

Prediction and Parametric Optimization on Mechanical Properties of Friction Stir Welding Joints of AA 6061 and AA 2014 Using Genetic Algorithm

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ABSTRACT: Friction Stir Welding is a solid state welding technique which heats metal to the temperature below re-crystallization. FSW avoids welding defects like porosity and hot cracking which are common in conventional welding techniques due to alloy's low re-crystallization temperature and higher heat dissipating nature. It was invented in 1991 by the welding institute. This process combining (the metal is not melted) deformation heating and mechanical work to obtain high defect free joints. In the present study, dissimilar joints of AA6061 and AA2014 aluminum alloys were successfully made by friction stir welding technique. The microstructure and mechanical behaviour of the welded joints were investigated at different welding parameters. A mathematical model was developed to demonstrate a relationship between the friction stir welding parameters and the mechanical properties of the dissimilar joints. The microstructures of various regions were observed and analyzed by means of optical microscopy. The design of experiment has been done with RSM with 15 numbers of experiments and prediction is done through ANOVA. Using ANOVA, the significance of welding parameters on mechanical properties of welded dissimilar joints is determined. And also by using GENETIC ALGORITHM the optimal process parameters of welded joints are determined.

KEYWORDS: Anova, Axial Force (AF), Genetic Algorithm, Tool Rotation Speed (TRS), Welding Speed (WS).

I. INTRODUCTION

The process of Friction Stir Welding has been widely used in the aerospace, shipbuilding, automobile industries and in many applications of commercial importance. Friction Stir welding can improve mechanical properties of welded materials and it is free from porosity or blowholes compared to conventionally welded materials [1]. Currently FSW is being considered as a most promising, efficient and environment friendly or green joining process. Today aerospace concepts need reductions in both the weight as well as cost of production of materials. So in these conditions, welding processes play an important role and programs have been set up to study their potential. Main purpose is to reduce the costs of manufacturing techniques to result in low cost and weight savings by reducing riveted/fastened joints and part count. By using Friction Stir Welding (FSW) we can achieve this goal. It consumes minimum energy, requires no additional cover gas or flux, does not involve add-on filler materials, can be applied to almost all types of joints such as butt joints, lap joints, T butt joints, and fillet joints and even dissimilar materials can also be joined. The process uses the non consumable specially designed rotating tool which is inserted into the material by giving the axial force and then translated along the joint to make the weld [2]. K.N.Krishnan studied the effect of post weld heat treatment on the properties of 6061 friction stir welded joints. He stated that the solution and ageing treatments to produce high hardness resulted in failure in the bending. The failure of the post weld heat treatment weld region in bending has been attributed to low fracture toughness, equiaxed grains and the presence of precipitate free zones [3]. M.Jayaraman et.al, discussed use of taguchi experimental design technique for maximizing tensile strength of friction stir welded cast Aluminum alloy

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A319. Using Anova and Signal to noise ratio of robust design, effect on tensile strength of FSW process parameters is evaluated and optimum welding condition for maximizing tensile strength is determined [4]. The authors also developed empirical relationships to predict the grain size and hardness of the weld nugget of the friction stir welded AA7075-T6 Aluminum alloy joints. Six factors, Five levels, central composite, rotatable design matrix is used for optimization of the experimental conditions. The empirical relationships are developed by response surface methodology incorporating tool and process parameters. A linear regression relationship is also established between grain size and hardness of the weld nugget of friction stir welded joints. The welded nugget grain size is related with hardness of the joint. The developed relationships are effectively used to predict the weld nugget grain size of the joint non-destructively by measuring the weld nugget hardness [5]. Investigated joining of two dissimilar aluminum alloys AA2014 and AA6061 using friction stir welding. The experiments were conducted on vertical end milling machine. The FSW has been conducted at range of 760-2000rpm by determining their mechanical properties with 15 no of experiments which is designed in RSM [6]. This is followed by the conduct of ANOVA ensuring the statistical significance of the process parameters [7]. Then non-traditional optimization technique namely GENETIC ALGORITHM (GA) has been used to derive the optimized process parameters of this welding technique. Thus after conducting all the experiment the testing is done and the optimization is done through using MATLAB 17 [8].

II. EXPERIMENTAL PROCEDURE

Friction stir welding is a process that produces a weld joint between two work pieces by heating, friction and plastic deformation caused by rapidly rotating tool that traverse the weld joint. A general tool is designed in the tapered type with a pin of diameter smaller than the shoulder. The pin is shorter than the thickness of the plates and its diameter is normally slightly larger than the thickness of the plates. The experiment is designed by using MINITAB 17 software tool in which the RSM technique is used for it. Based on the RSM, 15 numbers of experiments were designed. The rolled sheets of AA6061 and AA2014 alloys were applied as base materials, and their chemical compositions are presented in Table 1. The axis of the tool shoulder and pin is co-axial with the axis of rotation. The work piece used are AA2014 & AA6061 and the size of the work piece is 150*75*6 for normal welding & 150*50*6 (l*b*t) for I-section and the tool used is Tungsten Carbide tool with Taper pin Profile.

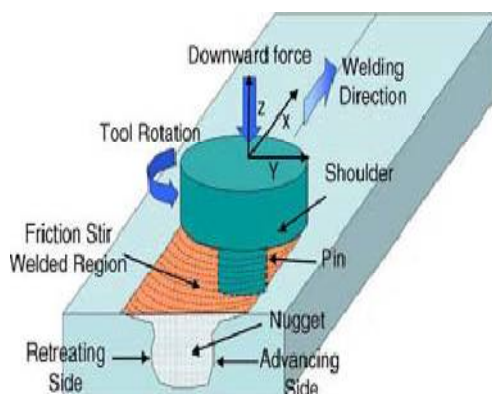


Figure 1: Schematic Diagram of Friction Stir Welding With a Rotating Tool

FSW TOOL PROFILE

The Friction Stir Welding technique uses a non-consumable rotating tool to make the joint. The tool consists of shank, body, shoulder, probe (or) pin. The tool used in this process was made of Tungsten carbide which has a Tapered Pin profile has shown in Figure 2.

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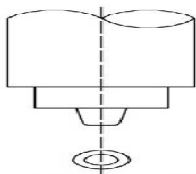


Fig 2. Tapered Pin profile

Table 1. Specified chemical composition of alloy AA 6061 (wt %) and AA2014(wt%)

Alloy(6061)	Composition	Alloy(2014)	Composition
Si	0.8-0.4	Si	0.5-1.2
Fe	0.7	Fe	0.7
Cu	0.15-0.40	Cu	3.9-4.5
Mn	0.15	Mn	0.4-1.2
Mg	0.8-1.2	Mg	0.2-0.8
Cr	0.04-0.35	Cr	0.1
Zn	0.25	Zn	0.25
Ti	0.15	Ti	0.15
Al	Bal	Al	Bal

III. RESULTS AND DISCUSSIONS

FSW technique is employed on 6061 and 2014 Aluminum alloys and tested using different parameters Tool Rotation Speed (N), Welding Speed(S), Axial Force (F). Genetic Algorithm (GA) is employed to optimize the Tensile strength, Impact strength and Hardness of the AA6061&2014 material for Friction Stir Welding. The results and discussion of the above performed Welding Technique. Tables are presented for responses using ANOVA calculations and GA results.

III.A. STATISTICAL ANALYSIS AND DEVELOPMENT OF MODEL

To predict the tensile, impact strengths and hardness, Analysis of variance (ANOVA) technique is applied to find out the significance of the parameters for validation. The percentage of contribution of tool rotational speed (N), welding speed (S), and axial force (F) on tensile strength, impact strength and hardness were studied and analyzed by using ANOVA technique.

PROCESS PARAMETERS (FACTORS) AND THEIR LEVELS

Below tables shows the process parameters and their design levels. These values are considered for carrying the project work, such as Tool Rotational Speed (N), Welding Speed(S) and Axial Force (F).

Table 2 . Process Parameters and their design levels using in FSW Technique

Process parameters	Range	Level 1	Level 2	Level 3
Tool Rotational Speed (N), rpm	760- 2000	760	1380	2000
Welding Speed(S), mm/min	11 – 37	11	24	37
Axial Force(F), KN	0.5-1.0	0.50	0.75	1.0

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Table3. Experimental Values For Tensile & Impact Strength &Hardness

S. No	Tool Rotational Speed (N) in rpm	Welding Speed (S) in mm/min	Axial Force (F) in KN	Tensile Strength (TS) in MPa	Impact Strength (IS) in KN/mm ²	Hardness (BHN)
1	760	11	0.50	92.46	3.68	71
2	760	24	0.50	101.62	3.27	72
3	760	37	0.75	112.45	3.41	75
4	760	11	1.0	95.79	2.93	73
5	760	37	1.0	114.12	4.02	75
6	1380	11	0.75	121.61	2.83	85
7	1380	37	0.50	127.44	3.86	78
8	1380	24	0.75	124.12	3.57	84
9	1380	24	0.50	123.28	4.59	79
10	1380	37	1.0	131.61	3.61	77
11	2000	24	0.50	126.61	4.63	74
12	2000	11	0.75	118.86	3.39	82
13	2000	37	0.75	130.78	3.96	80
14	2000	11	1.0	125.73	4.35	83
15	2000	24	1.0	132.91	4.33	81

Table4. ANOVA Results for Tensile Strength

Factor	Degrees of Freedom DOF	Sum of Squares SS	Mean Squares MS	Percentage of Contribution
N	2	1644.37	822.19	70.6645
S	2	356.64	178.32	15.3274
F	2	75.92	37.96	3.2628
RES	8	81.77	10.22	3.5141
TOTAL	14	2326.83	1048.69	100

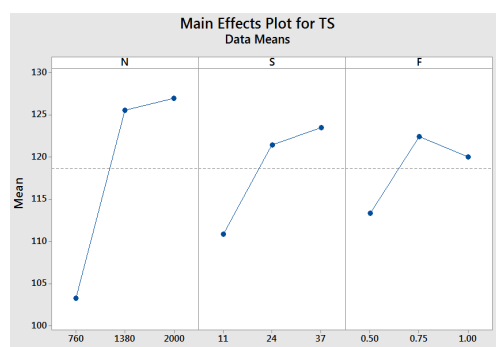


Fig.3. Main Effects plot for Tensile Strength

Table 5. ANOVA Results for Impact Strength

Factor	Degrees of Freedom DOF	Sum of Squares SS	Mean Squares MS	Percentage of Contribution
N	2	1.1894	0.59470	27.311
S	2	0.9996	0.49982	22.955
F	2	0.1276	0.06382	2.9300
RES	8	2.1348	0.26686	46.805
TOTAL	14	4.3546	1.42464	100

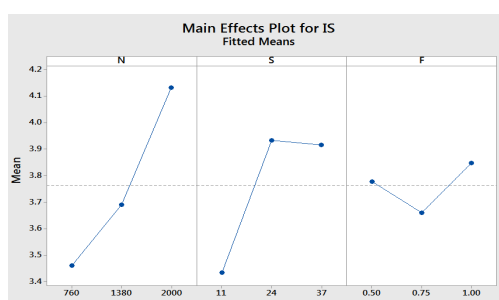


Fig.4. Main Effects plot for Impact Strength

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Table 6. ANOVA Results for Hardness

Factor	Degrees of Freedom DOF	Sum of Squares SS	Mean Squares MS	Percentage of Contribution
N	2	168.933	84.4667	59.28
S	2	31.429	15.7143	11.03
F	2	0.848	0.4241	0.29
RES	8	83.72	10.4654	29.39
TOTAL	14	284.933	111.071	100

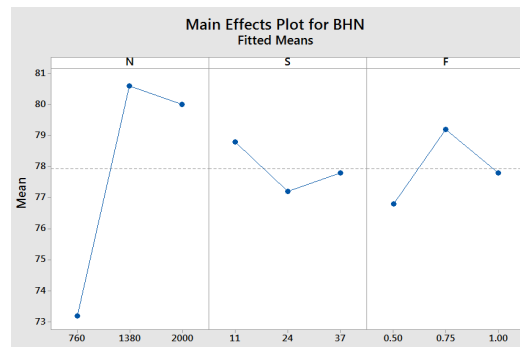


Fig.5 Main Effects plot for Hardness

The above tables and figures are showing that the results and main effect plots for mechanical properties of dissimilar joints of AA6061 and AA2014 using Tapered pin profile. From the Table4, The % Contribution of values for Tool Rotational Speed (70.6645), Welding Speed (15.3274) and Axial Force (3.2628). It is observed that the Tool Rotational Speed have great influence on Tensile Strength. Since this analysis is a parameter based design, from the above values it is clear that Tool Rotational Speed is the Major Factor to be selected effectively to get the good Tensile Strength., From the Table 5, The % Contribution of values for Tool Rotational Speed (27.311), Welding Speed (22.955) and Axial Force (2.9300). It is observed that the Tool Rotational Speed have great influence on Impact Strength. Since this analysis is a parameter based design, from the above values it is clear that Tool Rotational Speed is the Major Factor to be selected effectively to get the good Impact Strength From the Table 6, The % Contribution of values for Tool Rotational Speed (59.28), Welding Speed (11.03) and Axial Force (0.29).It is observed that the Tool Rotational Speed have great influence on Hardness. Since this analysis is a parameter based design, from the above values it is clear that Tool Rotational Speed is the Major Factor to be selected effectively to get the good Hardness.

III.B. ESTIMATION OF OPTIMUM PROCESS PARAMETERS FOR TENSILE, IMPACT STRENGTH AND HARDNESS

The present work is aimed to identify the most influencing significant parameters and percentage contribution of each parameter on responses of FSW joints by conducting minimum number of experiments using ANOVA. Based on the highest values of the Mean Levels for the significant factors N, S and F the overall optimum condition thus obtained were N3, S3 and F2.

The optimum value of Tensile Strength is predicted at the significant levels of Process Parameters. The estimated mean of the response characteristics can be computed as Tensile Strength,

$$(TS) = N3+S3+F2-2TS \text{ ----- Equation.}$$

Substituting the values of various terms in the above equation then,

$$\text{Tensile strength, } TS = 152.16 + 152.24 + 157.69 - (2*146.89) = 132.78 \text{ MPa} \quad [\text{Ref.9}]$$

In the same way for the optimum process parameters for **Impact Strength** the overall optimum condition is obtained at N3, S2 and F3.

The estimated mean of the response characteristics can be computed as Impact Strength,

$$(IS) = N3+S2+F3-2IS \text{ ----- Equation.}$$

Substituting the values of various terms in the above equation then,

$$\text{Impact strength } IS = 4.132 + 3.934+3.843 - (2*3.843) = 4.385 \text{ MPa} \quad [\text{Ref.9}]$$

Similarly the optimum process parameter for **Hardness** the overall optimum condition is obtained at N2, S1 and F2.

$$(BHN) = N2+S1+F2-2HV \text{ ----- Equation.}$$

The estimated mean of the response characteristics can be computed as Hardness,

Substituting the values of various terms in the above equation then,

$$\text{Hardness, (BHN)} = 80 + 78.0+79.6 - (2*77.93) = 82.34 \text{ MPa.} \quad [\text{Ref.9}]$$

III.C. GENETIC ALGORITHM

The GA was used to minimize the objective or fitness function. But it can also be used to maximize the fitness function $f(x)$ by minimizing $f(x)$ because the point at which the minimum of $f(x)$ occurred was the same as the point at which the maximum of $f(x)$ occurred. In this article, this technique was used to maximize the tensile strength, impact strength and hardness (UTS) functions. The optimization of process parameters is made using Genetic Algorithm. The optimization technique was performed using MATLAB. The inputs to be given in MATLAB are ranges of variables, no of iterations to be performed and objective function.

GAs are a particular class of evolutionary algorithms. The techniques common to all GAs are:

- Inheritance
- Mutation
- Selection
- Crossover (also called recombination)

REGRESSION EQUATIONS: A multi response regression equations were generated using MINITAB 17 Software for each set of experiments. These equations resemble the objective function used in GA optimization. Since to get the better tensile strength, impact strength and hardness value, the input parameters has to be maximized. Therefore these equations should be maximized to find optimum parameters. The equations are mentioned below.

For tensile strength:

$$fn=(0.02004*t+0.572*w+6.53*a+72.34); \quad [1]$$

For impact strength:

$$fn=(0.000592*t+0.0157*w-0.463*a+2.914); \quad [2]$$

For hardness:

$$fn=(0.00520*t+0.0444*w+4.71*a+63.29); \quad [3]$$

These three equations are maximized and the optimum values are obtained.

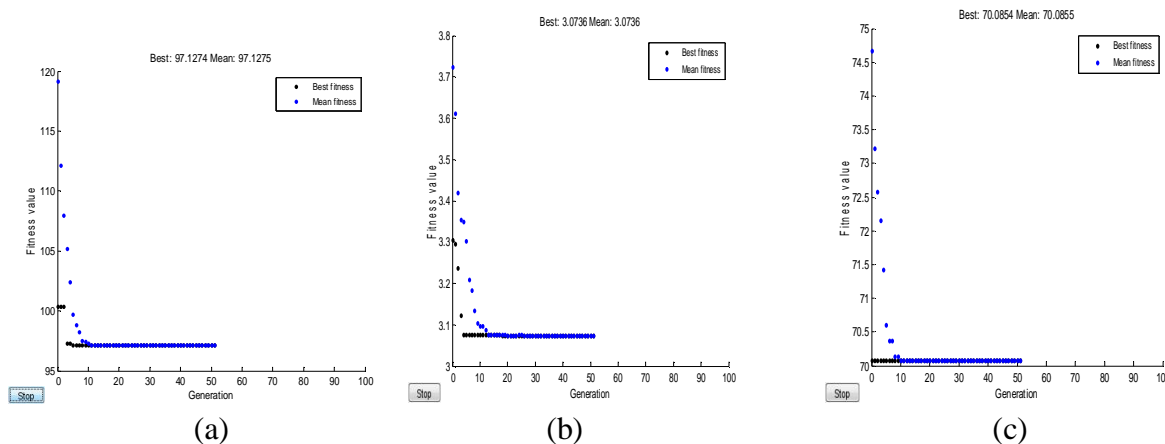


Fig.6. (a,b,c): Optimum Results of tensile strength, impact strength and hardness

Table7: Optimum Results

S. No	Tool Rotational Speed(N) in rpm	Welding Speed(S) in mm/min	Axial Force (F) in KN	Tensile Strength (TS) in MPa	Impact Strength (IS) in KN/mm ²	Hardness (HV)
1	760	11	0.50	97.124		
2	760	24	0.50		3.0736	
3	760	37	0.75			70.0854

III.D MICRO STRUCTURAL ANALYSIS

Samples of the weld metals are cut to the required sizes and polished using different grades of emery papers, final polishing is done using alumina paste in the disc polishing machine and the polished specimens are etched with the Keller's reagent: 150ml H₂O, 3ml HNO₃, 6ml HCL and HF. Microstructure analysis was carried out using a light optical Microscope (Make: NIKON-LV 150) incorporated with an image analysing software (MSQ). The microstructure of welded joints was evaluated by measuring size distribution in weld nugget (WN), thermo mechanically affected zone (TMAZ) and heat affected zone (HAZ). The results are given below. Figure.8 shows the microstructure of the welded joint for the following parameters

1. Tool rotational speed (N) rpm -1380
2. Welding speed (S) mm/min -24
3. Axial force (F) kn -0.75

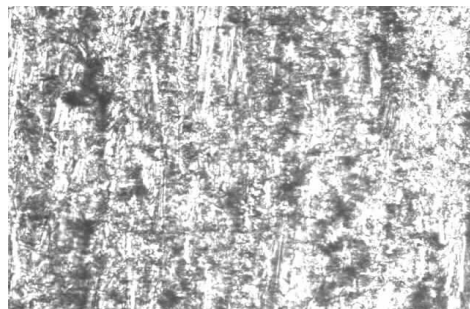
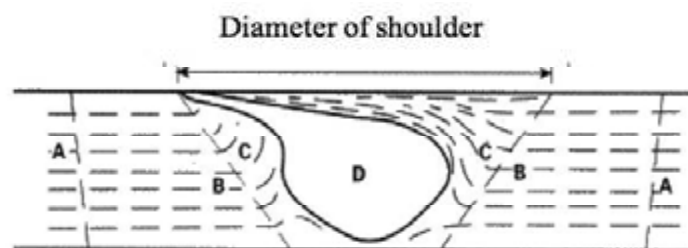


Fig.7 Optical Micro Structure using Tapered Pin Profile



In unaffected base metal zone [A], there is no change in neither property nor micro structure. This is the area which is far away from the weld zone unaffected by the heat or deformation. In heat affected zone [B], material is influenced by heat (thermal cycle) and leads to micro structural changes. Heat in this zone does not induce any plastic deformation. TMAZ [C] is a transition zone which is unique in FSW. During welding, this region experiences both temperature and deformation, which are not sufficient to induce the recrystallisation in the material. The portion where the actual stirring takes place which leads to micro structural changes and experienced the high strain is usually referred as Dynamically Recrystallized Zone (DXZ) or nugget zone [D]. The high temperature and severe plastic deformation during welding in the stirred zone results in a new equiaxed fine grain structure.

In Friction Stir Welding, the base metal is plastically stirred under the action of the rotating tool. Due to this severe plastic deformation, the coarse elongated grains are fragmented into fine, equiaxed grains. In most of the welded joints the weld nugget (WN) consists of fine equiaxed grains when compared with thermo mechanically affected zone (TMAZ) and heat affected zone (HAZ). It is observed all 15 Microstructures and their grain sizes, these grain sizes are based on their zone regions and various process parameters. The grain size is higher in Heat Affected Zone (HAZ), because this zone is closer to the weld centre, and no plastic deformation occurs in this area. The grain size will be

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smaller the TMAZ, because in this zone the tool material will be plastically deformed. The grain size will be lowest in Weld Nugget Zone. It is fully Recrystallized area. And the tool pin is fully occupied the zone.

IV. CONCLUSIONS

Weld joints of AA6061 and AA2014 obtained at tool rotation speed 2000rpm, welding speed 24mm/min, and axial force 1kn exhibits maximum **TENSILE STRENGTH** than the joints at other process parameters.

Weld joints of AA6061 and AA2014 obtained at tool rotation speed 2000rpm, welding speed 24mm/min, and axial force 1KN exhibits maximum **IMPACT STRENGTH** than the joints at other process parameters.

Weld joints of AA6061 and AA2014 obtained at tool rotation speed 1380rpm, welding speed 11mm/min, and axial force 0.75KN exhibits maximum **HARDNESS** than the joints at other process parameters.

From ANOVA results it can be concluded that the Tool Rotational Speed and Axial Welding Speed are the dominant parameters that have influence on the mechanical properties than the Welding Speed acting on the joints.

Genetic Algorithm has been made on single variable and multi response. The analysis shows that the response from algorithm is good and fast.. The tensile, impact strengths and hardness is good at the optimum values. In most of the joints the weld nugget (WN) consists of fine equiaxed grains when compared with thermo mechanically affected zone (TMAZ) and heat affected zone (HAZ).The structure at the nugget is fine and equiaxed with grain size significantly smaller than the parent material grain due to the higher temperature and extensive plastic deformation.

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