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Research Article

Experimental Investigation and Statistical Analysis of Friction Welding Parameters for Joining Dissimilar Materials, Al-63400 Alloy and Fe 410WA

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Abstract

Joining of dissimilar materials is of increasing interest for a wide range of industrial applications. There are various welding methods that have been developed to obtain stable joints in various applications. However friction welding is a solid state joining process used to join similar and dissimilar metals, not possible with other available welding methods. Friction welding method has been used extensively in the manufacturing methods because of the advantages such as high material saving, low production time, no filler material, environment friendliness, lower heat affected zone and good welded joints produced. In present study, joining of dissimilar metals Al- 63400 alloy and Fe 410WA is carried out using different parameters on continuous drive friction welding process. Encouraging results were obtained with dissimilar materials with minimum axial shortening and reasonably good tensile strength. The process parameters like rotational speed, friction pressure, upset pressure and upset time were varied and friction time kept constant. Taguchi's design for experiments is used for optimizing the welding parameters.

Keywords: *Axial shortening, Friction welding, Tensile strength, Taguchi design*

1. Introduction

Nowadays, welding between dissimilar materials is considerably gaining importance. Conventional structures made of steel have been replaced by lighter materials, capable of providing high mechanical strength, low volume of material and good corrosion resistance. It is difficult to weld Aluminum and Steel by fusion welding process because there is intermetallic phases involved at elevated temperatures such as Fe_3Al, FeAl, $FeAl_2$, Fe_2Al_5, $FeAl_3$. Friction welding process as defined is a solid state welding process which produces welds due to the compressive force contact of workpieces which are either rotating or moving relative to one another. Heat is produced due to the friction which displaces material plastically from the faying surfaces. Out of the two methods, direct drive friction welding and Inertia friction welding, in the present work direct drive friction welding process is used.

P. Shiva Shankar, (2013) carried out experimental investigation and statistical analysis of the friction welding parameters for the similar materials copper alloy CuZn 30 using Taguchi method for design of experiments. Optimization of parameters for tensile strength and upset (axial shortening) was done. He found that the optimal value of process variables for a higher tensile strength are 1500 r.p.m Speed, 5 sec friction time, 10 Bar friction pressure and 30 Bar forging pressure and the optimum values for less upset are 1400 r.p.m Speed, 4 sec friction time, 10 Bar friction pressure and 20 Bar forging pressure. Shubhavardhan R. N. *et.al*, (2012) studied friction welding of stainless steel and aluminium. Investigation suggested that the joint strength increased and then gradually decreased after reaching a maximum value with increasing upset pressure and upset time. Mumin Sahin, (2010) studied friction welding of different materials, stainless steel and Aluminum, stainless steel and Cu, Aluminum and Cu, found that due to existence of intermetallic phase, welding of nonferrous metals is difficult. Tensile strength for joints was considered as positive result compared with base materials. Sarala Upadhya *et.al*, (2007) observed microstructure and Mechanical Behavior of Rotary Friction Welded Titanium Alloys. They found that, rotational speed of 1500 rpm can produce a very good weld, while other parameters kept constant. P. Sathiya *et.al*. (2006) studied optimization of friction welding parameters using simulated annealing. The variation between theoretical and experimental values of flash features as flash width, flash height and flash thickness were analyzed with optimization algorithm called simulated annealing. M. Yılmaz *et.al*., (2003) investigated interface properties of aluminum and steel friction welded components. They found that tensile properties improve for steel-aluminium welds when the intermetallic thickness extends only to 0.2-1 µm, above this value welds with poor strength being produced. Bekir S. *et.al*., (1995) studied friction welding of Steel and Aluminum as well as Aluminum and Copper, investigation suggested that intermetallic layer thickens at the mid radius and becomes thin at the center and periphery of the weld. The tensile properties improve for a particular thickness of intermetallic layer. Further increase in the thickness of intermetallic layer reduces tensile properties.

In present study, friction welding of Al- 63400 and Fe 410WA was done by using continuous drive friction welding machine. The parameters used are rotational speed, friction time, friction pressure, upset time and upset pressure. The objective is to study and analyze the parameters considered using the Taguchi method to determine the optimum combination of the chosen parameters to minimize the axial shortening and maximize tensile strength.

2. Materials and Methods

The need of reduction in weight and increase in strength in many engineering applications increased the interest of fabrication of dissimilar metals. In the present study Aluminium alloy (Al63400) and Mild steel (Fe 410WA) were undertaken for study.

2.1. Materials

In present experiment, Aluminium alloy (Al-63400) and mild steel (Fe 410WA) were used. The chemical composition analysis of specimens was carried out for both the metals at M/S S. N. Metallurgical Services, Aurangabad (Maharashtra) India and results shown in table1 and table 2.

Table 1 Chemical composition of Al 63400 alloy (As per test results)

Chemical Analysis	Observations	Specified as per HE 9 grade
% Cu	0.030	0.10 max
% Si	0.48	0.30 – 0.70
% Fe	0.20	0.60 max
% Mn	0.07	0.30 max
% Mg	0.46	0.40 – 0.90
% Zn	0.16	0.20 max
% Al	98.50	----------

Remarks: The checked parameters of given sample conforms to HE-9 grade, which is equivalent to grade 63400 as per IS 733: 1983.

Table 2 Chemical composition of Mild Steel (As per test results)

Chemical Analysis	Observations	Specified as per HE 9 grade
% C	0.224	0.23 max
% Mn	0.62	1.50 max
% Cr	0.07	---------
% Ni	0.05	---------
% Mo	0.01	---------
% S	0.032	0.050 max
% Pl	0.029	0.050 max
% Si	0.15	0.40 max

Remarks: The checked parameters of given sample conforms to Fe 410 W A grade, as per IS :2062 : 1999, i.e. M.S. grade.

2.2. Specimen preparation

Both Aluminium (Al 63400) and Mild steel (Fe 410WA) specimens were machined to get smooth faying surface, of outer diameter 20mm and approximate length 100mm. Facing operation was done on all the specimens before friction welding, also Mild Steel specimens were cleaned with Acetone liquid solution and Aluminium specimens were cleaned with aluminium cleaner liquid, to avoid any impurities in the weld zone.

2.3. Parameters and Levels

From the literature review important, influencing parameters affecting the friction welding (FW) were identified. Trial experiments were conducted to determine the working range of the parameters. The feasible limits of the parameters were chosen in such a way that it is not affecting external defects. The important parameters influencing the tensile strength are shown in table 3.

Table 3 Friction welding parameters and their levels

Factor	Level-1	Level-2	Level-3
Rotational speed (rpm)	1300	1400	1500
Friction pressure (bar)	15	20	25
Upset pressure (bar)	32	40	48
Upset time (sec)	2.5	3.0	3.5

The other parameters of the process like friction time 0.5 sec, brake delay 0.3 sec, upset delay 0.1 sec and feed 85% are kept constant.

2.3. Method

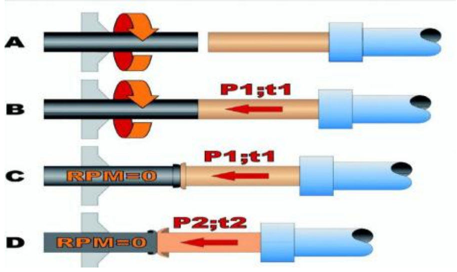

Fig.1 Stages of continuous drive friction welding process (A) Period of approximation; (B) P1, t1 application; (C) End of P1, t1 application, and braking of the machine (rpm= 0); (D) P2, t2 application and finish welding (Shubhavardhan R. N. *et.al*. 2012)

First one work piece is rotated and other is held stationary as shown in the Figure 1(A). When the appropriate rotational speed is reached, the two work pieces are brought together the axial force is applied, as shown in the Figure 1(B). Rubbing at the interface heats the work piece locally and upsetting starts, as shown in the Figure 1(C). Finally, the rotation of one of the work pieces stops and the upsetting is completed, as shown in the Figure 1(D). The weld produced is characterized by the narrow heat affected zone, the presence of plastically deformed material around the weld (flash), and the absence of fusion zone.

3. Experimentation

A continuous drive friction welding machine type FWT T-12, MTI USA make with a maximum load of 120 KN with cylinder area of 81 cm^2 by which the friction and forge pressure is applied with the help of support hydraulic arrangement, speed ranging 1000- 3000 rpm, pressure 10 – 50 bar. The hydraulic system is maintained by powerful servomotors driven by the hydraulic power pack. The speed of the friction welding machine is controlled by the magnetic brakes which more effective of all braking systems.

(a) Specimens before welding

(b)Specimens after welding

Fig.2 (a) Specimens before welding, (b) Specimens after welding

Axial length shortening (Upset)

The axial length of specimens is measured using digital Vernier Caliper before welding and after welding. The difference in lengths is called as axial shortening. From observation the shortening of axial length is observed in aluminium side only and there is no reduction in mild steel side.

After the weld the work pieces are machined so that the flash material is removed from the workpieces, then the standard test specimens are prepared for tensile test. It is observed that all the test specimens are broken at weld joint.

In this study L_9 orthogonal array is used as we have four parameters and three levels, accordingly nine experiments were conducted and every experiment was repeated for three times and average values are quoted in the table 4. Taguchi method stresses the importance of studying the response variation using the Signal-to-noise (S/N) ratio, resulting in minimization of quality characteristics variation due to uncontrollable parameters. Axial shortening and ultimate tensile strength are considered as quality characteristics. For minimum axial shortening Smaller the better system is applied (for making the system response as small as possible).

$$S/N = -10*\text{Log}\,(1/n*\Sigma\, Yi^2) \qquad (1)$$

For maximum tensile strength Larger the better system is applied (for making the system response as large as possible)

$$S/N = -10*\text{Log}[1/n*\Sigma(1/\, Yi^2)] \qquad (2)$$

Where, S/N = signal to noise ratio, Yi^2 = Variance of y, n = Number of observation.

Regardless of the category of performance characteristics, a greater S/N value corresponds to a better performance. Therefore, the optimal level of the friction welding parameters is the level with greatest S/N value. Based on the analysis of the S/N ratio, the optimal friction welding performance for the axial shortening and tensile strength are obtained.

In present study, Minitab 17, which is software for the Automatic Design and Analysis of Taguchi Experiments, was used to analyze the results and optimize the experiment conditions for setting the control variables.

3.1 Experimental Results

Table 4 Experimental Results table

RUN	Input Parameters				Response axial shortening (mm)			Mean (mm)	S/N Values
	RS rpm	FP Bar	UP Bar	UT Sec	1	2	3		
1	1300	15	**32**	2.5	7.1	7.4	7.9	**7.5**	**-17**
2	1300	20	40	3	8.9	9	9.3	9.06	-19.1
3	1300	25	**48**	3.5	10.4	10.5	10.5	**10**	-20.4
4	1400	15	40	3.5	7.1	8.8	9.3	8.4	-18.5
5	1400	20	48	2.5	10	10	10.9	10.3	-20.3
6	1400	25	32	3	7.6	7.7	8.2	7.83	-17.9
7	1500	15	48	3	9.2	9.8	9.9	9.63	-19.7
8	1500	20	32	3.5	7.5	7.7	8.1	7.76	-17.8
9	1500	25	**40**	2.5	7.8	9	9.5	**8.8**	-18.9

Table 5 Response Table for Means

Level	RS	FP	UP	UT
1	9.000	8.500	7.689	8.844
2	8.844	9.044	8.744	8.844
3	8.722	9.022	10.133	8.878
Delta	0.278	0.544	2.444	0.033
Rank	3	2	1	4

From Table 5, Response Table for Means suggests Delta values as highest for upset pressure has rank 1 then friction pressure has rank 2, rotational speed has rank 3 and upset time has rank 4, it means upset pressure is the most dominant factor followed by friction pressure, rotational speed and upset time, in getting smaller axial shortening.

Main effects Plot for Means

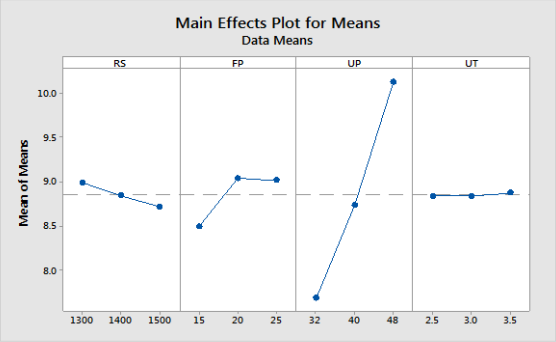

Fig.3. Figure showing effect of data means values for variables RS, FP, UP, UT for Axial shortening.

For axial shortening, when smaller is better condition that is for obtaining minimum loss of length, it is found that the optimum values of parameters are 1300 rpm rotational speed, 15 bar friction pressure and 32 bar upset (forging) pressure and 2.5 sec upset time for getting minimum axial shortening.

Table 6 Response Table for Signal to Noise Ratios Smaller is better for axial shortening.

Level	RS	FP	UP	UT
1	-19.01	-18.56	-17.72	-18.87
2	-18.90	-19.07	-18.86	-18.89
3	-18.79	-19.06	-20.11	-18.92
Delta	0.4	0.51	2.39	0.04
Rank	3	2	1	4

Main Effects Plot for SN ratios

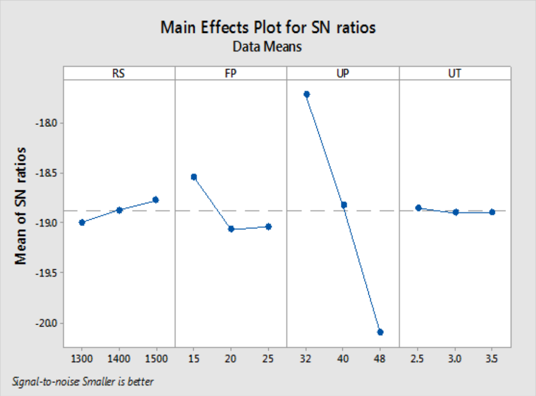

Fig.4 Figure showing effect of S/N values for variables RS, FP, UP, UT for Axial shortening

Table 8 Tensile Strength test results

Run	Breaking Load (N)	Tensile Strength (N/mm²)	Fractured at	S/N Values
1	48600	156.26	Weld	43.87
2	44000	141.47	Weld	43.01
3	54000	**173.62**	Weld	**44.79**
4	47000	149.60	Weld	43.49
5	40400	129.89	Weld	42.27
6	42000	135.01	Weld	42.61
7	40400	133.90	Weld	42.53
8	46000	146.42	Weld	43.31
9	46800	148.97	Weld	43.46

Table 9 Response Table for Signal to Noise Ratios (Larger is better) for tensile strength.

Level	Rotational Speed (rpm)	Friction Pressure (bar)	Upset Pressure (bar)	Upset Time (sec)
1	43.89	43.30	43.26	43.20
2	42.79	42.87	43.32	42.72
3	43.10	43.62	43.20	43.87
Delta	1.10	0.75	0.12	1.15
Rank	2	3	4	1

From table 9, Delta values as highest for upset time has rank 1 then rotational speed has rank 2, friction pressure has rank 3 and upset pressure has rank 4, it means upset time is the most dominant factor followed by rotational speed, friction pressure, and upset pressure, in getting for larger is better for tensile strength.

Main effects Plot for Means

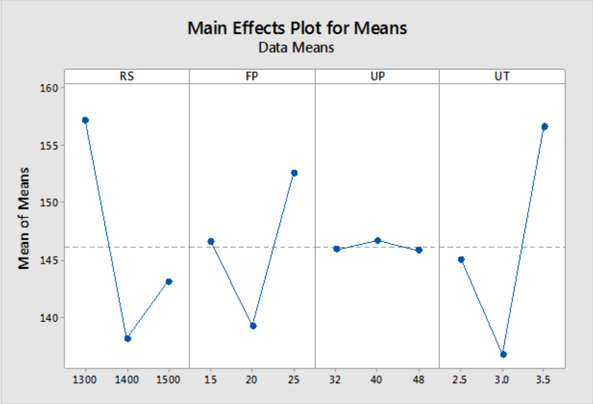

Fig.5. Figure showing effect of data means values for variables RS, FP, UP, UT for tensile strength.

For tensile strength, when larger is better condition that is for obtaining maximum tensile strength, it is found that optimum values of parameters are 1300 rpm rotational speed, 25 bar friction pressure, 48 bar upset pressure and 3.5 sec upset time for getting maximum tensile strength.

Main Effects Plot for SN ratios

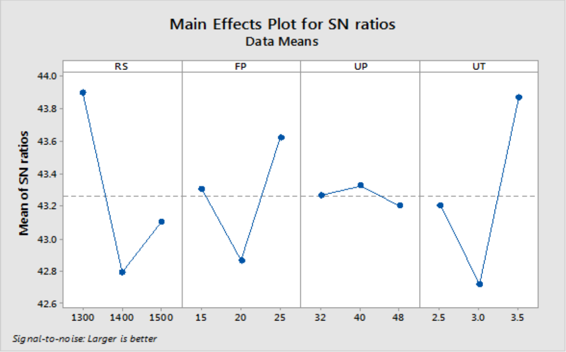

Fig.6 Figure showing effect of S/N values for variables RS, FP, UP, UT for tensile strength.

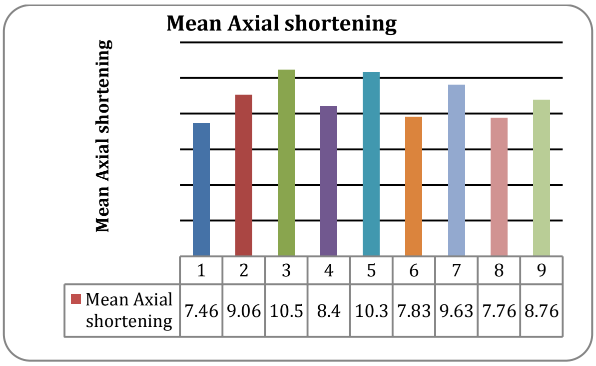

Fig.7 Figure showing graph of Axial shortening Vs Runs

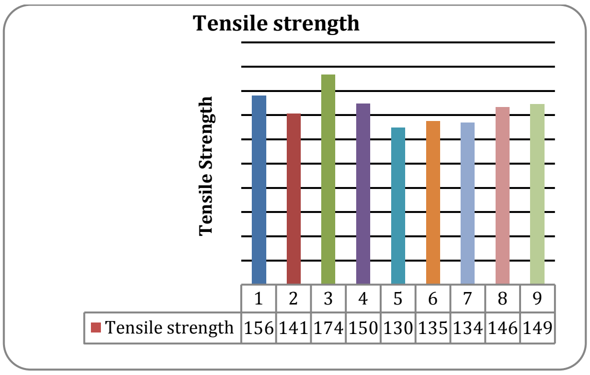

Fig.8 Figure showing graph of Tensile strength Vs Runs

Table 10 Orthogonal array and responses.

RUN	Input Parameters				Axial shortening Mean (mm)	Tensile Strength N/mm²
	RS rpm	FP Bar	UP Bar	UT Sec		
1	1300	15	**32**	2.5	**7.46**	156.26
2	1300	20	40	3.0	9.06	141.47
3	1300	25	**48**	3.5	**10.4**	**173.62**
4	1400	15	40	3.5	8.4	149.60
5	1400	20	48	2.5	**10.3**	**129.89**
6	1400	25	32	3.0	7.83	135.01
7	1500	15	48	3.0	9.63	133.90
8	1500	20	32	3.5	7.76	146.42
9	1500	25	**40**	2.5	**8.76**	148.97

Results and Discussion

From *table* 4 Run1 shows minimum loss of length 7.46 mm, where parameters are 1300 rpm rotational speed, 15 bar friction pressure, 32 bar upset pressure and 2.5 sec upset time, here S/N ratio value is maximum that confirms these are optimum values of the parameters. From table 5response table for means, delta value maximum for upset pressure, so upset pressure is most dominant factor. From figure 3, it is observed that as upset pressure increases axial shortening also increases. At Run1 upset pressure is minimum 32 bar so axial shortening is minimum that is 7.46 mm, but at Run 6 and Run 8 even upset pressure is minimum there is small increment in axial shortening due to change in other parameters. As upset pressure increases axial shortening also increases, at Run 3 upset pressure is maximum 48 bar and axial shortening is maximum that is 10.46 mm.

From table 8, tensile strength is maximum 173.62 N/mm^2 at Run 3 and optimum parameters are1300 rpm rotational speed, 25 bar friction pressure, 48 bar upset pressure and 3.5 sec upset time, here S/N ratio value is maximum that confirms these are optimum values of the parameters. From table 9, delta value maximum for upset time, so upset time is most dominant factor. From figure 5, main effect plot for means we can say that as upset time increases tensile strength decreases up to particular value of upset time and then again increases.

After seeing figure 7, figure 8 and table 10, one can clearly see at Run 1 the output axial shortening is minimum (7.46 mm) and tensile strength is also moderate (156.26 N/mm^2). At Run 3 the output axial shortening is maximum (10.4 mm) and tensile strength is maximum (173.62 N/mm^2). At Runs 2 and 9 axial shortening is moderate (9.06 mm and 8.76 mm respectively). However at Run 5 the output seems to have some noise so not considered.

From the above results it can be inferred that tensile strength of the joint is dependent on above parameters, but at the same time there are also other influencing factors affecting the tensile strength like temperature at the weld zone, intermetallic compounds formed at the interface, amount of friction at the interface and friction time etc.

Conclusions

1) It is observed that upset pressure is most important parameter for axial shortening, as upset pressure increases axial shortening also increases. For obtaining minimum axial shortening, it is found that the optimum values of parameters are 1300 rpm rotational speed, 15 bar friction pressure and 32 bar upset (forging) pressure and 2.5 sec upset time.

2) It is observed that upset time is most important parameter for tensile strength, as upset time increases tensile strength decreases up to particular value of upset time and then again increases. For obtaining maximum tensile strength, it is found that optimum values of parameters are 1300 rpm rotational speed,

25 bar friction pressure, 48 bar upset pressure and 3.5 sec upset time.

3) With the help of different mechanical tests, it was found that friction processed joint exhibited comparable strength with the base material.

4) It is observed that tensile strength is dependent on selected parameters, but at the same time there are also other influencing factors affecting the tensile strength like temperature at the weld zone, intermetallic compounds formed at the interface, amount of friction at the interface and friction time etc.

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