iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 3 Issue: Issue II Month of publication: June 2015

DOI:

Volume 3, Special Issue-I1, June 2015
ISSN: 2321-9653

International Journal for Research in Applied Science & Engineering Technology (IJRASET)

A Study on Mechanical and Metallurgical Properties of Friction Welded Dissimilar Materials

Sriram Ravi[1], Ramadoss.R[2]

[1]*P.G Student,Department of Mechanical Engineering, Easwari Engineering College,Chennai-600089, India.*

[2]*Professor, Department of Mechanical Engineering, Easwari Engineering College,Chennai- 600089, India.*

Abstract— Joining of dissimilar materials is of great importance in automobile, aerospace and nuclear applications. In this work, pure copper and austenitic stainless steel of grades (AISI 316 and 316L) is welded using continous drive friction welding process. Copper and stainless steel joints are useful in electrical cable connectors etc., in friction welding process, the important parameters which are to be considered are friction time, friction pressure, upset time, upset pressure and rotational speed. The effects of mechanical properties at the friction welded joints are analysed. 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 L_9 (3^4) orthogonal array technique. Nine experiments were conducted at three levels by varying four parameters.Micro-Vickers hardness test was conducted to identify the strength at the three microstructural zones such as weld zone , base metal zone and heat affected zone in stainless steel and pure copper.Tensile tests were conducted on the welded specimens as per ASTM E-8 Standards. From the tensile test, the ultimate tensile strength and percentage elongation was determined. The highest tensile strength shown by the welded joint was 13.75% higher than the parent material (copper).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.

Keywords—Friction Welding; Taguchi Method;Mechanical Testing;Scanning Electron Microscopy(SEM);

I. INTRODUCTION

Friction welding is one of the solid state welding processes in which the weld is formed by the heat generated between the two surfaces.Joining of dissimilar materials is of great importance in automobile and electrical industry.Due to high thermal conductivity of copper it can be used in electical connectors and windings.Copper and stainless steel joints can be used in cable connectors.Hence it is necessary to analyse the strength and weldability of this joints.The advantages of friction welding process are reduction in production time and cost saving.Friction welding is classified into two types.One type is Inertia drive friction welding and the other is Continous drive friction welding. In continous drive friction welding one of the workpieces is held stationary while the other is held for a certain rotating speed. The two workpieces are brought together under certain friction pressure for a certain period of time known as friction time.Then,the rotation is stopped and upset pressure is applied for a certain upset time.Then,the spindle is disengaged and the component is unloaded.In Inertia drive friction welding one part is held stationary while the other is clamped in the chuck which is attached to the flywheel.The flywheel and chuck is rotated for a certain speed to store a predetermined energy.Then,the rotation is stopped and the workpieces are brought in contact and weld is formed. Satyanarayana et.al welded austenitic–ferritic stainless steel, the interface of austenitic stainless steel side exhibited higher residual stress which may be due to its higher flow stress and higher coefficient of thermal expansion[1]. Mumin Sahin et.al applied post-weld annealing to the joints of high-speed steel and medium-carbon steel at 650°C for 4 hours to provide good tensile properties[2]. Ozdemir et.al conducted experiments at five different rotational speeds using a direct-drive type friction welding machine. The thickness of full plastic deformed zone (FPDZ) formed at interface reduced as a result of more mass discarded from the welding interface with increasing rotational speed. Thus, as the rotational speed increases the ultimate tensile strength also increases[3]. Meshram et.al studied the properties of dissimilar metal combinations.The influence of interaction time in continuous drive friction welding on microstructure and tensile properties was analysed. Increased interaction time led to decrease in strength in eutectoid forming and insoluble systems and improved strength in soluble systems[4]. Mumin Sahin et.al did experiments on austenitic stainless-steel and aluminium materials using the friction welding method.Some of the welds had poor strength due to the accumulation of alloying elements at the joint interface[5]. Sathiya et.al welded cylindrical specimens of austenitic stainless steel and ferritic stainless steel of similar composition and shape. Joints processed by this method exhibited better properties when compared to the fusion processed

Volume 3, Special Issue-I1, June 2015
ISSN: 2321-9653
International Journal for Research in Applied Science & Engineering Technology (IJRASET)

joints[6]. Friction welding process was done by Dey et.al to join Titanium to stainless steel AISI 304L. Post-weld heat treatment increased the bend ductility to 5° because of relieving of the effects of strain hardening and of residual stresses at the joint interface [7]. Mumin Sahin et.al welded copper and aluminium materials by friction welding.A grey layer was formed at the fracture surfaces. It was concluded that this layer decreased the strength of the joints[8]. Avinash Pachal et.al studied the objective of obtaining friction weld element of Aluminum 6351, steel 304 and optimizing the friction welding parameters.The effect of tensile strength of friction welding process parameter were evaluated and optimum welding condition for maximizing tensile strength was determined[9].

II. EXPERIMENTAL WORK

In this work austenitic stainless steel of grades AISI 316 and AISI 316L are welded with pure copper material.A KUKA continous drive friction welding setup was used for joining these dissimilar materials.This machine can be used to join circular and non-circular cross section materials. The base metals were tested for their hardness and tensile properties and the results obtained are tabulated in Table 1.

Table 1. Tensile Strength and Hardness of Parent Materials

S.No	Material	Tensile Strength (Mpa)	Hardness (HV)
1	AISI 316	550	350
2	AISI 316L	515	359
3	Pure Copper	232	82

A. *Chemical Analysis*

Austenitic stainless steels of grades AISI 316,316L and copper are chosen for the present study. The actual chemical composition of AISI 316 and 316L stainless steels,copper (in wt%) under study are found out by spectrometry and are tabulated in Table 2,3 with nominal composition .

Table 2. Chemical composition of AISI 316 And AISI 316L

Composition	Material	Elements								
		C	Si	Mn	P	S	Mo	Ni	N	Cr
Actual	AISI 316	0.074	0.26	1.79	0.045	0.029	2.00	10	0.06	16.97
Nominal	AISI 316	0.08	0.75	2.00	0.045	0.030	2-3	10-14	0.10	16-18
Actual	AISI 316L	0.008	0.27	1.45	0.035	0.012	1.97	10.10	0.04	16.15
Nominal	AISI 316L	0.030	0.75	2.00	0.045	0.030	2-3	10-14	0.10	16-18

Table 3. Chemical Composition of Copper

Element	Cu	P	Ni	Al	Zn
%	99.96	0.002	0.003	0.007	0.01

B. *Sample Preparation*

The specimens are of length 100mm and diameter 16mm prior to the friction welding process.The surfaces are machined to get perfect finish and cleaned with emery paper.The specimens are sprayed with acteone solution to prevent any micro particles accumulating on the surfaces.These micro particles may affect the weld strength of the material.Figure 1 shows the specimens before the friction welding process.

Volume 3, Special Issue-I1, June 2015
ISSN: 2321-9653
International Journal for Research in Applied Science & Engineering Technology (IJRASET)

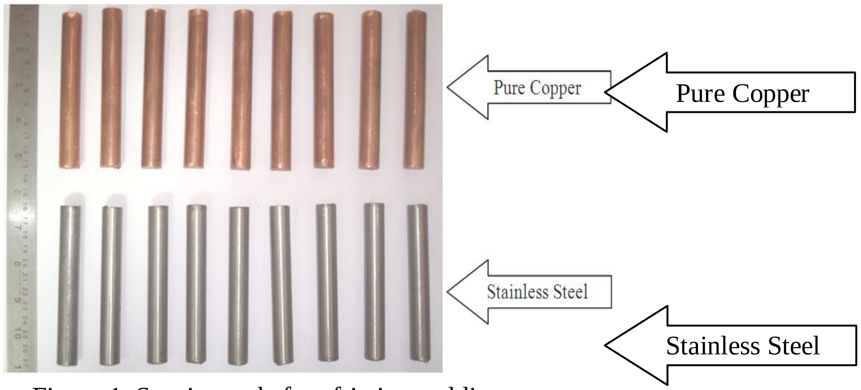


Figure 1. Specimens before friction welding process

C. Friction Welding Process

Friction welding process was performed by varying the process parameters.In this work rotational speed is kept constant, while other parameters such as friction pressure,friction time,upset time,upset pressure are varied using Taguchi(L_9) orthogonal array technique. Before deciding the parameters,samples are welded using different parameters and subjected to drop test.If the weld failed in the drop test then the parameters are not suitable and hence they are varied until suitable parameters are achieved. The parameters of the samples which do not fail in drop test are taken as the suitable parameters. Figure 2 shows the specimens after the friction welding process. The experimental factors and the levels are listed in Table 4. The mechanical properties are examined by Micro-Vickers hardness tests and tensile tests. The metallurgical properties are evaluated by SEM, EDX analysis. Metallurgical tests shows the phases which occurred during the process and the intermetallic compounds which are formed during the process.

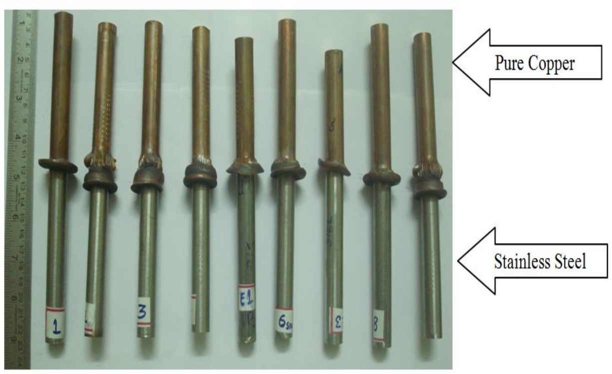


Figure 2. Specimens after friction welding process

Table 4. Experimental factors and their levels

S.No.	Factors	Unit	Levels		
			1	2	3
1.	Heating Pressure	Bar	15	17.5	20
2.	Upset Pressure	Bar	20	22.5	25
3.	Heating Time	Sec	4	5	6
4.	Upset Time	Sec	2	3	4

III. RESULTS AND DISSCUSSION

After the friction welding process,it has been observed that the deformation was confined mainly on the copper side when compared to the stainless steel side in both the cases.Varition of hardness value from the weld zone to the base metal zone is found out by Micro-vickers hardness test.Tensile test is done on the friction welded joints to find the ultimate tensile strength and percentage

Volume 3, Special Issue-I1, June 2015
ISSN: 2321-9653
International Journal for Research in Applied Science & Engineering Technology (IJRASET)

elongation.

A. Hardness Testing

Micro-vickers hardness testing was done to measure the variation in hardness across the weld zones of austenitic stainless steel AISI 316 and copper,AISI 316L and copper joints respectively.Micro-vickers hardness tests were done as per IS 1501 standards with an indentation load of 500 grams and dwell time of 10 seconds. Figure 3 shows the micro-vickers hardness profile across the weld interface.

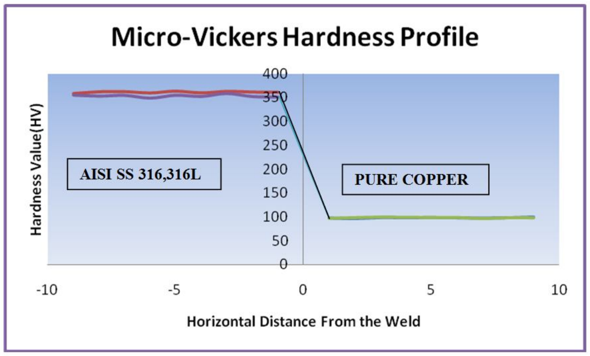


Figure 3. Comparison of Micro-Vickers Hardness Profile

The hardness value obtained is higher in case of AISI 316 when compared to AISI 316L. The reason for the variation of hardness may be due to carbon content in austenitic stainless steel.In copper the hardness value obtained was 100 HV. This may be due to formation of copper oxide compound which can be analysed by metallurgical tests. In the weld zone the hardness value becomes low and hence the profile appears to be a straight line. This may be due to the fact that the thermal conductivity of copper is high when compared to austenitic stainless steel.

Table 5. Experimental levels and results

Sl. No	Heating Pressure	Upset Pressure	Heating Time	Upset Time	Ultimate Tensile Strength (SS 316L vs Cu)	Ultimate Tensile Strength (SS 316 vs Cu)
	Bar	Bar	Sec	Sec	Mpa	Mpa
01.	15	20	4	2	163	233
02.	15	22.5	5	3	241	247
03.	15	25	6	4	259	270
04.	17.5	20	5	3	236	259
05.	17.5	22.5	6	4	250	258
06.	17.5	25	4	1	81	163
07.	20	20	6	4	40	142
08.	20	22.5	4	2	243	257
09.	20	25	5	3	248	243

B. Tensile Testing

Tensile tests are carried out on the welded specimens machined as per ASTM E 8 standards. Figure 4 shows the machined tensile test specimen used for the present study.The sides of the tensile test specimens are accurately machined parallel to the gaugelength

Volume 3, Special Issue-I1, June 2015
ISSN: 2321-9653
International Journal for Research in Applied Science & Engineering Technology (IJRASET)

of
50 mm long and 12.5 mm diameter. Tensile tests are performed to determine the ultimate tensile strength and percentage elongation.

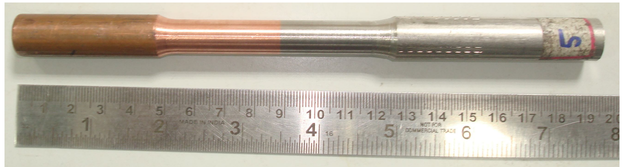


Figure 4. Specimen before tensile testing

The maximum tensile strength obtained in stainless steel AISI 316 and copper was 16% higher than the parent material copper and the lowest tensile strength obtained was 142 Mpa.In case of AISI 316L and copper the highest ultimate tensile tensile strength shown was 10.58% higher than the parent material.The lower tensile strength obtained was 40 Mpa. When the heating pressure was kept low and upset pressure was kept high it shows higher tensile strength.Table 5 shows the tensile test results for each specimen.The fractured surfaces of the weld specimens were analysed by Scanning Electron Microscope and the type of fracture was determined. Figure 5 shows the fractued surface under SEM.A dimple like structure is formed and hence confirm ductile fracture. This may be due to the formation of intermetallic compounds during the friction welding process.These intermetallic compounds affects the weld strength of the joints.Metallurgical tests are done to find the elements which affected the weld strength of the joint.

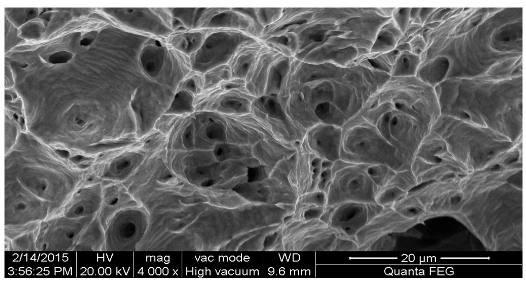


Figure 5. SEM image of the fractured surface

C. Metallurgical Testing

Samples of the weld are sectioned along the axis parallel to the weld.The samples are polished with emery paper and etched with 10% oxalic acid and HNO_3. The friction welded specimens are observed under optical microscope.In austentic stainless steel equiaxed grains are found near the weld zone while in copper side coarse alpha grains are found.Due to these coarse grains near the weld the hardness value of copper has increased near the weld interface. Figure 6 shows the optical image of the joint under consideration.

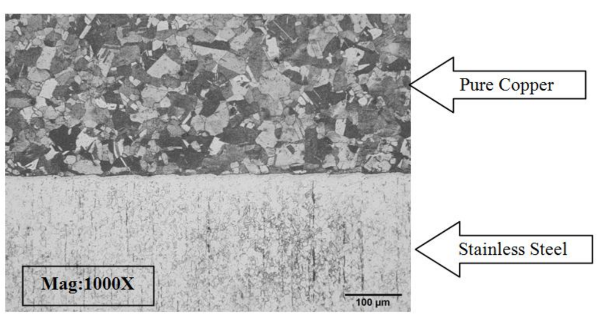


Figure 6. Optical image of the weld joint

D. SEM, EDX Analysis

After observing the interface of the friction welded specimens under optical microscope,the samples are analysed under Scanning electron microscopy(SEM) in order to investigate the phases which occurred during the welding process. A 200 kV field effect

Volume 3, Special Issue-I1, June 2015
ISSN: 2321-9653

scanning electron microscope was used to analyse the joints. In this technique a beam of tungsten light is passed on the weld and the region is marked as spectrum 6 in figure 7. EDX analysis is also done to know the intermetallic compunds which are present in the weld.The results of various elements present on the spectrum are shown in Table 7.

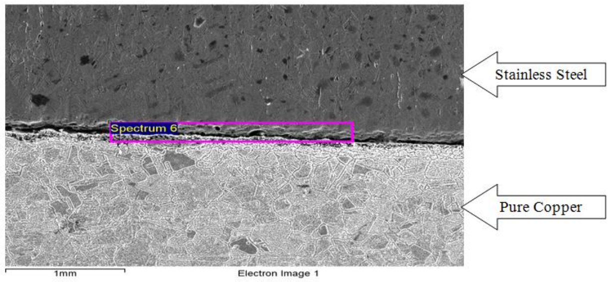


Figure 7. SEM image of the joint during EDX analysis (Magnification:1000X)

Table 7. Element Composition

Element	Weight%	Atomic%
O K	9.21	25.93
Al K	1.53	2.55
Si K	0.25	0.41
Cl K	1.97	2.51
Cr K	12.25	10.62
Mn K	1.15	0.95
Fe K	48.84	39.41
Ni K	6.06	4.65
Cu K	17.44	12.37
Mo L	1.29	0.60
Total	100.00	100.00

Figure 8 shows the EDX analysis of the joints.The grain size in austenitic stainless steel after welding is similar to parent material whereas in copper material indicates fine grains than the parent material. Due to fine grains, hardness value of copper is increased. Constituent elements of both materials had interdiffused through the weld interface, and some intermetallic compounds were formed at the weld interface [11]. Thus, the intermetallic compounds present are confirmed by EDX analysis.

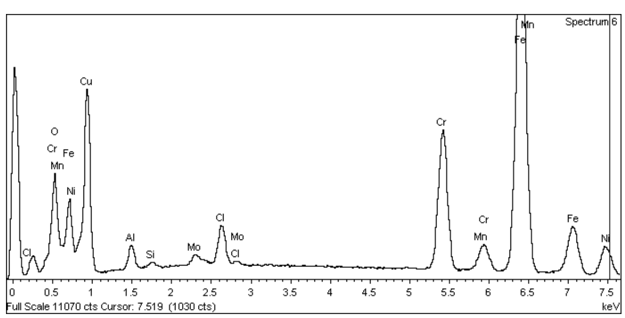


Figure 8. EDX analysis at the weld joint

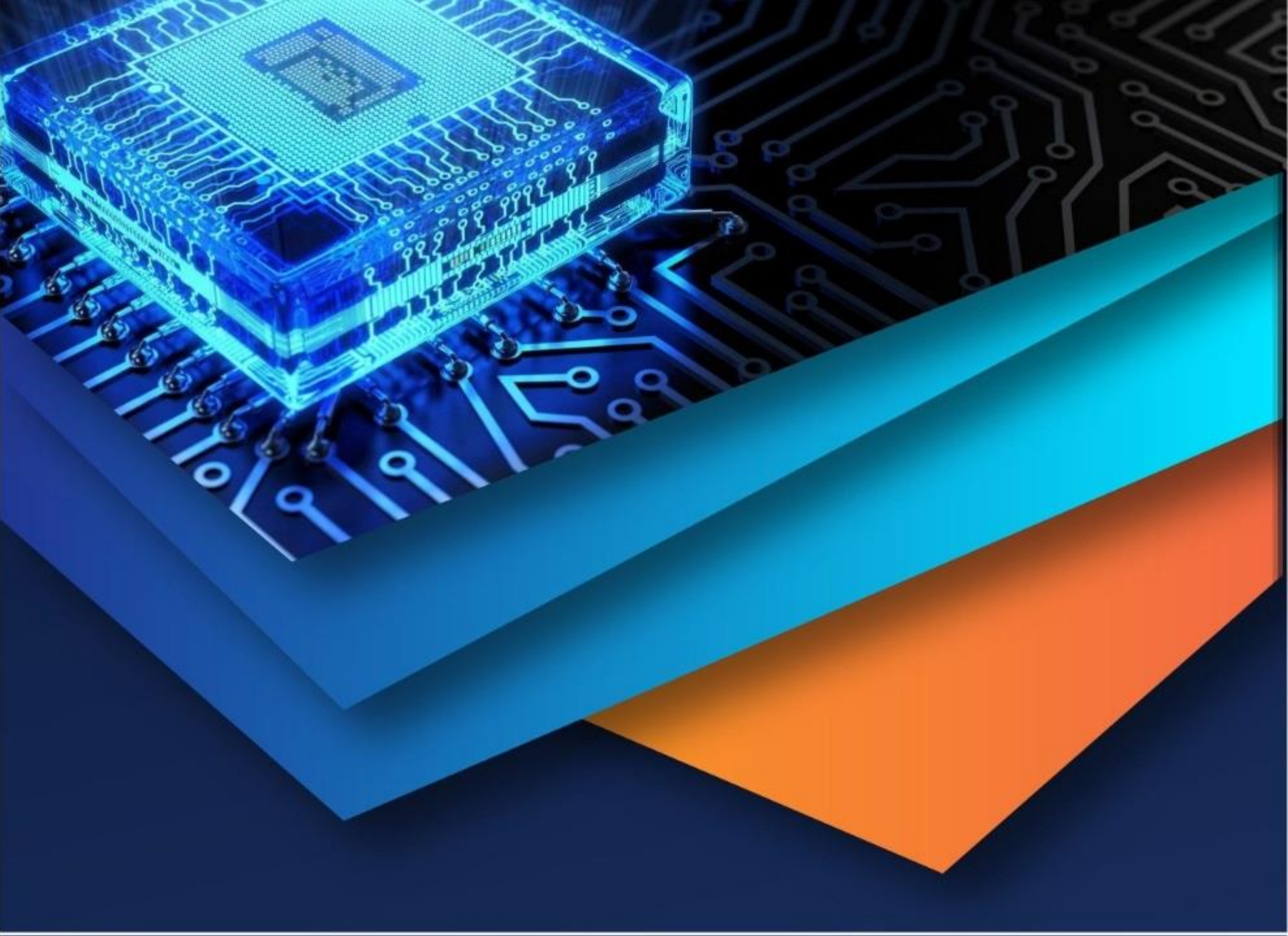
IV. CONCLUSION

This paper investigates the effect of carbon content variation in parent material austenitic stainless steel of grades AISI 316&316L when welded with copper.Based on mechanical and metallurgical tests the following conclusions are made :

- *A.* Friction welding process was succesfully done on the dissimilar joints such as austenitic stainless steel (AISI 316L) vs copper and austenitic stainless steel (AISI 316) vs copper
- *B.* Taguchi L_9 orthogonal array technique was used in the variation of process parameters.The same parameters was used to weld both the combinations.
- *C.* The hardness in the copper side was high in weld zone when compared to base metal zone.The reason being the formation of copper oxide compounds near the weld interface.In case of stainless steel the hardness value is low at the weld zone when compared to the base metal zone.
- *D.* The highest tensile strength obtained in stainless steel AISI 316 and copper was 270 Mpa and lowest was 142 Mpa.In case of stainless steel AISI 316L and copper was 260 Mpa and lowest tensile strength was 40 Mpa.
- *E.* When heating pressure was kept at low(15 bar) and upset pressure was kept high (25 bar) it results in good weld formation.
- *F.* Micro structural studies were done and ductile fracture occurred on the specimens during tensile testing.The intermetallic compounds which affected the weld strength are found by EDX analysis. The EDX results confirm that stainless steel and copper joints contain some intermetallic compounds. Formation of these intermetallic compounds affected the strength of the joints. Formation of the intermetallic compounds can be avoided by varying the rotational speed or by very fine polishing the surfaces before the friction welding process.

REFERENCES

[1] V.V. Satyanarayana, G. Madhusudhan Reddy, T. Mohandas ; Journal of Materials Processing Technology; “Dissimilar metal friction welding of austenitic–ferritic stainless steels”.
[2] Mumin Sahin ; Journal of Materials Processing Technology ; “Joining with friction welding of high-speed steel and medium-carbon steel”.
[3] N. Ozdemir,F.Sarsilmaz,A. Hasc ; “Effect of rotational speed on the interface properties of friction-welded AISI 304L to 4340 steel”.
[4] S.D. Meshram,T. Mohandas, G. Madhusudhan Reddy ; Journal of Materials Processing Technology; “Friction welding of dissimilar pure metals”.
[5] Mumin Sahin ; “Joining of stainless-steel and aluminium materials by friction welding”.
[6] P.Sathiya, S.Aravindan,A.Noorul Haq ;Materials and Design ; “Some experimental investigations on friction welded stainless steel joints”.
[7] H.C. Dey, M. Ashfaq, A.K. Bhaduria, K. Prasad Rao; Journal of Materials Processing Technology; “Joining of titanium to 304L stainless steel by friction welding”.
[8] Mumin Sahin ; “Joining of aluminium and copper materials with friction welding”.
[9] Hazman Seli, Ahmad Izani Md. Ismail, Endri Rachman, Zainal Arifin Ahmad ; Journal of Materials Processing Technology; “Mechanical evaluation and thermal modelling of friction welding of mild steel and aluminium”.
[10] Avinash S. Pachal, Amol bagesar ; International Journal of Emerging Technology and Advanced Engineering; “Taguchi Optimization of Process Parameters in Friction Welding of 6061 Aluminum Alloy and 304 steel”.
[11] M. Kimura, T. Iijima, M. Kusaka, K. Kaizu, A. Fuji ; Materials and Design; “Joining phenomena and tensile strength of friction welded joint between pure titanium and low carbon steel”.
[12] Shanjeevi.C, Satish Kumar.S, Sathiya.P ; International Conference on Design And Manufacturing ; “Evaluation of Mechanical and Metallurgical properties of dissimilar materials by friction welding”.
[13] CH.Muralimohan, V.Muthupandi, K.Sivaprasad; International Conferences On Advances In Manufacturing And Materials Engineering ;“Properties of friction welded titanium-stainless joints with a nickel interlayer”.



10.22214/IJRASET

45.98

IMPACT FACTOR: 7.129

IMPACT FACTOR: 7.429

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY