Experimental Evaluation and Analysis of Tensile Strength Behavior on Friction Welded AISI 4340 Steel Joints using Design of Experiments

M. Ganesan, P. Marimuthu

Abstract— **The quality of the welding is most significant for the engineering industries to satisfy the customer needs. Friction welding is the one of the solid state welding process for joining similar and dissimilar materials without the applications of filler rod. In this friction welding process, heat is generated at the interface of joining the specimen under plastic deformation by converting the rotational energy into heat energy. Recently AISI 4340 steel plays major role in the manufacturing, automobile, nuclear and marine industries. In this experimental investigation, KUKA continuous drive friction welding machine with constant rotating speed of 1500 rpm is used for joining the similar combination of AISI 4340 steel rods. The important friction welding parameters such as heating pressure, upset pressure and heating time were selected and studied at three different levels as per the recommendation of L_9 orthogonal array. The welded joint strength was estimated by using the computer controlled universal testing machine. In this research work an effort is attempted to evaluate the optimum level of tensile strength on Friction Welding of AISI 4340 steel joints using Design of Experiments concept. The experimental results shows that upset pressure plays important role in the friction welding process and the optimum level is recommended for further research.**

Index Terms— **Friction Welding, AISI 4340 steel, Welding parameters, Design of Experiments, Tensile Strength**

I. INTRODUCTION

Most of the manufacturing industries are preferred to develop the products by manufacturing processes like machining, casting, forging and welding. Friction welding is the one of the productive technique for joining the similar and dissimilar combination of materials. It is a compression welding process that produces a weld under compressive force contact workpieces rotating (or) moving relative to one another to produce heat and plastically displacement of the material from the faying surfaces. The major benefits of selecting friction welding processes are excellent weld quality, high dimensional accuracy, narrow heat affected zone, no need of filler material, minimum weld time and easily automated for mass production. The most significant parameters normally considered for the friction welding process are rotation speed, heating pressure, heating time, upset pressure, upset time, quality of the weld, strength and dimension of the test specimen. The bonding mechanism with dissimilar materials more complex than similar materials. The factors affecting the bonding mechanism are physical and mechanical properties, crystal structure and intermetallic compounds. The welding heat is generated during the friction stage and the weld is consolidated and cooled during the forging stage. The quality of the welding is depends on the proper selection of materials and welding variables. The main intention of this experimental investigation is to forecast the tensile strength of the friction welded joint on AISI 4340 steel.

Manuscript received Dec 17, 2015

M. Ganesan, Research Scholar, Department of Mechanical Engineering, PRIST University, Thanjavur, Tamilnadu, India

P. Marimuthu, Principal and Professor, Department of Mechanical Engineering, Syed Ammal Engineering College, Ramanathapuram, Tamilnadu, India

II. LITERATURE REVIEW

Friction welding is the environmental friendly joining process to reduce the raw materials cost and maintenance cost. It is high precision welding process can withstand high temperature variations at the joining interface of the faying surfaces. Normally variables considered for experimental investigations are heating pressure, heating time, upset pressure, upset time, rotation speed and geometry and chemical composition of the test specimen. The literature assessment on the solid state friction welding process is crucial to study the effect of parameters on the joining strength.

Sirajuddin Elyas Khany et al. (2015) presented an investigation of dissimilar materials joints of SS316 and EN-8 using friction welding process. The factorial design of experiments based on Taguchi analysis is conducted to attain the tensile strength measurements. The authors concluded that joint between the dissimilar materials combination like SS316 and EN-8 can be successfully carried out and the process parameters can be optimized. It is observed that forging pressure plays vital role in the joining of this combination of materials. Prasanna Vuppula et al. (2015) studied the weldability characteristics of friction welding using H30 aluminum with BS970 mild steel. The experimental setup was developed for conducting this investigation. They concluded that dissimilar joint of this combination of materials presented better tensile and hardness strength to analyze the resistance of the weld. Elkhawad Ali Elfaki et al. (2015) carried out the friction welding of dissimilar joints on High Speed Steel to Medium Carbon Steel. The authors had selected the input parameters like rotational, friction time and friction pressure. The authors concluded that friction time plays major role on the strength of the friction welded joint. Divagar S R et al.

(2015) surveyed about the friction welding process for joining the different materials combinations like aluminum, copper and stainless steel. The authors observed and reported that friction welding of steel provides good tensile strength and good weldability, high carbon steel present additional hardened than other materials. Vishnu P S et al. (2014) studied the high quality of weld produced in the medium carbon steel (AISI 1035) by using continuous drive friction welding process. The input process parameters considered for this investigation are friction force, upset force and rotational speed. The authors concluded that rotation speed plays major role in the joining of similar combination of materials AISI 1035 and optimization is carried out by Response Surface Methodology and Genetic Algorithm. Jagroop Singh et al. (2014) developed the facility for conducting the friction welding process on the centre lathe. The effect of joining the MS round metal pipe was investigated and determined the fatigue properties of the friction welded joint. Samuthiram et al. (2014) presented friction welding joints on EN-24 steel cylindrical rods by using the different process parameters like friction pressure, upset pressure and friction time. In this experimental work, friction pressure plays major role in the axial shortening, hardness and tensile strength. Amit Handa et al. (2014) studied the weldments among the austenitic stainless steel AISI 304 with low alloy steel AISI 1021 and optimizing the friction welding parameters to launch the weld quality. The authors developed the latest investigational model for conducting the experiments to optimize the tensile strength, fracture behavior; impact strength and micro hardness are evaluated. Dalip Kumar et al. (2013) investigated the microstructure and mechanical properties of mild steel and copper friction welded joint. They projected the innovative experimental set up for conducting the friction welding process. Based on the experimental investigation, hardness, tensile strength and microstructure were analyzed. The authors concluded that microstructure demonstrated the diffusion of copper into mild steel. Camilo Fernando et al. (2011) presented the experimental investigation on friction weldability of copper and steel dissimilar materials combinations. The input process parameters considered for this work is friction pressure, upset pressure, burn-off length and rotation speed. The maximum tensile strength of 270 MPa was obtained in this research work. SEM test was carried out on the optimum level of input parameters selected for this investigation.

Many researchers can carry out the trial and error based experimental analysis for conducting the investigation. Based on the literature review, it is found that friction welding process is one of the most excellent techniques for joining similar and dissimilar combination of materials and this process provides enhanced joining strength and reduces the welding cost as well as welding time. The significant objective of the present investigation is to join the similar material combination of AISI 4340 steel rods using design of experiments concept and found that process parameters plays vital role in the strength and quality of the welded joint.

III. EXPERIMENTAL WORK

Normally welding is the important terms used to join the similar or dissimilar materials with or without application of filler rod of any desired geometry. Friction Welding is one of the hot pressure welding techniques, in which the heat required for welding operations is generated through the relative motion of the two components by the application of pressure on the mating surfaces. The welding process is performed on the KUKA continuous drive friction welding machine with the maximum forging force of 300 KN and it is shown in Figure 1. In this research work, AISI 4340 steel rods have been selected and the test specimen was prepared from the raw materials having the dimensions of 100 mm length and 16 mm diameter after facing operations conducted on the Computer Numerical Control turning centre. Before conducting the friction welding process, the faying surfaces of the test specimen was cleaned with acetone solution for improving the quality of the joining strength. The chemical composition of the test sample is presented in the Table 1. Based on the customer requirements and machine specifications, the important friction welding process parameters influencing the tensile strength are heating pressure, heating time and upset pressure to develop the good quality of the welded joint is presented in the Table 2. The selection of input parameters plays crucial role for attaining the better effectiveness and superior mechanical strength of the friction welded joint. In this experimental investigation, rotating speed of 1500 rpm is kept constant for achieving the greater welding strength. Figure 2 shows the friction welded AISI 4340 steel joints for this experimental work. All the experiments were conducted based on the L_9 orthogonal array recommended by the design of experiments and it is given in Table 3.

Figure 1 Friction Welding Machine

Table 1 Chemical composition of AISI 4340 Steel

Element	Carbon	Sulphur	Manganese	Chromium	Silicon
%	0.02	0.02	1.8	19	0.68

Table 2: Friction Welding Process Parameters

Symbol	Input Parameters	Units	Levels		
			1	2	3
H P	Heating Pressure	Bar	12	19	25
U P	Upset Pressure	Bar	22	29	35
H T	Heating Time	Sec	3	5	7

Figure 2 Friction Welded AISI 4340 Steel Joints

Table 3: Design of Experiments for L_9 Orthogonal Array

Experiment Number	Input Parameters		
	H P	U P	H T
1	12	22	3
2	12	29	5
3	12	35	7
4	19	22	5
5	19	29	7
6	19	35	3
7	25	22	7
8	25	29	3
9	25	35	5

IV. RESULTS AND DISCUSSION

Friction welding can be used to join a wide range of similar and dissimilar materials, including metals, ceramics, plastics and metal matrix composites. The important process parameters for this friction welding process are heating pressure, upset pressure and heating time. The KUKA continuous drive friction welding machine with constant rotation speed of 1500 rpm is used for this experimental investigation. Based on the Taguchi Design of Experiments, 9 experiments were conducted on the AISI 4340 steel rods to predict the optimum level of input parameters with the output response of tensile strength using Minitab software version 16 is presented in the Table 4.

Table 4 Experimental Results

Experimental Run	Input Parameters			Results	
	HP	UP	HT	Tensile Strength	S/N Ratio
	Bar	Bar	Sec	N/mm^2	
1	12	22	3	118	41.4376
2	12	29	5	124	41.8684
3	12	35	7	138	42.7976
4	19	22	5	140	42.9226
5	19	29	7	154	43.7504
6	19	35	3	148	43.4052
7	25	22	7	140	42.9226
8	25	29	3	142	43.0458
9	25	35	5	147	43.3463

A. Response Table for S/N Ratio

The significant intention of this experimental investigation is to study the effect of input friction welding parameters on the tensile strength and hence 'Larger is Better' condition is selected. Based on the experimental work, the response table for the S/N ratio is presented in Table 5.

Table 5 Response Table for S/N Ratio

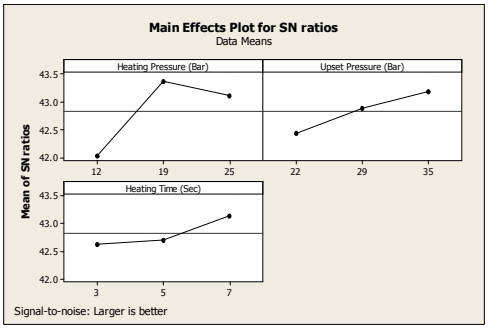
Level	Heating Pressure	Upset Pressure	Heating Time
1	42.03	42.43	42.63
2	43.36	42.89	42.71
3	43.10	43.18	43.16
Delta	1.32	0.76	0.53
Rank	**1**	**2**	**3**

The delta value is calculated from the highest average minus lowest average of each factor. The response table specifies the rank based on the delta values which evaluate the relative magnitude of the each effect. Based on the response table verified that heating pressure plays crucial role on the tensile strength, upset pressure is the next peak value followed by heating time.

B. Main Effect Plot

The most important result of input friction welding process parameters on the tensile strength of friction welded AISI 4340 steel is shown in Figure 3. The main effect plot represented that the optimal level of input process parameters for this experimental investigation. From this Figure 3, it is renowned that the effect of input process parameters increases with increase in the level selected for this research work. The optimal level of friction welding parameters for this investigation is 19 bar of heating pressure, 35 bar of upset pressure and 7 sec of heating time with constant rotation speed of 1500 rpm.

Figure 3 Main effect plot for S/N ratio

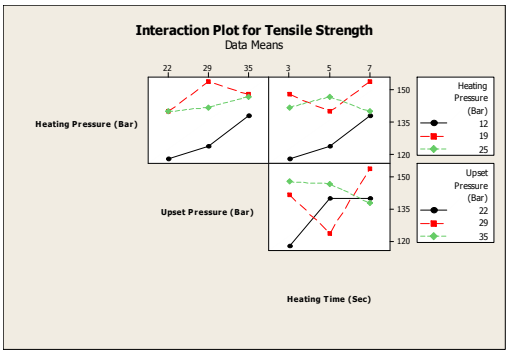


C. Interaction Plot

The interaction plot demonstrated the interaction between all the levels and parameters for effective optimization. The tensile strength for every experimental run is investigated by

using the interaction plot is shown in Figure 4. It is distinguished that the lines in the interaction plot are not parallel to each other for all level of input factors. Based on the interaction plot, it is concluded that maximum tensile strength for the friction welded AISI 4340 steel joints are heating pressure is 19 bar, upset pressure is 35 bar and heating time is 7 sec.

Figure 4 Interaction Plot for Tensile Strength



D. ANOVA

In this investigation, ANOVA is the statistical method used to compute the size of the difference between data set. The influences of welding parameters on the input process parameters are identified with the aid of analysis of variance table is presented in Table 6. Based on the ANOVA table, it is observed that heating pressure plays crucial role for affecting the tensile strength of the friction welded AISI 4340 steel rods. The confidence level is selected for this investigation is 95%.

Table 6 Analysis of Variance for Tensile Strength

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Heating Pressure (Bar)	2	712.67	712.67	356.33	56.26	0.017
Upset Pressure (Bar)	2	208.67	208.67	104.33	16.47	0.057
Heating Time (Sec)	2	114.00	114.00	57.00	9.00	0.100
Error	2	12.67	12.67	6.33		
Total	8	1048.00				

S = 2.51661 R-Sq = 98.79% R-Sq(adj) = 95.17%

CONCLUSION

The KUKA continuous drive friction welding machine is used for conducting the experimental investigation based on the Design of Experiment concepts to predict the optimal tensile strength of the AISI 4340 steel joints. The computer based tensile testing machine is used to evaluate the quality of the welded specimen. The authors reported the following significant conclusion based on the experimental results and analysis.

- Heating pressure plays significant role in the friction welded joint.
- The effective optimal parameters for this experimental investigation are heating pressure is 19 bar, upset pressure is 35 bar and heating time is 7 sec.
- Taguchi Design of Experiment is used efficiently in the optimization of friction welding process.
- Joining of AISI 4340 steel presented enhanced mechanical properties.

Based on the experimental investigation, it is found that the joining strength is superior at 'Larger is Better' condition. This study is precious for the researchers to develop the ability of the friction welded joint for AISI 4340 steel.

REFERENCES

[1] Sirajuddin Elyas Khany, S.N.Mehdi, G.M.Sayeed Ahmed (2015), "An Analytical Study of Dissimilar Materials Joint Using Friction Welding and It's Application", International Journal of Scientific and Research Publications, Volume 5, Issue 2, pp. 1-4.

[2] Prasanna Vuppula (2015), "Weldability of Friction Welding using H30 Aluminum with BS970 Mild Steel", International Journal of Engineering Research-Online, Volume 3, Issue 1, pp. 221-226.

[3] Abdelfattah Bilal Abdelsalam, Elkhawad Ali Elfaki, Mohammed Misbah Ridwan (2015), "The Influence of Friction Phase Parameters on the Joint Strength of High Speed Steel Welded to Medium Carbon Steel", International Journal of Mechanics and Applications, pp. 10-15.

[4] Divagar S R and Muthu Kumaran M (2015), "Joining The Different Materials Using Friction Welding - A Review", International Journal of Mechanical Engineering and Robotics Research, Volume 4, Issue 1, pp. 117-122.

[5] Vishnu P S and Sujith Joseph (2014), "Optimization of Friction Welding Parameters for J oining Medium Carbon Steels using Response Surface Methodology", International Journal of Engineering Research & Technology, Volume 3, Issue 10, pp. 338-345.

[6] Jagroop Singh and Karamdeep Singh (2014), "Fabrication of Friction Welding on Centre Lathe: A Case Study", International Journal of Research in Mechanical Engineering & Technology, Volume 4, Issue 2, pp. 145-147.

[7] Samuthiram G, Kannan TTM, Sureshkumar M, Ananda Natarajan V and Vijayakumar P (2014), "Evaluation of Mechanical Properties of Friction Welded Joints of EN-24 Steel Cylindrical Rods", International Journal of Mechanical Engineering and Robotics Research, Volume 3, Issue. 4, pp. 417-421.

[8] Amit Handa and Vikas Chawla (2014), "Investigation of mechanical properties of friction welded AISI 304 with AISI 1021 dissimilar steels", The International Journal of Advanced Manufacturing technology, Volume 75, Issue 9-12, pp. 1493-1500.

[9] Dalip Kumar, Antariksha Verma, Sankalp Kulshrestha and Prithvi Singh (2013), "Microstructure and Mechanical Properties of Mild Steel-Copper Joined by Friction Welding", International Journal of Mechanical Engineering and Technology, Volume 4, Issue 5, pp. 295-300.

[10] Camilo Fernando, Ananthapadmanaban D and Sathish R (2011), "Experimental Observations on Friction Weldability of Copper with Steel", International Journal of Applied Engineering Research, Volume 6, Number 20, pp. 2349-2355.