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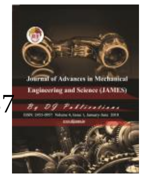

RESEARCH ARTICLE

Effect of Burn-Off Length for Friction Welded Dissimilar Joints of Inconel 718 and SS410

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ABSTRACT

This paper explicates the influence of burn-off length with varying rotational speed on microstructure and mechanical properties of the friction welded Inconel 718 and SS 410 dissimilar joints. The experiments are conducted for three different levels of rotational speed (1300 RPM, 1500 RPM and1800 RPM) and three different burn–off lengths (2 mm, 3 mm and 5 mm) by keeping friction pressure and friction time as constants. A detailed microstructural analysis is performed at the interface of all the joints. The tensile strength and micro harness tests are conducted and the corresponding results are recorded. It is found that at 1500 RPM, the mechanical properties are high due to smaller grain size at the interface region, and the ultimate tensile strength and hardness are found to be 605 MPa and 432 HV respectively.

Keywords: Friction welding, Burn-off length, Rotational speed, Microstructure, Tensile strength, Hardness.

1. INTRODUCTION

The dissimilar metal combination has significant consideration credited to the fast advancement of new materials for structural applications in various engineering fields [1-2]. Several methods of producing this combination include fusion welding, diffusion bonding, brazing and friction stir welding [3]. In these series, friction welding has been employed an effective joining technique applied in manufacturing components for aerospace and nuclear sectors and corrosion resistance [4]. Friction welding is a solid state process which increases the temperature of the interface using the generated frictional heat at the rubbing surface so that the two surfaces are forged together under high pressure [5, 6]. The joint is fabricated by keeping one of the rods stationary, and the other one rotates by increasing the rotational speed. Then axial pressure is applied constantly with the predetermined friction time, and locational heating developed at the interface forms the joint with the accumulated material. Rotation speed, friction pressure, friction time, forging pressure and forging time are considered as important parameters to drive the friction welding, and the effect of these process parameters influences the production of quality joints [7]. Extensive varieties of various divergent joint hx23452345, for example, steel/copper steel/aluminium, and aluminium/magnesium are manufactured without much difficulty. Steels are the most solid high quality and less cost auxiliary material. Thus bimetallic joint of steels with various metals are intrigued in the present assembling innovation. The past literature has extensive studies on joining of steels with aluminium and copper [4-9], yet joining with

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high temperature metals like titanium and Inconel combinations are sparse.

Many authors have discussed the feasibility to improve the physical and metallurgical properties of the friction welded dissimilar metals in the presence or absence of interlayer materials. [9] has obtained sound friction stir welded joints between 6061 Al and AZ31 Mg alloys. [10] has proposed the solid state bonding of 304L stainless steel with an aluminium alloy of AA1050 and has attained high strength joint due to the inter diffusion chemical components at the interface. [11] has experimented the interface properties in terms of rotational speed in friction welding of 304L and 4340 alloy steels [12, 13] have studied the effect of plastic deformation in friction welding for various kinds of steels. [14] has produced friction welded joint of Cp-Ti and SS304 with nickel interlayer that has yielded high hardness at the interface region. However, there are no reports for joining IN718 and SS410 by fiction welding which has various applications in nuclear power plant, aero–engine hot section, pump and valve shaft etc. The present research investigates the joining of IN718 and SS410 steel weld by continuous drive friction welding machine with constant friction and forging pressures, friction time and five different rotational speeds. The effect of increasing rotational speed at the interface on the strength and the microstructural properties are evaluated.

2. MATERIALS AND METHODS

In this examination, 12 mm diameter and 75 mm length of cylindrical rods of Inconel 718 and 410 martensitic stainless steels are used. A continuous drive friction-welding machine is used for fabricating joint and is shown in figure 1. The base metals are tested to examine the physical and mechanical properties and are shown in the tables 1 and 2. In this experiment, the martensitic steel SS410 rod is kept in spinning side and Inconel 718 is kept as stationary. Friction welding processes are carried out at friction speeds of 1300, 1500 and 1800 rpm, under 189 MPa friction pressure with burn-off lengths of 2, 3, and 5 mm. Then, a 190 MPa forging pressure is immediately loaded axially in duration of 10 s. The burn-off lengths (axial shortening) are measured by the difference between lengths of the samples pre and post-welding.

Figure 1.Friction welding machine

Table 1.Chemical composition (wt. %) of Inconel 718 and SS410

Material	Ni	Cr	Mo	C	Mn	Si	S
Inconel 718	53	19	3	0.06	0.32	0.31	0.13
SS410	0.7	12.3	-	0.13	0.83	0.8	0.03

Table 2.Mechanical Properties of base metals

Material	Tensile strength (Mpa)	Yield strength (Mpa)	% elongation	Micro hardness (HV)
Inconel 718	1035	1025	30	521
SS 410	657	595	23	221

The ultimate tensile strength for all the joints are evaluated in universal tensile testing machine and further Vickers micro hardness is estimated by hardness tester. The microstructural studies are carried out using optical microscope at the welded interface region. The chosen values of the friction welded parameters are presented in table A1. For tensile test, flash is machined from the welds before testing, and the base materials and joints are machined with 44 mm gauge length and 10 mm diameter in all parallel parts as per ASTM E8 standards. The dimensions of the tensile specimen are shown in figure 2.

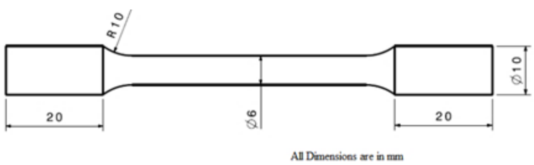

Figure 2.Tensile specimen dimensions

3. RESULTS AND DISCUSSION

A defect free dissimilar joint of Inconel 718 and SS410 is made by friction welding procedure by varying the rotational speed and burn-off length and keeping other parameters constant. The visual examination exhibits the flash width, which increases with increase in the rotation speed and burn-off length. The deformation of flash is observed to be more on SS410 side than IN718 due to high thermal conductivity.

3.1. Results of tensile strength

Tensile specimens are prepared from all the specimens and tested as per ASTM E8 standards for its ultimate tensile strength using universal testing machine of 100 KN capacity. Relations between the tensile strength versus the rotational speed and the burn-off length are shown graphically in figure B1. It is found that the strength of joints raises a maximum, and later, the tensile strength of the joints decreases when the friction time and pressure for the joints are increased. Because, when the friction time and friction pressure of the joints are increased more than the optimum parameters, it results in deformation. Therefore, the strength of joints decreases. At low rotational speed 1300 RPM and burn-off length 2 mm, the tensile strength is found to be 511 MPa and gradually increases to 605 MPa at 1500 RPM with burn-off length of 3 mm and gradually decrease to 538 MPa at 1800 RPM and burn-off length of 5 mm. At low rotational speed, for a constant friction pressure and friction time, there is no sufficient amount of heat generated to soften the metal to create a joint, which results in inferior welding. At high rotational speed, due to friction the metals to be joined are subjected to high heat and successively cooled at faster rate [15]. This enhances the plasticity of the metals making them to soften easily resulting in a lower tensile strength. However, in the comparison of three different burn-off lengths, the lower tensile strength is observed at 2 mm burn-off length and the higher tensile strength is likely to be produced when we increase the burn-off length to 3 mm. However, the tensile strength value is less when burn-off length of 5 mm is used. Thus at optimum parameters of 1500 RPM and 3 mm of burn-off length, adequate amount of heat is generated resulting in higher diffusion at the interface and higher tensile strength.

3.2. Results of micro hardness

Figure B2 shows that the hardness values increases as the burn-off length increases. It is observed that the values of the harness at the joint interface are higher than that of SS410 and Inconel 718 base metals. The hardness value at the interface region for all the welded specimen is calculated and found that at lower rotational speed with less burn-off length, the hardness is lower and the value increases as the burn-off length and rotational speed increase and falls down with further increase in burn-off length and rotational speed. The hardness value is 432 HV which is maximum at the rotational speed of 1500 RPM with the burn off length of 3 mm. The lowest hardness value is 257 HV noticed at the rotational speed of 1300 RPM with the burn-off length of 2 mm. The maximum hardness in the interface region is mainly due to severe plastic deformation with fine recrystallized grain structure.

3.3. Microstructure of weldment

Figure B3 shows the microstructural structure at the interface region of the joint for the three levels of samples for different parameters. The interface region experiences frictional heat due to the rubbing of faying surfaces that causes the changes in the grain size and forms the different zones. At 1500 RPM rotational speed and 3mm of burn off length, the parent metal grains are broken and elongated, and recrystallized grains structures are formed which favours the higher tensile strength and hardness. Two different grain sizes can be observed at the interface layer which confirms adequate mixing of two materials in this region and these grains are elongated perpendicular to the direction of the compressive force as shown in figure B3 for the sample S5. At 2 mm of burn off length and 1300 RPM, due to lack of sufficient amount of frictional heat, the grain structure is not closely packed and results in incomplete joint with plastic deformation when compared to the sample S6. At higher rotational speed with larger burn off length, the friction heat involves more heat thus resulting in huge expulsion of flashes and sudden cooling at the interface region [16]. This makes the region brittle and leads to degradation of mechanical properties.

4. CONCLUSION

Continuous drive friction welding on Inconel 718 and SS410 has been carried out for different rotational speed. From the microstructural analysis and the mechanical property evaluation, the following conclusion can be drawn.

- Dissimilar joint of Inconel 718 and SS416 using friction welding is fabricated successfully without any visible defects.
- Higher tensile strength and the hardness are observed at the rotational speed of 1500 RPM with burn-off length of 3 mm among all the samples. This concludes that increase in these parameters increases the mechanical properties up to the maximum value then declines due to larger expulsion of flashes at higher parameters.
- Hardness value at interface region has higher value than that of base metal SS410 due to severe plastic deformation with fine grains.
- Microstructural characterization at the interface region shows fine and elongated grain size. Interface region shows variations in grain size which confirms the mixing of two metals.

5. FUTURE SCOPE

1. Clear understanding of friction welding of hollow structures like pipes and tubes.
2. Investigation on fracture and fatigue mechanism of the joint.
3. Analysis of the effect of post-weld heat treatment on fatigue life.
4. Further research on the influence of heat treatment process of friction welded IN718 to SS410 joint.

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APPENDIX A

Table A1.Friction welded parameters values

Specimen	Rotational Speed (RS) (RPM)	Burn-off Length(BL) (mm)	Friction Pressure (FS) (MPa)	Forging Time (FT) (sec)
S1		2		
S2	1300	3	189	10
S3		5		
S4		2		
S5	1500	3	189	10
S6		5		
S7		2		
S8	1800	3	189	10
S9		5		

APPENDIX B

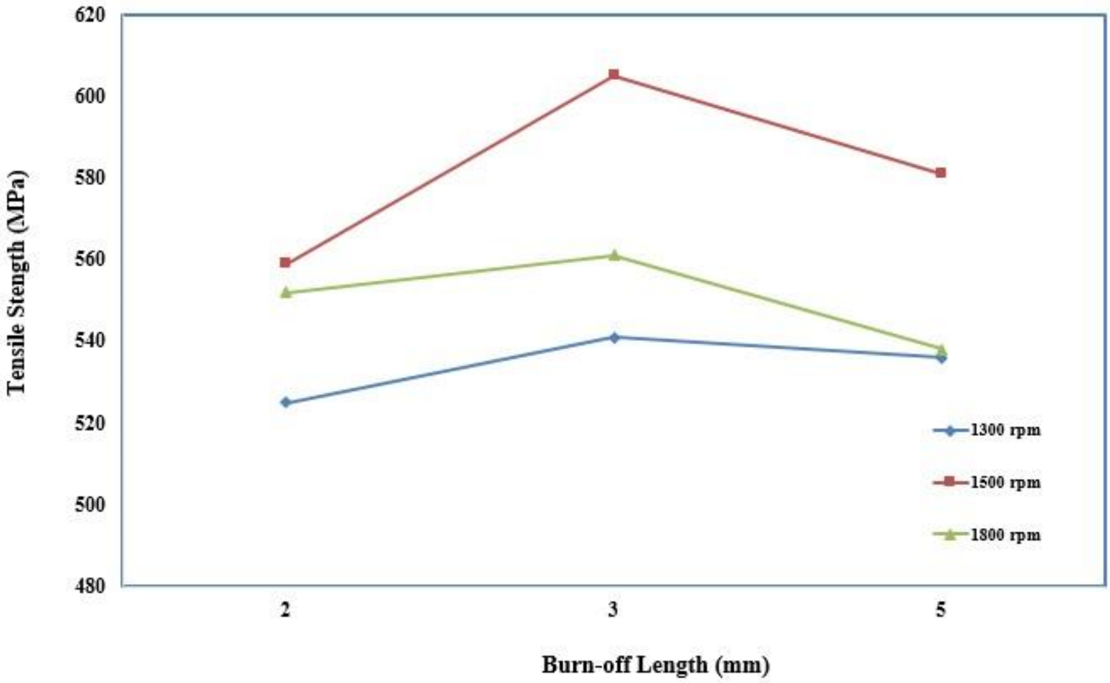

Figure B1.Variations of tensile strength with rotational speed and burn-off length

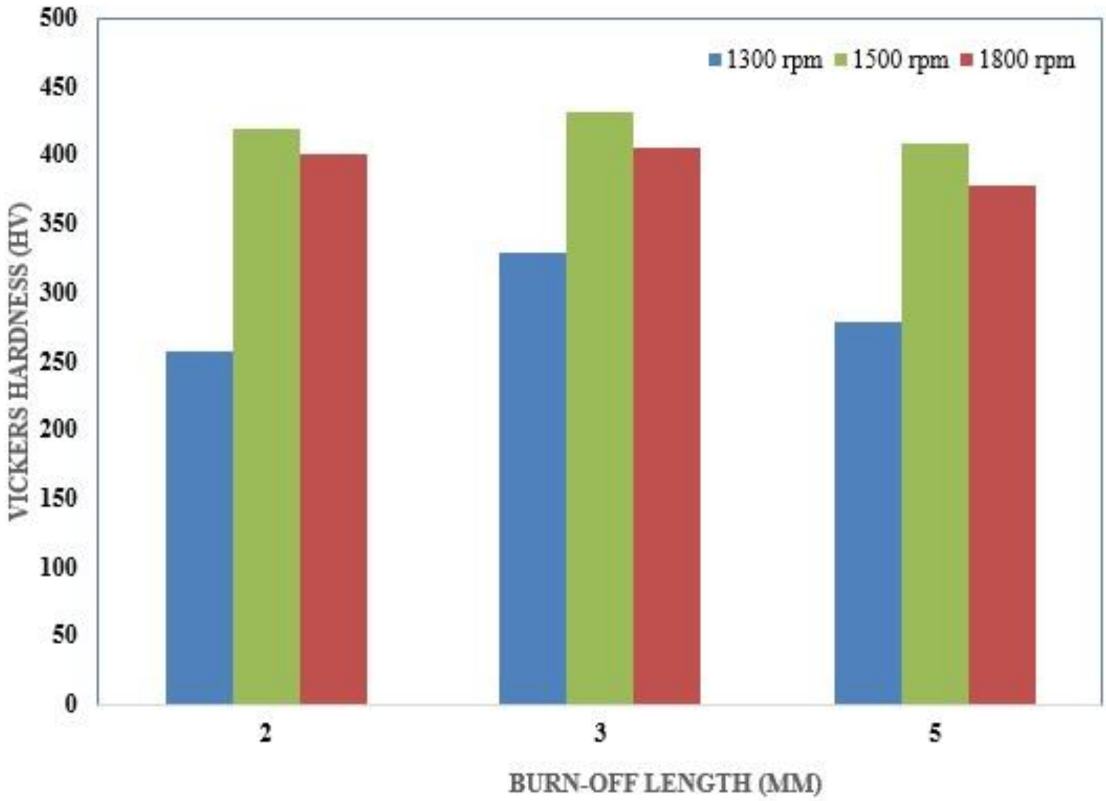

Figure B2.Variations of micro hardness with rotational speed and burn-off length

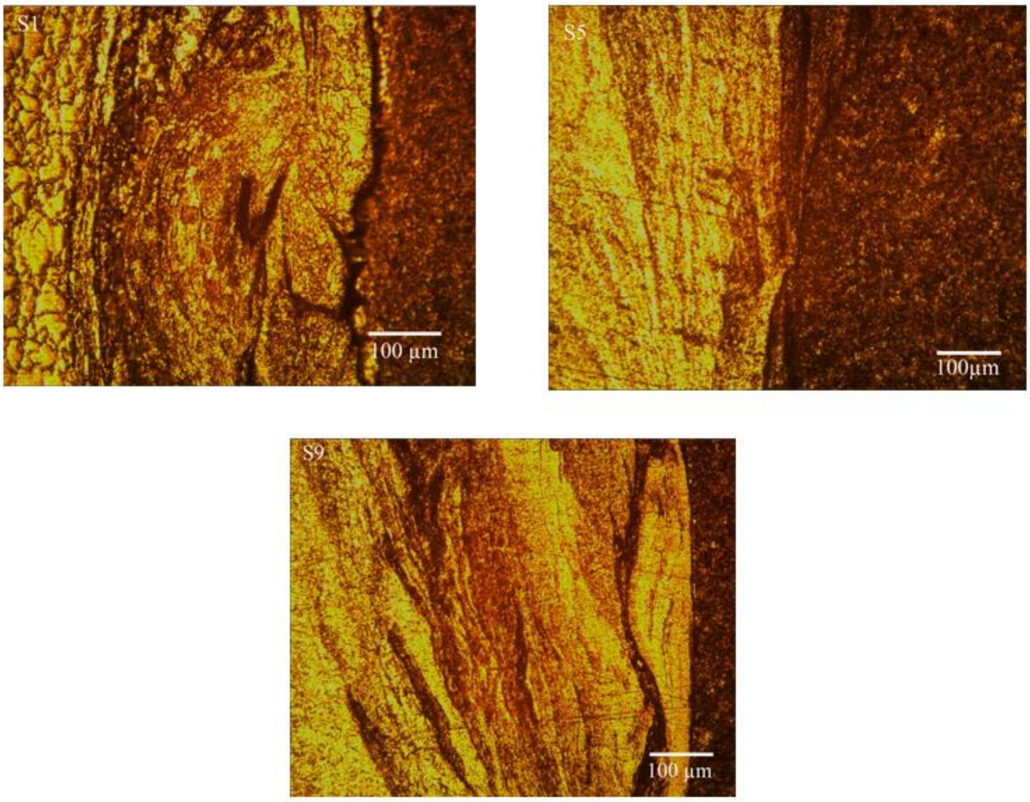

Figure B3.Microstructures at interface region for all samples S1, S5 & S9