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# Friction Welding of Austenitic Stainless Steel with Copper Material

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Shanjeevi Chinnakannan

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## Abstract

Austenitic stainless steels are most preferred over other types of stainless steel families. Welding of stainless steel using friction welding is widely seen in the current scenario. Since the time consumed for friction welding is very less, metallurgical defects are almost reduced without pre- and postheat treatment. The problems encountered in friction welding during joining of austenitic stainless steel are very limited when compared to fusion welding process. The studies have undergone with joining of austenitic stainless steel and copper material to evaluate the friction welding parameter for finding the good bond strength.

**Keywords:** friction welding, AFM, copper, stainless steel, microstructure

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## 1. Introduction to stainless steel

Among the various sources of materials available, selection of stainless steel is one of the important classes of engineering materials considered in the past and present scenario. According to chemical elements, the stainless steel is classified into different grades with respect to microstructures such as ferritic, austenitic, martensitic and duplex stainless steel (the combination of austenite and ferrite). These different grades have been used in various applications. The most common uses are listed below:

- Automotive and transportation
- Architecture and construction
- Food and catering

- Medical
- Energy and heavy industries

It is the primary stainless steel used in aviation construction. The grades with 3xx series are often referred as austenitic stainless steel. Each grade has followed with a specified letter that represents chemical element information. Low carbon austenitic stainless steel is represented with 'L'; High carbon steel with 'H'; Nitrogen bearing steel with 'N'; some cases with modified composition say 'LN' from base alloy.

## 2. Friction welding and its importance

Friction welding is a metal-joining process made by continuous-rubbing action at the interface of two different materials, which leads to heat dissipation. Due to continuous action of rotation, the heat generated at the interface results in deformation to the plastic stage by the conversion of mechanical energy into thermal energy under pressure resulting in good bond strength of the material.

Friction welding is more economical and time-consuming, which requires a low input of energy and high production rate with less material wastage in joining dissimilar metals or alloys. During friction welding of steels, the weld interface produces heat with temperature range of 900 to 1300°C.

## 3. Problems in fusion welding on stainless steel

In general, austenitic stainless steels are easily weldable [1]. Based on physical properties on ferritic, martensitic and duplex stainless steels, austenitic stainless steel is considerably different than others [2]. In fusion welding process, particularly in gas tungsten, electron beam and laser welding, there is a possibility with unexpected phase propagation. Due to metallurgical changes in weld interface, phase changes in delta ferrite formations, grain boundary corrosion and sigma phase will arise. For avoiding this, pre- and postheat treatment are needed to prevent the metallurgical defects [3–7]. Moreover, joining of austenitic stainless steel under cryogenic or corrosive environment, the ferrite quantity to be minimized or controlled to avoid property degradation during service. In addition to this, it may also have a chance to sensitization in fusion welds [8–10].

## 4. Effect of friction welding in austenitic stainless steel

Due to high ductility and excellent corrosion resistance, austenitic stainless steel is increased in wide range of applications. Even though stainless steel is effectively used in commercial applications, problems have often been reported during welding operation. Many of the researchers are working.

It is observed that publications of most of the research papers are concerned with similar and dissimilar welding of 300 series grade of austenitic stainless steel. When comparing with fusion welding process, joining of austenitic stainless steel is increased subsequently using solid state process during the last decade. In metal joining process, wide categories of variables included in each circumstance and hence standardization of welding is difficult to find out in industrial aspect for avoiding such difficulties, research work is carried out to set the better performance in welding of austenitic stainless steel.

## **5. Research findings on friction welding of austenitic stainless steel to other material combinations**

Many researchers have worked in friction welding which focused on joining similar and dissimilar combinations of austenitic stainless steel with different metal based alloys. Researchers have worked on dissimilar combinations of materials by resulting good bond strength under quality aspects in friction welding [11–14]. When a similar combination of austenitic stainless steel is performed, the value of tensile strength is decreased with increase in friction pressure [15]. Similarly, Paventhan et al. [16] studied a fatigue behavior by joining medium carbon steel and austenitic stainless steel by conducting experiments using bending fatigue testing. Further, experimental investigation was done on the friction welding of 6063 aluminum alloy with AISI 304 austenitic stainless steel by Sammaiah et al. [17] to determine the correlation between the microstructure and the joint strength. Similarly Fu et al. [18] investigated the welded joint of T2 copper and 1Cr18Ni9Ti stainless steel under the external electrostatic field and the distributions of elements in weld zone (WZ) were analyzed in the welded joint. The influence of welding parameters on hot corrosion was examined by Arivazhagan et al. [19] to study the weldment and corrosion behavior in elevated temperature on AISI 4140 and AISI 304. Subsequently, Sahin investigated a characterization of plastically deformed austenitic stainless steel by friction welding using statistical approach [20]. During fusion welding process of joining pure Ti to stainless steel, the formation of brittle intermetallic compounds developed in the weld metal. This problems lead to degrade the properties of weld joints. Muralimohan et al. [21] made an attempt to introduce thin Ni interlayer which overcomes the problems between Ti-SS by avoiding direct contact between two base metals. Satyanarayana et al. [22] studied the effect of austenitic-ferritic stainless steel combination in terms of microstructure and mechanical properties. The influence of strength and variations are compared together and its fracture behaviors are evaluated. Winiczenko and Kaczorowski [23] investigated the study of mechanical properties and microstructure of friction welded joint of ductile iron with stainless steel and studied the fracture morphology and phase transformations during friction welding. They also showed some enrichment of ductile iron with Cr and Ni atoms near to the weld joint through energy-dispersive X-ray spectrometry.

Some studies on similar and dissimilar combination of stainless steel materials are undergone to understand the impact and tensile strength behaviors using electron beam welding and friction welding [24]. The effect of tensile strength and impact at different loading rate was examined by Yokoyama et al. [25] on aluminum alloy and stainless steel using friction welding.

However, the combination of austenitic stainless steel to copper is very limited. This chapter shows a simple and novel approach to determine the welding parameters using Taguchi design by studying its mechanical and metallurgical properties.

## 6. Experimental details

The dissimilar joint combinations of austenitic stainless steel (304L) to copper material are taken into account for examination. The materials were chosen with a cylindrical rod of diameter 24 mm and length 75 mm. The surface is well polished and cleaned by using acetone. The chemical composition of base materials used for this experiment is shown in **Table 1**.

Element (%)	C	Si	Mn	P	S	Ni	Cr	Fe	Zn	Cu
AISI 304L	0.03	0.39	1.63	0.042	0.027	8.99	19.05	71.12	–	–
Copper	–	–	–	–	–	0.01		0.11	0.13	99.59

**Table 1.** Chemical composition of base materials.

The factors such as friction pressure, upset pressure, burn-off length and rotational speed is the main parameters involved in friction welding process. Taguchi's orthogonal array is a simple and largely useful method, for conducting experiments in a systematic way using a restricted number of experiments required for the investigation. The factors considered for the experimentation are listed in **Table 2**.

Factors	Levels		
	1	2	3
Friction pressure (MPa)	22	33	43
Upset pressure (MPa)	65	87	108
Burn-off length (mm)	1	2	3
Rotational speed (rpm)	500	1000	1500

**Table 2.** Experimental factors and their levels.

## 7. Surface appearance on weld

**Figure 1** shows the appearance of 304L SS and copper combination made by friction welding. The welded joint between 304L and copper material reveals the formation of flash regions which contains predominantly copper, shown in **Figure 3**. This is has a result of the lower flow stress of copper, the heat generated during welding temperature makes softer in copper and starts flowing in terms of flash formation as compared to austenitic stainless steel side.



**Figure 1.** 304L SS-Cu welded joints.

Due to the ductility in copper material, flash is produced on the copper side with reduced length than stainless steel side.

## 8. Mechanical testing

### 8.1. Tensile testing

The mechanical test was carried out on the weld line by sectioning the welded samples. Tensile test was carried out at room temperature using a WAW1000E universal testing machine having the maximum load of 100 kN and 5 mm/min crosshead speed. The welded joints were machined for tensile testing according to ASTM E8 standard and joint strength was analyzed in the weld region. A scanning electron microscope (SEM) was used for observing the fractured surface on tensile tested sample as well as the type of fracture obtained for the material.

The input parameters developed based on Taguchi method were utilized to evaluate the friction welded joints by conducting experiments. The tensile strength results of the welded joints are listed in **Table 3**. Most of the samples are fractured in copper side and not in austenitic stainless steel side (**Figure 2**). This is due to high ductility in copper material that fracture results in copper material. Due to chemical in-homogeneity and microstructural changes, the tensile strength values, might have some variations with all the input parameters.

Among all the samples made by friction welding, the sample S21 and S7 are obtained as lowest (183 MPa) and highest (205 MPa) of tensile strength values respectively. Though the UTS of 304L and Cu base material has 647 and 232 MPa, the friction welded joint results with a maximum of 205 MPa. It indicates clearly that, the maximum tensile strength is more or less equal to the base material of copper. With higher the friction and rotational speed and low upset pressure, minimum tensile strength was observed. Similarly, higher tensile strength was obtained by increasing

S. No	FP (MPa)	UP (MPa)	BOL (mm)	Rotational speed (r/min)	UTS (MPa)	Fracture location
1	22	65	1	500	201	Copper
2	22	65	2	1000	196	Copper
3	22	65	3	1500	192	Copper
4	22	87	1	1000	203	Copper
5	22	87	2	1500	198	Copper
6	22	87	3	500	197	Copper
7	22	108	1	1500	205	Copper
8	22	108	2	500	204	Copper
9	22	108	3	1000	199	Copper
10	33	65	1	500	196	Copper
11	33	65	2	1000	192	Copper
12	33	65	3	1500	187	Copper
13	33	87	1	1000	198	Copper
14	33	87	2	1500	194	Weld
15	33	87	3	500	193	Copper
16	33	108	1	1500	200	Weld
17	33	108	2	500	199	Copper
18	33	108	3	1000	195	Weld
19	43	65	1	500	192	Copper
20	43	65	2	1000	187	Weld
21	43	65	3	1500	183	Weld
22	43	87	1	1000	194	Weld
23	43	87	2	1500	189	Copper
24	43	87	3	500	188	Weld
25	43	108	1	1500	196	Copper
26	43	108	2	500	195	Weld
27	43	108	3	1000	190	Copper

**Table 3.** Taguchi's  $L_{27}$  orthogonal array.

upset pressure and rotational speed of the welded joint. When the rotational speed increases, irregularities in faces are smoothed out by lowering frictional contact with increase in upset pressure. As a result, the material becomes plastic and achieved with complete contact with interface of the other material. Hence, any impurities present on interface remains trapped with increase in quality of the welded joint. Fracture analysis was done by using scanning electron microscopy (SEM) in tensile tested specimens are shown in **Figure 3**. It shows a dimple pattern in the whole width of the specimen and confirms the ductile mode of fracture.

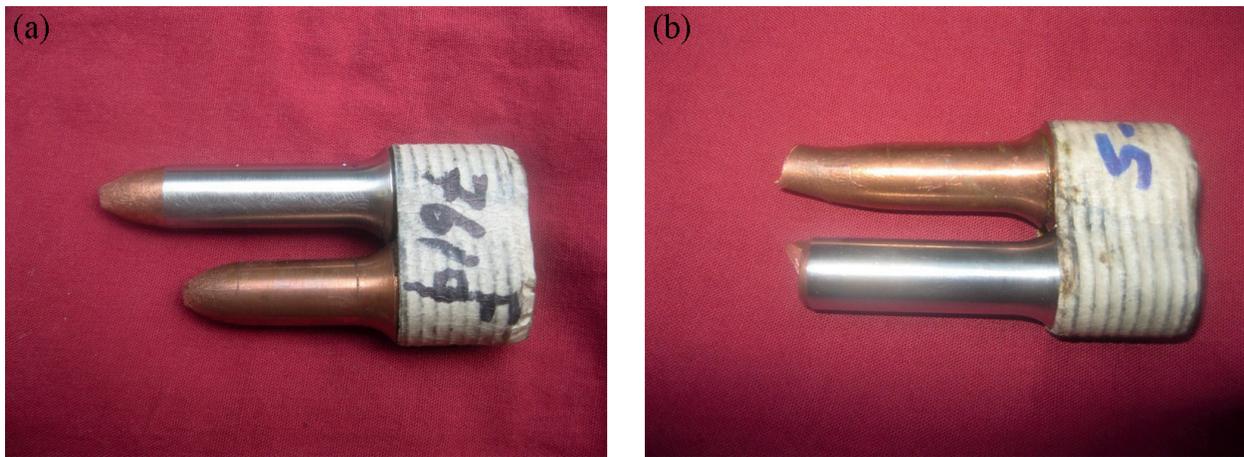


Figure 2. Tensile tested samples on 304L-Cu joint.

Energy dispersive analysis of X-rays (EDAX) analysis was carried out to study the phases that exist at the welding interface. The software permitted piloting the beam to scan along a surface or a line in order to achieve X-ray cartography or concentration profiles by elements [20]. SEM with EDAX analysis was carried out on the tensile fractured sample. SEM microstructure in the friction-welded 304L-Cu joint and EDAX analysis results are given in **Figure 4**, while the distributions of elements within the determined location are shown in **Table 4**. The analysis shows that the diffusion zones consisted of Cu and O atoms at the fractured surface. The diffusion zone is rich in Cu with a weight of 94.58%, followed by 5.42% O. Thus, the diffusion zone with a different element was confirmed with a copper material.

## 8.2. Impact testing

Impact testing was done by using Charpy V notch impact test machine to measure the impact toughness of joints at room temperature. The specimen size was 55 mm × 10 mm × 10 mm and the samples were prepared with ASTM standards. The samples to be tested were machined from the welded blocks. Notches were prepared precisely at the midpoint of the weld interface. The fractured surface of the impact tested sample was examined by using scanning elec-

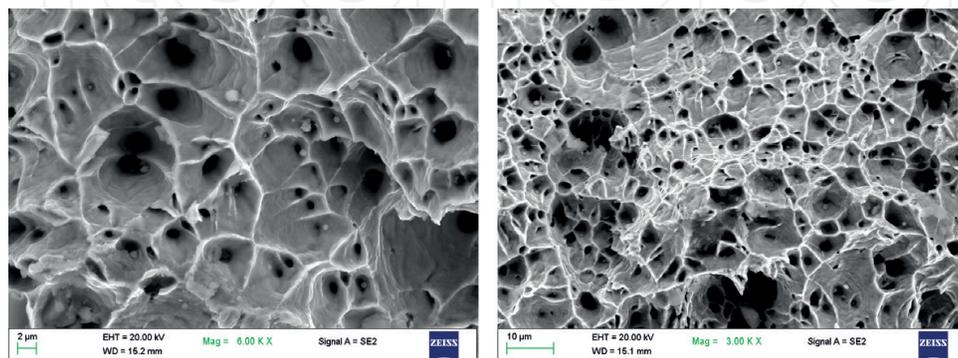
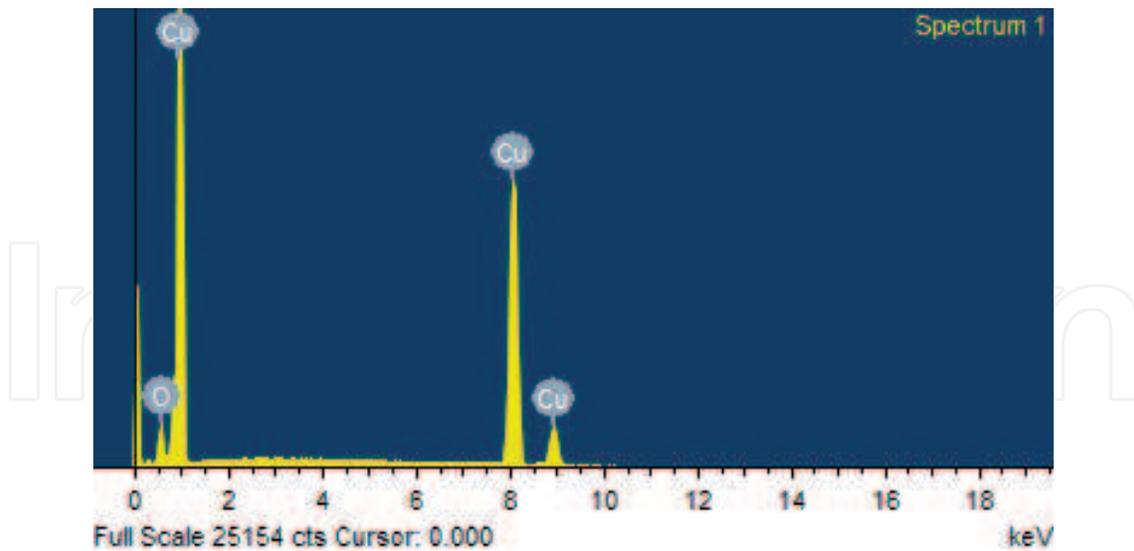


Figure 3. SEM image in tensile fractured sample on 304L-Cu.



**Figure 4.** EDAX analysis on tensile sample in 304L-Cu.

tron microscope (SEM). Experiments are conducted using Taguchi's  $L_9$  orthogonal array and the impact test results are presented in **Table 5**.

It was found that, the impact sample S7 has extremely low value of  $4 \text{ J/cm}^2$  and the impact sample S2 has the highest value of  $70 \text{ J/cm}^2$ . The impact tested samples are shown in **Figure 5**. With high frictional pressure and a decrease in upset pressure, the impact toughness value is much reduced in weld interface. Due to the low upset pressure, the interface having irregularities and bonding toughness is much affected. At the same time, if increased with upset pressure and decreased with friction pressure, the value of toughness is drastically increased.

Due to increase in heat during friction, the presence of intermetallic layers are formed which results in poor weld strength. Based on the experiment, the energy absorbed by the material results with accumulation of copper particles on stainless steel side rather than with low energy absorbed by the material. The fractured surface of the impact tested sample was examined by using scanning electron microscope (SEM) to study the behavior of the material with different magnifications. The fracture shows ductile mode of fracture with coarse dimple features exhibited in the copper material by showing different magnifications shown in **Figure 6**. Toughness is higher with the low friction pressure as a resulted of higher deformation and failure occurs slightly away from the interface as evidenced by showing ductile failure. This supports the argument that the joint has good interface, which is formed with good toughness.

Element	Weight (%)	Atomic (%)
O K	5.42	18.54
Cu K	94.58	81.46
Total	100%	

**Table 4.** EDAX analysis in tensile fractured sample on 304L-Cu joint.

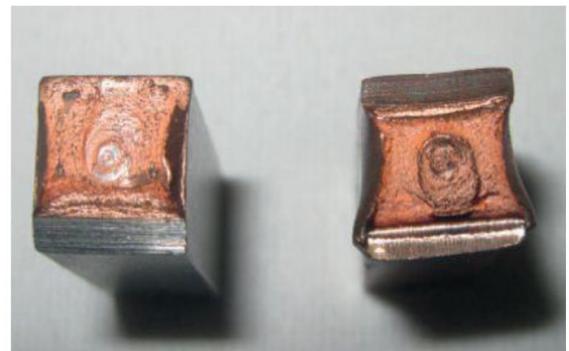
Experimental run	Input parameters				Impact strength (J/cm <sup>2</sup> )
	Friction pressure (MPa)	Upset pressure (MPa)	Burn-off length (mm)	Rotational speed (r/min)	
1	22	65	1	500	16
2	22	87	2	1000	70
3	22	108	3	1500	66
4	33	65	2	1500	28
5	33	87	3	500	32
6	33	108	1	1000	8
7	43	65	3	1000	4
8	43	87	1	1500	30
9	43	108	2	500	38

**Table 5.** Impact test results on 304L-Cu joint.

SEM with EDAX analysis is shown in **Figure 7** and their elements observed are listed in **Table 6**. The diffusion zone observed on the impact tested samples and shows with rich Cu in the fractured sample which is occurred in copper material rather than the stainless steel material.



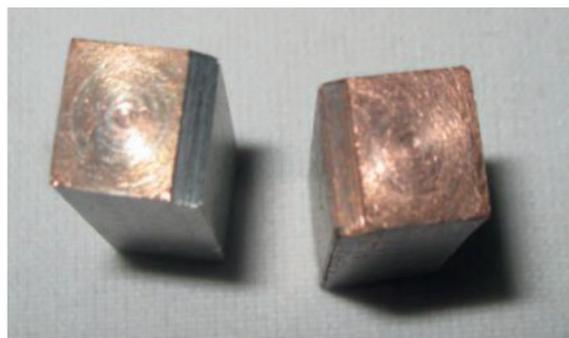
Sample 1



Sample 2



Sample 3



Sample 7

**Figure 5.** Impact tested samples on 304L-Cu joint.

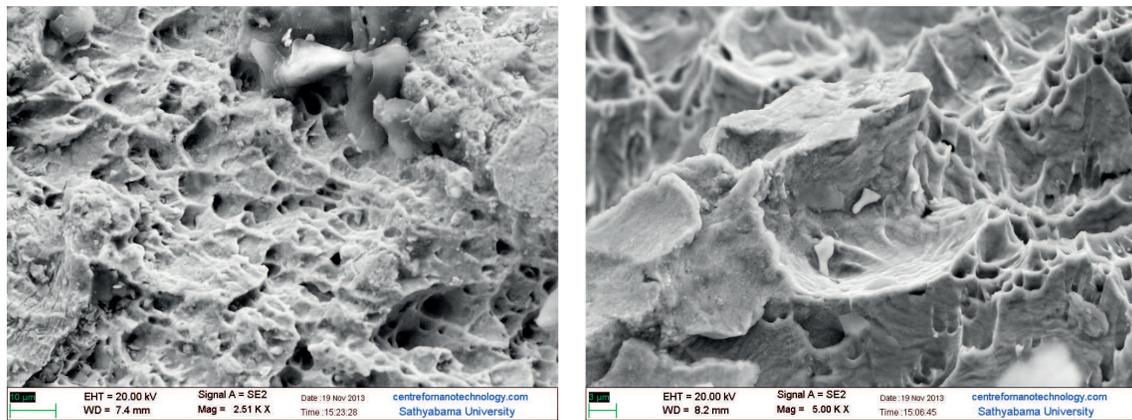


Figure 6. SEM image in impact fractured sample on 304L-Cu joint.

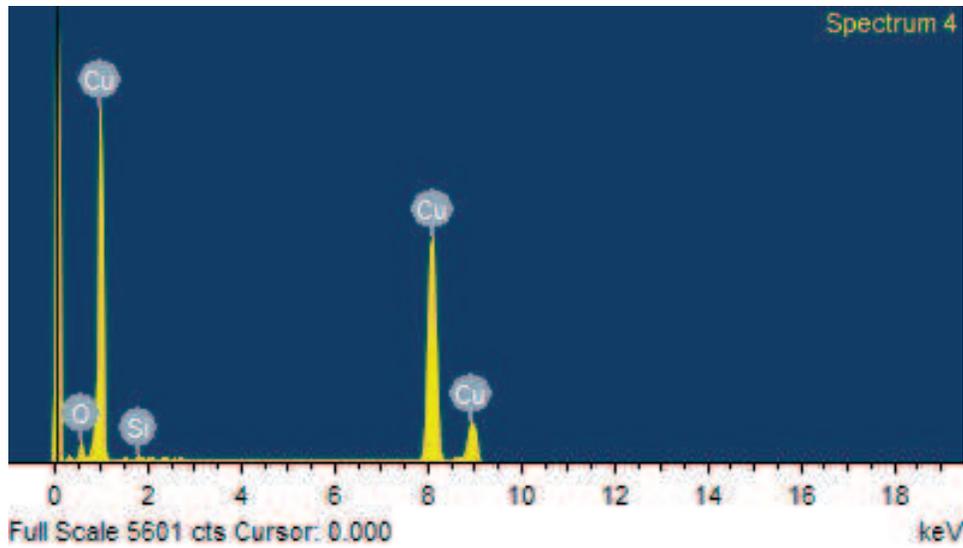


Figure 7. EDAX analysis on impact sample in 304L-Cu.

Element	Weight (%)	Atomic (%)
O K	3.61	12.90
Si K	0.32	0.65
Cu K	96.07	86.45
Total	100%	

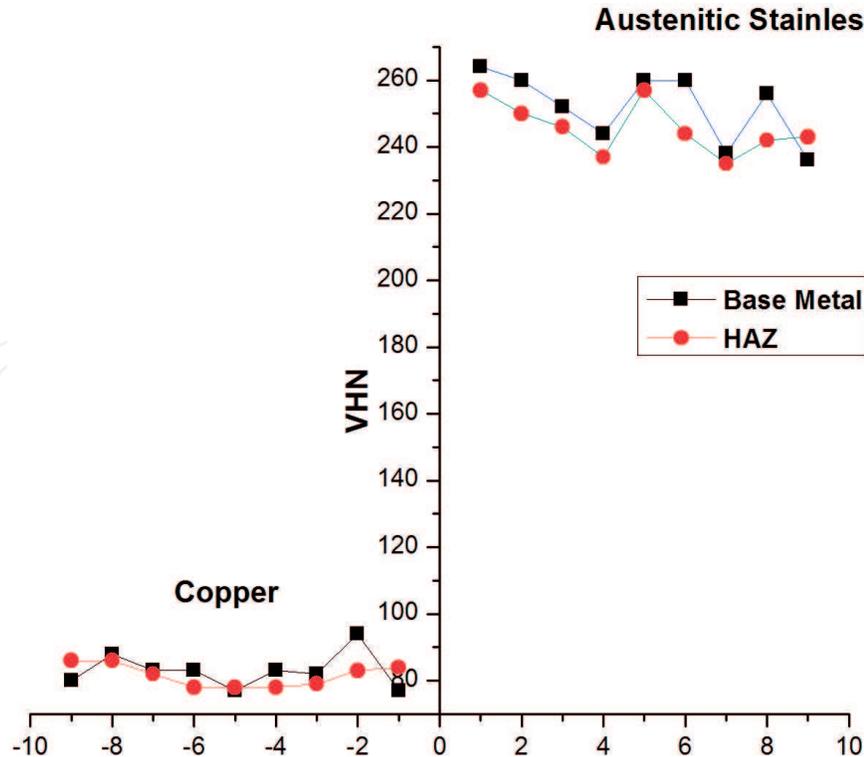
Table 6. EDAX analysis in impact fractured sample on 304L-Cu joint.

### 8.3. Hardness testing

Vickers micro-hardness measurements were made across the weld on all samples to identify the strength in the three microstructural zones such as weld zone (WZ), base metal zone (BMZ) and heat affected zone (HAZ) in the respective materials. Vickers micro-hardness test was carried out across the weld interface using a load of 500 g and dwell time of 15 s along the weld interface. Vickers micro-hardness measurements were carried out accordance with ASTM E384-09 and ASTM E407-99 standards, respectively. The hardness values are taken at each location while the average of three readings was taken for analysis.

In the case of hardness in welded joint of austenitic stainless steel and copper, it was not possible to take the hardness in the weld zone, as the weld is just a sticky mushy zone. Hardness variation was obtained using 500 g load by Vickers micro-hardness testing and measuring locations with 0.5 mm intervals taken into consideration. The hardness variations in horizontal distance to the center in the welding interface of the joints are shown in **Figure 8**.

It could be observed that, the hardness values of copper near to the weld interface are slightly increased when compared to the base material of copper. At the same time, hardness value of 304L SS slightly decreased near to weld interface when it compared to the base material of stainless steel. Due to heat dissipation at weld interface, intermetallic layers and thermal diffusivity occur which causes hardness variations.



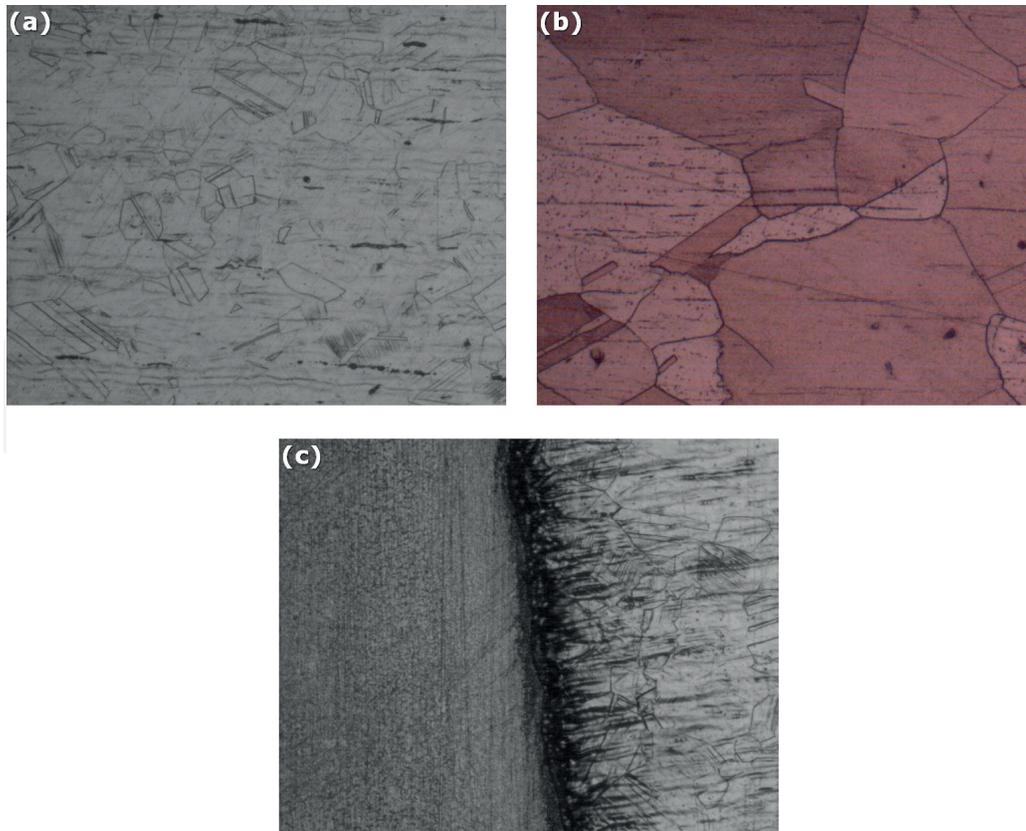
**Figure 8.** Hardness graph in 304L-Cu joint.

## 9. Metallographic examination

### 9.1. Optical microscopy

The optical microscope study was carried out to examine the grain behaviors in the interfaces and heat-affected regions. The microstructures were examined by sectioning the weld samples, parallel to the radial direction and the specimens were prepared according to standard metallographic procedures. The welded surface of the samples was ground with 1200 grinding paper and polished with 1  $\mu\text{m}$  diamond paste and the samples were etched with a vilella's reagent (5 ml HCl, 1 g picric acid, 100 ml ethanol and 2 drops zephiran). The specimen is well-polished and etched by 10% oxalic acid. The welded joint was examined using a metallurgical microscope and microstructural behaviors were analyzed in base metal, heat affected zone (HAZ) and the weld zone.

**Figure 9** shows the micrograph showing microstructures in weld region as well as heat-affected zone and parent metal across the interface. Due to the heat applied during the welding operations, the flash thickness was varied from one another resulting in plastic deformation at the interface. Due to cylindrical rods with a circular geometry, the rotational speed affects the frictional pressure from the weld center to the surface of the sample in radial directions. The parent metal of copper was observed with coarse alpha grains and by heat-affected zone, and the grains were recrystallized due to heat generated in the interface of weld region. In austenitic stainless steel, the parent metal was observed with carbide particles and annealed twin boundaries, whereas in the heat affected zone, recrystallized grains were appeared.

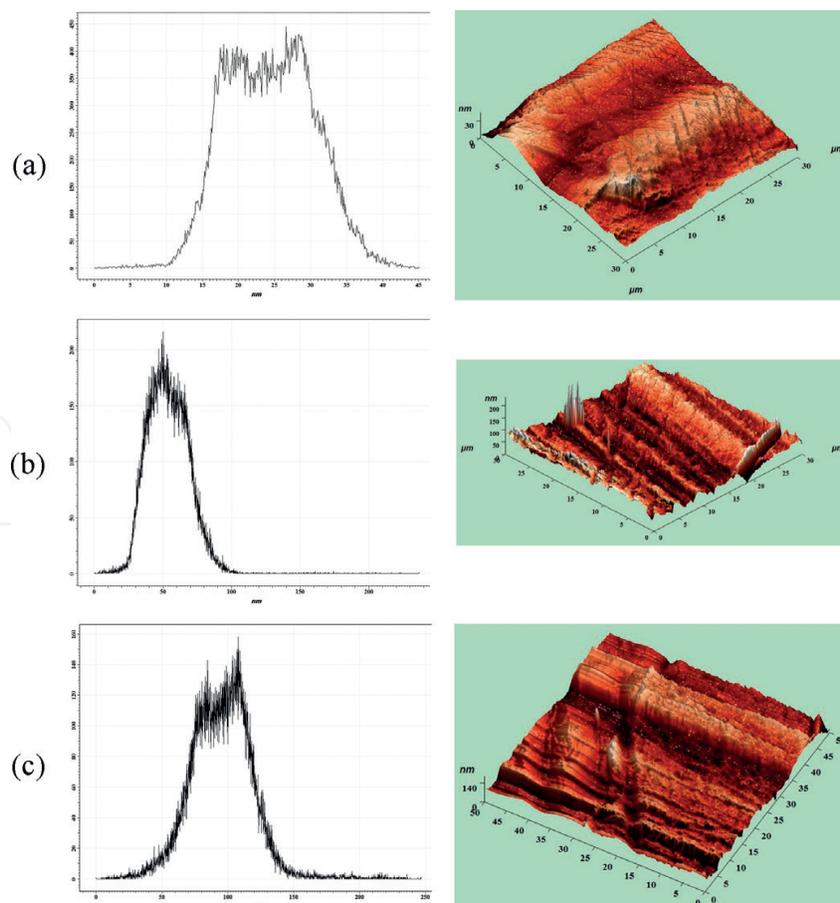


**Figure 9.** Microstructural observation of welded samples (a) Austenitic Stainless Steel, (b) Copper and (C) Weld Interface.

## 9.2. Atomic force microscopy

Atomic force microscopy (AFM) is a powerful technique which can allow direct spatial mapping of surface morphology having nanometer resolution. The roughness images were taken over by the integrated optical microscope and operated in tapping mode using silicon probes. Topographic and phase images were achieved concurrently by a resonance frequency of approximately 300 kHz for the probe oscillation and a free-oscillation amplitude of  $62 \pm 2$  nm. The microstructure of interphase layer of dissimilar material is seen in atomic force microscopy. The maximum roughness shows with 45 nm in 304L, 236 nm in copper and 246 nm on the interface. The maximum roughness in the interface zone has more or less equal to the same roughness as of copper.

From the roughness graph and 3D images (**Figure 10**), was observed that the difference between the average roughness of dissimilar material is very less and negligible in the interface region. When studying roughness size, the parent materials of 304L SS and copper are having peaks in the range of 15–35 and 30–90 nm, respectively. In the welding zone, the peak appeared is with a range of 60–130 nm showing considerable increase in roughness.



**Figure 10.** AFM histogram and 3D image in 304L-Cu (a) Austenitic Stainless Steel, (b) Copper and (c) Weld Interface.

## 10. Conclusion

In this study, the welding characteristics under different welding parameters are taken into account. From the mechanical and metallurgical characteristics on friction welding of austenitic stainless steel and copper, the following conclusions can be drawn.

- During friction welding, the metal tends to decrease in length of copper by showing a flash formation rather than stainless steel side.
- Tensile strength was achieved with a maximum of 205 MPa. The bond strength is achieved nearing to base material of copper material with increase in upset pressure.
- Energy absorbed by the welded sample is varied from 4 to 70 J/cm<sup>2</sup>. The bond strength is mainly depends upon one of the important welding parameter called upset pressure. This kind of statement is well suites in current study of impact. When the upset pressure is lowered, the impact toughness is much decreased to 4 J/cm<sup>2</sup>. But in case of high upset pressure, the resulting value is drastically increased to 70 J/cm<sup>2</sup>.
- Micro-hardness measurements in 304L-Cu results with absence of hardness value in weld zone. Due to sticky layer at the interface of stainless steel as well as copper joint, the weld zone is negligible and measured values in the HAZ and their base materials, respectively.
- Due to the absence of weld zone in 304L-Cu, surface roughness was studied using atomic force microscopy to identify the weld region. Measurement of roughness values made in weld interface is more or less equal to copper material.

Though austenitic stainless steels are used more than any other grades, the joining efficiency is differed with respect to welding parameters. Finally, it is suggested that there is a large scope in the research work on welding of 300 series grade with wide range of applications.

### Author details

Shanjeevi Chinnakannan

Address all correspondence to: shanjeevii@gmail.com

Department of Mechanical Engineering, Veltech Dr. RR & Dr. SR University, Chennai, India

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