Optimization of Process Parameters on Friction Welded AISI 410 Steel Joint

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Abstract - The present study is to optimize the process parameters for friction welding of AISI 410 - Martensitic Stainless Steel. Experiments were conducted according to L9 Orthogonal array. Process variables considered for this study are friction pressure, upsetting pressure, speed, friction time. High temperature Tensile strength and impact toughness were selected as the outputs of the welded joint. The regression analysis is used to model input and output parameters. The Taguchi analysis has been employed to optimize process parameters. Confirmation test was carried out by setting the optimized parameters. The microstructure analysis has been carried out to analyze various zones of welded joint namely plasticized zone, heat affected zone and base metal.

***Key Words*: Taguchi Analysis, High Temperature Tensile Strength, Microstructure, Hardness**

1.INTRODUCTION

Welding is a fabrication process that joins materials, usually metals or thermoplastics, by using high heat to melt the parts together and allowing them to cool, causing fusion. Welding is distinct from lower temperature metal-joining techniques such as brazing and soldering, which do not melt the base metal. The processing time required for friction welding is 75% lesser than the diffusion bonding which is another suitable technique to join different materials [1]. The frictions stir welded carbon steel joint exhibits tensile strength and percentage stretching very nearer to base metal [2]. The dissimilar FW Inconel 718 and AISI 410 joint achieve bond strength 50% of their one of the parent material Inconel 718 [3]. The spike in rotational speed caused a drop in tensile strength and impact toughness due to weld interface region gets softened in friction welding of AISI 430 [4]. The porosity formation is eliminated in friction welding of the steel pipe joint and residual stress propagation is more homogeneous [5]. The impact toughness of friction welded steel pipe joint is decreased as changes in microstructure and penetration of MnS but hydrogen cracking risk completely absent [6]. The more axial shrinkage attained in carbon steel side than stainless steel side as rate of stress and strain is Asymmetric [7]. The ANOVA analysis is used to predict effects of process parameters on the welded joint mechanical property and Taguchi analysis used to get optimal levels of factors [8]. The speed of rotation and an interlayer thickness are greatly influencing the tensile strength at the same time friction time having less influence on friction welded aluminum composite and steel joint [9].the modeling friction welding parameters of AISI 430 by buckingham's Pi Theorem [10]. in this work high temperature tensile stress is found based on L9 Orthogonal array and optimum level are predicted.

2.MATERIAL AND METHODS

The joints are fabricated by friction welding machine shown in made by RV machine tools with 12 kW rated motors. This Machine equipped with a hydraulic system with main spindle speed of 3000 rpm and it is inbuilt with numerical control system (Rexroth). The specimen cuts into 100 mm length each and 12 mm diameter. The AISI 410 material is fixed over the rotating chuck. The tensile strength of the AISI 410 material is 657 MPa. In this experimental parameter used are friction pressures, forging pressure, friction time, forging time and rotational speed. L9 orthogonal array is used to carry out the experiments with each trial 2 specimens fabricated [11]. The friction welding machine shown in the figure 1.The friction welded samples shown in figure 2. The parameter value fixed after conducting the trials and previous literature. High temperature Tensile test conducted as per ASTM E8 Standard and 550^{o}C temperature is maintained for 20 minutes.

Fig-1 Friction Welding Machine

Fig-2 Friction Welded Samples

Fig- 3 Friction Welded Samples after tensile test

The high temperature tensile test specimen after testing is shown in the figure 3.The experimental plan is available in table 1.

Table 1 Experimental Plan

S.No	Friction Pressure (A) (MPa)	Upset Pressure (B) (MPa)	Friction Time (C) (s)	Speed (D) (Rpm)
1	60	70	3	800
2	60	90	5	1000
3	60	110	7	1200
4	80	70	5	1200
5	80	90	7	800
6	80	110	3	1000
7	100	70	7	1000
8	100	90	3	1200
9	100	110	5	800

3. RESULTS AND DISCUSSION

3.1 Yield Strength

The friction welded samples are prepared based on the L9 Orthogonal array. The Taguchi analysis is used to predict optimum level to get maximum yield strength of the joint. The ANOVA analysis is carried out to find out the significant factor for the yield strength of the joint. The linear regression model is also prepared to predict the results in advance.

3.1.2 TAGUCHI Analysis for Yield Strength

The S/N ratio calculated for yield strength related to larger the best category as per equation 1. The S/N ratio for yield strength and ranking of parameters tabulated in table 3.The S/N ratio plot for tensile strength is shown in fig.4.The optimal level of factor identified as $A_3B_3C_3D_2$.The high value of friction pressure, upset pressure, friction time and medium value of rotational speed are optimized level of factors to get maximum yield strength.

Larger the best characteristics:

$$S/N\ Ratio(\eta) = -10\log_{10}\left(\frac{1}{r}\right)\sum_{i=1}^{r}\frac{1}{y_{ij}^2} \quad (1)$$

The experimental results are listed in table 2.

Table 2 Experimental Results

S.No	Yield Strength (MPa)	Ultimate Tensile Strength (MPa)	Hardness (VHN)
1	370	404	661
2	377	406	670
3	378	410	674
4	382	415	658
5	390	422	660
6	398	432	665
7	407	441	675
8	402	435	672
9	409	444	676

Table 3 The S/N Ratio Analysis of Yield Strength

Level	Friction Pressure (A) (MPa)	Upset Pressure (B) (MPa)	Friction Time (C) (s)	Speed (D) (Rpm)
1	51.48	51.73	51.82	51.81
2	51.82	51.81	51.80	51.91
3	52.17	51.93	51.85	51.76
Delta	0.69	0.19	0.05	0.15
Rank	1	2	4	3

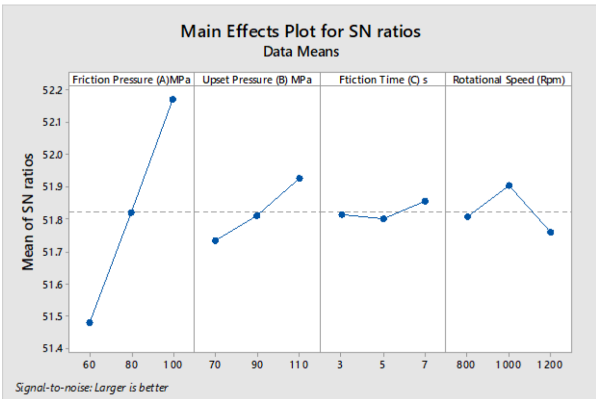

Fig-4 SN Ratio Plot for yield strength

3.1.3 Analysis of Variance (ANOVA) for Yield Strength

The analysis for yield strength is available in Table 4. In the F-Table at the 5 % significance is $F_{0.05,1,8}$=5.32. the F-Value greater than 5.32 are significant factors and remaining factors are Insignificant .Except the effect of friction time & rotational speed and other effects are significant. In this analysis friction pressure is observed that highly significant with 88.21%. The upset pressure contribution towards attaining the yied strength is 6.89 %. The factors friction time and rotational speed is observed that the Insignificant effect with a contribution of 0.25% and 0.5% respectively. The increase in friction pressure increases the heat generation at interface tends to make better bonding of material which leads to high yield strength.

Table 4 The ANOVA of Yield Strength

Source	DOF	Sum of Square	Mean Square	F-Value	% Contribution
Friction Pressure (A)	1	1441.5	1441.5	85.42	88.21
Upset Pressure (B)	1	112.67	112.67	6.68	6.89
Friction Time (C) (s)	1	4.17	4.17	0.25	0.25
Speed (D) (Rpm)	1	8.17	8.17	0.48	0.5
Error	4	67.5	16.88		4.13
Total	8	1634.0			

3.2 Ultimate Tensile Strength

The friction welded samples are prepared based on the L9 Orthogonal array. The Taguchi analysis is used to predict optimum level to get maximum tensile strength of the joint. The ANOVA analysis is carried out to find out the significant factor for the ultimate tensile strength of the joint. The linear regression model is also prepared to predict the results in advance.

3.2.1 TAGUCHI Analysis for Ultimate Tensile Strength

The S/N ratio calculated for yield strength related to larger the best category as per equation 1. The S/N ratio for yield strength and ranking of parameters tabulated in table 5.The S/N ratio plot for tensile strength is shown in fig.5.The optimal level of factor identified as $A_3B_3C_3D_2$.The high value of friction pressure, upset pressure, friction time and medium value of rotational speed are optimized level of factors to get maximum Ultimate Tensile strength.

Table 5 The S/N Ratio Analysis of ultimate tensile strength

Level	Friction Pressure (A) (MPa)	Upset Pressure (B) (MPa)	Friction Time (C) (s)	Speed (D) (Rpm)
1	52.18	52.46	52.54	52.53
2	52.53	52.48	52.49	52.59
3	52.87	52.46	52.55	52.46
Delta	0.68	0.18	0.06	0.13
Rank	1	2	4	3

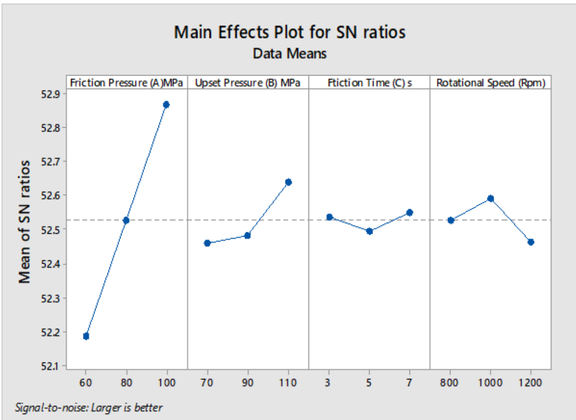

Fig-5.SN Ratio Plot for ultimate tensile strength

3.2.2 Analysis of Variance (ANOVA) for Ultimate Tensile Strength

The analysis for yield strength is available in Table 6. In the F-Table at the 5 % significance is $F_{0.05,1,8}$=5.32. The F-Value greater than 5.32 are significant factors and remaining factors are Insignificant. Except the effect of friction time & rotational speed and other effects are significant. In this analysis friction pressure is observed that highly significant with 88.95%. The upset pressure contribution towards attaining the ultimate tensile strength is 6.01 %. The factors friction time and rotational speed is observed that the Insignificant effect with a contribution of 0.03% and 0.88% respectively. The increase in friction pressure increases the heat generation at interface tends to make better bonding of material which leads to high tensile strength.

Table 6 The ANOVA of ultimate tensile strength

Source	DOF	Sum of Square	Mean Square	F-Value	% Contribution
Friction Pressure (A)	1	1666.67	1666.67	86.71	88.95
Upset Pressure (B)	1	112.67	112.67	5.86	6.01
Friction Time (C) (s)	1	0.67	0.67	0.03	0.03
Speed (D) (Rpm)	1	16.67	16.67	0.87	0.88
Error	4	76.89	19.22		4.10
Total	8	1873.56			

3.3 Vicker's Microhardness

The friction welded samples are prepared based on the L9 Orthogonal array. The Taguchi analysis is used to predict optimum level to get maximum hardness of the joint. The ANOVA analysis is carried out to find out the significant factor for the hardness of the joint. The linear regression model is also prepared to predict the results in advance.

3.3.1 TAGUCHI Analysis for Microhardness

The S/N ratio calculated for yield strength related to larger the best category as per equation 1. The S/N ratio for Microhardness and ranking of parameters tabulated in table 7.The S/N ratio plot for Microhardness is shown in fig.6.The optimal level of factor identified as $A_3B_3C_3D_2$.The high value of friction pressure, upset pressure, friction time and medium value of rotational speed are optimized level of factors to get maximum Microhardness.

3.3.2 Analysis of Variance (ANOVA) for Microhardness

The analysis for yield strength is available in Table 8. In the F-Table at the 5 % significance is $F_{0.05, 1,8}$=5.32. The F-Value greater than 5.32 are significant factors and remaining factors are Insignificant. The microhardness response concerned only friction pressure plays significant role and remaining factors such as upset pressure, friction time and rotational speed are Insignificant. In this analysis friction pressure is observed that highly significant with 41.95%. The upset pressure contribution towards attaining the hardness is 23.92 %. The factors friction time and rotational speed is observed that the Insignificant effect with a contribution of 10.27% and 2.08% respectively.

Table 7 The S/N Ratio Analysis of Vicker's Microhardness

Level	Friction Pressure (A) (MPa)	Upset Pressure (B) (MPa)	Friction Time (C) (s)	Speed (D) (Rpm)
1	56.50	56.45	56.47	56.46
2	56.40	56.49	56.49	56.52
3	56.58	56.54	56.52	56.50
Delta	0.17	0.09	0.05	0.06
Rank	1	2	4	3

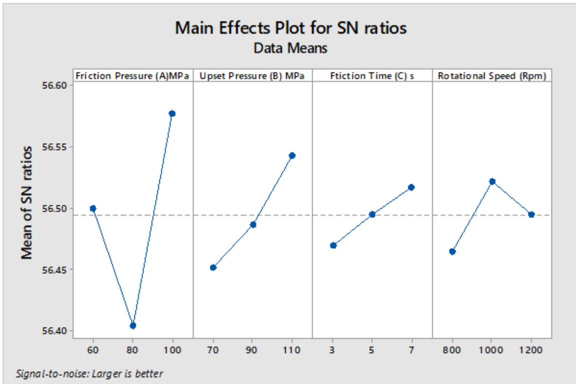

Fig-6 SN Ratio Plot for Microhardness

4. MICROSTRUCTURE ANALYSIS

Microstructural analysis of as received and welded samples was performed with optical microscope. Standard metallographic procedure of hot mounting, grinding, and polishing were performed to prepare the sample upto the surface roughness of 0.05 mm followed by etching. Samples were etched using balling reagent (100 ml ethanol þ 100ml HCl þ 5 g CuCl2). The base metal , heat affected zone , plastically deformed zone and weld zone for experimental trial 5 shown in the figure 7 ,8 and 9 respectively. The coarse microstructure seen in the heat affected zone in the figure 8.the finer grain structure found in plastically deformed zone which is shown in the figure 9. The central region consists of fine grains while peripheral region consists of coarse grains in weld zone which is shown in the figure.

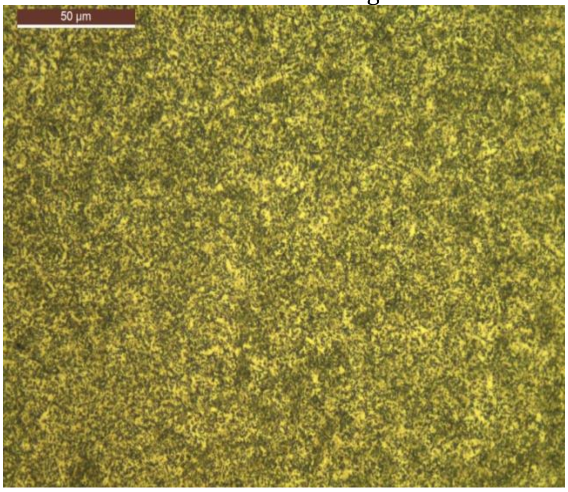

Fig-7 Microstructure of Base Metal

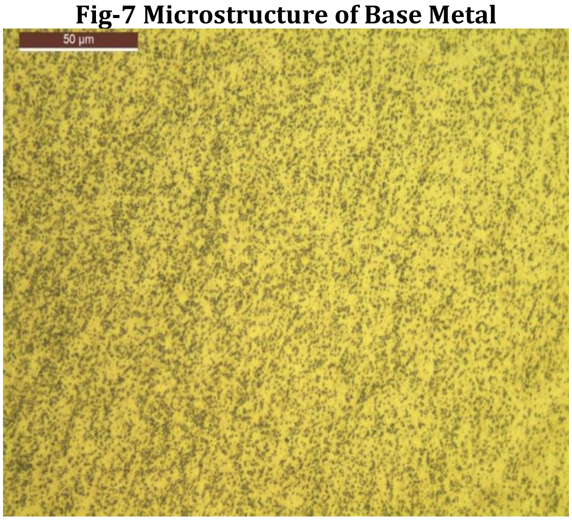

Fig-8 Microstructure of Heat Affected Zone

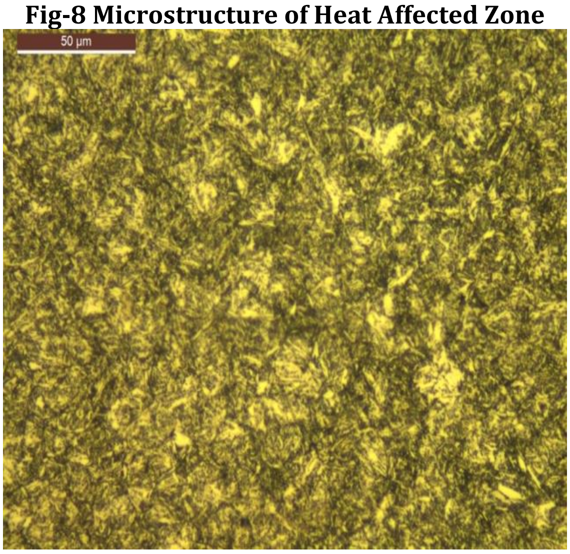

Fig-9 Microstructure of Plastically Deformed Zone

Table 8 The ANOVA of Microhardness

Source	DOF	Sum of Square	Mean Square	F-Value	% Contribution
Friction Pressure (A)	1	164.00	164.00	7.62	41.95
Upset Pressure (B)	1	93.50	93.50	4.32	23.92
Friction Time (C) (s)	1	40.16	40.16	1.85	10.27
Speed (D) (Rpm)	1	8.16	8.16	0.37	2.08
Error	4	85.05	21.62		21.75
Total	8	390.88			

5. CONCLUSION

1. Friction welding can be used to join martensitic stainless steel (AISI 410). The Processed joints exhibited better mechanical and metallurgical characteristics.
2. The high temperature tensile strength at 550^0C is found that maximum of 409 MPa which is nearly 37.74% lesser than the parent metal tensile strength is 657MPa.
3. The friction pressure plays significant role in all the output responses than other parameters.
4. The reason for low tensile strength at high temperature is softening of bonding surface due to high heat input.
5. The higher hardness value found at weld interface of 676 VHN where as the base metal hardness is only 304 VHN.
6. The microstructure analysis revealed that coarse grain found in heat affected zone and finer grain found in plastically deformed zone.

6. REFERENCES

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