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ANALYSIS AND OPTIMIZATION OF FRICTION WELDING PARAMETERS FOR AA6061-AA2014 DISSIMILAR JOINTS

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Abstract

Friction welding is a solid state welding used owing to its properties such as low heat input, high production efficiency and environment friendliness. Materials which aredifficult towelded by fusion welding processes can be successfully done friction welding. In this work, an effort was made to predict the maximum tensile strength of friction welded AA 6061 and AA 2014 aluminium alloy dissimilar joints incorporating the process parameters such as rotational speed, friction pressure and forging pressures which have immense on the strength of joints. The friction welding process parameters were optimized to achieve maximum tensile strength of the joint. The maximum tensile strength of 210MPa for the joints fabricated under the welding conditions ofrotational speed 1508 rpm, friction pressure of 8.16 MPa/secand forging pressure of 6.79 MPa/sec using the optimization techniques.

Keywords: Welding; Aluminium, Optimization, ANOVA

Introduction

Friction welding (FW) is a solid-state joining method inwhich the frictional heat is produced by the relative movementoftwo components under friction force. Once heat isgenerated, the rubbing action is terminated and the pressure is usuallyincreased in the forging stage to consolidate the weld. Since FW is a solid state joining process, all defectsassociated with melting and solidification in a typical fusion weldare absent in a friction weld. During friction welding, the heat ishighly concentrated at the weld interface.Small parts take only a few seconds to weld.Someof the advantages of friction welding compared to other solid-state welding processes are: conventionally short welding time,suitability for welding rod/pipe geometries and welding dissimilar metal combinations. FW could not require: filler metal, flux, shielding gas, special tooling, clamping, atmosphere control or surface preparation.

Paventhanet.al [1] predicted the selection offavor conditions for the friction welding of AISI 1040 grade medium carbon steel andAISI 304 austenitic stainless steel.[2]The Mechanical properties of Friction-Weldingbetween AISI 304Land AISI 4340 Steel as a function of rotational Speed [3]. Ishibashiet.al [4] chosestainless steel and high speed steel as representativematerials with an appreciably tediousweldabilityand their frequent welding conditions were established. SahinMumim [5] analyzed the variations in hardness and microstructureat the interfaces of friction welded steeljoints. [6]Theeffect of friction time on the fully plastically deformedregion in the vicinity of the weld was investigated by Sathiyaet.al [7].Ananthapadmanabanet.al [8] statedthe effect of friction welding parameters on tensile propertiesof steel. Satyanarayanaet.al [9] joined austenitic-ferritic stainless steel (AISI 304 and AISI 430) using continuous drive friction welding and examined optimum parameters, microstructures-mechanicalproperty and fracture behaviors. Yilmazet.al [10] investigated the variations in hardness and microstructures inthe welding zone of friction welded dissimilar materials. Effect of friction pressure on the propertiesof hot-rolled iron-based super alloy was investigatedby AtesHakanet.al [11]. Meshram et al [12] investigated the influence of interaction time on microstructureand tensile properties of the frictionwelding of dissimilar metal combinations.Lakshminarayanan et al [13] made a Comparison of RSM with ANN in Predicting Tensile Strength of FSW of AA7039 Aluminum Alloy Joints.

From the literature review [1 to 13], it is noted that welding of dissimilar materials focuses on micro structuralcharacteristics, micro hardnessvariations, and phase formation at the interface and tensileproperties evaluation. All the above mentioned investigationswere carried out on trial and other basisto attain optimum welding conditions. No systematicstudy has been reported so far to optimize the frictionwelding parameters to obtain maximum tensilestrength in AA6061-AA2014. Hence, anattempt was made to optimize friction weldingprocess parameters to achieve the maximum tensilestrength of AA6061-AA2014aluminium dissimilar joints..

Experimental Work

The base materials, Aluminum alloy AA6061 and Aluminum alloy AA2014used in this investigation were cylindrical rods of 12.7 mm in diameter and 75 mm in length.Chemical composition and mechanical properties were analyzed to confirm the base metal properties. The chemical compositions of the base metals are presented in Table 1.Tensile specimens were prepared to obtain the base metal tensile properties as per the standards ASTM E8M-04. Tensile test was carried out in100 kN, electro-mechanical controlled universal testing machine.

Table 1: Chemical composition of base materials.

Metals	w(Al)%	w(Cu)%	w(Fe)%	w(Cr)%	w(Mn)%	w(Mg)%	w(Si)%	w(Ti)%	w(Zn)%
AA6061	97.60	0.260	0.183	0.168	0.058	0.970	0.419	0.018	0.017

AA2014	91.70	4.650	0.018	0.540	0.820	0.790	1.100	0.085	0.060

Table 2:Mechanical properties of base materials.

Materials	Yield strength(MPa)	Tensile strength(MPa)	Elongation(%)
AA6061	276	310	17
AA2014	414	483	13

Developing experimental matrix and fabrication of joints

From the literatures, the predominant factors which had greater influence on tensile strength of friction welded joints were identified. They were Rotational speed, friction pressure and forging pressure. Feasible limits of the parameters were chosen in such a way that the friction welded joints should be free from any visible external defects.The chosen welding parameters and the levels are presented in Table 3.

As the range of individual factor was wide, a central composite rotatable (CCD) 3-factor, 5-level central composite rotatable design matrix was selected. The experimental design matrix consists of 15 sets of coded condition. The upper and lower limits of the parameters were coded as +1 and -1 respectively.

Cylindrical rods of AA6061and AA2014having 12.7 mm diameter were cut to the required length of 75 mm by power hacksaw. The surfaces to be joined were faced using a lathe machine to fabricate friction welded joints. Hydraulically controlled continuousdrive friction welding machine (capacities of20 KN) was used to weld the joints.The friction welded joints were made according to the condition dictated by the design matrix in Table 4, atstandardorder. Figs.1-2shows the photograph of the base metals before and after welding.

Fig 1: Before welding (AA6061and AA2014)

Fig 2: After welding (AA6061and AA201)

Table 3: Feasible working range of friction welding parameters.

No.	Factor	Units	Levels				
			-2	-1	0	1	2
1	Rotational speed	Rpm	1200	1258	1400	1540	1600
2	Friction pressure	MPa/Sec	3	4	6.5	9	10
3	Forging pressure	MPa/Sec	3	4	6.5	9	10

Recording tensile strength response

Tensile specimens from each welding condition were fabricated according to the American Society for Testing of Materials (ASTM E8M-04) standards to evaluate the tensile strength of the joints. Tensile test was carried out in 100 kN, electro-mechanically controlled universal testing machine. The specimen was loaded at the rate of 1.5 kN/min according to the ASTM specifications. The tensile tested specimen value of each condition is presented in Table 4.

Table 4: Design matrix and experimental results.

Exp.No	Coded Values			Actual Values			
				Rotational Speed (rpm)	Forging Pressure (MPa)/sec	Friction Pressure (MPa)/sec	Tensile strength (MPa)
1	1	1	-1	1540	9	4	160
2	1	-1	1	1540	4	9	190
3	-1	1	1	1258	9	9	167
4	-1	-1	-1	1258	4	4	178
5	-2	0	0	1200	6.5	6.5	176
6	2	0	0	1600	6.5	6.5	198
7	0	-2	0	1400	3	6.5	182
8	0	2	0	1400	10	6.5	198
9	0	0	-2	1400	6.5	3	166
10	0	0	2	1400	6.5	10	183
11	0	0	0	1400	6.5	6.5	202
12	0	0	0	1400	6.5	6.5	198
13	0	0	0	1400	6.5	6.5	199
14	0	0	0	1400	6.5	6.5	202
15	0	0	0	1400	6.5	6.5	201

Developing an empirical relationships and ANOVA for response surface quadratic model

In the present investigation, RSM has been applied for developing the empiricalequation in theform of multiple regression equations for the quality characteristic of the friction welded AA6061-AA2014aluminium alloys. In applying the response surface methodology, the independent variable was viewed as a surface to which a mathematical model is fitted.

Representing the tensile strength of the joint by TS, the response is a function of rotational speed (N), forging pressure (D) and friction pressure (P), and it can be expressed as

TS =f (rotational speed, welding speed, axial force, shoulder diameter, pin diameter, tool material hardness)

TS =f (N, D, F)

The second order polynomial (regression) equation used to represent the response surface 'Y' is given by [**14**]:

$$Y = b_0 + \sum b_i x_i + \sum b_{ii} x_i^2 + \sum b_{ij} x_i x_j + e_r \qquad (2)$$

and for six factors, the selected polynomial could be expressed as

$$(TS)=b_0+b_1(N)+b_2(D)+b_3(F)+b_{11}(N^2)+b_{22}(D^2)+b_{33}(F^2)+b_{12}(ND)+b_{13}(NF)+b_{23}(DF) \qquad (3)$$

Tensile strength of FSW joint of AA7075 alloy,

TS=$\{372.9+7.8(N)+5.65(D)+6.01(F)+1.26(ND)+15.90(NF)+6.53(DF)-7.16(N^2)-5.67(D^2)-13.4(F^2)\}$MPa.

Analysis of variance (ANOVA) technique was used to check the adequacy of the developed empirical relationship. In this investigation, the desired level of confidence was considered to be 95%. The relation- ship may be considered to be adequate, provided that 1) the calculated value of the F ratio of the model developed should not exceed the standard tabulated value of F ratio) the calculated value of the R ratio of the developed relationship should exceed the standard tabulated value of R ratio for a desired level of confidence.The high correlation existing between the experimental value and the predicted values of the tensile strength is given in Fig.3

Table 5:Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob> F	
Model	2955.333333	9	328.3703704	91.21399	< 0.0001	Significant
A-Rotational Speed	242	1	242	67.22222	0.0004	
B-Forging Pressure	128	1	128	35.55556	0.0019	
C-Friction Pressure	144.5	1	144.5	40.13889	0.0014	
AB	3.177254838	1	3.177254838	0.882571	0.3906	
AC	506.0560242	1	506.0560242	140.5711	< 0.0001	
BC	85.23412703	1	85.23412703	23.67615	0.0046	
A^2	396.2142857	1	396.2142857	110.0595	0.0001	
B^2	247.7142857	1	247.7142857	68.80952	0.0004	
C^2	1388.625	1	1388.625	385.7292	< 0.0001	
Residual	18	5	3.6			
Lack of Fit	4.8	1	4.8	1.454545	0.2943	not significant
Pure Error	13.2	4	3.3			

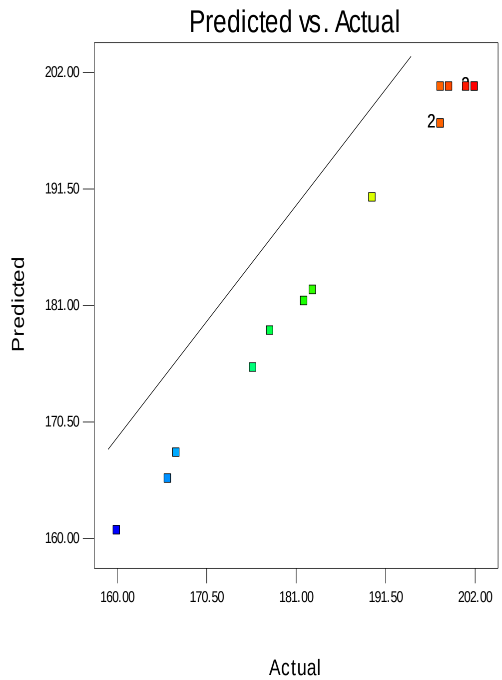

Fig.3:Experimental values Vspredicted values of the tensile strength of the FW joints.

Response surfaces have been developed for the models, considering two parameters in the middle level and plotting these in ‘X’ and ‘Y’ axes and response in ‘Z’ axis. The response surfaces clearly indicate the optimal response point. Contour plots play a very important role in the study of the response surface. By generating contour plots using software for response surface analysis, the optimum is located with reasonable accuracy by characterizing the shape of the surface.

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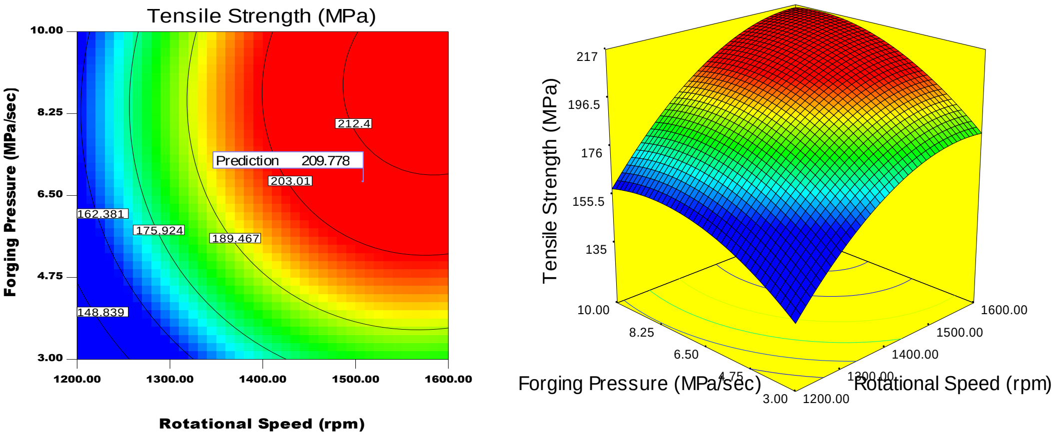

Fig. 4 Contour plot&response graph for tensile strength between rotational speed and forging pressure.

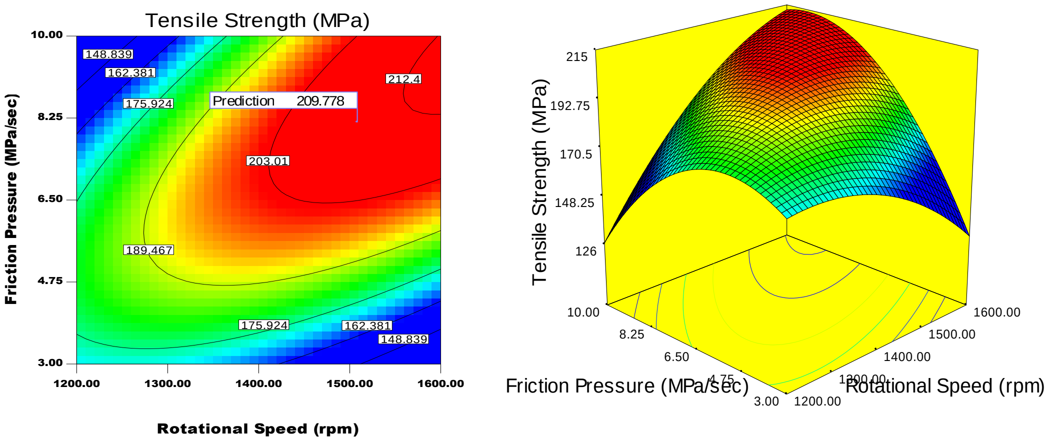

Fig. 5 Contour plot &response graph for tensile strength between rotational speed and friction pressure.

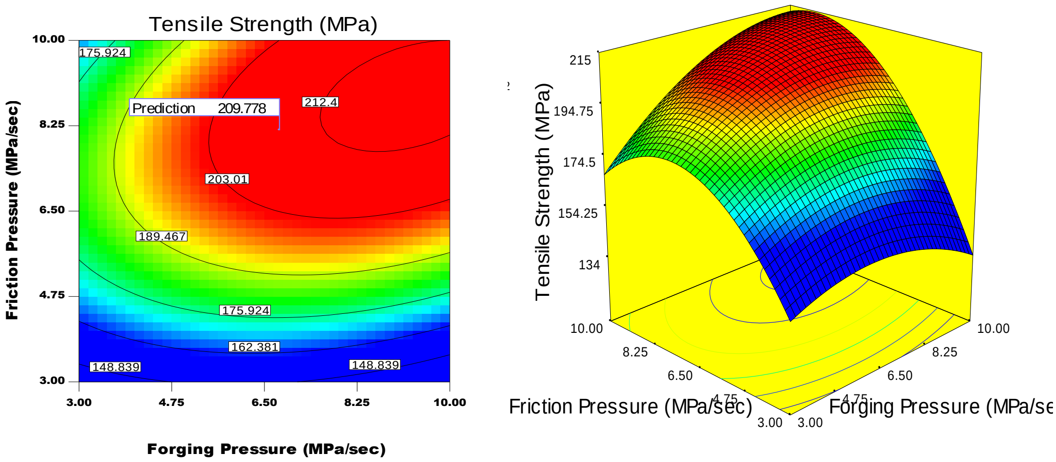

Fig.6 Contour plot &response graph for tensile strength between forging pressure and friction pressure.

By analyzing the response graphs and contour plots (Fig.4,Fig.5,and Fig.6), the maximum achievable tensile strength of the friction welded joints of AA6061 and AA2014 is found to be 210 MPa. The corresponding parameters that yielded the maximum tensile strength are: friction pressure of 8.16 MPa/s, forging pressure of 6.79 MPa/s and rotational speed of 1508 rpm.

Conclusions

The tensile strength of friction welded AA6061 and AA2014 was found by incorporating the parameters such as rotational speed, friction pressure and forging pressure.The predicted results can be listed as follows:

1) Empirical relationships were developed to predict the tensile strength of friction welded joints of AA6061 and AA2014 incorporating friction welding parameters.

2) The predicted tensile strength value from the design expert 8.0 software is compared with the experimental tensile strength in-order to find the influence of friction welding process parameters.

3) It is understood that the rotational speed of 1508 rpm and friction pressure of 8.16 MPa/sechas greater influence in tensile strength of welded joints. Similarly the forging pressure of 6.79 MPa/sec impacts the tensile strength.

4) A maximum tensile strength of 210MPa could be obtained under the welding conditions of rotational speed of 1508 rpm,friction pressure of 8.16 MPa/sec and forging pressure of 6.79 MPa/sec.

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