Two dissimilar aluminium alloys of grade 7075 and 6061 are fabricated for the respective dimensions i.e. 150mm x100mmx6mm by means of cutting machine. After the cutting process the work pieces are subjected to clean by acetone solution to remove the unwanted particles.

### *C. Tool Details*

The tool must be made of material that which can with stand to extreme conditions for the welding process. For our work we use H13 or HSS steel tool is used which is represented in Fig 2. The tool which we used has a shoulder of 20 mm diameter, pin width of 4mm; length of pin 5mm.A tapper of 2x3mm diameter must be obtained for taper cylinder. And three different pin profiles are used for various examinations that are (a) Taper cylinder pin profile, (b) Cylinder pin profile, (c) Square edge pin profile which were mentioned in Fig 3.

**Fig 2: HSS tool used in friction stir welding**

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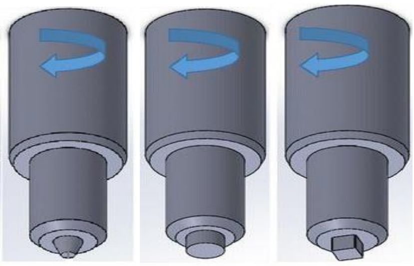

**(a) (b) (c)**

**Fig 3: Various tool tip pin profiles used**

(a) Cylinder (b) cylindrical pin (c) square pin profile



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### *D. Experimental setup*

Milling machines of type semi automatic (FN2 V) which is shown in Fig 4 is used for FSW of dissimilar AA joints. The speed of the machine ranges from 35.5 to 1800 rpm and the main motor has 5.5/1500kw/rpm and feed motor 1.5/1500. The Table II represents the salient features of the machine.

**Table II: Specifications of the machine**

| DESCRIPTION | DIMENSIONS |
|---|---|
| Machine type | Semiautomatic(FN2 V) |
| Overall Dimensions (L x W) | 1520 x 310 mm |
| Clamping Length (L x W) | 1350 x 310 mm |
| Power operated table transverse | 800mm |
| Power operated table longitudinal | 400mm |
| Power operated table cross vertical | 265mm |
| Number of speeds | 18 |
| Speed range | 35.5-1800 |
| Main motor | 5.5/1500 kW/rpm |
| Feed motor | 1.5/1500kw/rpm |

**Fig 4: Friction stir welding machine**

**Fig 5: Friction stir Welding of test specimen**

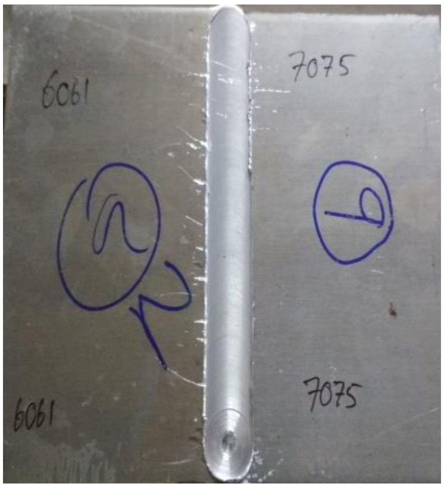


**Fig 6: work piece after machining**

The materials that are used in this work are AA7075 and AA 6061 plates with nominal compositions which are shown in previous tables. They are exposed to cleaning and checked for dimensions before starting the process. A hardened H13 tool was used that consist shoulder diameter of 20mm, pin diameter of 4mm, pin length of 5mm and a tapper of 2x3mm diameter .. In view of previous study work and their results of the preparatory experiments, three level of rotation of tool and three levels of traverse speeds were selected, and on addition three different tool pin profiles are considered in this work. The process parameters are represented in Table III Then this process is done on nine work pieces according. The FSW joints were performed accordingly by Taguchi L9 orthogonal array. The FSW process is exhibited in Fig 5.

**Table III: Process parameters and their levels**

| S. No | Process parameters | Notation | Level 1 | Level 2 | Level 3 |
|---|---|---|---|---|---|
| 1 | Rotational Speed(rpm) | R S | 710 | 900 | 1120 |
| 2 | Welding Speed (mm/min) | W S | 60 | 80 | 100 |
| 3 | Tool pin profile (shape) | T P | Taper cylinder | Cylinder | Square edge |

Processing is done by varying different levels and parameters for obtaining good quality welds. Totally nine work jobs are welded by the use of vertical milling machine. A sample work material which is subjected to FSW process is shown in Fig 6.

## IV. RESULTS AND DISCUSSION

### *A. Mechanical Testing's*

Mechanical tests or engineering tests were employed to determine several mechanical behaviors of materials such as strength, hardness, brittle nature etc. In this work the mechanical tests such as tensile, impact, bending and hardness tests are performed and evaluated.



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**Table IV: Combined Test Result table**

| S.No | Rotational Speeds(rpm) | Weld Speeds (mm/min) | Tool Profile | Ultimate Tensile Strength(N/mm$^{2)}$ | Hardness values(BHN) | Impact Values(J) | Ultimate Load(KN) BEND |
|---|---|---|---|---|---|---|---|
| 1 | 710 | 100 | 1 | 149.072 | 74.73 | 4 | 5.24 |
| 2 | 900 | 60 | 1 | 178.711 | 71.23 | 6 | 5.12 |
| 3 | 1120 | 80 | 1 | 154.255 | 75.16 | 12 | 6 |
| 4 | 710 | 80 | 2 | 216.492 | 75.73 | 12 | 5.92 |
| 5 | 900 | 100 | 2 | 216.587 | 79.30 | 12 | 6.24 |
| 6 | 1120 | 60 | 2 | 206.897 | 72.26 | 18 | 6.28 |
| 7 | 710 | 60 | 3 | 143.174 | 62.60 | 14 | 5.04 |
| 8 | 900 | 80 | 3 | 189.236 | 65.16 | 22 | 5.76 |
| 9 | 1120 | 100 | 3 | 173.228 | 73.23 | 18 | 0.84 |

So by this the ultimate tensile strength of nine different tensile specimens is prepared and is evaluated as per ASTME8M-04 standard. The prepared samples were tested on universal testing machine in Hyderabad engineering labs, Hyderabad. The prepared tensile pieces are shown in figure below. So the ultimate tensile strength is observed as 216.587 N/mm$^2$. This is obtained at a R S having 900rpm and W S having 100mm/min by using cylindrical tool tip profile. For obtaining the ultimate load the bend test is performed. Similarly the maximum hardness value is obtained by the test results at 79.3 at 900rpm and at a welding speed of 100mm/min by using cylindrical tool tip. The impact test is carried out by Krystal equipment of model KI-300.The average maximum impact value is 22 obtained at 8$^{th}$ specimen i.e. at 900rpm and at welding speed of 80mm/min by having square edge tool pin profile. In Table IV the output of various test results are shown. The samples that are subjected to testing are shown below in Fig 7 and Fig 8.

**Fig 7: Tensile test Specimens**

**Fig 8: Bending, hardness and impact specimens**

### *B. REGRESSION ANALYSIS*

The regression analysis was conducted by the data results that were obtained after the weld joining process. It is used to derive linear equations which relate the dependent to the independent variables. The regression analysis can be processed in Minitab software. The equations derived from multiple regression analysis are stated in below equations,

Ultimate Tensile strength (N/mm$^{2)}$ = 149.6 + 0.0183 R S


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0.084 W S +3.9 T P

Hardness values (BHN) = 59.10 + 0.00621 R S + 0.1764 W S – 3.36 T P

Impact values (J) = -8.15 + 0.01457 R S -0.0333W S + 5.33 T P

Ultimate load (KN) = 11.84 - 0.00260 R S -0.0343 W S – 0.787 T P

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### *C. ANOVA*

ANOVA analysis is a statistical model and can be done in Minitab. Analysis of variance is used to identify the process parameters that are analytically significant.

**Table V: ANOVA for Ultimate tensile strength**

| Source | DF | Seq SS | Contribution | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|---|---|
| R S | 2 | 990.9 | 15.25% | 990.9 | 495.44 | 1.99 | 0.334 |
| w s | 2 | 169.0 | 2.60% | 169.0 | 84.48 | 0.34 | 0.746 |
| T P | 2 | 4838.7 | 74.49% | 4838.7 | 2419.3 | 9.74 | 0.093 |
| Error | 2 | 497.0 | 7.65% | 497.0 | 248.51 | | |
| Total | 8 | 6495.5 | 100.00% | | | | |

**Table VI: ANOVA table for Hardness value**

| Source | DF | Seq SS | Contribution | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|---|---|
| R S | 2 | 9.903 | 4.47% | 9.903 | 4.951 | 0.90 | 0.525 |
| w s | 2 | 74.782 | 33.72% | 74.782 | 37.391 | 6.83 | 0.128 |
| T P | 2 | 126.108 | 56.87% | 126.108 | 63.054 | 11.52 | 0.080 |
| Error | 2 | 10.950 | 4.94% | 10.950 | 5.475 | | |
| Total | 8 | 221.743 | 100.00% | | | | |

**Table VII: ANOVA table for Impact values**

| Source | DF | Seq SS | Contribution | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|---|---|
| R S | 2 | 54.22 | 20.47% | 54.22 | 27.111 | 4.69 | 0.176 |
| w s | 2 | 24.89 | 9.40% | 24.89 | 12.444 | 2.15 | 0.317 |
| T P | 2 | 174.22 | 65.77% | 174.22 | 87.111 | 15.08 | 0.062 |
| Error | 2 | 11.56 | 4.36% | 11.56 | 5.778 | | |
| Total | 8 | 264.89 | 100.00% | | | | |


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**Table VIII: ANOVA table for Ultimate load**

| Source | DF | Seq SS | Contribution | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|---|---|
| R S | 2 | 2.926 | 12.86% | 2.926 | 1.463 | 0.45 | 0.689 |
| w s | 2 | 5.249 | 23.07% | 5.249 | 2.625 | 0.81 | 0.552 |
| T P | 2 | 8.094 | 35.58% | 8.094 | 4.047 | 1.25 | 0.445 |
| Error | 2 | 6.480 | 28.49% | 6.480 | 3.240 | | |
| Total | 8 | 22.749 | 100.00% | | | | |

If a factor has obtained higher percentage contribution means there is more chance for better effect on the execution of welding process. From the outcome secured from ANOVA are as follows for different responses,

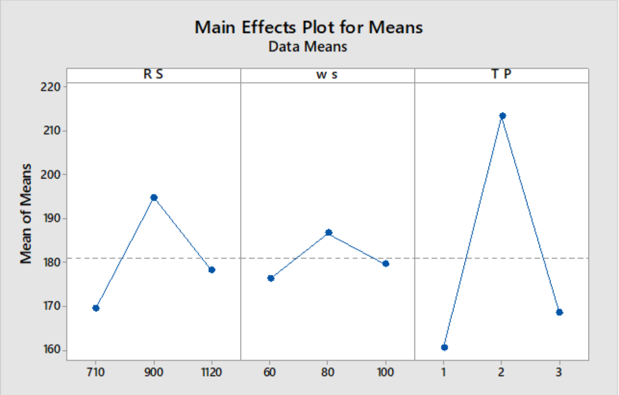
a) The parameter that mostly influences the tensile results in analysis of variance is the tool profile of almost 74.49% of its total contribution and rotational speed has 15.25% and welding speed has 2.60% of its total contribution.
b) Similarly for hardness results in ANOVA analysis the most influenced parameter is tool profile with 56.87% and welding speed with 33.72% and rotational speed with 4.47% of its total contribution.
c) From impact test results performed in friction stir welding the most influenced parameter is tool profile with 65.77% and rotational speed with 20.47% and welding speed with 9.40% of its contribution.

d) From bend test results in ANOVA the significant influenced parameter is tool profile with 35.58% and welding speed with 23.07% and rotating speed with 12.86% and the remaining is error in contribution.

### *D. TAGUCHI METHOD*

Taguchi method also stated as robust method of design pioneered by Dr. Taguchi. This method greatly improves the design and engineering productivity. Taguchi method is very effective on regard of its simple experimental design and systematic approach to produce better quality at lower costs. The optimum results can be obtained by providing the input functions and can easily produce better results. By this effect of input variables the results can be formed by S/N ratio and response means. The Larger is better criteria is employed to our problems The Taguchi method can be carried out in 2 steps

**Step1** the S/N ratio can be used to identify the control factor that reduces variability
**Step2** To identify the control factors that brings mean to position may or may not have impact on S/N ratio.
The Larger is better criteria is employed to our problems.

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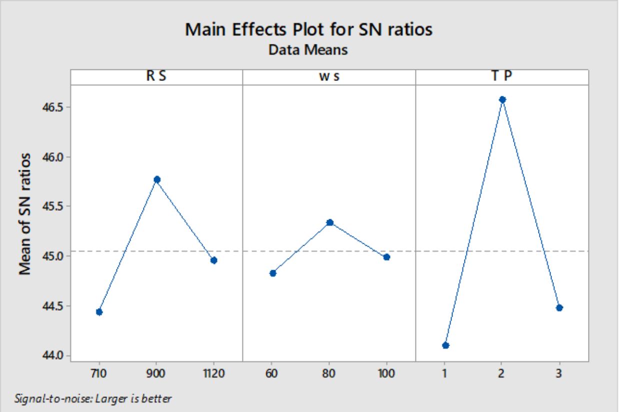


(b)

**Fig 9**: **Main effects plots for Ultimate tensile strength**
(a) Mean of Means (b) Mean of SN ratios


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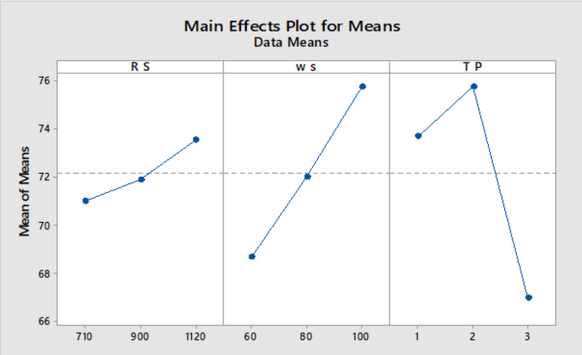


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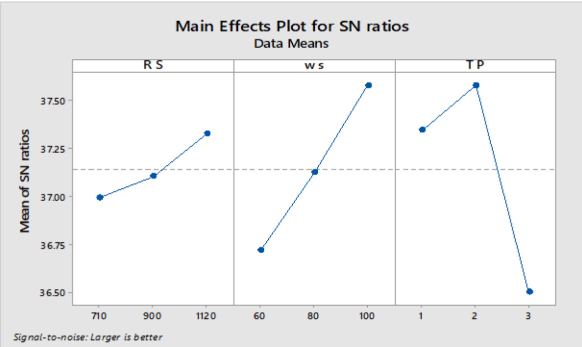
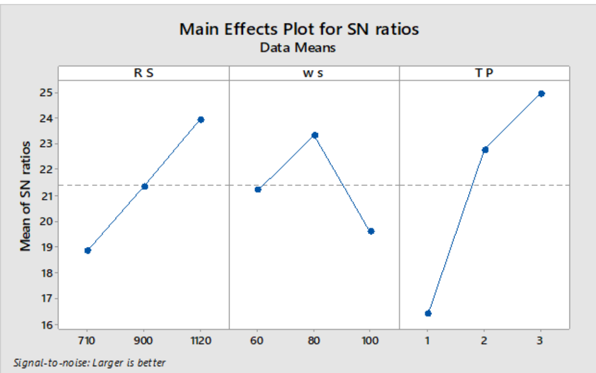



(b)

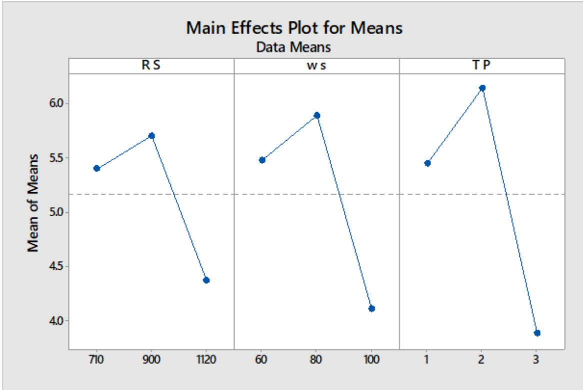
**Fig 10: Main effects plots for hardness value**
(a) Mean of Means (b) Mean of SN ratios


(a)

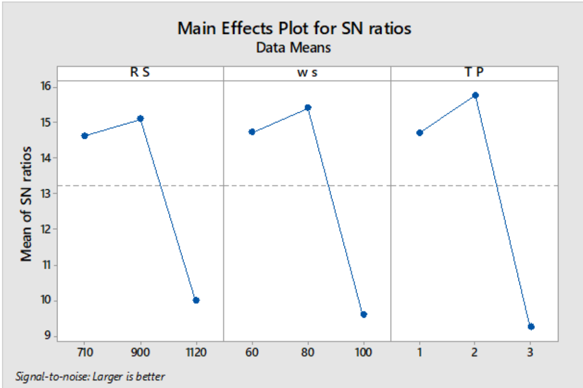



(b)

**Fig 11: Main effects plots for impact values**
(a) Mean of Means (b) Mean of SN ratios




(a)




(b)

**Fig 12: Main effect plots for Ultimate load**
(a) Mean of Means (b) Mean of SN ratios

**Table IX: Validation of Performance Results**

| OPTIMUM CONDITIONS | |
|---|---|
| Ultimate Tensile Strength value | Rotational speeds – 900<br>Welding speeds- 80<br>Tool profile- 2 |
| Hardness value | Rotational speeds- 1120<br>Welding speeds- 100<br>Tool profile- 2 |
| Impact value | Rotational speeds- 1120<br>Welding speeds- 80<br>Tool profile- 3 |
| Ultimate load | Rotational speeds- 900<br>Welding speeds- 80<br>Tool profile- 2 |

## V. CONCLUSION

AA6061 and AA7075 alloys are successfully welded by FSW process by changing the process parameters and adjusting the levels. The input parameters that are selected during the FSW are rotating speeds, welding speeds, tool pin profile, while the output responses are taken as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ultimate tensile strength, Hardness value, Impact value, Ultimate load. Regression, ANOVA and Taguchi model is generated by using MINITAB18 to predict the responses.

- From tensile result ANOVA table we can found that tool profile is the major influence factor followed by rotational speed and welding speed
- The optimum tensile strength can be obtained at a Rotational Speed of 900, Welding Speed of 80 and cylindrical tool pin profile.
- From Hardness value result ANOVA table we can observe that tool profile plays important role followed by welding and rotational speeds based on its contribution.
- The optimum hardness value is predicted by Taguchi method at an rotating speed 1120, welding speed 100 and cylindrical pin profile tool.
- From impact value result ANOVA table we can observe that tool profile plays major contribution followed by rotating and welding speeds.
- The optimum impact value can be attained at a rotating speed of 1120, welding speed 80 and square pin profile tool is used.
- From ultimate load result ANOVA table we can observe that tool profile plays important role followed by welding and rotational speeds based on its contribution.
- The ultimate load can be obtained at a rotating speed of 900, weld speed of 80 and uses cylindrical tool pin profile.

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