

# Investigation on the Effect of Friction Welding Parameters on Impact Strength in Dissimilar Joints

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**Abstract.** Due to increase in demand of joining dissimilar material combinations in applications such as cryogenic fluids, power generation industries and reactor cooling systems, the solid state welding is most suitable in the current scenario. In this study, the experiment is undergone to evaluate the impact strength on the friction welded joint of copper and AISI 430 ferritic stainless steel material in the weld interface. The experiment is conducted by varying the input parameters such as friction pressure, upset pressure, burn-off length and rotational speed using Taguchi's L9 orthogonal array. The welded joints were examined under scanning electron microscopy (SEM) and type of failure mode is discussed.

## 1. Introduction

Friction welding process is increasing rapidly in dissimilar material combinations with defect free joint and also with less time consumption. Joining of copper and ferritic stainless steel is widely used nowadays for many industrial applications such as power generation industries, refrigeration cabinets, food processing, electrical cabinets, and automotive industries, chemical and nuclear industries. Friction welding is a solid state joining process by continuous rubbing action which produces heat between the circular interfaces to make plastic state. When sufficient energy is developed, the rotation stops and upset or compressive force is given to consolidate the weld and form a solid state bond. Friction pressure, upset pressure, burn-off length and rotational speed are the most important parameters to be used in the friction welding process.

Tomoyuki et al was examined to investigate the feasibility of the friction welding of the ferritic and martensitic steel combinations [1]. Paulraj Sathiyaraj et al investigated on similar material of ferritic stainless steel by friction welding. An experimental study was focused on the effect of welding parameters on multiple performance characteristics by friction welding process. Experiments conducted based on Taguchi method showed that the joints exhibited high quality weld for the optimized process parameters [2]. A study was focussed on dissimilar material of austenitic stainless steel and low carbon using friction stir welding process. It was found that due to hot deformation in the welded zone, the austenite region produces small austenite grains is then transformed to fine ferrite and pearlite structure when reaches to room temperature [3].

Sammaiah et al experimentally investigated on the friction welding of 6063 aluminium alloy with AISI 304 austenitic stainless steel to determine the correlation between the microstructure and the joint strength. Few researchers have worked with copper combinations as well. Seong-Yeon Kim et al determined the factors affecting the joint performance of copper to titanium material and found that



upset pressure plays a major role. It was stated that the tensile strength of dissimilar joint increased with increasing upset pressure [5].

A combination of sintered powder metallurgical steel to wrought copper material was made by friction welding and found more deformation on copper side due to high thermal conductivity [6]. Mumin sahin discussed the mechanical and metallurgical variations at weld interface of austenitic stainless steel and copper material with friction welding [7]. Subsequently the study was also focused on mechanical and metallurgical properties of austenitic stainless steel and copper material including surface roughness in the weld interface. The tensile strength in welded joint shows higher than copper material [8]. Radoslaw et al investigated the study of mechanical properties and microstructure of friction welded joint of ductile iron with stainless steel and studied the phase transformation and fracture morphology during friction welding [9].

Madhusudhan et al studied the microstructure and mechanical properties of similar and dissimilar welds of austenitic stainless steel, ferritic stainless steel and duplex stainless steel by using 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 [10]. Subhash et al studied the friction welding of austenitic stainless steel and low alloy steel 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 [11].

Yokoyama et al evaluated the tensile strength and absorbed energy under high and low loading rates. The tensile strength and energy of the friction welded joint increase with a high loading rate and fracture position of the joints varied with respect to the different loading rate [12]. Jian et al studied the friction stir welded 18Cr-2Mo ferritic stainless steel thick plate and the microstructure and mechanical properties are evaluated by showing fine grained equiaxed ferrite in the welded joint [13]. Based on the literature findings, the joining of dissimilar materials are studied widely based on strength and metallurgical aspects of ferritic stainless steel with other combinations and good amount of literature are available in friction welding process. However the dissimilar joint of ferritic stainless steel and copper material are very limited. In this study, the effect of impact strength and its fracture behaviours are discussed.

## 2. Experimental Procedure

Dissimilar materials of copper and ferritic stainless steel with cylindrical rods of 25 mm diameter were purchased. The chemical composition of the dissimilar material is given in Table 1 and 2. The friction welded samples are machined to a diameter of 24 mm and 75 mm in length. The surface is well polished and cleaned by using acetone. Experiments are conducted based on Taguchi's L9 orthogonal array with three levels and four factors is shown in Table 3. The joints made by friction welding are shown in Figure 1.

**Table 1.** Chemical composition of Ferritic stainless steel

Element	C	Si	Mn	P	S	Ni	Cr	Fe
%	0.076	0.551	0.689	0.023	0.016	0.19	16.52	81.58

**Table 2.** Chemical composition of Copper

Element	Cu	Fe
%	99.99	<0.01

**Table 3.** Experimental Factors and their Levels

Parameters	Level 1	Level 2	Level 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

**Figure 1.** Friction welded joints**Table 4.** Experimental Results

S.No	Friction Pressure (MPa)	Upset Pressure (MPa)	Burn-off length (mm)	Rotational Speed (rpm)	Impact Strength (J/cm <sup>2</sup> )
1	22	65	1	500	42
2	22	87	2	1000	38
3	22	108	3	1500	34
4	33	65	2	1500	36
5	33	87	3	500	38
6	33	108	1	1000	36
7	43	65	3	1000	14
8	43	87	1	1500	46
9	43	108	2	500	44

### 3. Results and Discussion

#### 3.1. Macroscopic analysis

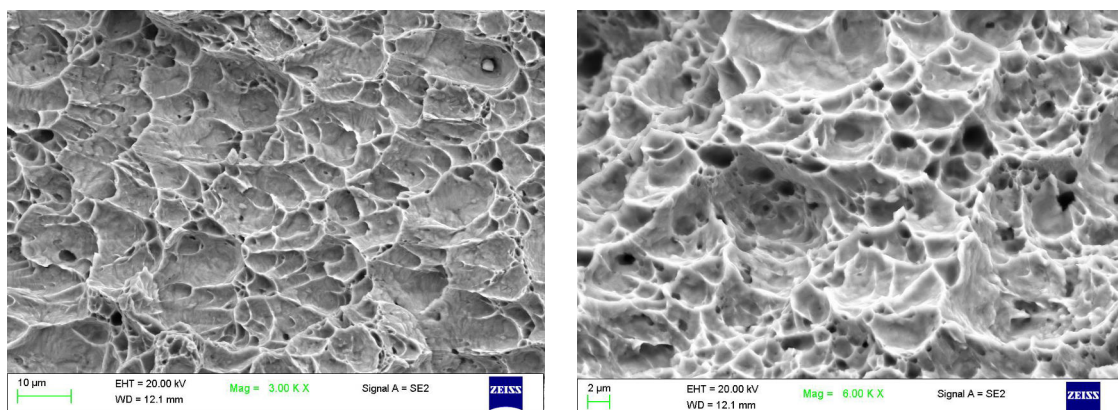
At a macroscopic visual inspection, friction joint is characterized by the presence of plastically deformed flash material, extruded in both parallel and normal directions in respect to the force-motion plane, as shown in Figure 1. The flash length was comparable along the two extrusion directions. Flash material was expelled even from the corners, which is considered to be a necessary condition for obtaining sound joint.

#### 3.2. Mechanical Properties

The impact test is conducted as per ASTM standard and impact values of the welded joint are listed in Table 4. On the basis of the impact strength of dissimilar friction-welded joints, the fractures occurred in the weld interface is shown in Figure 2. The experimental values of impact toughness values were ranged from 14 to 46 J/cm<sup>2</sup>. As upset pressure decreased, the toughness decreases results in lower value of 14 J/cm<sup>2</sup>. When the upset pressure increases, the joint was evidently superior to that of lowering upset pressure and results in higher value of 46 J/cm<sup>2</sup>.



**Figure 2.** Impact fractured sample on ferritic stainless steel and copper



**Figure 3.** SEM analysis of impact fractured sample on ferritic stainless steel and copper

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. Since, ductile type of fracture appeared in copper side, SEM result shows with dimple features as observed in Figure 3.

#### 4. Conclusion

The dissimilar material combination of ferritic 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 ferritic 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 also varied. Higher the burn-off length with low upset pressure decreases in impact toughness of friction-welded joint whereas with low burn-off and high upset pressure results in increase in toughness of welded joint.
- The lowest impact toughness obtained in friction welded joint was 14 J/cm<sup>2</sup> and highest impact toughness shows with 46 J/cm<sup>2</sup>.
- 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.

#### References

- [1] Tomoyuki Uwaba, Shigeharu Ukai, Tatsuyoshi Nakai, Masayuki Fujiwara, "Properties of friction welds between 9Cr-ODS martensitic and ferritic–martensitic steels", *Journal of Nuclear Materials*, 367–370, 1213–1217, 2007.
- [2] Paulraj Sathiyaraj, S.Aravindan, A.Nooral Haq, "Optimization for friction welding parameters with multiple performance characteristics", *Int.J.Mech Mater Des*, 3:309-318K.Y, 2006.
- [3] M. Jafarzadegan, A. Abdollah-zadeh, A.H. Feng, T. Saeid, J. Shen, H. Assadi, "Microstructure and mechanical properties of a dissimilar friction stir weld between austenitic stainless steel and low carbon steel", *Journal of Materials Science & Technology*, Volume 29, Issue 4, Pages 367-372, April 2013.
- [4] P. Sammaiah, Arjula Suresh, G. R. N. Tagore, "Mechanical properties of friction welded 6063 aluminum alloy and austenitic stainless steel", *J Mater Sci*, 45:5512–552, DOI 10.1007/s10853-010-4609-y, 2010.
- [5] Seong-yeon kim, Seung-boo jung, Chang-chaee shur, Yun-mo yeon, Dae-up kim, "Mechanical properties of copper to titanium joined by friction welding", *Journal of Materials Science*, 38, 1281 – 1287, 2003.
- [6] Jayabharath.K, Ashfaq.M, Venugopal.P, Achar.D.R.G. Investigations on the continuous drive friction welding of sintered powder metallurgical (P/M) steel and wrought copper parts. *Materials Science and Engineering A*, 454-455: 114-123, 2007.
- [7] Mumin Sahin, "Joining of stainless steel and copper materials with friction welding", *Industrial Lubrication and Tribology*, 61/6: 319–324, 2009.



- [8] Shanjeevi.C, Satish Kumar.S, Sathiya.P, "Evaluation of Mechanical and Metallurgical properties of dissimilar materials by friction welding", *Procedia Engineering* ,64 1514-1523, 2013.
- [9] Radosław Winiczenko, Mieczysław Kaczorowski, "Friction welding of ductile iron with stainless steel", *Journal of Materials Processing Technology*, Volume 213, Issue 3, Pages 453-462, March 2013.
- [10] G. Madhusudan Reddy & K. Srinivasa Rao, "Microstructure and mechanical properties of similar and dissimilar stainless steel electron beam and friction welds", *Int J Adv Manuf Technol*, 45:875–888, 2009.
- [11] G Subhash Chander , G Madhusudhan Reddy , A Venugopal Rao, " Influence of rotational speed on microstructure and mechanical properties of dissimilar metal AISI 304 - AISI 4140 continuous drive friction welds", *Journal of Iron and Steel Research, International*, 19(10): 64-73, 2012.
- [12] T.Yokoyama, K.Ogawa, "Impact tensile properties of 6061 aluminium alloy to SUS 304 stainless steel friction-welded butt joints", *Welding International*, 17 (7) 514–523, 2003.
- [13] Jian Han, Huijun Li, Zhixiong Zhu, Frank Barbaro, Laizhu Jiang, Haigang Xu, Li Ma, "Microstructure and mechanical properties of friction stir welded 18Cr–2Mo ferritic stainless steel thick plate", *Materials & Design*, Volume 63, Pages 238-246, November 2014.
- [14] Sathiya.P, Aravindan.S, Noorul Haq.A, "Effect of friction welding parameters on mechanical and metallurgical properties of ferritic stainless steel", *Int.J.Adv.Manuf Technology*, 31: 1076-1082, 2007.
- [15] G.Taguchi, "Taguchi on Robust Technology Development Methods", ASME press, New York, pp.1-40, 1993.
- [16] G.Taguchi and S.Konishi, "Taguchi methods, orthogonal arrays and linear graphs. In: *Tool for Quality Engineering*", American Supplier Institute, pp.35-40, 1987.