Parameter Optimization on Friction Welding of Aluminium Alloy 6082T6 & Copper

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***Abstract*— Friction welding (FRW) is a solid-state welding process that generates heat through mechanical friction between a moving work piece and a stationary component, with the addition of a lateral force called "upset" to plastically displace and fuse the materials. FRW is widely used in the nuclear industry, reactor cooling systems, transport of cryogenic fluids, fluid piping and containment vessels because of the combination of fast joining time, and direct heat input at the weld interface, yields relatively small heat-affected zones and can be joined with less preparation. The joining of dissimilar materials is becoming increasingly important in industrial applications due to their numerous advantages. The present study investigates the mechanical and metallurgical properties of friction welded aluminium-copper bars, via continuous drive friction welding process, which combines the heat generated from friction between two surfaces and plastic deformation and a friction welder having been designed and built for this purpose. The effects of the three main parameters: Friction pressure, forging pressure and friction time. And the mechanical properties of the weld such as tensile strength, and the metallurgical properties of the weld are examined using SEM analysis and optical microscopy.**

***Index Terms*—About four key words or phrases in alphabetical order, separated by commas.**

I. INTRODUCTION

Friction welding (FRW) is a solid-state welding process that generates heat through mechanical friction between a moving work piece and a stationary component, with the addition of a lateral force called "upset" to plastically displace and fuse the materials. During Friction welding a number of solid state processes occurs using the frictional heat generated through the direct interaction between moving work pieces, with addition of a waging force to plastically diffuse material between the two work pieces. Many unalike material combinations can be joined and there are a number of operations in which this can be carried out. Friction welding of smaller parts can be carried out using center lathe with appropriate clamping and fixtures and machining settings but for bigger parts special machines have to be used.

Here in this study the friction welding of Aluminium Alloy6082T6 and Copper has been done. The problem in dissimilar welding is the formation of intermetallic compounds at the interface. The optimization of parameters for this welding is studied by Design of Experiments (DOE). The intermetallic compounds can be studied through Scanning Electron Microscopy (SEM).

II. METHODS AND MATERIALS

A. Design of Experiment:

Every experimenter has to plan and conduct experiments to obtain enough and relevant data so that he can infer the science behind the observed phenomenon. He can do so by, Design of experiments as well planned set of experiments, in which all parameters of interest are varied over a specified range, is a much better approach to obtain systematic data. Mathematically speaking, such a complete set of experiments ought to give desired results. Usually the number of experiments and resources (materials and time) required are prohibitively large. Often the experimenter decides to perform a subset of the complete set of experiments to save on time and money! However, it does not easily lend itself to understanding of science behind the phenomenon. The analysis is not very easy (though it may be easy for the mathematician/statistician) and thus effects of various parameters on the observed data are not readily apparent. In many cases, particularly those in which some optimization is required, the method does not point to the BEST settings of parameters. A classic example illustrating the drawback of design of experiments is found in the planning of a world cup event, say football. While all matches are well arranged with respect to the different teams and different venues on different dates and yet the planning does not care about the result of any match (win or lose)!!!! Obviously, such a strategy is not desirable for conducting scientific experiments (except for co-ordinating various institutions, committees, people, equipment, materials etc.).

TAGUCHI Method :

` Dr. Taguchi of Nippon Telephones and Telegraph Company, Japan has developed a method based on " ORTHOGONAL ARRAY " experiments which gives much reduced " variance " for the experiment with " optimum settings " of control parameters. Thus the marriage of

Design of Experiments with optimization of control parameters to obtain BEST results is achieved in the Taguchi Method. "Orthogonal Arrays" (OA) provide a set of well balanced (minimum) experiments and Dr. Taguchi's Signal-to-Noise ratios (S/N), which are log functions of desired output, serve as objective functions for optimization, help in data analysis and prediction of optimum results.

B. MATERIAL SELECTION

ALUMINIUM ALLOY:

6xxx series - Alloys in this group contain silicon and magnesium in approximate proportions to form magnesium silicone, thus making them heat-treatable. Though less strong than most of the 2xxx or 7xxx alloys, the magnesium-silicon alloys possess good formability and corrosion resistance, with medium strength. **T6 -**Solution heat treated and artificially aged.

Table1. Chemical Composition of AA6082T6

Chemical Element	% Weight
Manganese (Mn)	0.60
Iron (Fe)	0.30
Magnesium (Mg)	0.95
Silicon (Si)	1.15
Copper (Cu)	0.04
Zinc (Zn)	0.20
Titanium (Ti)	0.10
Chromium (Cr)	0.15
Aluminium (Al)	Remaining

Mechanical properties of AA6082T6

Table2. Mechanical properties of AA6082T6

Mechanical Property	Value
Tensile Strength	340 MPa
Hardness Vickers	95 HV

COPPER:

Table3. Properties of COPPER

Thermal conductivity	401 $W\cdot m^{-1}\cdot K^{-1}$
Electrical resistivity	$1.673X10^{-8}\Omega\cdot m$ (at 20 °C)
Young's modulus	115GPa
Shear modulus	48 GPa
Bulk modulus	140 GPa
Poisson ratio	0.34
Vickers hardness	353MPa

Table4. Composition of Copper

Composition	99.9% pure copper

Taguchi Design using MINITAB

Level : 3

Factors : 4 (Fr_p, Fo_p, Fr_t, Fo_t)

Factors selected for DOE : 3 (Fr_p, Fo_p, Fr_t)

Factors and level

Table5. Factors and level

	1	**2**	**3**
Frp MPa	34.6	43.3	52.0
Fop MPa	34.6	43.3	52.0
Frt s	50	53	54
Fot s	2	2	2

Taguchi Orthogonal Array Design

Table6. Taguchi Orthogonal Array Design

S.No.	A	B	C
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3

6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Welding Parameter:

Table7. Welding Parameter

S.No.	Fr_p MPa	Fo_p MPa	Fr_t s	Fo_t s
1	34.6	34.6	50	2
2	34.6	43.6	52	2
3	34.6	52.0	54	2
4	43.6	34.6	52	2
5	43.6	43.6	54	2
6	43.6	52.0	50	2
7	52.0	34.6	54	2
8	52.0	43.6	50	2
9	52.0	52.0	52	2

C. WELDING OF SAMPLES

The samples are welded as per the Taguchi's design of experiments parameters by the rotary friction welding machine.

Fig.1. Welded Samples

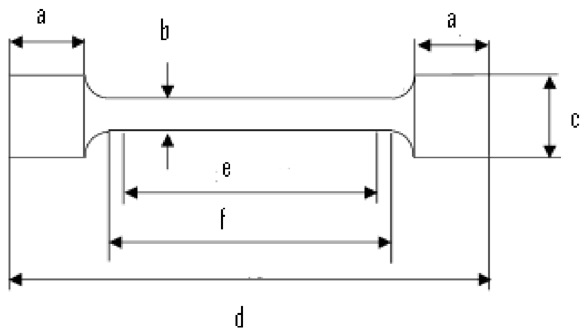
III. RESULTS AND DISCUSSION

TENSILE TEST

The following results were drawn after conducting the Mechanical testing and Microstructural evaluation.

Tensile Test Specimen preparation

Tensile Test Specimens are prepared as per standard - AWS B4.0:2007



a-50mm, **b**-9mmΦ, **c**-12mmΦ, **d**-150mm, **e**-35mm, **f**-45mm **R**-3mmDimensions are as per standard - **AWS B4.0:2007**

Fig.2. Dimensions for tensile test.

Fig.3. Tensile Test Specimens

The tensile Strength increases as the forging load increases and after a certain load it decreases. Also the same decreases as the friction load increases. The tensile test results are shown in table 4.1.

Taguchi Analysis:

Response Table for Signal to Noise Ratios

Signal to Noise Ratios obtained from the MINITAB software is shown in the table.4.2. Larger is better in the signal to noise ratio for the optimization of the parameters.

Response Table for Signal to Noise Ratios

Table8. Response Table for Signal to Noise Ratios

Level	Frp	Fop	Frt
1	47.09	43.65	47.21
2	45.20	47.02	45.25
3	45.13	46.75	44.96
Delta	1.95	3.37	2.26
Rank	3	1	2

Optimized Parameter:

Frp MPa	FoP MPa	FrT s	FoT s
43.6	43.6	50	2

MICRO STRUCTURE EVALUATION

The specimen cut across transverse to the welding direction has been polished in the subsequent emery papers such as 220, 0.347, 600, 800 emery sheet and followed by cloth polishing. After that the welded specimen was etched to reveal the micro structures.

Microstructure of the parent metals and the weld zone of the weld sample of optimized parameter are as shown in the figures.

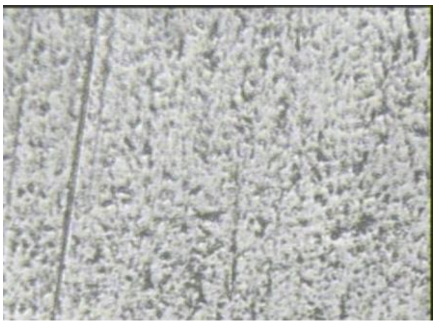


Fig.4. AA6082T6 (450X)

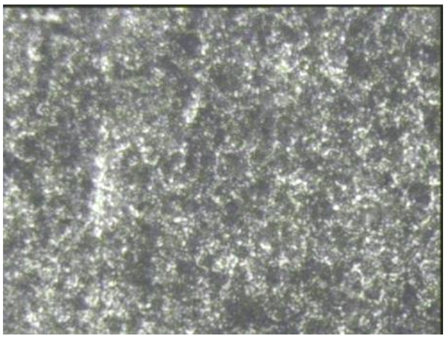


Fig.5. Copper (450X)

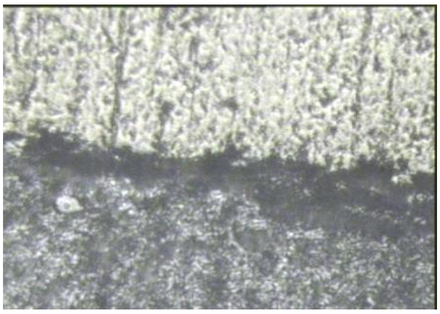


Fig.6. Weld Zone (450X)

MICROHARDNESS TEST

Micro hardness across the welded joint, have been carried out in polished and etched sections, as per the standard ASTM E 384 – 99. The hardness was carried out with Matsuzaur MMTX3 Micro hardness tester using 200gf with dwell time of 15s.

Micro hardness data across weldment of the optimized parameter

The micro hardness is tested on the optimized parameter weld sample and the readings are shown in the table10.

Table10. Micro hardness data across weldment of the optimized parameter

REGION	DISTANCE	HARDNESS VALUE HV
AA6082T6 Base metal	0.2	63.1
	0.4	63.1
	0.6	61.0
	0.8	65.4
Welded Zone	1.0	86.3
Copper Base Metal	1.2	79.2
	1.4	78.5
	1.6	82.4
	1.8	82.4

SEM ANALYSIS

The fracture surface is examined with electron microscope at a high magnification, it is found that the fracture obtained is brittle and some amount of Aluminium alloy surface is pealed of and stick on the Copper surface. Hence it is realized that some metal flow occurs from Aluminium alloy to the Copper during the time of friction welding. The following are the images obtained from SEM analysis. Here the fracture surface of Copper side is shown in figure 7 and figure 8.

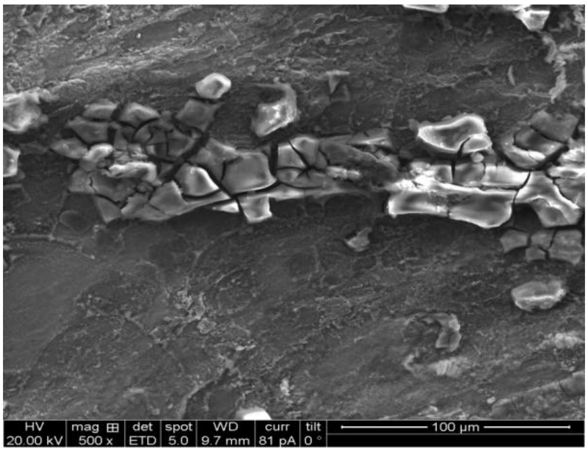


Fig.7. Fracture surface analysis of Tensile tested specimen 500X.

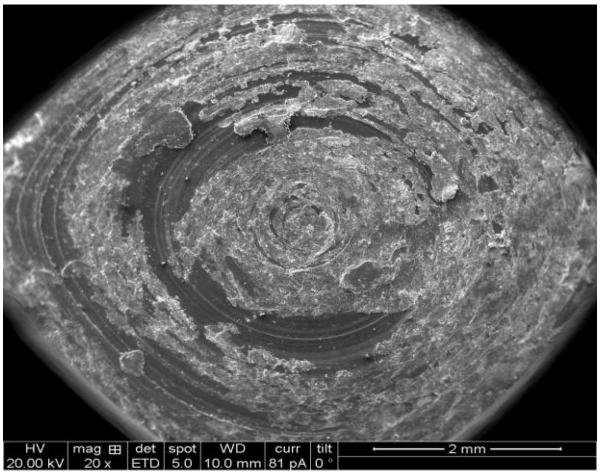


Fig.8. Fracture surface analysis of Tensile tested specimen at 20X

IV. CONCLUSION

1. Dissimilar welding of Aluminium alloy6082 and Copper can do effectively.
2. The optimized parameter is, Friction pressure, Fr_p- 43.6 MPa, Forging pressure, $Fo_{p\text{-}}$43.6 MPa, Friction time, $Fr_{t\text{-}}$50s and Forging time, $Fo_{t\text{-}}$2s
3. The Micro hardness of the optimized parameter at the weld zone and is 86.3 HV.
4. SEM images are also analyzed and found that the fracture is brittle and some metal flow occurred from AA6082T6 to Copper during the welding.

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