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An Experimental Approach to Study the Effect of Process Parameters on Tensile Strength of Friction Welded Interface of Dissimilar Metals AISI304/4340

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ABSTRACT

Rotary Friction Welding is successfully used for joining of stainless steel 304 and low alloy steel 4340 by varying three parameters namely rotational speed, friction pressure and friction time at three different levels. Fixed parameters are length and diameter of the specimen. Taguchi approach is used to design experimental layout. A total number of experiments conducted is nine. For each experiment, three specimens are made. In this study, it is found that for achieving a sufficient tensile strength on the joint-interface, the friction time should be held as short as possible, while the rotational speed and friction pressure should be as high as possible.

Keywords: *Rotary Friction Welding, Friction Pressure, Joint-Interface, Taguchi Approach*

1. INTRODUCTION

Friction welding method was investigated in the 1960s by Vill and Tylecote. Friction welding has been used in the United States and Europe for more than 50 years. While well-known to some, it's been a very well-kept secret. Sometimes it is referred to as spin weld or spin welding because one part is rotated in process. As customers learn and understand the process, benefits become clearly obvious.

Friction welding is one of the joining techniques and is a solid state joining process in which components are brought into contact and with one of them remaining stationary, the other is rotated while pressure is applied. When the temperature of the interface has reached an appropriate value for plastic deformation, the rotation is halted, while the pressure remains unchanged or increased [1–4].

A wide range of materials may be joined by friction welding – similar metals, dissimilar metals, alloys, and non-metals. At present joining of dissimilar metals has increased due to the fact that friction welding does not involve melting and the weld zone undergoes thermo-mechanical working that results in a refined grain structure in the bond zone [5] whereas fusion welding for the joining of austenitic stainless steels to low alloy steels is a major problem due to the difference in their coefficients of thermal expansion.

There is no requirement of the filler metals and high cooling rate favours the formation of a fine microstructure so that can enhance material strength [6]. The friction welding process also permits the production of high-quality joints with little or no need for post-weld machining. Many factors affect the quality of friction welds, including friction time, forging time, friction pressure, forging pressure, rotational speed and so on. In this study austenitic stainless steel AISI 304 and low alloy steel, AISI 4340 are joined on Rotary Friction Welding (RFW) by using three parameters at three different levels. From the point of view of economics, in fossil fuel fired power plants, the use of stainless and low alloy steels in combination becomes essential to take 'simultaneous advantages of the high strength of low alloy steel and the corrosion resistance of stainless steel.

Design of experiment (DOE) and statistical techniques are widely used for optimization of process parameters [6]. In the present study, the welding process parameters of the laser beam can be optimized to maximize the tension strength, bending strength of the work piece also reducing the number of experiments without affecting the results [5].

The optimization of process parameters can improve quality of the product and minimize the cost of performing lots of experiments and also reduces the wastage of the resources. The optimal combination of the process parameters can be predicted.
This work is concerned with the effects of welding process parameters on the tensile strength of AISI304 and AISI4340. The objective of this study is to find out the optimal combination of the parameters such as rotational speed, friction pressure and friction time and maximize the tensile strength. Experiments are designed by the Taguchi method using an L- 9 orthogonal arrays that is composed of three columns and nice rows. This design is selected based on three welding parameters with three levels each. The selected welding parameters for this study are rotational speed, friction pressure and friction time. The S/N ratio for each level of process parameters is computed based on the S/N analysis. There are three categories of the quality characteristic in the analysis of the signal-to-noise (S/N) ratio, i.e. the smaller-the-better, the larger-the-better and the nominal-the-best. In this experiment, the target is to maximize the tensile strength and bending strength, therefore, the optimal level of the process parameters is the level with the highest S/N ratio i.e larger the better [5, 6]. Statistical analysis of variance (ANOVA) is also performed to indicate which process parameters are statistically significant; the optimal combination of the process parameters can then be predicted [5].

The process can be described best in the three stages as follows:
STAGE 1: Component in the spindle is brought up to pre-determined rotational speed and then a pre-determined axial force is applied. (Figure 1.1)
STAGE 2: These conditions are maintained for a pre-determined amount of time until desired temperatures and material conditions exist. (Figure 1.2)
STAGE 3: Rotational speed is then stopped and axial force is applied until desired upset is obtained. Then the components are unloaded and the cycle is repeated.

Figure 1.1

Figure 1.2

Figure 1.3

1.1 FRICTION WELDING
Friction welding (FRW) is a solid-state welding process that generates heat through mechanical friction between work pieces in relative motion to one another, with the addition of a lateral force called "upset" to plastically displace and fuse the materials.
The ability to create near-net shape blanks offers manufacturers an opportunity to reduce material consumption and shorten machining cycle time. Joining dissimilar metals like stainless steel alloys to other metals provides unique design flexibility.

1.1.1. Inertia / Spin / Rotational Welding
This system consists of two chucks for holding the materials to be welded, one of which is fixed and the other rotating. Before welding one of the work pieces is attached to the rotating chuck along with a flywheel of a given weight. The piece is then spun up to a high rate of rotation to store the required energy in the flywheel.

Once spinning at the proper speed, the motor is removed and the pieces forced together under pressure. The force is kept on the pieces after the spinning stops to allow the weld to set. Three interrelated parameters control the character of the weld. These are:

- Initial sliding velocity at the faying surface
- Moment of the inertia of the flywheel
- Axial thrust force at the welding interface

All these depend upon the combination of materials and the configuration of the weld.
For more understanding:

- One component rotated rapidly, the other is stationary. (Figure 1.4)

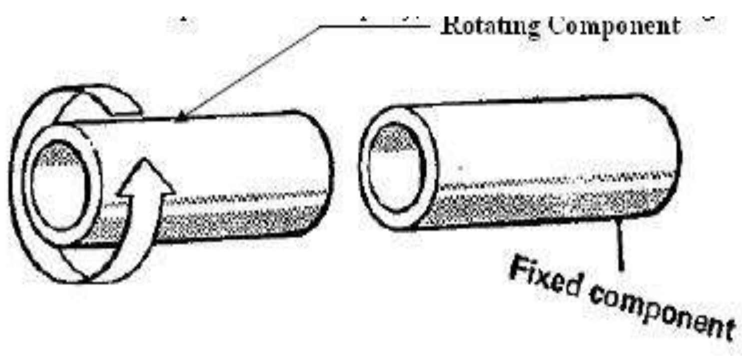

Figure 1.4 Showing Rotating and Fixed Components

- Rotating and stationary components brought together into contact and force applied. (Figure 1.5)

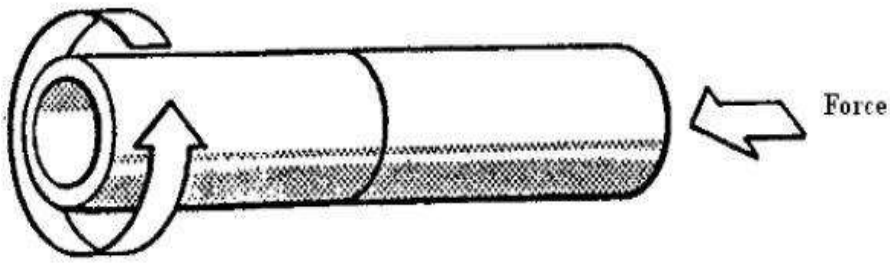

Figure 1.5 Both the Components Are on Same Axis

- An axial force is increased to bring components into a plastic state at the interface.(Figure-1.6)

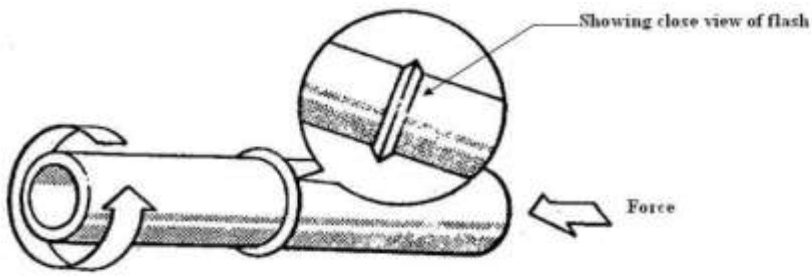

Figure 1.6 Flash Formed By Increasing Force

- Rotation is stopped and more axial force is applied known as forge force. (Figure-1.7)

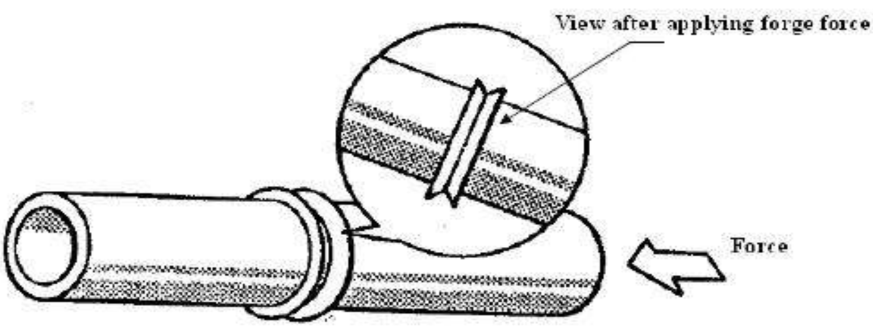

Figure 1.7 Components after Welding

- Result - A full cross sectional weld in the parent material after machining operations. (Figure-1.8)

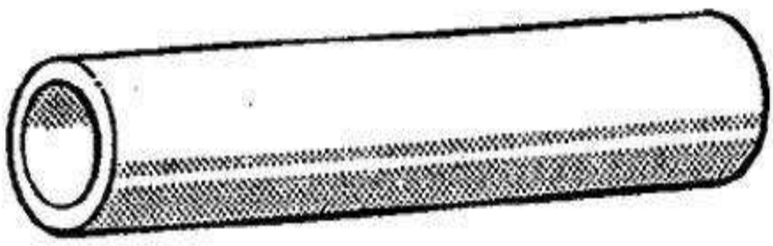

Figure 1.8 Single Piece Rod after Machining Operations

2. LITERATURE SURVEY

Hong Ma, Guoliang et al. 2015: Friction welded stainless steel 304 to carbon steel 1045 (length 50mm and diameter 10mm) and studied their microstructure variation and mechanical properties [8]. They found that on carbon steel side, a thin proeutectoid ferrite layer forms along weld interface where as on stainless steel side, austenite grains are refined to submicron scale. The δ-ferrite existing in stainless steel decreases from base metal to weld interface and disappears near the weld interface. They also found that the micro-hardness at the weld interface is higher than that in TMAZ and HAZ due to the formation of carbide layer and fine grains whereas tensile strength and elongation first rise to the maximum, and then decrease with increase in friction pressure and friction time.

Serdar Mercan et al. July 2015: Examined the effect of welding parameters on the fatigue properties of dissimilar AISI 2205-AISI 1020 (length 70mm and diameter 12mm) joined by friction welding [9]. They found that welding connections at 1300rpm and different frictions pressures at 30or50Mpa the tensile strength and fatigue strengths increased where as for the same pressures welding connection at 1500rpm the tensile strength and fatigue decreased.

Y. Fu et al. 2015: Joined blocks of cold rolling steel of AISI 321 stainless steel at different parameters considering friction time of 10s, the frequency of 35Hz, the amplitude of 3mm and pressure of 50MPA and studied microstructure evaluation of AISI 321 stainless steel [10]. The results show that Rotary friction welding AISI 321 joint has a distinct weld zone (WZ) and thermo-mechanically affected zone (TMAZ). They concluded that Microstructural analyses show substantially defect-free AISI 321 stainless steel joint. The welded joint can be divided into the WZ, the TMAZ, and the PM. The WZ presents a narrow band of about 400μm thick, which is characterized by a fine-grained recrystallized structure with the average grain size of 2.3μm. In addition, the WZ shows a strong (001) <110> type texture, namely rotation-cube texture. The TMAZ changes in thickness and shows a typical streamline distribution. The direction of the streamlined structure shows the flow and deformation direction of yielded material during welding.

F. Rotundo et al. 2010: The aim of this study is to evaluate the possibility of using the linear friction welding (LFW) technique to produce sound joints on a 2124Al/25 vol. % SiCp composite [11]. The MMC joints were subjected to micro structural and mechanical characterization, including hardness, tensile and fatigue tests, without any post weld heat treatment. The micro structural analyses showed substantially defect-free joints, with a uniform particle distribution in the central zone and a relevant plastic flow of the aluminium matrix alloy. The hardness decrease in the welded zone was approximately 10% with respect to the base material. The joint efficiency was higher than 80%, both with respect to the ultimate tensile strength and fatigue strength at 107 cycles. S-N probability curves were calculated using the maximum likelihood method. Generally, the fracture occurred in the Thermo-Mechanically Affected Zone (TMAZ), with a relevant reduction in the elongation to failure.

Hazman Seli et al. 2010: In friction welding of two dissimilar materials, two rods are welded together by holding one of them still while rotating the other under the influence of an axial load which creates frictional heat in the interface [12]. In this study, mechanical properties of mild steel and aluminium welded rods were evaluated to understand the thermal effects, and an explicit one-dimensional finite difference method was used to approximate the heating and cooling temperature distribution of the joint. The thermal effects of the friction welding were observed to have lowered the welded materials hardness compared to the parent materials. The tensile strength of the welded rods is lower than the parent rods due to incomplete welding. The preliminary predictions were compared to actual thermocouple data from welds conducted under identical conditions and were shown to be in fair agreement. The finite difference method proposed in this work will provide guidance in weld parameter development and will allow a better understanding of the friction welding process.

H.C. Dey et al. 2009: This paper gives the details of mechanical tests, microstructure analysis using optical and scanning electron microscopy [13]. The dissimilar metal joint of titanium (Ti) to 304L stainless steel (SS) is essential in the nuclear industry for the dissolution of spent fuel that is carried out in boiling nitric acid in the dissolver vessel (made of Ti) and the dissolved solution is transported through the 304L SS pipes to the other plant components made of 304L SS. Because of the radioactive environment, leak tightness and corrosion resistance of this dissimilar joint are important.

In this work, friction welding process was attempted to join Ti to 304L SS. Direct friction welding of Ti to 304L SS results in a stronger weld in which failure occurs in the Ti base metal during tensile testing.

However, the joints have almost zero bend ductility that has been attributed to the formation of inter-metallics due to mechanical alloying, strain hardening of Ti near the joint interface and residual stresses. Post-weld heat treatment marginally increases the bend ductility to 5°because of relieving of the effects of strain hardening and of residual stresses at the joint interface. Corrosion test in boiling nitric acid is as per ASTM A-262 practice.

D. Ananthapadmanaban, v et al. 2009: Joined mild steel and stainless steel (length 75mm and dia. 15mm) by friction welding maintaining a constant rotational speed of 1500rpm at different friction pressure, upset pressure and burn-off length [14]. They examined the quality of the weld by tensile and hardness test and fractured surface by using scanning electron microscopy. The results indicated that Vickers hardness increases at the interface with increased hardness at (HAZ) SS side for all samples. Tensile strength first increases then decreases with the certain increase. SEM micrographs of the fractured surface show ductile fracture with a dark region which may be due to element sulphur and phosphorous.

Koen Faes et al. 2009: A new welding method for fully automatic welding of pipelines has been developed by Keon Faes et. Al [15]. The proposed welding procedure, called Friex, is a new variant of the well-known friction welding process. An intermediate ring is rotated in between the pipes to be welded to generate the heat necessary to realize the weld. In the first part of this paper, the working principles of the Friex welding process are briefly described. The influence of the rotation speed on the weld properties is discussed for welding 3 in. pipes in the pipeline steel API-5L X52. Two normalized fine-grained sheets of steel were used for the welding ring. The optimization of the thickness of the welding ring is also discussed in this paper.

Mumin Sahin 2009: An experimental set-up was designed in order to achieve friction welding of plastically deformed austenitic-stainless steels [16]. AISI 304 austenitic-stainless sheets of steel having equal and different diameters were welded under different process parameters. Strengths of the joints having equal diameter were determined by using a statistical approach as a result of tension tests. Hardness variations and microstructures using scanning electron microscope (SEM) analysis in the welding zone were obtained and examined. Subsequently, the effect on the welding zone of plastic deformation was analyzed. It has been established that plastic deformation of AISI 304 austenitic-stainless steel has neither an effect on the process nor on the strength of the welding joint.

D. Ananthapadmanaban, et al. 2009: The aim of this work was to study mechanical property variation under different friction welding conditions for mild steel stainless steel joints by D. Ananthapadmanabam et. Al [17]. Yield strength, ultimate tensile strength, percentage elongation of the welded joints and hardness variations across the weld interface has been reported. The integrity of the joints has been investigated using optical microscopy and scanning electron microscopy.

Sahin M et al. 2008: In this stainless-steel and aluminium were joined by friction welding. Friction time, friction pressure, upset time, upset pressure has been measured the welding was investigated by micro hardness and tensile strength and welded portion was analyzed by EDX (Energy Dispersive X-Ray). The optimum parameter was observed 4 sec Friction Time, 30Mpa Friction Pressure, 12sec Upset Time, 60Mpa Upset Pressure. The interface of joint tensile strength was increased and then decrease by the variation of friction time. The impurities in between interface may tend to produce the poor joint also. The hardness of base metal and joint are proximity to each other.

P. Sathiya et al. 2008: This study emphasizes on joints of two types of industrially important stainless steels such as austenitic and ferritic stainless steels [19]. The present study utilized a continuous drive friction welding machine to process similar joints. Cylindrical specimens of austenitic stainless steel and ferritic stainless steel of similar composition and shape (equal diameter and length) were used in this study. The processed joints were tested through uni-axial tension test, impact test, and hardness test. Microstructural studies were also carried out. The characteristics such as tensile strength, toughness, hardness across the joint zone and microstructural aspects exhibited by friction processed joints were compared to the respective parent materials. Joints processed by this method exhibited better properties when compared to the fusion processed joints.

N. Ozdemir et al. 2007: The aim of this study is to investigate experimentally the interface properties in terms of rotational speed in friction-welded AISI 304L to AISI 4340 alloy steel [20]. Friction welding was conducted at five different rotational speeds using a direct-drive type friction welding machine. Friction pressure, forging pressure, friction time and forging time are fixed. The integrity of joints was investigated by scanning electron microscopy, while the mechanical properties assessments included micro hardness and tensile tests. The experimental results showed that the thickness of full plastic deformed zone (FPDZ) formed at interface reduce as a result of more mass discarded from the welding interface with an increase of the rotational speed. It was also observed that the width of the FPDZ has an important effect on the tensile strength of friction-welded samples and the tensile strength increases with the increase of the rotational speed.

Mumin Sahin July 2007: Joined austenitic stainless steel AISI 304 parts (diameter 10mm) by rotary friction welding. He changed friction time and friction pressure keeping other parameters constant. Later he examined the strength of joint by tensile, fatigue and notch impact test and results were compared with the strength of the base material. He concluded that tensile strength of joint increases together with friction time and friction pressure then decreases, fatigue strength of welded joint decreases as compared to base material and Vickers hardness of the joint decreased at interface zone whereas notch-impact toughness is twice as that of AISI304 parts, base metal which can resist against dynamic and static loads.

Mumin Sahin, et al. 2007: Joined two similar metals i.e. AISI 1040 having the same diameter of 10mm by using optimum parameters having friction time of 5s and friction pressure of 30Mpa keeping the upset time and upset pressure constant at the 20s and 110MPa and investigated the welding strength by tensile tests, fatigue tests, notch-impact tests and hardness tests. He concluded that tensile strength first increases then decreases with a change in friction pressure and friction time keeping upset pressure 110MPa and upset time 20s constant, fatigue strengths of welded parts are very close to those of 1040 steel, base metal, the notch-impact toughness is slightly bigger than that of AISI 1040 parts, base metal. As a result, welded parts can easily resist both static and dynamic loads while maximum Vickers hardness on horizontal distance is obtained from the weld interface, maximum hardness on vertical distance is obtained towards end parts.

3. EXPERIMENTATION

3.1 EXPERIMENTAL SETUP DESIGN

The experimental setup has been fabricated for the production of friction welded joints. For this, the conventional heavy duty direct drive lathe machine has been modified to suit the requirements of friction welding machine. The existing lathe machine model **"**HMT**"** speed range 30–2000 rpm, is used for this experimentation work. The modifications are done by fitting two tail stocks on the lathe machine. A triangular fixture is designed and fitted with these two tail stocks, to measure the axial pressure applied to the specimens. For the fabrication of the load cell, the master brake cylinder made by TATA is used and the fluid filled inside the brake cylinder for transmitting the power is DOT-4. Pressure gauge, with a range of 0–100 MPa, is mounted on the brake cylinder so as to measure axial pressure. Hydraulic ram fitted pressure gauge is used in between two tail stocks supported by the triangular fixture. The handle of the original tail stock is removed to accommodate the load transmitting rod so that the barrel of this tail stock is being guided by the load transmitting rod. At the end of this barrel, a specimen holder is fitted. This holder securely holds one of the specimens very rigidly.

Figure 3.1: A Lathe Machine With A Setup Used For Experiment **Figure 3.2: Joining of Specimen in Progress**

Table 3.1: Technical Specifications of The Lathe Machine

Height of centres	Mm	220
Swing over bed	Mm	500
Swing over cross slide	Mm	270
Swing in gap (optional)	Mm	720
Distance between centres	Mm	1000/ 1500/ 2000 /3000
Spindle Nose/ Bore	Mm	A2-6* / 53
Spindle speed range	Rpm	16 from 40-2040 forward 7 from 60-1430 reverse
Spindle power	kW	11
Feed rang (longitudinal)	mm/rev	60 from 0.04 – 2.24
Feed range (cress)	mm/rev	60 from 0.02 - 1.12
Lead screw pitch	mm	6
Metric threads	mm	48 from 0.5 – 28

Inch threads	tpi	60 from 56 – 1
Module threads	mm	40 from 0.25 – 14
Diametral pitch (optional)	mm	43 from 0.25 – 14
Tailstock sleeve travel	mm	200
Power supply	415 v, 3 Phase, 50 Hz AC	7.5 (std.) / 11.0 (opt)
Weight	Kg	1000

3.2 Experimental set-up

The friction welding set-up is designed and constructed for the experimental part of this study. The photo of the set-up is shown in Fig 3.1

3.3 Specimen Specifications

The following are the specifications which will be used:

- Length of specimen: 60mm (each)
- Diameter of specimen: 12mm

3.4 Chemical Composition

The chemical composition of the specimens of AISI304 and AISI4340 is checked with the help of a Spectrometer.

Table 3.2 Chemical compositions of Stainless steel 304 by weight%

Material	Weight%
C	0.033
P	0.037
S	0.005
Mn	1.46
Si	0.28
Cr	18.31
Ni	8.34
Mo	0.313
Fe	71.22

Table 3.3 Chemical compositions of parent metal AISI 4340 by weight%

Material	Weight%
C	0.41
P	0.018
S	0.007
Mn	0.64
Si	0.25
Cr	0.87
Ni	1.77
Mo	0.26
Fe	95.77

Two cylindrical specimens of same size 60 mm lengths & 12mm diameter are used in the experiment. Austenitic stainless steel AISI 304 and low alloy steel AISI 4340 are friction welded using Rotary friction welding.

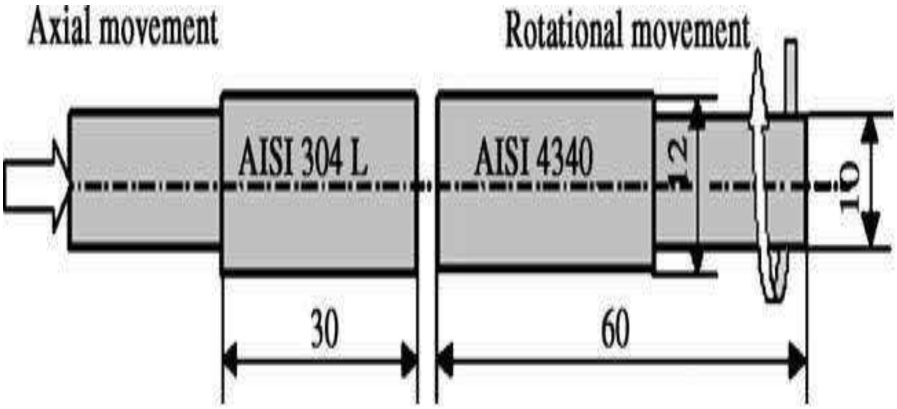

Figure 3.6: The Welding Assembly of Friction Welded Aisi 304/4340 Components

Fig 3.7 Joining of AISI304/4340 at Lathe Machine

A special set up is made is order to join stainless steel and low alloy steel of diameter 12mm and lengths 60mm each. Firstly it was observed that the metals did not join due to the movement of a specimen later the problem of movement of a specimen was overcome by using collet nut which was inserted in the chuck thus metals are successfully joined.

Figure 4.8 Samples of AISI 304 and AISI 4340 joined by RFW

Figure 4.9 Joint-interface of AISI 304/434

3.5 VARIED PARAMETERS

3.5.1 Friction Pressure

This is the longitudinal force applied to the faying surfaces at the time when relative movement between the specimens is ceasing and/or has ceased. This is usually higher than the friction force.

3.5.2 Revolutions per Minute

It is the revolutions of the rotating chuck in a minute. Revolutions can be set according to the requirement.

3.5.3 Friction Time

It is the time taken to joining the two similar or dissimilar metals.

3.6 FIXED PARAMATERS

The following parameters are kept constant throughout the experiment.

- Diameter of the specimen: 12mm
- Total length of the specimen: 120mm (60mm each)

3.7 TEST MATRIX

Three parameters rotational speed, friction pressure and friction time which have been vary are shown in table 3.4

Table 3.4: Test matrix showing parameters varied at different levels and no. of specimens for each Experiment

No. of Experiments	Rotational Speed (rpm)	Friction Pressure (MPa)	Friction Time (sec)
1.	1120	30	5
2.	1120	40	8
3.	1120	50	12
4.	1400	30	8
5.	1400	40	12
6.	1400	50	5
7.	2000	30	12
8.	2000	40	5
9.	2000	50	8

3.8 TESTING OF FRICTION WELDED SPECIMENS

4.8.1 Tensile testing

The tensile testing of friction welded specimens is performed on the Universal Testing Machine (Figure 4.9)

Figure 3.11 Specimen to be tested on UTM

Figure 3.12 Universal Testing Machine (UTM)

Figure 3.13 Specimen under Load on UTM

4. RESULTS & DISCUSSIONS

The effects of parameters i.e. rotational speed, friction pressure and friction time are evaluated using ANOVA - Taguchi analysis. A confidence level of 95.7% has been used for the analysis. One repetition of every 9 trials is completed to measure the Signal to Noise Ratios (S/N Ratio). In order to evaluate the influence of each selected factor on the responses. The S/N ratios for each control factor had to be calculated. Suitable S/N ratio must be chosen. It is possible to choose the S/N ratio depends on the aim of the design. In this study, the S/N ratio is selected according to the criterion the bigger-the better, in order to maximize the responses.
The experimental lay-out for the welding process parameters using the L9 orthogonal array is shown in Table 4.1. Show how each factor affects the response characteristic. The main effect plots for S/N ratio exhibited in Fig. 4.2 created by MINITAB 15.

Taguchi Design

Taguchi Orthogonal Array Design L9 (3*3) Factors: 3 Runs: 9 Columns of L9 (3*3) Array 1 2 3

5. RESULTS FOR TENSILE STRENGTH

The results of the tensile strength measurements for the AISI 4340/AISI 304 are examined using Universal Testing Machine (UTM). The results of tensile strength for each of the 9 samples are shown in Table 4.1

Table for 4.1 Results for TENISLE STRENGTH

S. No.	Rotational Speed (rpm)	Friction Pressure (MPa)	Friction Time (sec)	Tensile Strength (MPa)	SNRA13	MEAN13
1.	1120	30	5	440	52.8690	440
2.	1120	40	8	515	54.2361	515
3.	1120	50	12	500	53.9794	500
4.	1400	30	8	641	56.1375	641
5.	1400	40	12	622	55.87581	622
6.	1400	50	5	732	57.2902	732
7.	2000	30	12	540	54.6479	540
8.	2000	40	5	590	55.4170	590
9.	2000	50	8	600	55.5630	600

5.1 ANALYSIS OF VARIANCE - TENSILE STRENGTH

The result of tensile strength is analyzed using ANOVA for identifying the significant factor affecting the performance measure. The analysis of variance ANOVA for the mean tensile strength at 95.7% confidence level is given in the table below. The various data for each factor and their interaction is P value find for the significant of each if the value is more than 0.05 then the factors or interactions are significant. ANOVA table for means shows that value of rotational speed is, friction pressure value is, and friction time value is, which is insignificant, in the table 5.4 ranks are shown for different factors. The first rank is given to rotational speed which means that rotational speed has the highest contribution for tensile test, the second rank is given to friction pressure and the third rank is given to friction time which means that friction time has the less contribution in a tensile test.

Linear Model Analysis: Means versus, Rotational Speed, Friction Pressure and Friction Time

Table 4.2 Analysis of Variance ANOVA for MEANS

Term	DOF	Seq SS	Adj SS	Adj MS	F	P	Contri %age	Status
Rotational Speed	2	48606	48606	24303	18.60	0.049	80.50	Significant
Friction Pressure	2	45677	7420	3710	2.84	0.045	75.65	Significant
Friction Time	2	2097	2097	1048	0.80	0.555	3.47	Insignificant
Residual Error	2	2614	2614	1307	----	----	----	----
Total	8	60736	----	----	-----	----	----	----

Table 4.3 Response Table for MEANS

Level	Rotational Speed (rpm)	Friction Pressure (MPa)	Friction Time (sec)
1	485.0	540.3	587.3
2	665.0	575.7	585.3
3	576.7	610.7	554.0
Delta	180.0	70.3	33.3
Rank	1	2	3

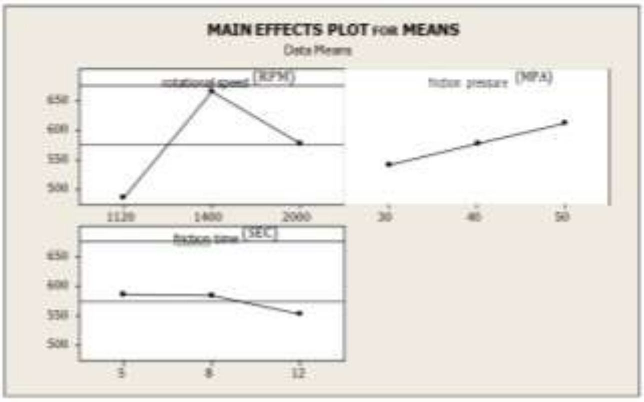

Figure 4.1 Main Plot for Means

Figure 4.1 shows that the tensile strength is more at 1400rpm and 50MPa friction pressure as compared to 1120rpm at different friction pressure and 2000rpm at varied friction pressure. Among the three different parameters, the best result is at found 1400rpm when the pressure is maximum and friction time is minimum. The tensile strength slightly decreased with increasing rotational speed. The fracture mainly occurred at the AISI 304 steel side.

5.5 OPTIMAL DESIGN FOR TENSILE STRENGTH

The same level of all the significant factor provides a higher mean value and reduced variability so nothing has to be compromised. The level of a factor which improves average and uniformity may conflict, so a compromise may have to be reached. Also, compromise has to occur when multiple responses to improve the other deteriorate.

In this experiment of the main effect plot in Figure 4.1 Is used to estimate the mean Bending strength from table 4.2 it is concluded that highest bending strength is observed when the rotational speed is 1400rpm, friction pressure is 50Mpa and friction time is 5sec.

Table 4.4 Significant factors

Factor	Mean Affecting		Variation Affecting	
	Contribution	Best level	Contribution	Best level
Rotational Speed A	Significant	Level-(2)1400	Significant	Level-(2)1400
Friction pressure B	Significant	Level-(3)50	Significant	Level-(3)50
Friction Time C	Significant	Level(1)5	Significant	Level-(1)5

In the experimental analysis, the tensile strength with the higher average response is better characteristic. Depending on the characteristic Different treatment and combination is used to obtain an optimizing result. After conducting the experiment the optimum treatment condition with in the experiment determined on the basis of prescribed combination factor levels is determined to one of those in the experiment.

Mean Value = μ A2 B3 C1 = A2 + B3+ C1-2T

$=\mu_{A2B3C1}$ = 665.0+610.0+587.3-2(575.56) = 1862 -1151.12

= 710.78

Confidence Interval around Estimated Mean

The confidence interval is a maximum and minimum value between which the true average value should fall some stated percentage of confidence. The estimate of the mean μ is only the point estimate based on the average of results obtained from the experiment statistically provide 50% chance of the true average value being greater than μ and**,** a 50%**,** chance of the true average being less than μ.

$$CI_1 = \sqrt{Fa, v1, v2Ve/\eta eff}$$

Where FaV_1V_2=F ratio

a =Risk (0.001) Confidence=1-a

V_1= DOF for mean which is always =1

V_2 =DOF for error =V_e

ηeff =Number of tests under that condition using the participating factor.

ηeff =(N/1+DOF$_{A1+B3+C1}$) =9/1+2+2+2= 1.28

$CI_1 = \sqrt{(1.512 \times 1.18/1.28}\ = 1.35$

So that confidence interval around the tensile strength is given =710.78 ± 1.35 Mpa

6. CONCLUSIONS

In the presented study, AISI304 to AISI4340 are joined by Rotary Friction Welding (RFW) at different rotational speeds, friction pressure and friction time. The effect of tensile strength, bending strength and microstructure of friction welded interface of AISI304/4340 is investigated. From this study, it is concluded that:

- The tensile strength and bending strength are mainly affected by rotational speed and friction pressure.
- The low values of tensile strength and bending strength can be attributed to the presence of aligned chromium precipitation.
- By increasing, rotational speed and friction pressure tensile and bending strength of the interface can be increased.

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