Experimental Investigation And Thermal Analysis of Heat Affected Zone of Stainless Steel (SS304) Using RFW Process

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Abstract

Rotary friction welding is widely used as a solid state welding method for joining of similar or dissimilar metals. It is an advanced joining technique that generates frictional heat and material goes under plastic deformation at the welding location, thereby affecting the formation of a joint while the material is in solid state. After heat generation phase an additional forging force is applied which completes coalescence. Since no melting of material occurs during friction welding, but metal gets deform after heat generation at welding zone. The principal advantages of frictional welding, low distortion, absence of melt-related defects and high joint strength. In this paper the study has been carried out by using the friction welding process on all geared lathe machine. The material selected for study and experimentation of RFW is stainless steel SS 304 and specimen dia. ϕ 8 mm and ϕ 10 mm. The various parameters studied for the process is rpm, weld time, temperature, pressure, heat affected zone etc., the 2D modeling and steady state transient thermal analysis has been carried out for the selected specimen.

Keywords
Rotary friction welding, Thermal Analysis, Tensile test, Hardness, Microstructure.

1. Introduction
Welding is a fabrication technique which is used extensively for joining of metals. There are two main classification of welding process, i.e. fusion welding and solid state welding. In the fusion type of welding process, the joint edges are melted and in solid state welding process, these edges are heated to become a red-hot temperature and subjected to pressure applied to create a welding joint. The former method has a disadvantage of substantial micro-structure and property changes. Friction welding is a type of solid state or forge welding, where welding takes place by the application of friction between two mating surfaces of metal along with application of pressure, required heat can be generated by rubbing two metals on each other and the temperature can be elevated to the level where the parts subjected to the friction may be welded together. The fundamental principle of friction welding is to use the heat generated through rotational friction to produce a clean joint, without the formation of a liquid phase. This contact force first generates heat at the interface. Once the material has become sufficiently soft, the forging pressure has applied against the two components forces the heated interface material into the flash, removing any surface contaminants and producing a clean joint. The rotary friction welding method is the simplest one, but it has an inherent limitation, i.e.it cannot be employed for the welding of parts with a non-circular cross-sectional area. Therefore the rotary friction welding is a solid state joining process that produces coalescence by harnessing heat developed through controlled rubbing of the faying surfaces. Due to the heat, the material start to deform and at which the plasticized material starts to form a layers also, at intervene with one another and it gives the results in good quality of weld.

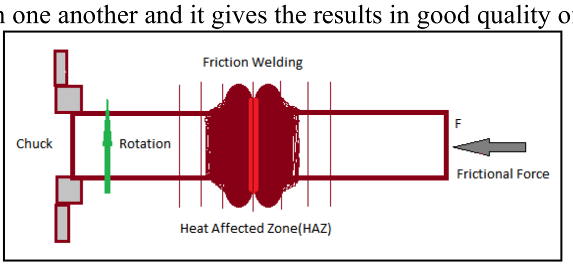


Figure 1. Schematic RFW Process.

1.1. Objective

The objective of this research work is to conduct the experiment and trails on rotary friction welding by using all geared lathe machine, to observed and measure the temperature rise and the pressure applied during welding. The tensile test and microstructure analysis of the welded part is to be carried out. The 2D Modeling & steady state transient thermal analysis is performed of the rotary friction welding using ANSYS software for specimen dia.ϕ 8 mm and dia.ϕ 10 mm.

2. Literature Review

Friction welding is a commercial process which has developed early 1940’s with the advancement in technology. Preliminary trials were made using lathe machines for the friction welding process and the trials were conducted during, which has considered impractical due to incorrect process techniques. According to the American Welding Society, the origins of friction welding in the 1891, when the first patent on the friction welding process was issued in the USA. Research work progressed throughout Europe as many patents were issued from 1920 to 1944. During the era of 1960's, friction welding was further developed in the USA by AMF, Caterpillar, and Rockwell International. Rockwell built its own machines to join spindles to truck differential housings by using friction welding, AMF produced machines to weld steering worm shafts, and Caterpillar’s machines welded turbochargers and hydraulic cylinders.

The Welding Institute (TWI) in 1961 and the Caterpillar Tractor Co. modified the friction welding to develop the method of inertia welding process in 1962. After that friction welding has found applications in different engineering sector. Before 1980s. TWI has demonstrated the viability of the Friction Welding technique for metals using modified equipment. The RFW process has only found industrial application in aircraft engine manufacture, in part due to the high cost of the welding machines. The first patent of friction welding process was granted to J.H. Belington. He applied friction welding to weld metal pipes. Studies on welding of plastic materials were carried out in the 1940s in USA and Germany. A Russian machinist named A. J. Chdikov has conducted experimental scientific studies and suggested the use of RFW as a commercial process. He patented this process in 1956. Many researchers have been worked on HAZ portion and study carried out on thermal analysis as well as parametrical analysis of rotary friction welding. Studies of friction welding in England were carried out by Friction welding is a widely used welding method in the industry after electron beam welding.

3. Experimental Setup

Friction welding set-up has been build for making the sound frictional welded joints, for this the existing lathe machine has been modified to perform friction welding. Rotary Friction welding process experiment carried out on medium duty all geared lathe machine with suitable modifications to suit the requirements of this experimentation work at 1500 rpm spindle speed. All geared lathe machine (NAGMATI make model 175) used for the experimentation. The Specifications of Machines as follows: Bed length-5’3” flame harden, Centre height 175 mm, Admit Between Centre 700 mm, Spindle Bore 40 mm, Motor power 2 HP, rpm-1500. The specimen dia.ϕ 8 mm and dia.ϕ 10 mm used for SS304 material and these specimens were then fitted on the friction welding set-up machine. In this method, one component is held stationary while the second component is rotated at constant speed. The required rotational speed was constant and set by the machine and subsequently the axial alignment of the specimens was checked. When the forging temperature was achieved, the rotation of the head stock was ceased. After this, the forging pressure was applied to form the welds. The welds were prepared at different forging pressures in the steps. The supports design and developed for attachment and alignment of specimen. As shown in figure 4,5 and 6.The temperatures, time taken for welding, tensile test of welded joint were evaluated.

Figure 2. Experimental setup.

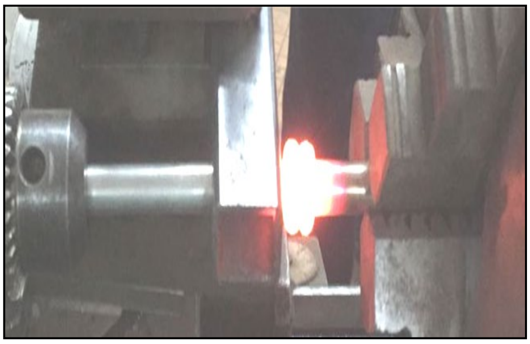


Figure 3. Friction welding Specimen.

3.1. Pressure and infrared pyrometer

The hydraulic jack, which has been adjust the pressure to be applied on specimen. It has the capacity of 2 tons. An infrared pyrometer is a non contact type infrared thermometer with type k input measurement. This is used to provide fast, easy and accurate temperature readings. It has the temperature range of 50°-1550°C. Accuracy ±1.5% of reading. Response time 250 ms, Optical resolution 30:1.

3.2. Support for specimen and drill chuck.

To reduce the vibration during high speed rotation in this experiment two supports used one for the drill chuck and other for the specimen. Fig.no.4 shown below is used to support the specimen. The drills chuck of 8 mm and 10 mm are used to drill two (0.5+ tolerance used) holes with minimum tolerance so that the specimen fits and avoids vibration during the welding process. We are using a hollow square pipe of cross section 25x25x2 mm and having a length of 200 mm.

Figure 4. CAD model for support.

Fig.no.5 (MS pipe of ϕ 60 mm) shown below is used to support the drill chuck to avoid the vibration which are occurred during the welding process. The hollow circular pipe of ϕ 60 mm and length 30 mm used. And it is connected to the square pipe of cross section 25 x 25 x 2 mm. (as shown in fig.no.6).

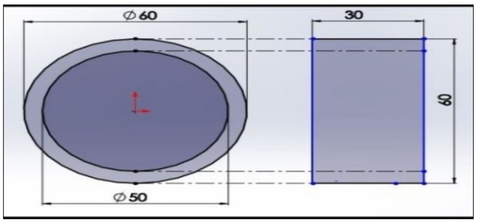


Figure 5. Dimensions of Support (pipe)

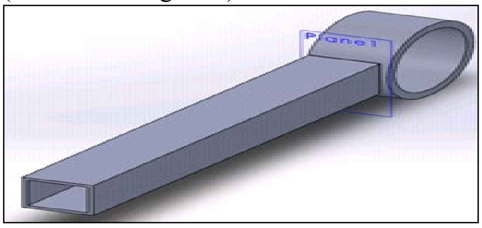


Figure 6. Support for Drill chuck

3.3 Material Selection

In this study and experimental work SS304 an alloy material is used, which is iron based and suitable for a wide range applications in the areas such as chemical, dairy equipments, food processing, pharmaceutical equipments, cryogenic vessels, heat exchangers and beverage sectors.

Table no. 1: Material composition of SS304.

MATERIAL	Cr	Ni	Mg	C	Si	P
COMPOSITION (%)	18.0-20.0	8.0-10.5	2.0	0.08	1.0	0.045

Specimens Preparation : ϕ8 mm & ϕ10 mm.Qty:05 each.

Figure 7. Dimensions for specimen of ϕ8 mm.

Figure 8. Dimensions for specimen of ϕ10 mm.

3.4. Experimental observations

During rotary friction welding experimentation as shown in figure no.2 the following observations were studied, and the Table no.3, 4 shows the temperature and time taken during welding process, which is measured by infrared pyrometer at different pressure for specimen dia.ϕ8 mm & dia.ϕ10 mm.

Table no. 3: Observation for SS304 Specimen of ϕ8 mm.

Specimen	**Dia. (mm)**	**Length (mm)**	**Speed (rpm)**	**Pressure (Kg/cm^2)**	**Temp (°C)**	**HAZ(mm)**		**Time (min)**
						HAZ 1	**HAZ 2**	
1	8	100-100	1500	**40**	**701**	**11**	**12**	**4.06**
2				**42**	**778**	**13**	**14**	**4.30**
3				**42**	**730**	**13**	**13**	**3.27**
4				**44**	**890**	**15**	**14**	**3.30**
5				**44**	**882**	**13**	**12**	**3.13**

Table no. 4: Observation for SS304 Specimen of ϕ10 mm

Specimen	**Dia. (mm)**	**Length (mm)**	**Speed (rpm)**	**Pressure (Kg/cm^2)**	**Temp (°C)**	**HAZ(mm)**		**Time (min)**
						HAZ 1	**HAZ 2**	
1	10	100-100	1500	**40**	**885**	**10**	**11**	**3.35**
2				**42**	**973**	**12**	**13**	**2.50**
3				**42**	**951**	**12**	**11**	**2.20**
4				**44**	**914**	**13**	**14**	**3.10**
5				**44**	**990**	**12**	**11**	**3.56**

Figure 9. Welded Specimen of ϕ 8 mm.

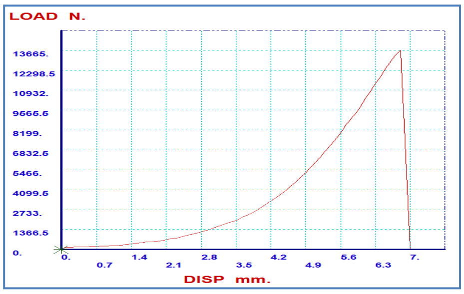
Figure 10. Welded Specimen of ϕ10 mm.

During this experimentation for dia.8 mm and dia.10 mm.length 100-100 kept constant and speed 1500 rpm also kept consatnt and axial pressure vary and temperature measured by using infrared pyrometer and after speciman trail the HAZ measured by scale on bothside during experiment trails time has been measured by using stop watch.

4. Result and Discussion

4.1 Tensile test for dia.ϕ8 mm and dia.ϕ10 mm

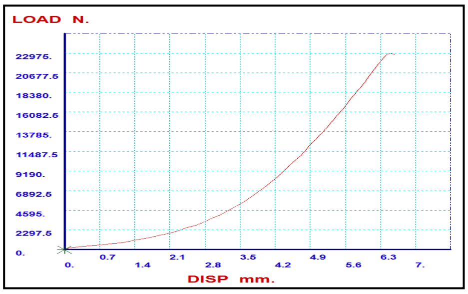
Rotary friction welded joints were subjected to a variety of mechanical tests to determine their suitability for the applications. They were necessary to carry out so as to ensure the quality, reliability and strength of the weld joint. Generally, two methods of testing the quality of the friction welded joint; one is destructive testing and other one is non-destructive testing. Usually mechanical properties like tensile strength, impact strength and hardness are evaluated. In this study, the tensile testing was performed using Universal testing machine (UTM) with capacity of 20 tons. The tensile testing used for checking the tensile strength of material (Load Vs Displacement). This test was carried out on the SS 304 for dia. 8 mm and dia.10 mm. materials to measure its strength in tension. During tensile test the specimen was undergo axial tensile load till its failure occurs and the result analysis of tensile test shows that highest maximum tensile strength for specimen of ϕ8 mm is 271.67 MPa at 1500 rpm and the strain obtained is 6.9 %. The highest maximum tensile strength for specimen of ϕ10 mm is 292.364 MPa at 1500 rpm and the strain obtained is 6.6 %.



Graph 1. Tensile strength graph for ϕ 8 mm.

Table no.5: Tensile strength data for ϕ 8 mm.

DATA	VALUE
Diameter	8 mm
Guage Length	100 mm
Maximum Load	13661.3N
Break Elongation	6.9%
Tensile Strength	271.67 MPa
Cross Section Area	50.28 mm^2



Graph 2. Tensile strength graph for ϕ10 mm.

Table no.6: Tensile strength data for ϕ10 mm.

DATA	VALUE
Diameter	10 mm
Guage Length	100 mm
Maximum Load	22971 N
Break Elongation	6.6 %
Tensile Strength	292.361 MPa
Cross Section Area	78.567 mm^2

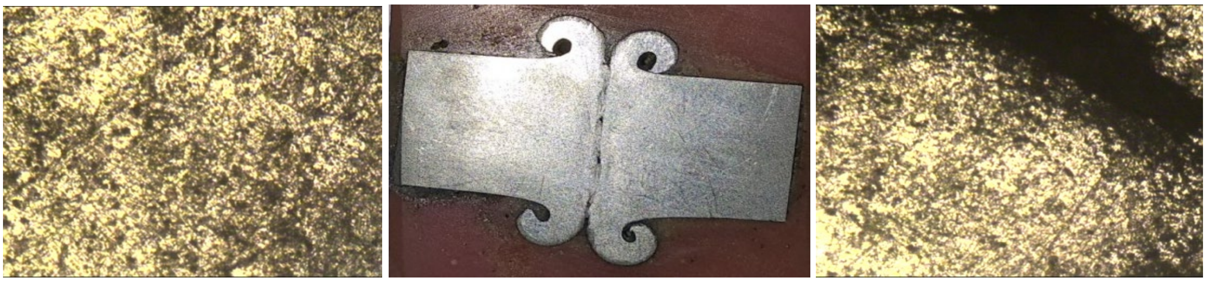
5. Microstructure test

Metallographic inspection in association with the investigation technique which completes the information supplied on the basis of the metallurgical study of the welds. To support the visual inspection of failure, the fracture analysis was carried out by the Scanning Electron Microscope (SEM). The analysis has done to show the fracture behavior of tensile test which justifies the visual inspection results of brittle and ductile failures. The magnified images were captured at the fractured locations taken at 100X magnification.

5.1 Preparation of specimen (ϕ8 mm and ϕ10 mm)

Step 1: Firstly, the specimen is cut with the help of wire cutting machine. Step 2: After wire cutting material seems to be like as shown in Fig 11b and Fig.no.12b, after which it is polished with silicon emery polish paper with the grades 300, 600, 900, 1200 and 1500. Step 3: Then it is final finished using diamond paste and for final testing the specimen is prepared using vieilla's reagent.

During welding, the temperature reached to 890°C for specimen no.4 ϕ8 mm (Ref. Table no.3) and 990°C for sepcimen no.05 (Ref.Table.no.3) respectively. So, welded part converts into austenitic phase and after cooling to the room temperature in steady air, achieved tempered martensite phase. The micro structure of base metal is shown in figure 11a and figure 12a. It is in austenitic steel with coarse grains. The micro structure of welded part is shown in figure 11c and figure 12c. It is in tempered martensite with the austenitic phase.



11a. 11b. 11c.

12a. 12b. 12c.

Figure 11a and 12a. Microstructure for base material. Figure 11b and 12b. Sectional wire cutting of weld. Figure 11c and 12c. Microstructure for weld.

In the friction welding the frictional heat at the interface when dissipated through the parent material would result in a temperature gradient causing zones of material with different microstructure. A finer grain structure can be observed in the Fully Deformed Zone (FDZ) where, as at the nearby zone called the Partly Deformed Zone (PDZ). In the PDZ grain size is coarse compare to the FDZ. The grains at heat affected zone are relatively coarse as compared with fully deform zone and partially deform zone. The parent material microstructure is presented in undeformed zone.

Table no.7: Microstructure data for ϕ8 mm & ϕ10 mm.

Data	Base metal	After Heating	After cooling	HAZ
Specimen of ϕ8 mm	Austenitic	Coarse austenitic	Martensite	Coarse Pearlite
Specimen of ϕ10 mm	Austenitic	Fine austenitic	Martensite	Fine Pearlite

6. Thermal Analysis

Two circular cross sections bars as shown in fig.7 & 8 of material SS 304 of having length 100 mm for ϕ8 mm & ϕ10 mm respectively has undergone rotary friction welding on lathe machine with modification as per setup provided. During thermal analysis the highest temperature at the welded joint and both ends at HAZ are considered. The temperature results were observed and temperature distribution in between the two ends. The HAZ portion of total 60 mm observed for the side and temperature at the center point of the welding is achieved maximum as shown in fig.13a and 14a.

For ϕ 8 mm: T1 = 890°C and T2=164°C, T3 = 181°C respectively at end both side. And, **For ϕ 10 mm:** The temperature at the center is T1 = 990°C and at the ends are T2 = 218°C and T3 = 209°C respectively. The values considered are for SS304 material is as, Thermal conductivity = 18.5 W/m-K, Convective heat transfer coefficient of air with bulk temperature 30°C = 15 W/m^{2}K, Specific heat = 590 J/Kg-K, Density = 8000 Kg/m^3. The analysis is to be done after the rotation of lathe machine is stopped. The 2D model generated after considering the welded specimen has undergone turning process for removing burr. Material as isotropic and uniform convective heat transfer coefficient and thermal conductivity at all temperature, then steady state transient heat transfer analysis has been carried out. The following representation shows the Heat Affected Zone in fig.13a and 14a. and Meshing and thermal load shows in the fig.13b and 14b. The 2D transient state analysis has been done and result of nodal solution as shown in fig.13c and 14c.

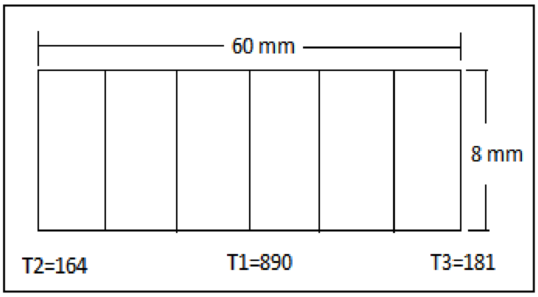


Figure 13a. HAZ Temp. for ϕ 8 mm.

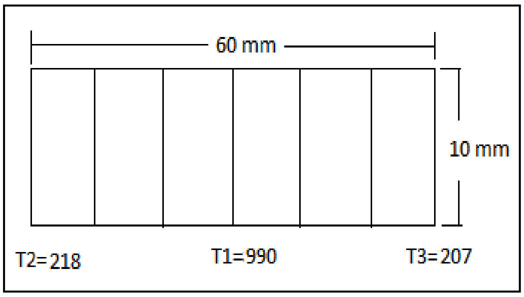


Figure 14a. HAZ Temp. for ϕ10 mm.

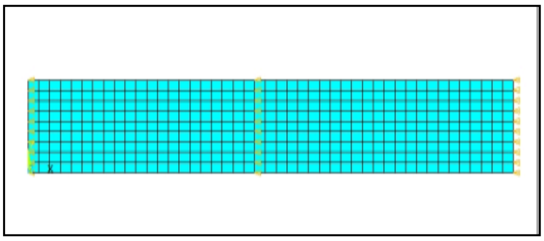


Figure 13b. Meshing and thermal load

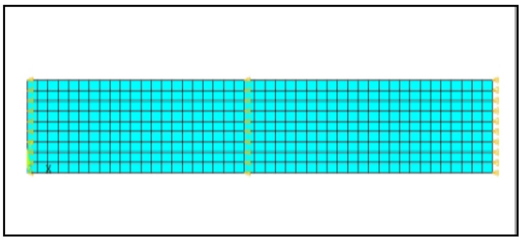


Figure 14b. Meshing and thermal load.

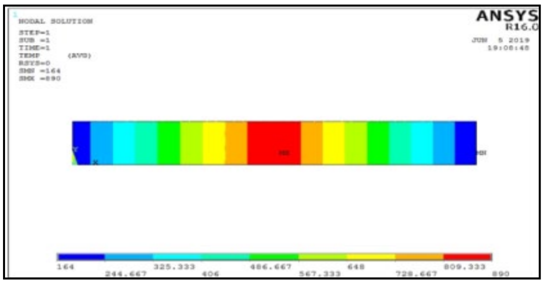


Figure 13c. Nodal solution of ϕ8 mm.

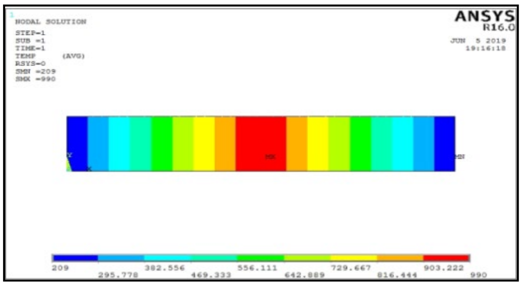
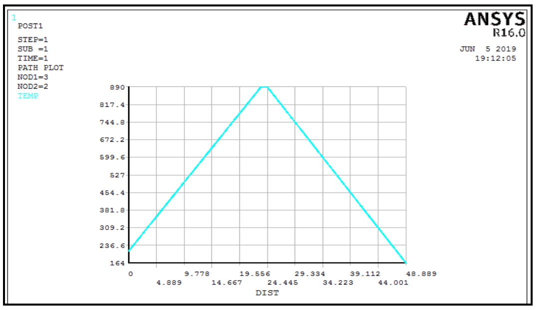
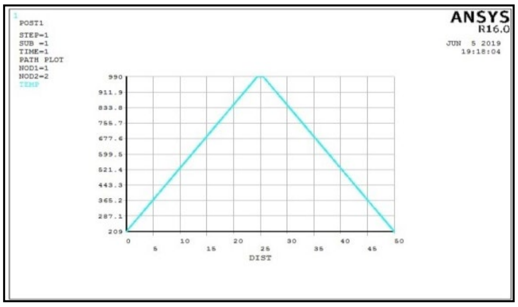


Figure 14c. Nodal solution of ϕ10 mm.



Graph 4. Temp. distribution (ϕ8 mm)



Graph 5. Temp. distribution (ϕ10 mm)

Dist. (mm)	-20	-10	0	10	20
Temp. (°C)	403	609	890	590	375

Table no. 8: Analytical Temperatures of ϕ8 mm.

Dist.(mm)	-20	-10	0	10	20
Temp. (°C)	490	670	990	650	460

Table no. 10: Analytical Temperatures ϕ10 mm.

Dist.(mm)	-20	-10	0	10	20
Temp (°C)	419	623	890	603	391

Table no. 09: Experimental Temp. of ϕ8 mm.

Dist.(mm)	-20	-10	0	10	20
Temp (°C)	483	657	990	662	445

Table no. 11: Experimental Temp. of ϕ10 mm.

The temperature at the center is 890°C and at the ends are 164°C and 181°C respectively.

The temperature at the center is 990°C and at the ends are 218°C and 209°C respectively.

Future Scope
Explore the evaluation of microstructure by using different diameter. Measure and correlate fatigue and corrosion properties with different friction welding parameters. Welding parameters (Weld time, Burn off length, rpm.) which could be varied individually to see their individual effects rather than combining these parameters. After residual stress measurements, we can carry out the fracture analysis of welding components and modeling of residual stress generation during friction welding could also be carried out.

Conclusion
This work concerns the rotary friction welding of stainless steel SS 304, specimen dia. ϕ 8 mm and ϕ 10 mm. The various parameters studied for the process is rpm, weld time, temperature, pressure, heat affected zone, and the 2D modeling and steady state transient thermal analysis has been carried out for the selected specimen. This experimental work showed that this steel was successfully welded by rotary friction welding process. According to tensile test result analysis that the tensile strength for specimen of ϕ8 mm is 271.67 MPa and the strain obtained is 6.9 %. And for specimen of ϕ10 mm is 292.361 MPa and the strain obtained is 6.6 % respectively. It has been observed that if the diameter increases tensile strength also increases.

From the experimentation it has been observed that as the rotational speed increases the tensile strength increases. According to thermal analysis the stresses generated because of temperature distribution along weld specimen. The micro-structure analysis is done for metallurgical phase which are generated at welded joint. From the micro-structure study it has been observed that after heating for ϕ8 mm coarse austenitic grains are formed and for ϕ10 mm fine grains are formed. After cooling for ϕ8 mm coarse martensitic grains are formed and for ϕ10 mm tempered martensitic grains are formed. By taking the cross section of specimen it has been observed that actual heat affected zone (HAZ) for ϕ8 mm & ϕ10 mm is not more than 30 mm. According to thermal analysis stresses generated because of temperature distribution along weld specimen. This is measured analytically and validated with the experimental temperatures.

The experimental rotary friction welding set-up was found to be successful for the production of friction welds. The rotational speed of the job has been found to be an influential parameter for the friction welding process, which has been optimized for the process based on the results of the study. The mechanical properties of the friction welds were found to vary with the applied axial pressure.

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