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Process Parameter Optimization of Friction Welding of Al 6061 with Flat-Convex Interface Geometry

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***Abstract*— Friction welding is a solid state welding technique in which the coalescence of materials occurs through plastic deformation at the welding location due to frictional heat generated during rubbing motion of workpieces with each other and forging pressure applied. Recent studies revealed that the characters of friction weld are influenced by the shape of interface geometry of mating parts. Present study investigates the influence of process parameters like speed of rotating specimen, interface geometry and forging pressure on the physical properties like ultimate tensile strength, hardness and mechanical property like modulus of rigidity of the welds formed. The comparison of friction welded specimens with flat-convex interface with that of flat-flat interface reveals that the weld characters are improved and so optimization of process parameters are also done using statistical tools like ANOVA table and grey relational analysis. The mean effect of speed of rotating specimen, forging pressure and the distance to the convex face on each response characters were also studied.**

Keywords*— *Friction Welding, Interface Geometry, Ultimate Tensile Strength, Hardness, Torsion

I. INTRODUCTION

Friction Welding (FW) is an eco-friendly, non-consumable welding technique which was discovered at 1940s. It is a solid state of welding process in which the coalescence of the material occurs due to the heat generated through mechanical friction between a moving workpiece and a stationary component.

In friction welding, the heat is generated directly at the weld, where the bond is to be developed.ie. the frictional heat is generated in the interface up to maximum joint heat where plastic deformation is reached rapidly. Then the rotation is stopped to let the welded joint cool down freely and the forging pressure is applied. Thus the Friction welding Parameters which affects in the production of sound welds are [6] :

- Speed of rotating specimen
- Effect of axial pressure
- Time taken for heat generation
- Mating surface condition of specimens
- Geometry of the specimen
- Material property of the specimen
- Upsetting pressure

Friction welding is a multi input welding process and the quality of the weld may depend upon different process parameters. Inorder to get the desired response characters the process parameters while welding should be at optimum level. The friction welding process can be completely automated by PLC and PC control. This enables monitoring, testing and recording of process parameters to guarantee quality. Here lies the importance of optimization of process parameters.

The conventional welding processes currently used in fabrication processes have the limitations which are associated-with low joining rates, requirement for skilled labour, use of expensive filler materials, and possible use of pre-heat, restrictions on welding position and metallurgical nature concerned with weld defects and joint properties. These limitations can be overcame by performing either friction welding or electron beam welding.

II. DESIGN OF EXPERIMENTS

A. *Selection of Friction Welded Parameters*

In friction welding process where metallic bonding is produced at temperatures lower than the melting point of the base metals. Friction time, friction pressure, forging time, forging pressure and rotation speed are the main parameters in the friction welding method [4]. In the present study, variables considered are:

1. Speed of rotating specimen (rpm)
2. Forging pressure (N/mm²)
3. Distance to the convex face (mm)

The process parameters workable range for the experiments was chosen in order to attain the weld quality including less heat affected zones with defect free root by the consumption of minimum energy as input. Therefore, three levels of the friction welding parameters were selected as shown in Table I.

TABLE I. FRICTION WELDING PARAMETER AND THEIR LEVELS

Process Parameters	**Levels**		
	1	***2***	***3***
Speed of rotating material (rpm)	1200	775	500
Forging pressure (N/mm²)	2	3	4
Radius of convex face (mm)	1	3	5

B. *Selection of Orthogonal Array*

The total degrees of freedom need to be computed, to select an appropriate orthogonal array for experiments. The degrees of freedom are defined as the number of comparisons between process parameters that need to be made to determine which level is better and specifically how much it is better than others.

Since the present study is of three-level process parameter counts for two degrees of freedom. The degrees of freedom for the orthogonal array should be greater than or at least equal to those for the process parameters [4]. In this study, an L9 orthogonal array was used ie. a total of nine experimental runs must be conducted, using the combination of levels for each control factor as indicated in Table II.

TABLE II. L9 ORTHOGONAL ARRAY

Experiment Number	**Levels**		
	A	***B***	***C***
01	1	1	1
02	1	2	2
03	1	3	3
04	2	1	2
05	2	2	3
06	2	3	1
07	3	1	3
08	3	2	1
09	3	3	2

The selected parameters are listed in Table I along with their applicable codes and values for use in the Taguchi parameter design study.

III. EXPERIMENTAL STUDIES

A. *Friction Welding Setup used*

Fig 1. Friction Welding Setup (1.Gear Mechanism 2.Rotating chuck 3.Piston Arrangement 4.Non-rotating Chuck 5.Hydraulic Hand Pump)

The setup used to conduct friction welding process is a medium duty lathe only. Three different speeds suited for the joining of aluminium rods can be set with the lathe used. Inorder to maintain constant loading during the process to develop frictional heat and to produce instant upset loading at the time of joining a hydraulic system is used. The range of load it can produce and measure from 1 to 20 KN. The frictional welding setup is shown in Figure 1.

B. *Material Used*

For the current study, 21mm diameter cylindrical rods are selected for conducting friction welding. Al6061 alloy are commonly not subjected to conventional welding processes where flux, filler materials and shield gas are used. Because they are having high hydrogen solubility, tends to form aluminium oxide and will get solidification shrinkage. Since friction welding can be performed with the absence of the above specified Al6061 can be easily welded [6]. These Aluminium alloys are of high strength and low weight so these materials are having significant application in automotive parts like suspension rods, steering columns, gear box forks and drive shafts and engine valves etc. are now manufacturing by friction welding process. This alloy is used in aerospace and marine applications because of its good weldability, stress corrosion resistance and mechanical properties over a wide range of temperature.

C. *Preparation of Specimens for Friction welding Process*

The type of interface geometry which was selected to conduct friction welding was flat-convex combination. Flat surfaces were created by conducting facing operation and convex surfaces needed were created by conducting ball turning operation. A medium duty lathe was used for conducting facing and ball turning. The profile of the workpieces, (one with flat face and other with convex face) which were used for the friction welding is shown in figure 2.

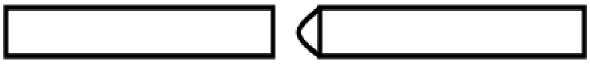

Fig 2. Type of Weld Interface Used

D. *Procedure for Friction Welding*

Material preparation was done by cutting Al 6061 rods to form specimens of required length using a medium duty lathe by conducting parting operation. Facing operation was done at the ends of all the specimens. Ball turning operation was done to obtain convex interface geometry.

Friction welding was done by fixing the specimen with flat surface as the rotating specimen and the specimen with convex surface as the non-rotating specimen. The rotating specimen was fitted to the headstock chuck and the non rotating specimen was fitted to the hydraulic loading unit. The regulation of speed was done by the gear system in the headstock.

The rotating specimen is rotated at a high rpm. Axial pressure is applied on the non-rotating specimen so that these two will come in contact will each other. Heat is generated due to the friction between rotating and non-rotating specimens and soon the materials will enter a plastic state. At this moment motion on the rotating specimen is stopped and a higher forging pressure is applied. Due to the combined effect of heat generated and pressure applied, solid state welds are formed. Table III shows the total number of welds obtained by friction welding for conducting different destruction tests like tension test, hardness test and torsion test, inorder to determine the characters of the friction welds.

TABLE III. TOTAL NUMBER OF WELDS OBTAINED USING FLAT-CONVEX INTERFACE GEOMETRY

Test	**No. of Specimens Prepared by Varying Speed of Rotation (rpm)**			**Total Welds**
	500	***775***	***1200***	
Tension Test	3	3	3	9
Hardness Test	3	3	3	9
Torsion Test	3	3	3	9
TOTAL				27

E. Specimen Preparation for Tension Test (ASTM D 8)

Cylindrical rods were cut into 15cm pieces for preparing convex surfaces and 45cm pieces for preparing flat surfaces so as to meet the requirement of the friction welding setup. Friction welding was conducted for flat-convex interface by varying the speed of rotation and the convex radius by maintaining the forging pressure between 2N/mm² and 4N/mm². The required specimen length for tensile testing was 30cm. Figure 3 shows the specimens on which the tensile test was conducted.

Fig 3. Friction Welded Specimens for Tensile Test

F. Specimen Preparation for Hardness Test (IS1500-2005)

Cylindrical rods were cut into 15cm pieces for preparing convex surfaces and 45cm pieces for preparing flat surfaces so as to meet the requirement of the friction welding setup. Friction welding was conducted for flat-convex interface by varying the speed of rotation and the convex radius by maintaining the forging pressure between 2N/mm² and 4N/mm². The required specimen length for hardness testing was 6cm. Figure 4 shows the specimens on which the hardness test was conducted.

Fig 4. Friction Welded Specimens for Hardness Test

G. Specimen Preparation for Torsion Test (IS 1500-2005)

Cylindrical rods were cut into 15cm pieces for preparing convex surfaces and 45cm pieces for preparing flat surfaces so as to meet the requirement of the friction welding setup. Friction welding was conducted for flat-convex interface by varying the speed of rotation and the convex radius by maintaining the forging pressure between 2N/mm² and 4N/mm². The required specimen length for torsion testing was 30cm. Figure 5 shows the specimens on which the torsion test was conducted.

Fig 5. Friction Welded Specimens for Torsion Test

IV. RESULTS AND DISCUSSIONS

A. Result of Mechanical Tests

The results obtained by conducting the tensile, hardness and torsion tests were compared with the results obtained in previous studies. Figures 6, 7 and 8 shows the graphical representation of comparison between the response characters of parent metal (PM) with the weld obtained by flat-flat (F-F) interface and flat-convex (F-C) interface.

It is observed that the characters of friction welds with flat-convex interface geometry is better than that of friction welds with flat-flat interface geometry. The ultimate tensile strength of the friction welds with flat-convex interface geometry is lesser than that of parent metal but greater than the welds formed with flat-flat interface geometry. The hardness and modulus of rigidity of flat-convex interfaced friction welds are higher than that of parent metal and weld with flat-flat interface geometry.

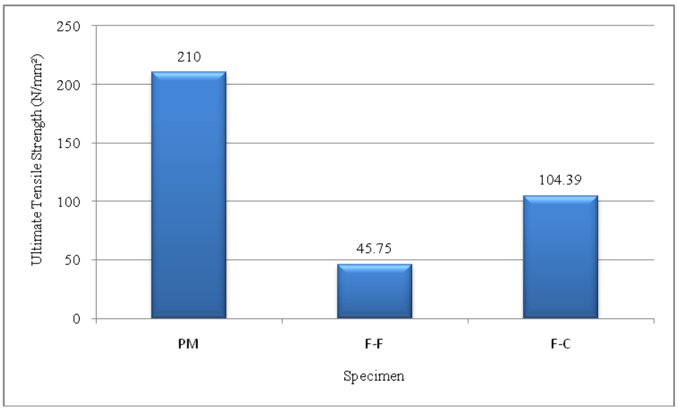

Fig 6. Comparison of Ultimate Tensile Strength

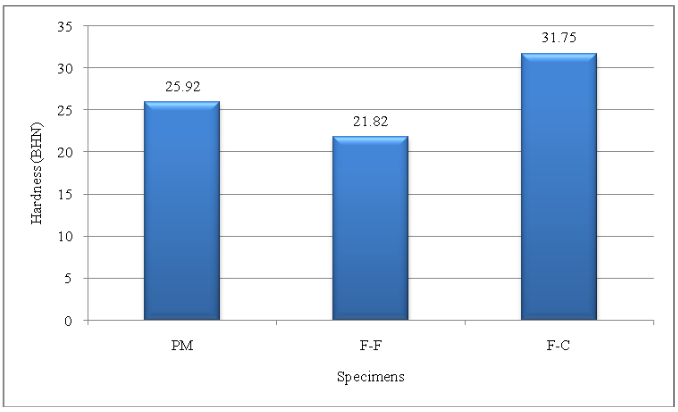

Fig 7. Comparison of Hardness

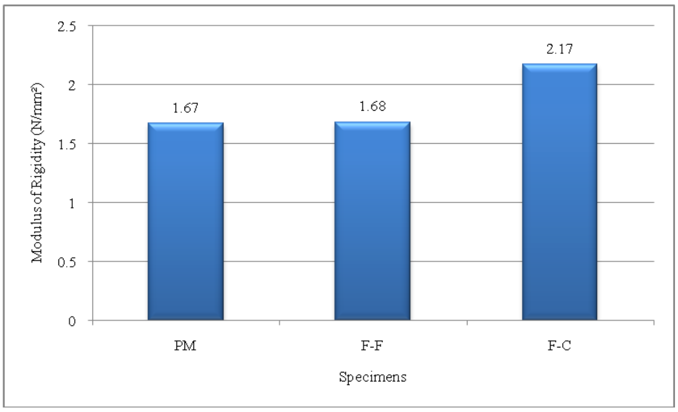

Fig 8. Comparison of Modulus of Rigidity

B. *Grey Relational Analysis*

In the grey relational analysis, experimental results (ultimate) tensile strength, hardness and modulus of rigidity) were first normalized and then the grey relational coefficient was calculated from the normalized experimental data to express the relationship between the desired and actual experimental data. Then, the grey relational grade was computed by averaging the grey relational coefficient corresponding to each response characters. The overall evaluation of the multiple process responses is based on the grey relational grade. For the multi response process grey relational grade can be treated as the overall evaluation of experimental data. The ranking of a factor is the level with the highest grey relational grade.

The grey relational coefficients for the response characters, φ can be calculated as:

$$\varphi_1(\mathrm{k}) = \frac{\Delta_{\mathrm{min}} + \delta\Delta_{\mathrm{max}}}{\Delta_{0\mathrm{i}}(\mathrm{k}) + \delta\Delta_{\mathrm{max}}}$$

where Δ_{oi} is the difference of absolute value between $x_0(k)$ and $x_i(k)$ (normalized values); δ is the distinguishing parameter; Δmin, smallest value of Δ_{0i}; and Δmax, largest value of Δ_{0i}. After averaging the grey relational coefficients, the grey relational grade γ_i be obtained as:

$$\gamma_i = \frac{1}{n}\Sigma\,\varphi_i\ (\mathrm{k})$$

where, γ_i is the Grey Relational Grade and n is the number of response factors.

C. *Analysis of Variance*

ANOVA is a statistical tool used to investigate which factors significantly affect the performance characteristic by separating the total variability of the grey relational grades, which is measured by the sum of the squared deviations from
the total mean of the grey relational grade. Information about how significant the effect of each controlled parameter is on the quality characteristic of weld can also be obtained by using ANOVA.

The mean effect of speed of rotation, forging pressure and radius of convex face on three levels are plotted in figures 9, 10 and 11 respectively.

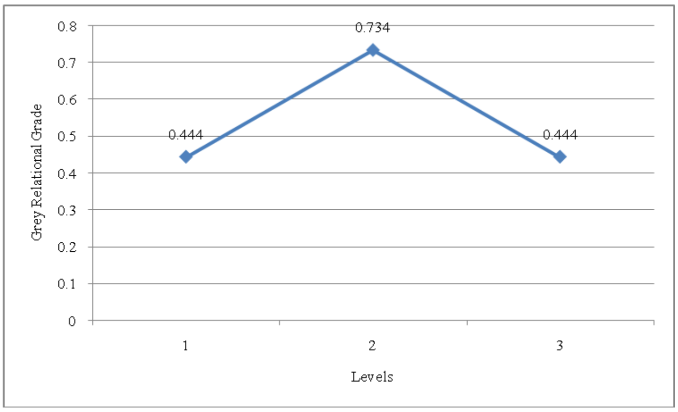

Fig 9. Mean Effect Plot for Speed of Rotation

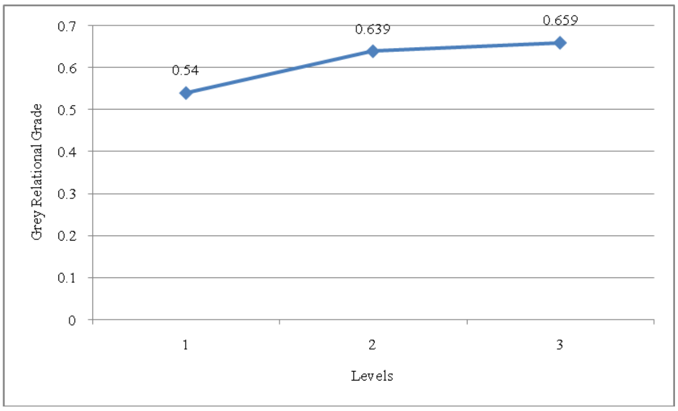

Fig 10. Mean Effect Plot for Pressure

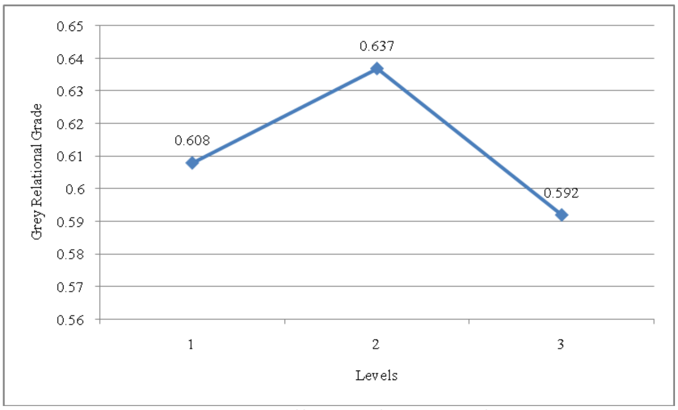

Fig 11. Mean Effect Plot for Radius of Convex Face

V. CONCLUSION

In this study response characters like ultimate tensile strength, hardness and modulus of rigidity of 27 welds were observed. Inorder to obtain a total of 27 welds surface preparations like facing and turning were done on 54 workpieces. Through frictional welding, being a solid state process, low distorted, defect free and high joint strength welds were obtained. By conducting destructive tests like tensile test, brinell hardness test and torsion test it is observed that the characters of the friction welds with flat-convex interface geometry are greater than that of with flat-flat interface geometry. In the case of ultimate tensile stress of weld with flat-convex interface geometry is lesser than that of the parent metal but greater than weld with flat-flat interface geometry. The hardness and modulus of rigidity of the weld with flat-convex interface geometry is greater than both parent metal and the weld with flat-flat interface geometry. By using grey relational analysis and ANOVA, it is also observed that the characters of the weld formed are not only influenced by the interface geometry but also the speed of rotation and forging pressure that is applied on the workpieces during friction welding . It is also found that the speed of rotation have greater influence on the properties of the weld formed.

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