Taguchi based Optimization of Process Parameters for Friction Stir Welding of AA7075 & C11000

Santosh N. Bodake[1] Prof. (Dr.) A. J. Gujar[2]
[1]PG Student [2]Professor
[1,2]Department of Mechanical Engineering
[1]Ashokrao Mane Group of Institutions, Vathar, Shivaji University, Kolhapur, India
[2]D. Y. Patil College of Engineering & Technology, Kolhapur, Shivaji University, Kolhapur, India

Abstract— AA 7075 is an aluminium alloy, with zinc as the main alloying constituent. It has high strength, with similar to many steels, have good fatigue strength and average machinability, but has less resistance to corrosion than many other Al alloys. AA7075 are frequently used in transport applications such as marine, aviation and automotive due to their high strength to density ratio. Strength and light weight also desirable in fields such as Rock climbing equipment, bicycle components and airframes are commonly made from 7075 aluminium alloy. AA 7075 has low weldability due to reduced solidification microstructure, and when welded by fusion welding techniques go down its mechanical properties. Friction stir welding (FSW) is solid state, reliable joining techniques to retain the properties of the alloy as there is no melting of metal takes place, welding takes place due to the forging effect. As process parameter affects a lot on strength of joint so it is important to optimize process parameters. Process parameters for friction stir welding are tool pin profile, tool rotary speed, welding speed, and welding axial force, tool tilt angle and Tool shoulder. From above process parameters of FSW tool rotary speed, welding speed, and welding axial force effects most on mechanical strength. Current work deals with experimental investigation of optimization of friction stir welding process (FSW) to arrive at desirable mechanical properties of aluminum 7075 and C11000 plates. Responses recorded are Ultimate tensile strength, and hardness of weld zone. After conducting experimentation testing is done to measure ultimate tensile strength and micro Vickers hardness. Results are analysed in Minitab 16 for optimizing process parameters.

Key words: Friction Stir Welding (FSW), Aluminium Alloy

I. Introduction

Friction stir welding (FSW) is a comparatively latest and promising solid state joining process developed and patented by The Welding Institute (TWI) Figure 1.1 shows the graphic drawing of FSW process. The work piece is positioned on a backup plate and clamped rigidly by a fixture to stop lateral movement during FSW. An especially designed tool with a pin extending from the shoulder is rotated with a speed of some hundreds rpm and gradually plunged into the joint line. The pin generally has a diameter one-third of the shoulder and typically has a length slight less than the thickness of the work piece. The pin is forced into the work piece at the joint until the shoulder contact the surface of the work piece (figure 1.1). As the tool descend further, its surface friction with work piece creates additional heat and plasticizes a cylindrical metal column around the inserted pin and the immediate material under the shoulder. The weld usually thins the parent metal by about 3-6 % of original thickness. The work piece to be joined and the tool are moved relative to each other such that the tool tracks along the weld interface. The rotating tool provides the 'stir' action, plasticizing metal within a thin zone while transport metal from the leading face of the pin to the trailing edges.

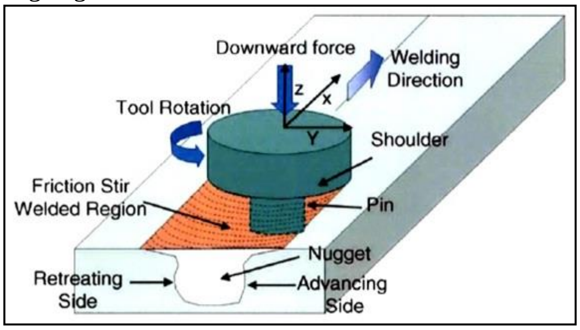


Fig. 1.1: Schematic Drawing of Friction Stir Welding

II. Objectives

a) To study the feasibility of joining aluminum to copper, i.e.C11000 to AA7075 by studying the mechanical properties.
b) Preparing experimental setup for friction stir welding for joining AA7075 and C11100.
c) To study the effect of friction stir welding process parameters on ultimate tensile strength of welded material.
d) Optimum process parameters for FSW of AA7075 and C11000 using Taguchi L18 orthogonal array design.

III. Literature review

Sadeesh P. et al. [1] used material i.e. 5mm thick plate of AA 2024-T4 (Al-Cu alloy) and AA 6061-T4 (Al-Mg-Si alloy). The plates were cut into rectangular shapes of 100 × 50 mm and the welding had been carried out. Tool used in his study was AISI H13 tool steel, which has high thermal fatigue resistance. The different shape pin profiles used in this work were cylindrical threaded pin, cylindrical pin, squared pin, tapered pin and stepped pin. The process parameters used were tool shape, rotational speed, traverse speed, tilting angle. AA2024 was placed on the advancing side due to its higher mechanical strength and the tool pin was positioned at center of joint line. Optical microscope, scanning electron microscope and energy dispersive spectroscope were used to study microstructure of welded joint. Samples were prepared according to the ASTM E8 standards for tensile test and the tests were carried out at a strain rate of 0.5mm/min. Micro hardness were carried out at a load of 100gf with dwell time of 10 seconds and distance of 0.25mm interval across the welded joint. It was found by studying literature that the rotational speed of 710 rpm, traverse speed of 28mm/min and D/d ratio of 3, for cylindrical pin, were most efficient.

Sahu and Pal [2] were carried out experiments by using Taguchi's L18 factorial design of experiment. Grey rational analysis was used for optimizing processes parameters. Percentage effect of individual process parameter on the weld quality was measured. They used AM20 Magnesium alloy to form square but joint. Tool used in his work was H13 tool steel with shoulder diameter 16-24 mm, and pin diameter 6 mm. Four process parameters were used namely, tool rotation speed, welding speed, shoulder diameter and plunge depth. After welding tensile test were conducted to find out ultimate tensile strength and yield strength. They found optimized process parameters were plunge depth at 0.12 mm, rotational speed at 1100 rev/min, welding speed at 98 mm/min and shoulder diameter at 24 mm.

Pankaj Neog et al.[3]were conducted welding on 6.35mm thick plate of AA7075-T6 alloy using friction stir welding technique. He used square butt joint in the experiments as it found better result. Welding process parameters were rotational speed, welding speed and axial load, output variable as tensile strength. There was a positive relationship between the load and tensile strength. If axial load increases tensile strength also increases.

E. Fereiduni et al. [4] used Al-5083 and steel alloy St-12 alloy sheets with the thicknesses of 3 and1 mm as a material for friction stir welding. To record the temperature variation at the joint interface during the process a hole with the diameter of 1.5 mm at a distance of 5 mm from the center of the well was drilled and K-type thermo couple used. The tool used for friction stir spot welding was made of heat treated H-13 tool steel and hardness of 52–54 RC. Rotational speeds of 900 and 1100 rpm were used with the dwell times of 5, 7, 10, 12 and 15 seconds to weld material. Then tensile and shear test are carried out on three specimens for each processing condition and the average values were recorded. Tensile tests were carried out on Instron tensile testing machine. The cross-section of the St-12 sheet was etched by the 2% nital etchant solution to observe the microstructure of the steel side. The grain structure of the Al sheet was studied near the exit hole. As dwell time increases joint strength increases up to certain limit and then start declining.

Joon-Tae Yoo et al. [5] tested mechanical properties and macro structure of friction stir welded joint using Radiography test for Al-Li alloy. Rotation speed and travel speed were selected as process parameters to compare the results. Tensile test was conducted to verify the strength and elongation of welded joint using defect free specimens. After welding, nondestructive tests by x-ray and macro observations of stir zone are conducted to verify the soundness of welding area. Tensile strength and elongation show different value according to process range. The maximum tensile strength was measured 73.4% of base material. Increasing travel speed cause irregular boundary shape in advancing side boundary little defect start formation between advancing side and stir zone. From 300mm/min, unstable boundary shape may be started. Increasing rotation speed also cause unstable boundary in advancing side. Defects were started when it doesn't have enough time for mixing the material in high travel speed zone.

Raza Moshwan et al. [6] used3 mm thick AA 5052-O aluminum alloy plates in his experiment. Specimens were welded using constant tool traverse speed of 120 mm/min and by changing rotating speeds from 800 to 3000 rpm. Then welded joints studied for its appearances, microstructural and mechanical properties. It was observed that joint produced at 1000 rpm gain a maximum tensile strength which was 74% of the base material strength. The stir zone produced finer grain compare to base material. The average micro hardness of the nugget zone was lower than the base material hardness. The heating and excessive deformation due to tool rotation during friction stir welding process resulted in diffusion of magnesium atom from the grain interiors to the grain boundaries to form more b-phase (Mg2Al3) particles.

Shaikh and Dabade[7] conducted experiments on Al 6061-T6 and Electrolytic tough pitch Copper ETPC11000,effect of friction stir welding process parameters, such as tool rotational speed, welding speed and axial load on tensile strength of friction stir welding were studied. Tool material was used with high wear resistance and toughness. Taguchi method was used for design of experiments and MINITAB software was used for result analysis. They found that, rotational speed of 675 rpm, welding speed of 40 mm/min and axial force of 1500 N produce higher tensile strength. But the use of combination of rotational speed of 510 rpm, welding speed 30 mm/min, axial force 1000 N produce lower tensile strength.

A. Summary of Chapter

For friction stir welding number of process parameters affects weld mechanical properties. Which are tool rotational speeds, welding speed, axial force, tool geometry and tool angle.

Rotational speed produces the frictional heat required to plasticize the material. The weld produces at low speed have good mechanical properties than the weld produces at higher speed. The mechanical properties increase with the rotational speed and welding speed but up to a certain level then they starts decreasing. There is a positive relationship between the axial load and tensile strength. If axial load increases tensile strength also increases. Also as dwell time increases joint strength increases up to certain limit and then start declining. Increasing rotation speed cause unstable boundary defect in advancing side. Aluminium and copper joint is brittle in nature, more downward force, higher welding speed and rotational speed produces strong joint. Performance of AA7075 and C11100 friction stir welding detailed experimentation and testing procedure is not yet carried out.

IV. EXPERIMENTAL SETUP & PROCESS PARAMETER SELECTION

The experiments were carried out on a Vertical Milling Machine (Pedersen VPU1) (Figure 4.1) has the following specifications:

Table size	:	600 x 1800 mm
Rotation speed	:	30to 675 RPM
Feed Rate	:	12 to 430 mm/min
Input Power supply	:	3 phase, AC 415 V, 50 Hz
Average power consumption	:	6 to 7 KVA

Table 3.1: Machine Specification

Fig. 3.1: Milling Dynamometer

A. FSW Tool

Tool material selected was OHNS EN31, FSW tool is Prepared With Keeping D/d ratio of 3, D is diameter of shoulder and d is diameter of tool pin, Shoulder diameter was 18mm and pin diameter was 6 mm Pin length kept were 4mm. External treads of M14 are produced to fit this tool in to tool holder. Also Slot is provided above the shoulder for setting Spanner. Threaded pin profile is used for getting better weld quality. Total length of FSW tool was 45mm. after machining of FSW tool that is hardened to 50-60 HRC to sustain load and wear during the welding process. Figure 3.2 shows FSW tool.

Fig. 3.2: FSW Tool

B. Work Piece Material

Chosen materials for FSW technique are AA7075 aluminium alloy and Electrolytic Tough Pitch Copper ETPC11000 used for joining two dissimilar materials by using friction stir welding technique. Samples were prepared of dimensions 100*43*4 as shown in table 3.2, Figure 3.3 shows Sample of specimen prepared for welding.

Sr. No	Material	Specifications
1	Sheet metal AA7075	100 mm (length) × 43 mm (width) × 4 mm (thick)
2	Sheet metal C11000	100 mm (length) × 43 mm (width) × 4 mm (thick)

Table 3.2: Samples sizes of Plates to weld

C. Welding Parameters

For FSW, two parameters are very important: tool rotation rate (rpm) in clockwise or counterclockwise direction and tool traverse speed (mm/min) along the line of joint. The rotation of tool results in stirring and mixing of material around the rotating pin and the translation of tool moves the stirred material from the front to the back of the pin and finishes welding process. Higher tool rotation rates generate higher temperature because of higher friction heating and result in or intense stirring and mixing of material. However, it should be noted that frictional coupling of tool surface with workpiece is going to govern the heating. So, a monotonic increase in heating with increasing tool rotation rate is not expected as the coefficient of friction at interface will change with increasing tool rotation rate. FSW Process Parameters and their levels are shown in table 3.3 below

Level	Tool Rotational Speed (RPM)	Welding Speed (mm/min)	Axial Load (N)
Level I	510	12	1000
Level II	675	16	1500
Level III	-	22	2000

Table 3.3: FSW Process Parameters & Their Levels

D. Tensile Testing of Specimen

Figure 3.3 shows drawing produced in Auto CAD for cutting tensile specimen according to standard of ASTM E8

Figure 3.3: ASTM E8 Standard Specimen

ASTM E8 describes tensile testing of metals such as steel or metal alloys. This test determines important mechanical properties such as yield strength, ultimate tensile strength, elongation, and reduction of area. E8 tensile tests determine the ductility and strength of various metals when the materials undergo uniaxial tensile stresses. Such information is important for alloy development, design, quality control, and comparison of different sets of metals. An electro-mechanical or hydraulic universal testing machine equipped with the appropriate specimen grips, an extensometer and software capable of strain rate control and recording stress – strain data is necessary to conduct this test.

Fig. 3.4: ASTM E8 Standard Cut Specimens

For checking tensile test first standard specimen should be prepared according to ASTM standard. The standard specimen prepared for tensile test is shown in figure 3.4

V. RESULTS & CONCLUSIONS

A. Analysis of Variance (ANOVA) for Tensile Strength

This method was developed by Professor R. A. fisher. ANOVA is an extremely useful technique which is used when multiple sample cases are involved. The basic principle of ANOVA is to test the means of the population by examining the amount of variation within each of this sample relative to the amount of relation between the samples. In terms of variation within the given population, it is assumed that the value of (y_{ij}) differ from the mean of this population only because of random effects that is there are influences on (y_{ij}) which are unexplainable, where as in examining difference between the mean of the j^{th} population and the grand mean is attributable to what is called air treatment effect. Thus it has to make to estimate of population variance, in other words, one based on between sample variance and the other based on within sample variance. Then these two instruments of population variance are compared with F-test.

This value of F ratio be compared to the F-limit for given degree of freedom. If the F value worked out is equal or exceed the F-limit table value, it may conclude that there are significant differences between the sample means.

ANOVA test is performed to find the significant factor statistically. The purpose of ANOVA is to find out the significant process parameters which affect the tensile strength of FSW butt joints. The ANOVA result for tensile strength is calculated and given in Table 6.2. S/N ratios calculated and tabulated in table 6.1. In this study, results of ANOVA show that the rotational speed and welding speed is highly significant factor and plays an important role to affecting the tensile strength of FSW butt joints. In this experiments rotational speed 675 rpm, welding speed 16 mm/min and axial force 1500 N produces higher tensile strength 170.04 N/mm^2.

Sr. No.	Rotational Speed (RPM)	Welding Speed	Axial Force (N)	Tensile Strength (N/mm2)	S/N Ratio	Hardness (HV)
1	510	12	1000	82.10	38.2869	164.00
2	510	12	1500	86.51	38.7413	162.79
3	510	12	2000	82.67	38.3470	149.42
4	510	16	1000	98.11	39.8343	167.64
5	510	16	1500	113.86	41.1274	157.01
6	510	16	2000	115.86	41.2787	159.14
7	510	22	1000	92.88	39.3584	145.17
8	510	22	1500	84.00	38.4856	163.39
9	510	22	2000	96.27	39.6698	152.76
10	675	12	1000	113.68	41.1137	165.82
11	675	12	1500	118.13	41.4472	150.94
12	675	12	2000	124.07	41.8733	169.47
13	675	16	1000	135.87	42.6625	159.14
14	675	16	1500	170.04	44.6110	160.66
15	675	16	2000	154.97	43.8050	146.99
16	675	22	1000	112.40	41.0153	164.00
17	675	22	1500	133.40	42.5031	154.28
18	675	22	2000	130.11	42.2862	168.25

Table 4.1: Process Parameters & Output Variables

B. ANOVA Calculations

Factor	Type	Levels	Values
Rotational speed	fixed	2	510, 675
Welding speed 22	fixed	3	12, 16,
Axial force 1500, 2000	fixed	3	1000,

– Analysis of Variance for Tensile Strength, using Adjusted SS for Tests

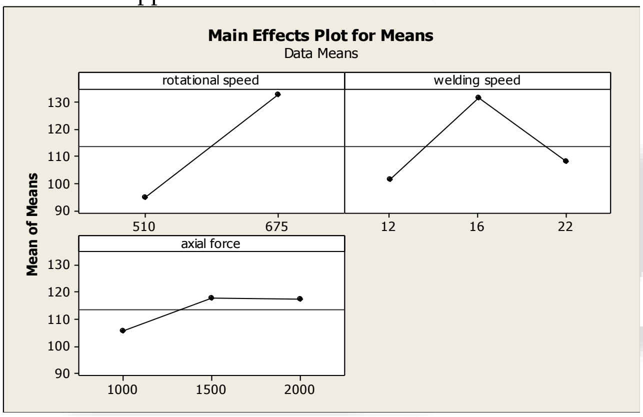
Source	DF	Seq SS	Adj SS	Adj MS	F	P	Contribution %
Rotational speed (RPM)	1	6437.7	6437.7	6437.7	105.87	0.000	60.04
Welding Speed (mm/min)	2	3012.1	3012.1	1506.1	24.77	0.000	28.09
Axial force (N)	2	543.3	543.3	271.6	4.47	0.035	05.07
Error	12	729.7	729.7	60.8			06.81
Total	17	10722.8					100
S = 7.79786 R-Sq = 93.20% R-Sq(adj) = 90.36%							

Table 4.2: ANOVA for Tensile Strength

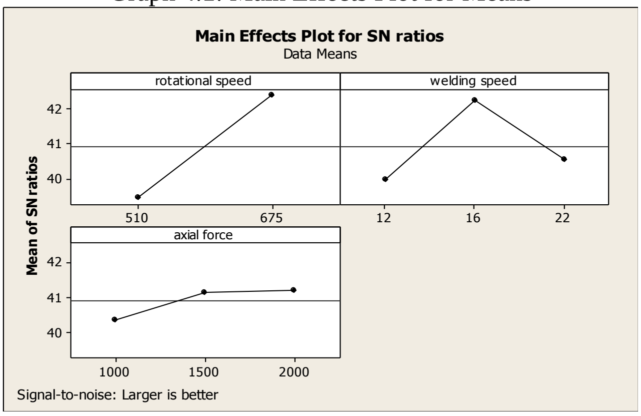
C. Main Effects Plot for Tensile Strength

Analyzing the in Graph 4.1, an increment in tensile strength was observed, when the rotational speed of tool and welding speed increased tensile strength start increasing up to certain limit and again start reducing with increase in welding speed. And as axial force increases tensile strength also start to increase but up to certain limit then it starts to reduce slowly. Higher strength values were obtained in conditions with high speeds, medium welding speed. Since they lead to sufficient welding temperature and weld width. The highest strength values in welded parts were reached in 675 rpm rotational speeds as shown in table 4.1. Ideal temperatures occurred in Al-Cu FSW at this rotation speed, so that a thinly dispersed and homogeneous mixture is obtained. The strength of intermetallic phase increases with the effect of heat during FSW.

The higher tensile strength of the AlCu weld joints mostly depends on the distribution of fine particles and the small intermetallic thickness formation and grain boundary strengthening in the nugget zone. Due to the stirring of the tool, the Cu particles were fragmented from the Cu side and distributed in the stir zone. These fine Copper particles were entirely transformed into hard brittle intermetallic due to the interfacial reaction with the Al matrix. The tensile tests as a whole shows that there is adequate temperature during FSW and so the homogeneous mixture conditions leading to an Al-Cu reaction are reached. As a result of tensile tests, ruptures usually occur in weld zone and heat affected zone (HAZ) in aluminum welds. The reason for the rupture occurrences in Al side are explained with factors is that the formation of the weld zone happened to be on the Al side.



Graph 4.1: Main Effects Plot for Means



Graph 4.2: Main Effects Plot for S/N ratios

VI. Conclusions

In this study, FSW Al–Cu joints were successfully achieved by friction stir welding of dissimilar metal by Butt joints. Analysis of tensile strength of friction stir welding of Cu-Al lap joints is performed and following conclusions are drawn.

1) The AA7075 aluminium alloy and Cu ETP-C11000 were successfully friction stir butt welded using a threaded cylindrically pin with Right handed threaded type M6 in diameter and 4mm of length at rotation speed of 675 rpm and 510 rpm, welding speed of 12, 16, 22 mm/min.
2) The butt joint produced by FSW at 675 rpm (tool rotation speed), 16 mm/min (welding speed), and 1500 N (axial force) produces higher tensile strength [170.04 N/mm2].
3) The ultimate tensile strength of FSW butt weld reaches to 54.85 % of the base metal ultimate tensile strength.
4) From Tensile test we can conclude as rotational speed increases weld strength also increases, as welding speed increases welding straight also get increases but up to certain limit then it start declining and as axial force increases welding straight also get increases but up to certain limit then it start declining in scope of experimentation.

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