Characterization studies on weld strength of Rotary Friction Welded Austenitic Stainless Steel Tubes

Abstract: Austenitic stainless steel (SS304) tubes of outer diameter 19 mm, 2mm thickness are joined together by rotary friction welding (RFW). The characterization studies are done by varying heating load, forging load, heating time, forging time and keeping constant spindle speed of 1100 rpm. The tensile and microhardness test were conducted for each fabricated joints to evaluate the mechanical properties of welded samples. The joint strength increased with increase in forging load and heating load. The maximum joint strength of 780 N/mm^2 and hardness of 210HV achieved for weld parameter of forging load 1400 kg and forging time 4 sec. The microstructure analysis revealed coarse grain structure in the weld zone compared to base metal. Scanning Electron Microscopy (SEM) analysis reveals the welded sample joints had experienced a ductile mode of fracture.

Keywords: Friction welding, Austenitic stainless steel 304, Mechanical properties, tensile test, tube welding.

1. Introduction

Rotary friction welding is a class of solid state welding process in which the weld joint produce the heat below the melting point of base metal being joint without addition of filler metal[4]. The main variables in friction welding method includes heating load ,forging load, heating time, forging time and spindle speed[1][6]. Difficulties encountered during fusion welding of stainless steels include stress corrosion cracking, delta ferrite and sigma phase formation and heat affected zone (HAZ) is prone for sensitization by formation of intergranular Cr-rich carbides, which deteriorates the corrosion properties of the welded joint[8]. However solid state welding can eliminate the above metallurgical problems. In particular friction welding can be used[8]. Hence, there is a need to develop highly efficient joining methods for a specific application such as tube to tube, tube to tube plate joint than fusion welding [8] which can achieve higher strength and quality more consistently than with the fusion welding processes [1]. Friction welding process gives high production rate and replacing the other joining process and by this method it is useful for similar and dissimilar material, ferrous and non ferrous materials welding [2].SS304 has excellent resistance over wide range of atmospheric environments and many corrosive media. The application of SS304 includes chemical, petrochemical, fertilizer industry, heat exchanger tube and food processing industries [3]. In this investigation, characterization studies are done for welding of SS304 tubes using Design of Experiments (D.O.E).

2 .Experimental procedure

The sample preparation is 80mm tube length, 2mm tube thickness, 19mm outer diameter. Two parts are joined in rotary friction welding method .The chemical composition and properties are listed given below the table 1 and table 2. During welding the temperature is measured for initial and final temperature by using Infrared thermal camera shown in figure 3.

Table1. Composition of stainless steel 304

Elements	C	Mn	Si	Cr	Ni	S	P	Fe
Wt %	0.08	**1.97**	**1.05**	**18.5**	**8.2**	0.05	0.05	Balance

Table2. Mechanical Properties For Stainless Steel 304

PROPERTIES	Tensile strength	Yield strength	Vicker micro Hardness
METRIC	715 MPa	254 MPa	230 HV

2.2 Method:

Rotary friction welding method is used for joining the SS304 tubes. Friction welding of 3Tonne capacity is used for this study. The figure 1 shows the Rotary friction welding machine used in this study. Trial experiments were conducted to determine the working range of factors and possible limits of parameters were chosen in such a way that the friction welded joints should be free from any visible defects. The factors and levels are shown in table 3and rotation speed is kept constant as 1100 rpm.

Table 3 – Important factors and levels

Factors	Levels		
	1	**2**	**3**
Heating Load, H_L,kg	1200	1300	1400
Forging Load, Fo_L,kg	1200	1300	1400
Heating Time, H_t ,s	18	20	22
Forging Time, Fo_t ,s	2	3	4

Figure 1 - Rotary Friction welding machine

2.3 Design of Experiment:

Taguchi method is used in this investigation in which the design was used for minimizing the number of experiments to be performed and obtained model was tested for its adequacy [**taguchi ref**]. As the range of individual factor was wide, four-factor, three-level was selected and the experimental design matrix is shown in the table 4 consisting 9 sets of experiments to be performed. With respect to the design matrix the welding parameters are tabulated in table 5. The fabrication of tube joints are performed for 9 sets of parameters. Figure 2 shows the welded tube specimen.

Table 4 – DESIGN MATRIX

S.No	H_L	Fo_L	H_t	Fo_t
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Table 5 – WELDING PARAMETERS

S.No	H_L	Fo_L	H_t	Fo_t
1	1200	1200	18	2
2	1200	1300	20	3
3	1200	1400	22	4
4	1300	1200	20	4
5	1300	1300	22	2
6	1300	1400	18	3
7	1400	1200	22	3
8	1400	1300	18	4
9	1400	1400	20	2

Figure 2.Welded samples

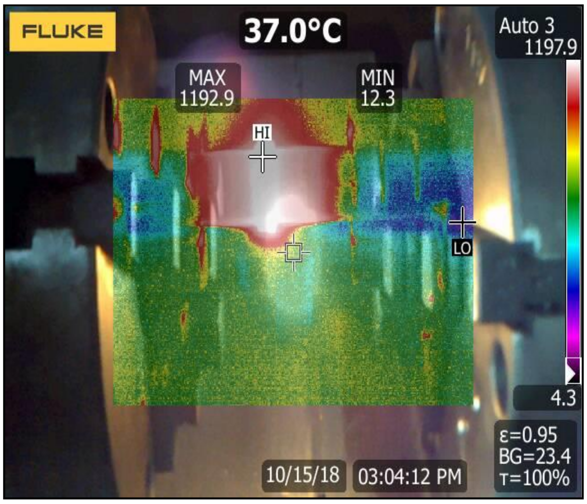

Figure 3.Temperature profile for Exp.No.9

3. Results and discussion

3.1Tensile test result

The tensile testing was carried out as per the ASTM E8/E8M-16a standards in the Universal Testing Machine of 100KN capacity. At room temperature the tensile strength of the stainless steel is the maximum range 0f 550Mpa-700Mpa.during tensile testing the specimen was broken at the weld region. The tensile strength of the experiment is varying according to the process parameter such as Heating Load (Fr_L),Forging Load(Fo_L),Heating Time(F_t),Forging Time(Fo_t).The tensile test result shows that the tensile strength increases ,if the forging load increases .[1]

Table4. Tensile strength

Exp No.	Tensile strength N/mm^2
1	700
2	680
3	777
4	761
5	780
6	778
7	774
8	769
9	780

Table 5.Analysis of Variance

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	4	5492.33	5492.33	1373.08	7.2982	0.040066
H_L	1	2281.50	2281.50	2281.50	12.1267	**0.025298**
Fo_L	1	1666.67	1666.67	1666.67	8.8587	0.040886
Fr_t	1	1176.00	1176.00	1176.00	6.2507	0.066757
Fo_t	1	368.17	368.17	368.17	1.9569	0.234409
Error	4	752.56	752.56	188.14		
Total	8	6244.89				

Response Table for Signal to Noise Ratios

Larger is better

Level	H_L	Fo_L	Fr_t	Fo_t
1	57.32	57.43	57.48	57.53
2	57.76	57.60	57.57	57.62
3	**57.78**	**57.82**	**57.81**	**57.72**
Delta	0.46	0.39	0.33	0.19
Rank	1	2	3	4

After obtaining the tensile strength, analysis of variance is done. Table 7 shows the ANOVA values in which forging load has lesser *P* value from this it is clear that forging load is the effective parameter [8]. A regression equation (1) is developed and adequacy checking is done for Tensile strength. Figure 4 shows the comparison of experimental values and Calculated value for tensile strength.

$$TS = 127.222 + 0.195\ FrL + 0.166667\ FoL + 7\ Frt + 7.83333\ Fot \quad \text{-----------} (1)$$

Table 5 Calculated Tensile strength

Exp No.	Tensile strength N/mm^2
1	702.8891
2	741.3891
3	779.8891
4	752.0557
5	767.0558
6	763.5558
7	777.7224
8	774.2224
9	789.2225

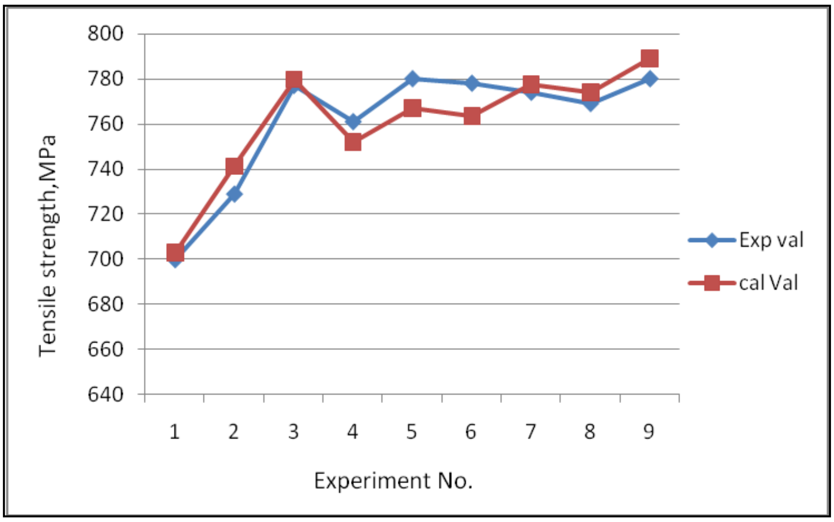

Figure 4 Experimental Vs Calculated value of tensile strength

3.1.1 Optimized Parameter:

From the above Tensile strength values it is observed that exp no. 9 has achieved maximum value of 780 MPa. So this parameter is considered to be the optimum weld parameter which is shown below in table 5.

Table6.Optimum welding condition

Material	Heating load Fr_L(kg)	Forging load Fo_L (kg)	Heating time Fr_t (sec)	Forging time Fo_t (sec)
SS304	1400	1400	22	4

3.2 Scanning Electron Microscopy (SEM):

Tensile strength values for the experiment shows that Ep.No.9 has the highest value 0f 780Mpa and Ep.No 1 gives least value of 700Mpa.after tensile the samples are prepared for SEM use for fined the fracture mode and any interface formation in weld joint[6]. The SEM results used to understand the joints had experienced a ductile mode of fracture.

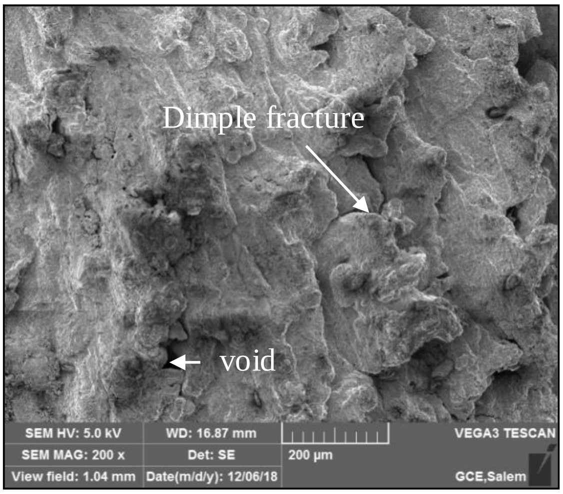

Figure 6 Exp.No.1

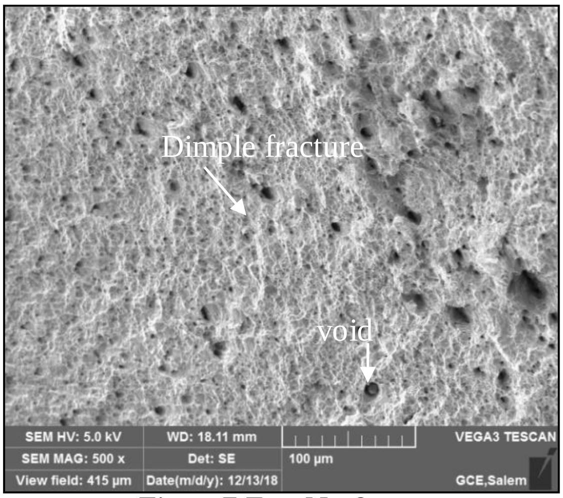

Figure7 Exp.No.9

3.3 Microstructure and Micro hardness analysis:

As per ASTM E384 standard Vickers micro hardness tester was used with indentation load of 500 grams, dwell time of 10 s. [6] . [1] The hardness of weld metal higher than partially deformed zone (PAZ), the hardness value of partially deformed zone is lower than base metal .this due to dominant thermal effect at the weld interface. [8].

The micro structure of weldments as in Fugure 8(a-d) is studied for 200x magnification in weld zone, PDZ, base metal. The grains are elongated in rolling direction in the weld zone. The austenite grain boundaries are partially deformed in partially deformed zone(PDZ) compared to base metal grain boundaries[2].

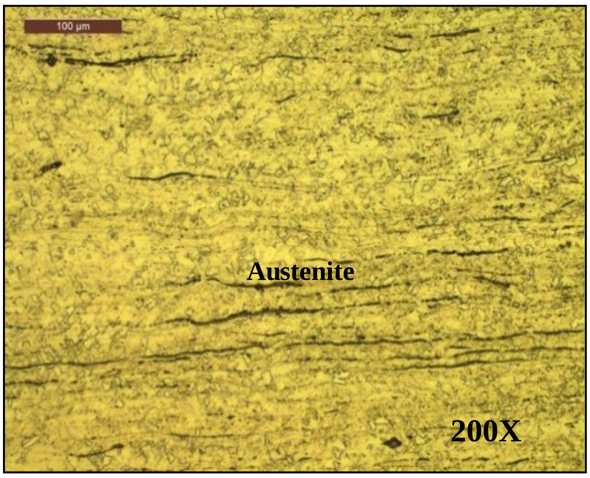

Figure 8 (a) Base metal

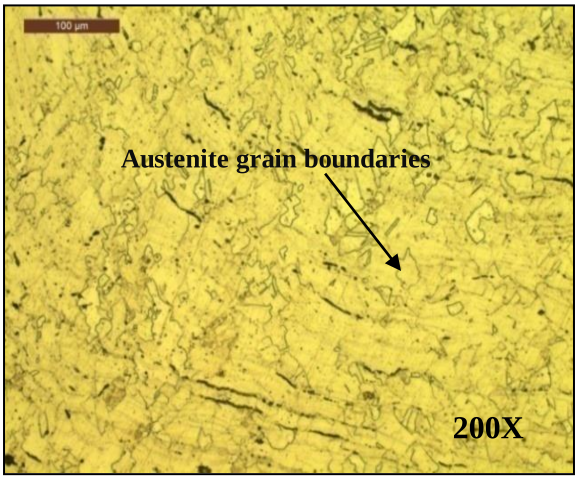

Figure 8 (b) PDZ

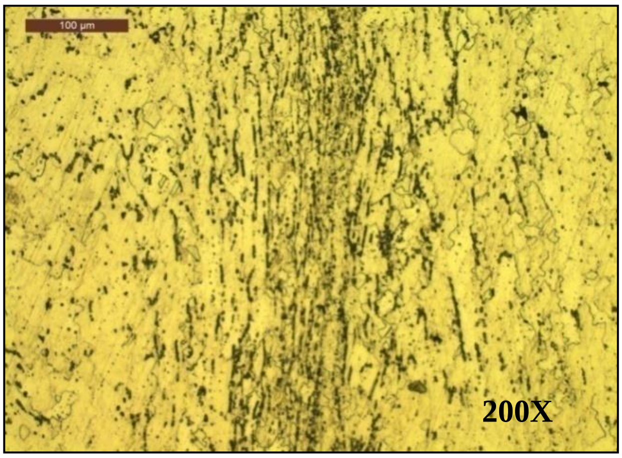

Figure 8 (d) Weld zone

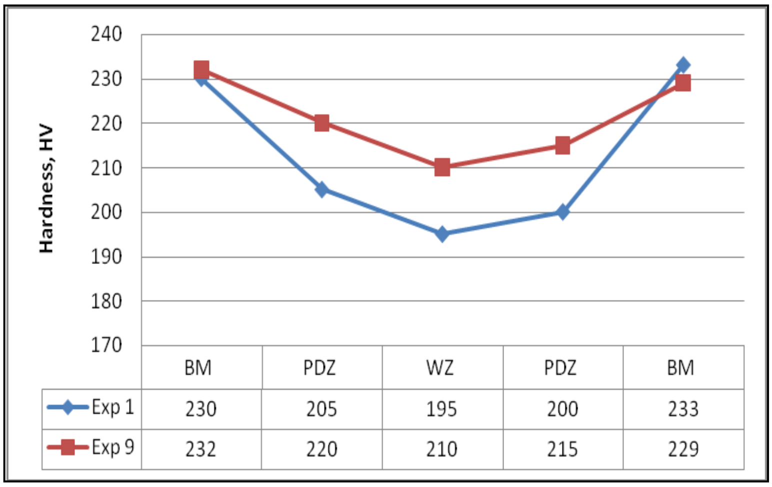

Figure 7 Microhardness Survey

Table 7 Microhardness values

	Hardness, HV	
Zones	Exp 1	Exp 9
BM	230	232
PDZ	205	220
WZ	195	210
PDZ	200	215
BM	233	229

3.6 Bend test

Bend tests were performed on friction welded SS304 using a span radius of 12mm.indicated friction weld SS416 a non welded sample failed between 10and 12 degrees.[9] the bend test was carried out on a specimen length 152mm, which is simply supported, with a span radius of 12mm.the maximum bending load one tonne , with an average angle of 30 degrees and the deflection 30.1mm for Exp.no. 9. Figure 12. Shows the SEM observation results on the fractured surface of the bend test sample. From this it can be observed that the surface appears to be in ductile mode fracture.

Figure11. Bend test specimen

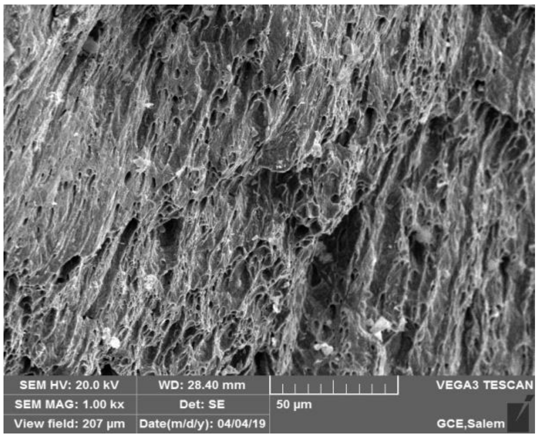

Figure12.SEM image for bend test

3.7 Impact test

Low impact strength indicated friction welded parts.[10] .At room temperature the impact studies made using a standard charpy impact tester.the impact strength value of Exp. no 9 for 130 J. Figure13 shows the macro structure of impact test sample .figure 14 SEM image for impact test sample. Form this SEM analysis surface appears to be in ductile mode, without dimples.

Figure 13.Macrostructure of impact test Sample

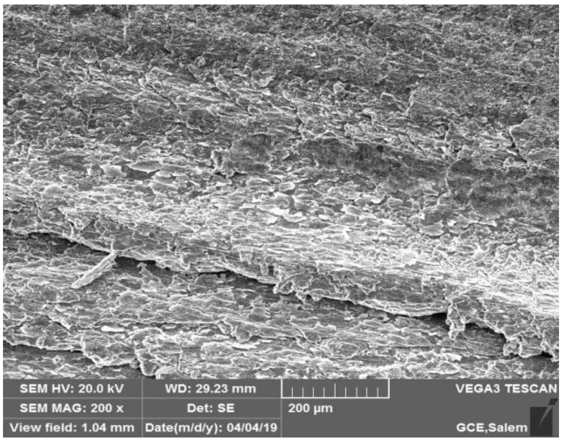

Figure14.SEM image of impact test sample

4. Conclusion

Rotary friction welding method for austenitic stainless steel (304) tubes are successfully jointed. Friction welding process avoided the formation of brittle phases at the weld interface and solidification problems with the formation of smooth weld interface.

1. The Tensile strength of the joints increased with the increase in forging load and heating load.
2. The SEM results shows the deep dimples confirms the ductile mode of failure.
3. Micro-hardness of the joints decreased towards weld interface from base metal due to the presence of coarse grains in the weld interface.
4. Microstructure analysis and XRD analysis shows no intermetallics formed in the weld interface.
5. Bend test results gives good ductility confirms a sound weld joint .

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