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STUDIES ON IMPACT TOUGHNESS AND FRACTURE ANALYSIS OF AUSTENITIC STAINLESS STEEL AND COPPER JOINTS BY FRICTION WELDING

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ABSTRACT

The joining of dissimilar material is most essential nowadays due to its increasing in a wide range of industrial applications. Friction welding is a solid state joining process, has a great potentials in welding of dissimilar materials due to its environmental friendliness and less time consuming. The main aim of this paper is to study the dissimilar material joints of austenitic stainless steel and copper which finds application in cryogenic fluids, power generation industries and reactor cooling systems. The dissimilar joints are produced by varying friction pressure, upset pressure, rotational speed and burn-off length to determine its influence on impact strength of the weld joint. The weld interface shows high impact toughness under high upset pressure and rotational speed with low friction pressure with the combination of parameter. The impact failure of joints was examined under scanning electron microscopy (SEM) and type of failure modes is discussed.

Keywords: Friction Welding, Impact Strength, Scanning Electron Microscopy.

1. Introduction

Friction welding is a solid state bonding process widely used nowadays in current applications. During welding process, the frictional heat is generated and results in a continued plasticization of the interfacial region between the components. A flash is formed through the displacement of plastically deformed material towards the weld edges. Joining of dissimilar materials is of increasing interest for a wide range of industrial application in chemical, petrochemical, nuclear, and electronic industry for the purpose of increasing component. Stainless steel and copper are used for reactor cooling systems and power generation industries due to their high resistance to corrosion, high thermal conductivity and good conductor of electricity.

Joining of dissimilar materials such as copper and steel has great importance in applications, although problems exist due to brittle intermetallic compound and high thermal conductivity. Friction welding is taken into account for considering strong welds to minimize this problem [1]. Madhusudhan et al studied the microstructure and mechanical properties of similar and dissimilar welds of austenitic stainless steel (AISI 304), ferritic stainless steel (AISI 430), and duplex stainless steel (AISI 2205) by using electron beam welding and friction welding process. The impact strength and notch tensile strength of electron beam and friction weldments are studied and it shows lower toughness in both the weldments than parent metals [2]. Ma et al investigated the microstructure, impact toughness and fracture characteristics of linear friction welded Ti–6Al–4V joint. The crack developed by impact results short distance along the weld centre and crack initiation in heat affected zone. The result shows a sound weld with higher impact toughness in weld zone than the parent material [3]. Subhash et al studied the friction welding of austenitic stainless steel (AISI 304) and low alloy steel (AISI 4140) related to the microstructure and mechanical properties. Hardness in the weld interface is harder than the parent metals. Notch tensile strength and impact toughness increases with increase in rotational speed and decreases constantly [4]. Sathiya et al experimentally investigated the dissimilar welded joints of austenitic stainless steel and ferritic stainless steel of different mechanical properties exhibited by friction processed joints. The properties of the friction welded joint shows better properties when compared to the fusion processed joints. The joints exhibited 95% of the parent material’s tensile strength and the failure obtained in the weld interface region [5]. Kagaya et al conducted a charpy impact testing at various temperatures in order to clarify the absorbed energies, transition temperatures and fracture behaviour at the

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weld interface of SCM415 / SCM415 friction welded joints and compared with the impact properties of the base metal [6]. Yokoyama et al evaluated the tensile strength and absorbed impact energy under high and low loading rates. The tensile strength and absorbed energy of the friction welded joints increase with a high loading rate and fracture position of the joints varied with respect to the different loading rate [7]. Ito et al investigated analytically and verified by experimental means to improve the impact strength properties of Cu/Al friction-welded joints through the stress concentration at the interface of welded joints. The FEM analyses results indicate the intersection of the weld interface strongly affects the impact fracture behavior [8].

Based on the literature findings, the welding of similar and dissimilar welding from stainless steel and copper to other combination have been studied based on strength and metallurgical aspects. However, the study on impact toughness of austenitic stainless steel and copper joint is very limited. In this present work, impact study is made in austenitic stainless steel and copper material by friction welding and fracture analysis is evaluated in welded regions.

2. Experimental Details

The dissimilar materials of austenitic stainless steel and copper are in the form of cylindrical rods of 24 mm in diameter and 75mm in length. The chemical composition of the dissimilar material is given in Table 1 and 2. The welding surfaces of both the materials were machined and the surfaces are cleaned by acetone in order to remove the contaminants of the surface.

Table 1. Chemical composition of Austenitic stainless steel

Element	C	Si	Mn	P	S	Ni	Cr
%	0.03	0.39	1.63	0.04	0.03	8.99	19.05

Table 2. Chemical composition of Copper

Element	Cu	Fe
%	99.99	<0.01

The friction welding machine was employed to weld dissimilar joints and the machine is capable of operating in the speed of 1 to 2500 rpm with a computer controlled operating system as shown in Fig. 1.

The machine has a stroke of 300 mm and a maximum upset force of 200 kN can be applied. The welded joint produces different sizes of flash at

Fig. 1 Friction Welding Machine

combination of parameters. The metal tends to reduce more in copper side than the austenite side in the welded joint. The main parameters involved in friction welding are friction pressure, upset pressure, rotational speed and burn-off length and the experiments were conducted by using Taguchi's L_9 orthogonal array with three levels and four parameters are presented in Table 3. The welded joints were tested for all samples as shown in Fig. 2 and the value of the impact strength was recorded and the results are presented in Table 4.

Table 3: Friction welding parameter and its levels

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

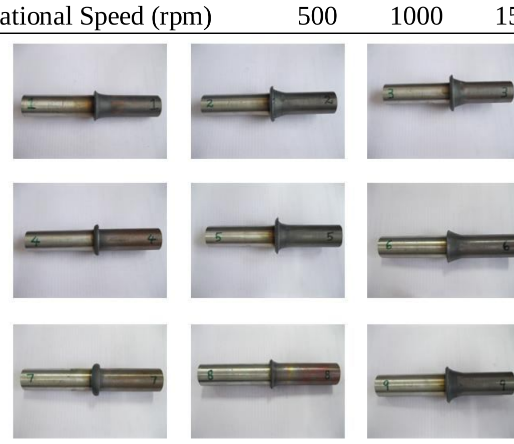

Fig. 2 Friction welded joints

Table 4: Experimental results based on orthogonal array

Exp No	Input parameters				Impact Strength (J/cm^2)
	Friction Pressure (MPa)	Upset Pressure (MPa)	Burn -off Length (mm)	Rotational Speed (rpm)	
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

3. Results and Discussion

3.1. Impact Properties

Samples were made for the impact test and the samples were machined from the welded blocks. A drop-hammer impact testing machine was used to measure the impact toughness of joints at room temperature. The fractured surface of the impact tested sample was examined by scanning electron microscope (SEM). The impact toughness of the joints is tested by Charpy V notch impact test machine and the samples were prepared as per the ASTM standards. Notches were prepared exactly at the midpoint of the weld interface. The fractured surface of welded joint for all the samples are shown in Fig. 3 – 11.

Fig. 3 Fractured sample 1 after impact testing

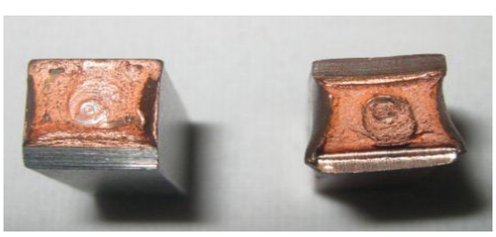

Fig. 4 Fractured sample 2 after impact testing

Fig. 5 Fractured sample 3 after impact testing

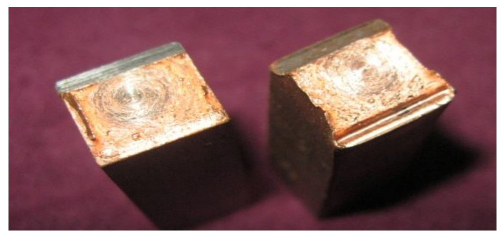

Fig. 6 Fractured sample 4 after impact testing

Fig. 7 Fractured sample 5 after impact testing

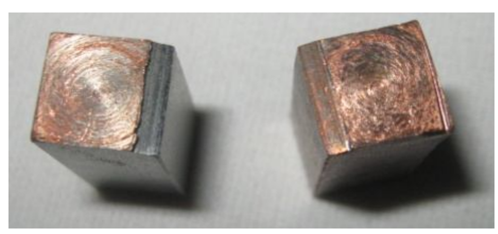

Fig. 8 Fractured sample 6 after impact testing

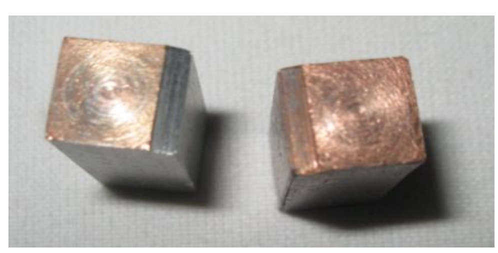

Fig. 9 Fractured sample 7 after impact testing

Fig. 10 Fractured sample 8 after impact testing

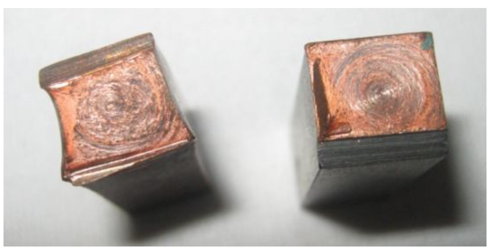

Fig. 11 Fractured sample 9 after impact testing

On the basis of the impact strength of dissimilar friction-welded joints, the fractures occurred in the weld interface for all the materials. It is found that, the impact sample 7 has extremely low value of 4 J/cm^2 shown in Fig. 9 and the impact sample 2 has the highest value of 70 J/cm^2. The impact toughness increases with a decrease in friction pressure for both the high upset and burn-off length as shown in Fig. 4. This is resulting due to fine grain formation with higher degree of working at the weld interface. Due to temperature rise at the weld interface and presence of intermetallic layers, alloying elements accumulate resulting in poor weld strength. The friction welded joint with a high absorbed energy shows more deformation in the copper material, whereas the friction welded joint with a low absorbed energy fractures in the weld interface without showing any clear plastic deformation.

3.2. Fractography

The fractured surface was analyzed in SEM technique to study the behaviour of the material. The fracture shows ductile mode of fracture with dimple formation in the copper material with different magnifications as shown in Fig. 12. Toughness is higher with the low friction pressure due to higher deformation and failure occurs slightly away from the interface is evidenced by showing ductile failure. This supports the fact that joint has good interface, which is formed with good toughness.

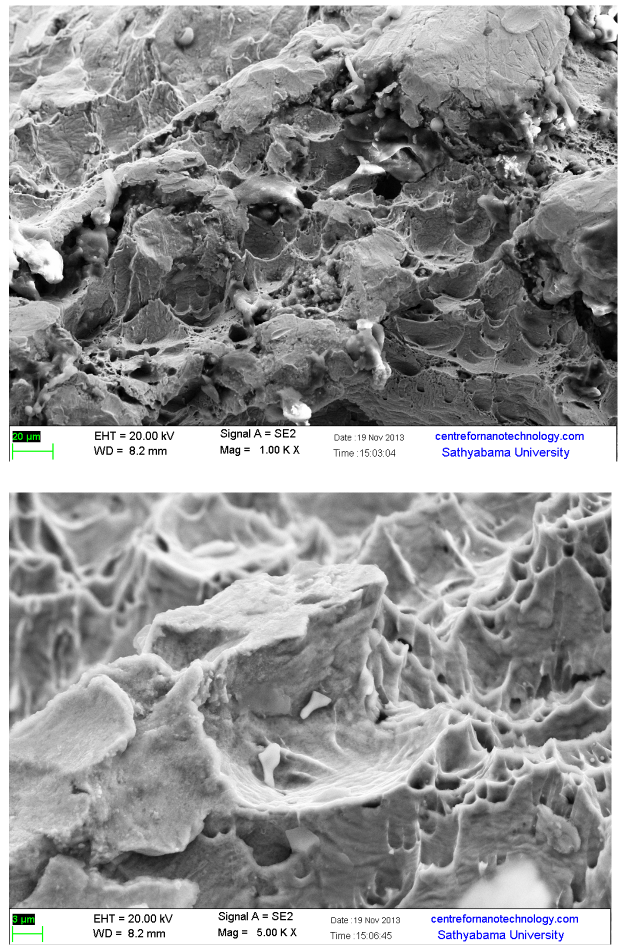

Fig. 12 SEM micrographs of fractured surface with different magnifications

4. Conclusions

The dissimilar material combination of austenitic stainless steel and copper material are friction welded and its toughness of the weld interface was evaluated. Based on the result analysis, the following conclusions were obtained.

- Friction welding has been successfully joined with austenitic stainless steel and copper material. The impact toughness values obtained on joints were varied with one another.
- The quality and the strength of the bond produced are varied. Higher friction pressure with low upset pressure decreases in impact toughness of friction-welded joint whereas with lower friction pressure and high upset pressure results in increase in toughness of bonded material.
- The lowest impact toughness obtained in friction welded joint was 4 J/cm^2 and highest impact

toughness shows with 70 J/cm^2. Due to temperature rise at the weld interface and presence of intermetallic layers, accumulation of alloying elements results with poor impact toughness of the welded joint.

- Fracture analysis was made in the impact tested sample with different magnifications result in ductile mode of fracture with dimple formation.

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Nomenclature

Symbol	Meaning	Unit
MPa	Mega Pascal	N/mm^2
rpm	Revolution per minute	rpm
J	Joules	J/cm^2
ASTM	American Society for Testing and Materials	
AISI	American Iron and Steel Institute	
SEM	Scanning Electron Microscopy	

