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An Investigation of Mechanical And Metallurgical Properties of Friction Welded Steel Joint

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Abstract:- Friction welding is a solid state welding process which can be used to join similar as well as dissimilar materials. The rotational speed is kept constant and the other process parameters such as heating pressure, upset Pressure, heating time and upset time are varied using Taguchi L9 orthogonal array technique.Micro Vickers hardness test was conducted to identify the strength .As per ASTM standardsTensile test were conducted on the welded specimens. SEM, EDX were conducted at the friction welded joints to know the phases which occurred during the welding process and the inter-metallic compounds which affected the weld strength. Two dissimilar steel material such as SS316-SS304 and SS316L-SS304 are welded using friction welding in order to increase the mechanical and metallurgical properties of the material.

I. INTRODUCTION

The ideas of using heat obtained by friction in welding and forming of materials are not new. Friction welding obtained by frictional heat is a commercial process, which has found several applications in different parts of the world with the advancement in technology. First, simple devices having lathe machine type and metal rods have been used in butt welding trials. However, these studies can only be regarded as preliminary technical trials with little practical importance. The first trial of friction welding goes back to the 15th century and the first patent wasgranted to J.H. Bevington. A Russian machinist named A. J. Chdikov has realized scientific studies and suggested the use of this welding method as a commercial process. He has successfully done a welding process between two metal rods and patented this process in 1956. Vill and his colleagues have further investigated the process with a number of studies. Researchers of American Machine and Foundry Corporation named Holland and Cheng have worked on thermal and parametrical analysis of friction welding. By the way, the first studies of friction welding in England were carried out by the Welding Institute in 1961. By modifying the friction welding, the Caterpillar Tractor Co. in the USA developed the method of inertia welding in 1962. Afterthis study, conventional friction welding has been regarded as the Russian type process and inertia welding asthe Caterpillar type process. With these advances, applications of friction welding have found several applications throughout the world. Friction welding is one of the most widely used welding methods in the industry after electron beam welding.

II. FRICTION WELDING

Friction welding (FRW) is a solid-state welding process that generates heat through mechanical friction between workpieces in relative motion to one another, with the addition of a lateral force called "upset" to plastically displace and fuse the materials. Because no melting occurs, friction welding is not a fusion welding process in the traditional sense, but more of a forge welding technique.

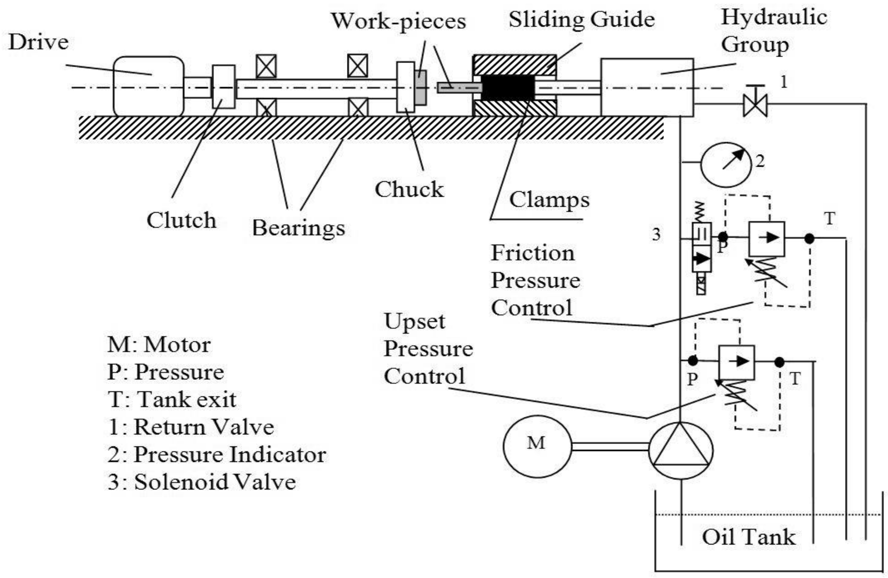

Fig 1. Friction welding.

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Friction welding is used with metals and thermoplastics in a wide variety of aviation and automotive applications. Friction welding is a type of forge welding, i.e. welding is done by the application of pressure. Friction generates heat, if two surfaces are rubbed together, enough heat can be generated and the temperature can be raised to the level where the parts subjected to the friction may be fused together.

In conventional friction welding, relative rotation between a pair of workpieces is caused while the work pieces are urged together. Typically thereafter once sufficient heat is built at the interface between the workpieces, relative rotation is stopped and the workpieces are urged together under forging force which may be same as or greater than the original urging force.

"Friction welding" (FW) is a group of solid-state [welding] processes using heat generated through mechanical friction between a moving workpiece, with the addition of an upsetting force to plastically displace material. Many dissimilar metal combinations can be joined and there are a number of process variations including:

III. TYPES OF FRICTION WELDING

A. Linear friction welding

Linear Friction Welding (LFW) is seen a key technology for the aerospace industry as it enables the joining of difficult to bond materials, can be used as a repair process, and to build the complex structures required for today's gas turbines. Essentially, it is a non-melting fusion process producing high integrity welds with little prior surface preparation required.Linear friction welding, (so named because the relative motion is linear across the interface, rather than rotary), is already used to join blades onto discs in the aero engine industry. Lower cost linear friction welding machines are now being developed for automotive applications, such as the fabrication of brake discs, wheel rims and engine parts. As the parts to be welded are forced into intimate contact, a fully reversed motion is imposed on part of the system. This generates frictional heat in the immediate region about the weld plane, thereby softening a finite volume of material.As the weld proceeds, a portion of this visco-plastic layer is extruded at the periphery of the weld interface, in rippled sheets of metal known as flash. This should ensure that any interfacial contaminant is expelled. The combination of fast joining times of the order of a few seconds, and the direct heat input at the weld interface, gives rise to relatively small heat affected zones. This, by judicious selection of components geometry, this also limits process induced distortions.

B. Spin welding

Four different phases can be distinguished in the vibration welding process; the solid friction phase, the transient phase, the steady-state phase and the cooling phase.

In the solid friction phase, heat is generated as a result of the friction between the two surfaces. This causes the polymer material to heat up until the melting point is reached. The heat generated is dependent on the applied tangential velocity and the pressure.

In the second phase, a thin molten polymer layer is formed which grows as a result of the ongoing heat generation. In this stage heat is generated by viscous dissipation. At first only a thin molten layer exists and consequently the shear rate and viscous heating contributions are large. As the thickness of the molten layer increases the degree of viscous heating decreases.

Thereafter, (start of third phase) the melting rate equals the outward flow rate (steady state). As soon as this phase has been reached, the thickness of the molten layer is constant. The steady-state is maintained until a certain "melt down depth" has been reached at which point the rotation is stopped.

At this point (phase 4) the polymer melt cools and solidification starts, while film drainage still occurs since the welding pressure remains. After all the material has solidified, drainage stops and the joint is formed."

C. Rotational friction welding

Rotary friction welding, in which one component is rotated against the other, is the most commonly used of the processes, and many carbon steel vehicle axles and sub-axles are assembled in this way. The process is also used to fabricate suspension rods, steering columns, gear box forks and driveshafts, as well as engine valves, in which the ability to join dissimilar materials means that the valve stem and head can be made of materials suited to their different duty cycles in service.

D. Inertia friction welding

Inertia Friction Welding is a variation of friction welding in which the energy required to make the weld is supplied primarily by the stored rotational kinetic energy of the welding machine. In Inertia Welding, one of the work pieces is connected to a flywheel and the other is restrained from rotating. The flywheel is accelerated to a predetermined rotational speed, storing the required energy. The drive motor is disengaged and the work pieces are forced together by the friction welding force. This causes the faying surfaces to rub together under pressure. The kinetic energy stored in the rotating flywheel is dissipated as heat through friction at the weld interface as the flywheel speed decreases. An increase in friction welding force (forge force) may be applied before rotation stops. The forge force is maintained for a predetermined time after rotation ceases.

E. Friction stud welding

Friction stud welding provides the capability to weld a pattern of studs to the hull of a disable submarine, to which a pad- eye can be attached for the SRC haul-down cable and life support gas can be provided by means of a hot tap process using hollow studs. Combined with an ADS, the system provides rescue capabilities well beyond 300 feet (91m).

Concurrent with the Navy's application for underwater friction stud welding for submarine rescue, Oceaneering pursued the application commercially for offshore platform repairs. However, initial research showed that there was a limited amount of accurate public information on the mechanical properties of underwater friction stud welding. As such, the use of this process for any offshore repair without a full evaluation for mechanical, corrosion, and fatigue would not be acceptable.

F. Friction stir welding

Friction stir welding also produces a plasticised region of material, but in a different manner. A non-consumable rotating tool is pushed into the materials to be welded and then the central pin, or probe, followed by the shoulder, is brought into contact with the two parts to be joined. The rotation of the tool heats up and plasticises the materials it is in contact with and, as the tool moves along the joint line, material from the front of the tool is swept around this plasticised annulus to the rear, so eliminating the interface. Friction stir welding (FSW) is a novel welding technique invented by The Welding Institute (TWI) in 1991. FSW is actually a solid-state joining process that is a combination of extruding and forging and is not a true welding process.

IV. PROCESS PARAMETERS

The Friction Welding Process depends on the following parameters

- **Rotational speed :** Rotational speed of an object rotating around an axis is the number of turns of the object divided by time
- **Heating pressure :** The pressure that is applied while the object is getting heated is called Heating Pressure
- **Forging pressure :** The localized compressive pressure that is applied of the object is called Forging Pressure
- **Heating time:** The time in which the heating of the object takes place is called Heating time.
- **Breaking time:** It is the ultimate time which consists of all the necessary requirements of an object to fail/break.
- **Forging time :**The time under which the forging pressure is applied is called forging time.

V. MATERIAL SELECTION

A. Choice Of Metal

Material selection is a step in the process of designing any physical object. In the context of product design, the main goal of material selection is to minimize cost while meeting product performance goals.

B. Mechanical Properties

Grade	Tensile strength (Mpa)	Yield strength (MPa)	Elongation (%in 50 mm)	Hardness	
				Rockwell	Brinell
304	515	205	40	92	201
316L	485	170	40	95	217
316	708	206	30	79	146

C. Chemical Composition of SS316, 316L, 304

Grade		C	Mn	Si	P	S	Cr	Mo	Ni	N
316	Min	-	-	-	0	-	16	2.00	10.0	-
	Max	0.08	2.0	0.75	0.045	0.03	18.0	3.00	14.0	0.10
316L	Min	-	-	-	-	-	16.0	2.00	10.0	-
	Max	0.03	2.0	0.75	0.045	0.03	18.0	3.00	14.0	0.10
304	Min	-	-	-	-	-	18.0	-	8.0	-
	Max	0.08	2.0	0.75	0.045	0.030	20.0	-	10.5	0.10

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VI. TAGUCHI METHOD

A. Introduction

Taguchi methods are statistical methods developed by Genichi Taguchi to improve the quality of manufactured goods and more recently also applied to engineering biotechnology marketing and advertising Professional statisticians have welcomed the goals and improvements brought about by Taguchi methods, particularly by Taguchi's development of designs for studying variation.

The main objective in the Taguchi method is to design robust systems that are reliable under uncontrollable conditions the method aims to adjust the design parameters (known as the control factors) to their optimal levels, such that the system response is robust – that is, insensitive to noise factors, which are hard or impossible to control. The method presented in this study is an experimental design process called the Taguchi design method. Taguchi design, developed by Dr.Genichi Taguchi, is a set of methodologies by which the inherent variability of materials and manufacturing processes has been taken into account at the design stage.

In contrast, TAGUCHI approach is based on executing one large comprehensive experiment. This approach is not based on the principal of sequential experiment. More specifically a comprehensive experiment is planned assuming that the comprehensive experiment is planned assuming that the objective and all the data analyzed by analysis of variance in term of measure devised by Taguchi know as *signal –to-ratio's.* Finally, based on this calculation, taguchi shows how to choose the ―optimum ―condition.

Taguchi proposed that engineering optimization of a process or product should be carried out in a three-step approach:

a. system design,
b. parameter design,
c. Tolerance design.

System design is the conceptualization and synthesis of a product or process to be used. The system design stage is where new ideas, concepts and knowledge in the areas of science and technology are utilized by the design team to determine the right combination of materials, parts, processes and design factors that will satisfy functional and economical specifications.

Parameter design is related to finding the appropriate design factor levels to make the system less sensitive to variations in uncontrollable noise factors, i.e., to make the system robust. In this way the product performs better, reducing the loss to the customer. The final step in Taguchi's robust design approach is tolerance design;
Tolerance design Occurs when the tolerances for the products or process are established to minimize the sum of the manufacturing and lifetime costs of the product or process. In the tolerance design stage, tolerances of factors that have the largest influence on variation are adjusted only if after the parameter design stage, the target values of quality have not yet been achieved.

The steps included in the Taguchi parameter design are: selecting the proper orthogonal array (OA) according to the numbers of controllable factors or parameters; running experiments based on the Orthogonal array ; analyzing data; identifying the optimum condition; and conducting confirmation runs with the optimal levels of all the parameters. The main effects indicate the general trend of each parameter. Analysis of variance (ANOVA) is the statistical treatment most commonly applied to the results of the experiments to determine the percentage contribution of each parameter against a stated level of confidence of Taguchi suggests two different routes for carrying out the complete analysis. In the standard approach the results of a single run or the average of repetitive runs are processed through the main effect and ANOVA (raw data analysis). The second approach, which Taguchi strongly recommends for multiple runs, is to use the signal-to-noise (S/N) ratio for the same steps in the analysis.

B. Taguchi Optimization Technique – L_9 Array

While there are many standard orthogonal arrays available each of the array is meant for a specific number of independent design variable and levels. For example , if one wants to conduct an experiment to understand the influence of 4 different independent variable with each variable having 3 set value (level Values), then an L9 orthogonal array might be the right choice. The L9 orthogonal array is meant for understanding the effect of 4 independent factors each having 3 factor level values. This array assumes that there is no interaction between any two factor. While in many cases , no interaction model assumption is valid, there are some cases where there is a clear evidence f interaction. A typical case of interaction would be the interaction between the material properties and temperature.

S No	Parameters	Unit	Level 1	Level 2	Level 3
1	Heating Time	Sec	X1	X2	X3
2	Heating Pressure	Bar	Y1	Y2	Y3
3	Upset Time	Sec	Z1	Z2	Z3
4	Upset Pressure	Bar	R1	R2	R3

The Table shows an L_9 orthogonal array.

There are totally 9 experiments to be conducted and each experiment is based on the combination of level values as shown in the table. For example, the third experiment is conducted by keeping the independent design variable 1 at level 1, variable 2 at level 3, variable 3 at level 3, and variable 4 at level 3.

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$L_9\ (3^4)$ Orthogonal array					
	Independent Variables				Performance Parameter Value
Experiment #	Variable 1	Variable 2	Variable 3	Variable 4	
1	1	1	1	1	p1
2	1	2	2	2	p2
3	1	3	3	3	p3
4	2	1	2	3	p4
5	2	2	3	1	p5
6	2	3	1	2	p6
7	3	1	3	2	p7
8	3	2	1	3	p8
9	3	3	2	1	p9

VII. MATERIAL JOINING PROCESS

A. BHEL –Bharat Heavy Electricals Limited

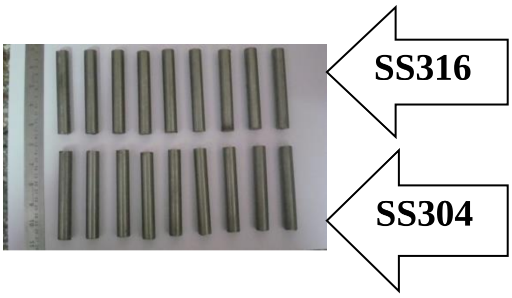
Bharat Heavy Electricals Limited (BHEL) owned by the Government of India, is an engineering and manufacturing company based in New Delhi, India. Established in 1964, BHEL is India's largest power plant equipment manufacturer. The company has been earning profits continuously since 1971-72, except in FY 2015-2016, and paying dividends uninterruptedly since 1976-77.

B. Welding Research Institute (WRI):

It was established in November 1975 by Government of India with UNIDO and UNDP assistance under the management of Bharat Heavy Electricals Limited, Tiruchirappalli, India. WRI has been constantly interacting with world renowned institutions for updating the knowledge base on latest technologies and assimilating experience. This Institute has been established to cater to the welding needs of the Indian welding industries and for contributing to the growth of welding and allied technologies.

Friction Welding Photographs

- Before Welding Process

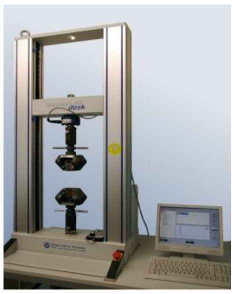


- After Welding Process

VII. MECHANICAL TESTING PROCESS

A. Universal Testing Machine

A universal testing machine (UTM), also known as a universal tester, materials testing machine or materials test frame, is used to test the tensile strength and compressive strength of materials. The "universal" part of the name reflects that it can perform many standard tensile and compression tests on materials, components, and structures (in other words, that it is versatile).



B. Hardness Testing

- VICKERS HARDNESS TESTIING

The Vickers hardness test was developed in 1921 by Robert L. Smith and George E. Sandland at Vickers Ltd as an alternative to the Brinell method to measure the hardness of materials. The Vickers test is often easier to use than other hardness tests since the required calculations are independent of the size of the indenter, and the indenter can be used for all materials irrespective of hardness. The basic principle, as with all common measures of hardness, is

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to observe the questioned material's ability to resist plastic deformation from a standard source. The Vickers test can be used for all metals and has one of the widest scales among hardness tests. The unit of hardness given by the test is known as the Vickers Pyramid Number (HV) or Diamond Pyramid Hardness (DPH). The hardness number can be converted into units of pascals, but should not be confused with pressure, which also has units of pascals. The hardness number is determined by the load over the surface area of the indentation and not the area normal to the force, and is therefore not pressure.

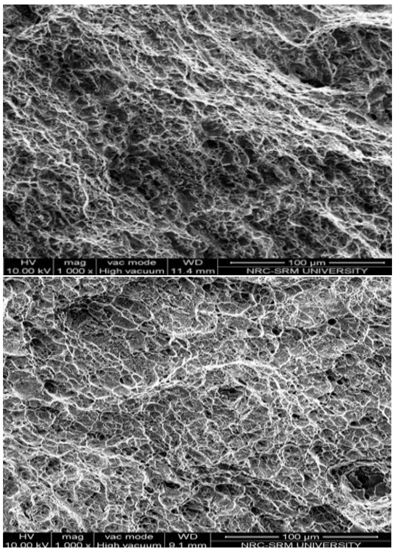
VIII. MICROSTRUCTURE ANALYSIS

A. Scanning Electron Microscope

A scanning electron microscope (SEM) is a type of electron microscope that produces images of a sample by scanning it with a focused beam of electrons. The electrons interact with atoms in the sample, producing various signals that contain information about the sample's surface topography and composition. The electron beam is generally scanned in a raster scan pattern, and the beam's position is combined with the detected signal to produce an image. SEM can achieve resolution better than 1 nanometre. Specimens can be observed in high vacuum, in low vacuum, in wet conditions (in environmental SEM), and at a wide range of cryogenic or elevated temperatures.

The most common SEM mode is detection of secondary electrons emitted by atoms excited by the electron beam. The number of secondary electrons that can be detected depends, among other things, on specimen topography. By scanning the sample and collecting the secondary electrons that are emitted using a special detector, an image displaying the topography of the surface is created.

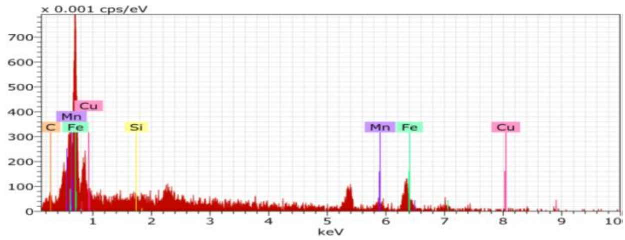
SEM IMAGES



B. Energy Dispersion X-Ray Analysis (Edx):

Energy-dispersive X-ray spectroscopy (EDS, EDX, EDXS or XEDS), sometimes called energy dispersive X-ray analysis (EDXA) or energy dispersive X-ray microanalysis (EDXMA), is an analytical technique used for the elemental analysis or chemical characterization of a sample. It relies on an interaction of some source of X-ray excitation and a sample. Its characterization capabilities are due in large part to the fundamental principle that each element has a unique atomic structure allowing a unique set of peaks on its electromagnetic emission spectrum.

C. EDX analyses at weld zone (AISI SS316L-AISI SS 304):

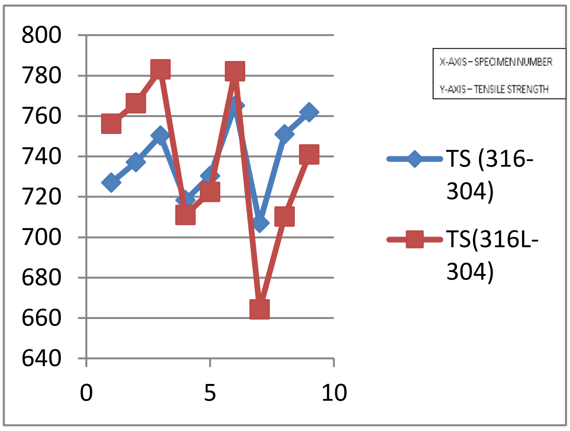


MICRO VICKERS HARDNESS TEST RESULTS (HV 0.5) (STAINLESS STEEL AISI 316L -- STAINLESS STEEL AISI 304) STANDARD USED: IS 1501(PART-1)

SAMPLE ID	SAMPLE SIDE	OBSERVED VALUES						WELDED ZONE
SAMPLE ID: 1	SS 316L SIDE	358.2	341.1	361.3	353.8	349.5	**Avg :352.58**	**364.38**
	SS 304 SIDE	360.8	362.3	358.9	359.1	363.9	**Avg :361.00**	
SAMPLE ID: 2	SS 316L SIDE	352.6	356.8	358.2	355.3	348.9	**Avg :354.36**	**365.55**
	SS 304 SIDE	360.8	367.2	364.1	358.3	356.8	**Avg :361.44**	
SAMPLE ID: 3	SS 316L SIDE	351.2	346.9	356.8	355.4	354.2	**Avg :352.90**	**366.33**
	SS 304 SIDE	370.1	365.9	362.3	359.8	354.7	**Avg :362.56**	
SAMPLE ID: 4	SS 316L SIDE	349.9	352.6	357.1	352.4	350.4	**Avg :352.48**	**364.22**
	SS 304 SIDE	358.6	360.8	363.4	362.8	354.9	**Avg :360.10**	
SAMPLE ID: 5	SS 316L SIDE	350.2	358.0	360.9	352.5	348.5	**Avg :354.02**	**365.05**
	SS 304 SIDE	362.9	360.9	360.5	369.6	359.1	**Avg :362.60**	
SAMPLE ID: 6	SS 316L SIDE	358.2	341.1	361.3	353.8	349.5	**Avg :352.78**	**366.18**
	SS 304 SIDE	360.8	362.3	358.9	359.1	363.9	**Avg :361.00**	
SAMPLE ID: 7	SS 316L SIDE	352.6	356.8	358.2	355.3	348.9	**Avg :354.36**	**363.72**
	SS 304 SIDE	360.8	367.2	364.1	358.3	356.8	**Avg :361.44**	
SAMPLE ID: 8	SS 316L SIDE	351.2	346.9	356.8	355.4	354.2	**Avg :352.90**	**365.00**
	SS 304 SIDE	370.1	365.9	362.3	359.8	354.7	**Avg :362.56**	
SAMPLE ID: 9	SS 316L SIDE	349.9	352.6	357.1	352.4	350.4	**Avg :352.48**	**366.38**
	SS 304 SIDE	358.6	360.8	363.4	362.8	354.9	**Avg :360.10**	

IX. RESULTS

A. Tensile Strength Variation:



X. CONCLUSION

The hardness in the welded zone was higher than heat affected zone in case of AISI 316L vs AISI 304. In case of AISI 316 vs AISI 304 the hardness value at the weld zone is lower than the heat affected zone.

- The highest tensile strength obtained in stainless steel AISI 316L and AISI 304 was 783.13 Mpa and lowest was 664.25 Mpa. In case of stainless steel AISI 316 and stainless steel AISI 304 the highest tensile was 765.18 and the lowest tensile strength was 707.12 Mpa.

- The flash formation of both sides was equal and this may be due to the same thermal conductivity of the two materials.

- The joint strength obtained for AISI 316L VS AISI 304 with optimized process parameters are heating pressure 15 bar, upset pressure 30 bar, heating time is 6 seconds.

- The joint strength obtained for AISI 316 VS AISI 304 with optimized process parameters are heating pressure 25 bar, upset pressure 30 bar, heating time is 6 seconds.

- Microstructure analysis was done and ductile fracture occurred on the specimens.

The EDX results confirm that the joints contain inter-metallic compounds and these compounds affect the weld strength.

REFERENCE

[1] D. Ananthapadmanaban, V. Seshagiri Rao, Nikhil Abraham, Rao.K. Prasad A study of mechanical properties of friction welded mild steel to stainless steel joints Materials and Design, Volume 30, 2009, pp. 2642–2646 Article | PDF (600 K) | View Record in ScopusCiting articles (49).

[2] S.B. Dunkerton Toughness properties of friction welds in steels Weld J, Volume 65, Issue 8, 1986, pp. 193s–202s

[3] K. Jayabharath, M. Ashfaq, P. Venugopal, D.R.G. Achar Investigations on the continuous drive friction welding of sintered powder metallurgical (P/M) steel and wrought copper parts Materials Science and Engineering A, Volume 454–455, 2007, pp. 114–123 Article PDF (3198 K) | View Record in ScopusCiting articles (34)

[4] Mumin Sahin Joining of stainless steel and copper materials with friction welding Industrial Lubrication and Tribology, Volume 61/6, 2009, pp. 319–324

[5] Mumin Sahin Joining of stainless steel and aluminium materials by friction welding Int. J. Adv. Manuf Technology, Volume 41, 2009, pp. 487–497

[6] Mumin Sahin Joining of aluminium and copper materials with friction welding Int J Adv Manuf Technol, Volume 49, 2010, pp. 527–534

[7] Radosław Winiczenko, Mieczysław Kaczorowski Friction welding of ductile iron with stainless steel Journal of Materials Processing Technology,, Volume 213, Issue 3, March 2013, pp. 453–462

[8] P. Sathiya, S. Aravindan, A. Noorul Haq Effect of friction welding parameters on mechanical and metallurgical properties of ferritic stainless steel Int. J. Adv. Manuf Technology, Volume 31, 2007, pp. 1076–1082 View Record in Scopus | CrossRefCiting articles (50)

[9] Sare Celik, Ismail Ersozlu Investigation of the mechanical properties and microstructure of friction welded joints between AISI 4140 and AISI 1050 steels Materials and Design, Volume 30, 2009, pp. 970–976

[10] P. Sathiya, S. Aravindan, A. Noorul Haq Some experimental investigations on friction welded stainless steel joints Materials and Design, Volume 29, 2008, pp. 1099–1109