Hardness and Micro-structural Study of Inertia Friction Welding of Dissimilar High Temperature Alloys

Ravi Kumar M[*1], Dr. Reddappa H N[*2], M. Sreenivasa Reddy[#3]
[*1]Research scholar VTU-Belgaum, Faculty Dept. of ME RLJIT-Doddaballapur
[*2]Professor, Dept. of ME BIT-Bangalore
[#3]Professor, HOD, Dept. of ME RLJIT-Doddaballapur

***Abstract*— the present study is on the development of inertia friction welding (IFW) of dissimilar high temperature alloys (Inconel 718 and Stainless Steel 304) to study the hardness and microstructural properties. Inertia Friction Welding is a solid state joining process which is more advantageous due to the low heat input, production efficiency, simple manufacturing process and environment friendly. Inertia friction welding process can be used to join rods of similar/dissimilar cross sections and materials without using any filler material, shielding gas and flux. The process parameters such as friction force, forging force, forging time, spindle speed and burn-off length are the major factors in determining the strength of the weld joints. The weld joints were tested for their hardness and microstructural properties.**

Keywords: Inertia friction welding, Inconel 718, Stainless steel 304, Hardness, Microstructure.

I. INTRODUCTION

Inertia Friction Welding is a solid state joining process which is more advantageous due to the low heat input, production efficiency, simple manufacturing process and environment friendly. Inertia friction welding process shown in fig. 1 can also be used to weld different types of ferrous metals, non-ferrous metals and dissimilar metals that cannot be welded by conventional welding processes.

Alloy 718 is a precipitation hardenable nickel-based alloy designed to display the exceptionally high yield, tensile and creep-rupture properties at temperatures up to 700°C. Alloy 718 has excellent weldability when compared to the nickel-based super alloys hardened by an aluminum and titanium. This alloy has been used for the jet engine and high-speed airframe parts such as buckets, wheels, spacers, and high temperature fasteners and bolts [1]. Stainless steel 304 is the standard "18/8" stainless steel; it is the most widely and versatile used stainless steel, available in a wider range of products, forms and finishes than any other. Grade 304 has outstanding forming and welding characteristics. The balanced austenitic structure of grade 304 enables it to be severely deep drawn without the in-between annealing, which has made this grade dominant in the manufacture of drawn stainless parts such as hollow-are, sinks and saucepans [2]. Super alloys are been joined to high strength low alloy steels in the gas turbine engine applications by means of mechanical fastening [2].

When attempts were made to join these alloys by conventional fusion welding methods, the fusion zone of composition can become significantly enriched in Fe and C due to dilution effects, and this composition modification can significantly alter the solidification behavior and associated cracking tendency. The friction welding process produces a metallurgical bond through the frictional heating and the simultaneous deformation along an interface separating the two materials to be fixed as shown in the figure 1. Heat generated along the interface flows either axially away from the interface or radially along the interface. Since the joining is performed in a solid state, extensive migration of elements will not take place. In addition, as the materials are been subjected to hot working, the weld zone exhibits good grain size. The other advantages of solid state welding are that the welds are free from porosity, segregation and liquation cracking that are common in the conventional fusion welding.

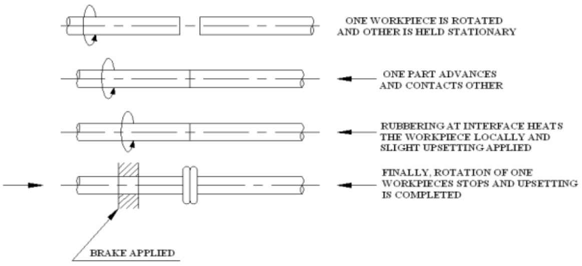


Figure.1: Inertia Friction Welding Process

II. MATERIAL & EXPERIMENTAL DETAILS

A. Materials

Inconel 718 and Stainless Steel 304 materials are selected for the study, since they are high temperature alloys which are used in aerospace application. Table 1 shows the Chemical Composition of Inconel 718 and table 2 shows the Chemical Composition of Stainless Steel 304.

TABLE 1
CHEMICAL COMPOSITION OF INCONEL 718

Element	Content (%)
Ni (+Co)	50 – 55
Cr	17 – 21
Fe	Bal
Co	1
Mo	2.8 - 3.3
Nb (+Ta)	4.75 - 5.5
Ti	0.65 - 1.15
Al	0.2 -0.8
C	0.08
Mn	0.35
Si	0.35
B	0.006
Cu	0.3

TABLE 2
CHEMICAL COMPOSITION OF STAINLESS STEEL 304 [D]

Element	Content (%)
Carbon	0.048
Silicon	0.411
Manganese	1.323
Phosphorous	0.040
Sulphur	0.017
Nickel	8.859
Chromium	18.95

B. *Inertia friction welding machine*

The development of inertia friction welding was carried out by using 3T machine as shown in the figure 2 and machine specifications are shown in Table 3.

Figure.2: Inertia Friction Welding Machine

TABLE 3
FRICTION WELDING MACHINE SPECIFICATIONS [E]

Manufacturer	ETA Technology
Max. Forge Force	30 KN
Max. diameter at weld	10 mm
Max. stem pin length	150 mm
Max. length of head pin	220 mm

C. *Selection of welding parameters*

- The welding procedure was studied [3].
- Based on the study, spindle speed, forging force, friction force and burn-off length were selected as the varying process parameters [4].
- Forging time of 3 seconds was kept constant for all the welding trials.
- Varying process parameters are tabulated in the Table 4.

TABLE 4
LEVELS OF PROCESS PARAMETERS

Process Parameters	Level 1	Level 2	Level 3
Forging Force (T)	2.5	2.75	3
Friction Force (T)	1	1.25	1.5
Spindle speed (rpm)	1250	1500	1750
Burn-off length (mm)	4	5	6

D. *Preparation of specimens*

Inconel 718 material was available in the form of rectangular bar (25 x 15 mm). This was machined to circular bar of 10 mm diameter by turning operation as shown in Figure 3. Stainless steel 304 (bright extruded material) was obtained in the required dimension of 10 mm diameter as shown in Figure 4.

Figure.3: Inconel 718 rectangular bar machined to round bar

Figure.4: Bright extruded bar of SS 304

Friction welding was carried out and the weld produced is characterized by the narrow heat affected zone (HAZ), the presence of plastically deformed material around the weld area and absence of the fusion zone. The weld specimen is as shown in figure 5.

Figure.5: Weld specimen

E. *Features of flash*

The variation of flash feature with the process parameter such as forging time, forging force, spindle speed, friction force and burn-off are presented in Table 5.

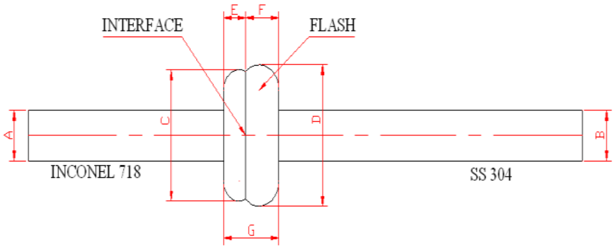


Figure.6: Pictorial representation of flash formed in the welded specimen.

Where, A – Diameter of inconel 718 specimen, mm.

B – Diameter of SS 304 specimen, mm.

C – Flash height, mm (inconel 718)

D – Flash height, mm (SS 304)

E – Flash thickness, mm (inconel 718)

F – Flash thickness, mm (SS 304)

G – Flash width, mm

TABLE 5
WELD JOINT FLASH GEOMETRY DETAILS

Specimen No.	A	B	C	D	E	F	G
1	10	10	15.28	16.42	2.11	4.02	6.13
2	10	10	14.87	16.32	3.06	4.39	7.45
3	10	10	14.55	16.38	3.35	4.99	8.34
4	10	10	15.78	17.28	3.88	4.57	8.45
5	10	10	14.76	16.28	3.09	4.00	7.09
6	10	10	14.79	15.85	2.81	4.41	7.22
7	10	10	15.34	17.22	3.88	4.5	8.38
8	10	10	15.13	16.68	3.27	4.81	8.08
9	10	10	14.62	15.32	2.24	4.13	6.37

III. RESULTS AND DISCUSSIONS

A. *Vickers hardness test results*

Hardness is the property of a material that enables to resist plastic deformation, usually by penetration. However, the term hardness may also be referring to resistance to bending, scratching, and abrasion or cutting [16].

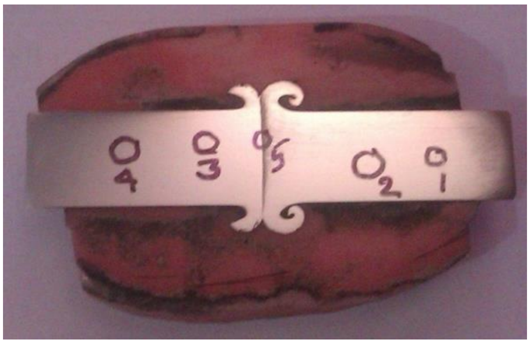


Figure 6: Specimen subjected to Vickers Hardness test

TABLE 5:

VICKERS HARDNESS TEST RESULTS

Position No.	Region	Load (kgf)	Indenter	Hardness (HV-5)
1	SS 304	5	Diamond	361
2	HAZ of SS 304	5	Diamond	525
3	HAZ of Inconel 718	5	Diamond	487
4	Inconel 718	5	Diamond	329
5	Weld region	5	Diamond	274

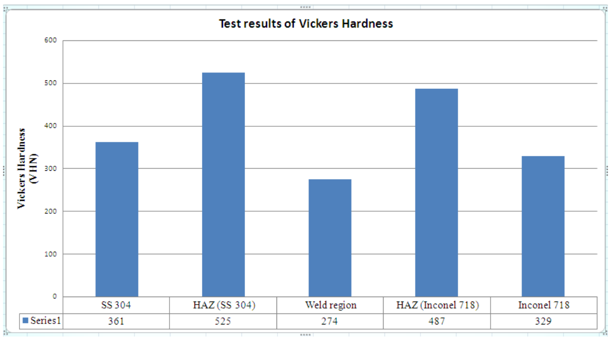


Figure 7: Graph of Vickers hardness test results

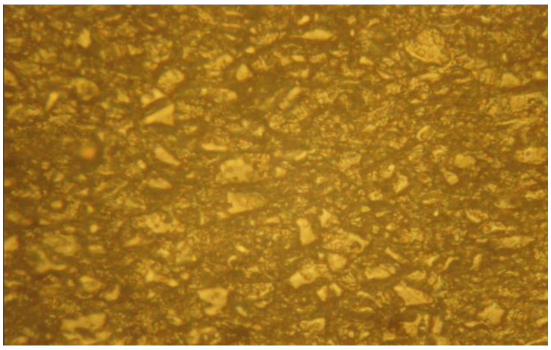
Figure 6 shows the confirmatory test specimen subjected to Vickers hardness test at five different regions and corresponding hardness values are tabulated in the table 5 and shown in figure 7. It is observed that the hardness at the weld region is less when compared to that of HAZ and base metal.

B. *Microstructure analysis.*

Analysis of confirmatory test specimen was carried out to study the structure type through optical microscopy. The microstructure of two different materials is as been shown in figure 8 and 9. In the figure 10 the interface structure of two different weld materials can be observed.

Micro Structure	The microstructure consists of irregular austenite grains and etch pits at dispersed carbide particles.

Figure 8: Microstructure of Inconel 718



Micro Structure	The microstructure consists of randomly distributed, precipitated gama prime Ni_3 (AlTi) and carbide particle in matrix of gama solid solution.

Figure 9: Microstructure of Stainless Steel 304

Conclusion	In the above photo white portion belongs to SS 304 and dark portion belongs to Inconel 718.

Figure 10: Friction welded joint region

CONCLUSION

The main aim was to develop friction welding process for joining of dissimilar high temperature alloys by varying the process parameters such as Spindle speed, forging force (upset force), friction force and burn- off length. The significant outcomes of the study are listed in this section.

i. Vickers hardness of 274 HV-5 was obtained at the weld region of confirmatory specimen.
ii. Optical microscopy was performed on the confirmatory specimen and it can be observed that bonding between two work pieces is good.

ACKNOWLEDGEMENT

I sincerely thank to **Dr. A. N. Nandakumar**, Principal, RLJIT for his support. I express deep wholehearted gratitude to **Prof. M. Sreenivasa Reddy**, HOD Mechanical Dept., RLJIT. I wish to pay my heartfelt thanks to **Mrs. Jayamma** and **Miss. Savitha S. R** for their continues support.

REFERENCES

[1] R. Paventhan, P. R. Lakshminarayanan, V. Balasubramanian, Prediction and optimization of friction welding parameters for joining aluminium alloy and stainless steel, Transactions of Nonferrous Metals Society of China, Trans. Nonferrous Met. Soc. China 21(2011) 1480-1485, October 2010.

[2] P. Sathiya, S. Aravindhan, A. Noorul Haq & K. Panneerselvam, Optimization of friction welding parameters sing simulated annealing, Indian Journal of Engineering & Materials Sciences, Vol. 13, pp.37-44, February 2006.

[3] Dr. K. Narasimha Murthy, Dr. V.P. Raghupathy & Mr. D. Sethuram, Two Day Workshop on Friction Welding & Friction Stir Welding, November 2011.

[4] Mumin Sahin, Friction Welding of Different Materials, International Scientific Conference, Gabrovo, 2010.

[5] D.A. Hartman, In- Process Quality Control of Friction Welding, Manufacturing Behavioral Science, 2010.

[6] Resit Unal, Edwin B. Dean, Taguchi Approach of Design Optimization for Quality and Cost: An Overview, Annual Conference of the International Society of Parametric Analysts, 1991.

[7] A. Vairis and M. Petousis, Designing experiments to study welding processes: using the Taguchi method, Journal of Engineering and Technology, Review 2(1) (2009) 99-103, 2009.

[8] Halil Ibrahim Kurt and Ramazan Samur, Study on Microstructure, Tensile Test and Hardness 304 Stainless Steel Jointed by TIG Welding, International Journal of Science and Technology Volume 2 No. 2, February 2013.

[9] Sujith Sathian, Metallurgical and Mechanical Properties of Ni-Based Superalloy Friction Welds, Department of Metallurgy and Materials Science University of Toronto, Canada, 1999.

[10] Shubhavardhan R.N and Surendran S, Friction Welding To Join Stainless Steel and Aluminum Materials, International Journal of Metallurgical and Materials Science and Engineering (IJMMSE), Vol.2, Issue 3, Sep 2012.

[11] A. Nowotnik, J. Sieniawski, G. Mrowka-Nowotnik, Identification of Dynamically Precipitated Phases in Hot-Working Inconel 718 Alloy, Journal of Achievements in Materials and Manufacturing Engineering, Vol. 31, Issue 2, Dec 2008.

[12] Xingbo Liu, Bruce Kang, William Carpenter and Ever Barbero, Investigation of the Crack Growth Behavior of Inconel 718 by High Temperature Moire Interferometry, Journal of Materials Science, 2004.

[13] Rajender Prasad, Minitab: An Overview, IASRI, Library Avenue, New Delhi-110012.

[14] M. Aruna and V. Dhanalaksmi, Design Optimization of Cutting Parameters When Turning Inconel 718 With Cermet Inserts, World Academy of Science, Engineering and Technology 61, 2012.

[15] Krzysztof Jemielniak, Rough Tuning of Inconel 718, Advances In Manufacturing Science and Technology, Vol. 33, No. 3, 2009.

[16] Shubhavardhan RN and Surendran S, Friction Welding to Join Dissimilar Metals, International Journal of Emering Technology and Advanced Engineering, ISSN 2250- 2459, Volume 2, Issue 7, July 2012.

[17] M.B. Henderson, D. Arrell, M. Heobel, R. Larsson and G. Marchant, Nickel-Based Superalloy Welding Practices For Industrial Gas Turbine Applications.

[18] M. Preuss, P.J. Withers and G.J. Baxter, A Comparison of Inertia Friction Welds in Three Nickel Base Superalloys, Materials Science and Engineering A 437, 38- 45, 2006.