Investigation and Joint effect Analysis of Ti-6AL-4V & SS-304L in Aerospace Applications

R. RAMESH KUMAR*,[1], J. M. BABU[1]

*Corresponding author
[1]Department of Mechanical Engineering,
Vel Tech Rangarajan Dr. Sagunthala R & D Institute of Science and Technology,
400 Feet Outer Ring Road Avadi, Chennai, Tamil Nadu, India,
ramesh.mech37@gmail.com*

DOI: 10.13111/2066-8201.2020.12.3.16

Received: 16 March 2020 / Accepted: 16 July 2020/ Published: September 2020

Abstract: *The friction welding basic principle is connecting two materials with the help of friction generated between them using pressure and frictional time. The material used for this is Ti-6AL-4V & SS-304L with aluminum interlayers. The mechanical and metallurgical experimental strengths are investigated successfully. Titanium and stainless steel joined materials are commonly used for different aerospace, chemical, automotive and nuclear applications. The primary investigation of this present work is the connection between titanium and stainless steel with an aluminum interlayer. Initially, stainless steel and aluminum joints were made, and then the aluminum other surface was connected with titanium alloy. Joined welded samples are analyzed with scanning electron microscopes. Welded joint strength and characteristics were determined with the help of the tensile test, micro hardness and impact test. These investigation results were studied and compared with previous experimental studies.*

Key Words: *Tensile, SEM, Hardness, RSM, Microstructure*

1. INTRODUCTION

Titanium and stainless-steel alloys are high carbon saturated materials. Masaaki, K. et al. (2018) [8] explains how to connect two dissimilar metals with less time duration, and more energy saving welding process. Most titanium materials are available in grade 1, grade 2, grade 3, grade 4, and grade 5. Grade 5 Titanium alloy is used in this study. Poklyatsky et al. (2019) [12] derived chemical compositions providing good quality bonding with better performance in aerospace applications. TI-6AL-4V alloy contains Materials properties are FE-0.40%, AL-6.19%, V-4.04%, and the remaining amount is pure titanium. R. Adalarasan et al (2016) [13] explained the effect of materials junction parameters and characteristics investigation in the area of frictional welding. Vanadium and Ferrite particles were bond with aluminum materials. This friction welding process generates high temperature and heat dissipation energy. In these parameters are detailed by Hamade, R et al. (2019) [1] the setup is the transfer heat source of mechanical energy into thermal energy. These parameters were formed by constant tool rotation with high friction pressure and friction time. TIG welding method and frictional welding methods are investigated and evaluated by using aluminum alloys and heat treatment process derived by Kho et al. (2018) [2]. Welded aluminum samples tool strengths and aluminum materials deformed shapes are evaluated with chemical combinations made by

Kimura, M et al. (2018) [3]. Materials and manufacturing demands are very high in the world. Stainless steel materials hardened temperatures are very high. Stainless steel materials and aluminum compositions are very high. Microstructural, SEM results are displayed. broken material characteristics derived by Kong, Y.-S. and Park, Y. W. (2019) [4]. The Frictional metal welding process is connected with high forging pressure with high temperatures. These high-temperature welded samples are cooled with co_2 particles, process which is explained by Krasnovsky, K., et al. (2019). Stainless steel materials, chemical composition, are V-0.058%, CR-19.10%, MN-1.77%, MO-0.197%, Titanium -0.019, NI-8.11%, the remaining balance amount of Fe consequential by Labesh Kumar et al. (2019) [5]. High-speed strength servo motors are attached to welded machines and the friction joint is evaluated the parameters and material characteristics are investigated by Lalwala, M. & Menghani, J. (2018) [6]. But many trails were failing to connect dissimilar materials investigated by Łukaszewicz, A. (2018) [7]. Finally, we joined the aluminum material with both different ends. Miara et al. (2018) [9] found that the aluminum material thicknesses were 50mm and 100mm in both materials. Plastic joined methods, and testing methods have been developed by the PWHT method. These material joined temperatures are calculated with design procedures made by Miura et al. (2018) [10]. Frictional sequences with the help of heating variant. Materials bonded characteristics, performance have been evaluated by boundary value problems solved by Nagatsuka, K. (2018) [11]. Zn coated used for stainless steel performance by using friction rotary welding. This combined Zn, stainless steel efforts connect between aluminum alloys and steel. The Tool shows and mechanical controls are listed in these investigations: material characteristics and tensile results achieving as a good joint investigated by Poklyatsky, A. G. and Motrunich, S. I. (2019) [12].

Low carbon joints, characteristics are explained entirely. Low-speed frictional welding machines and material strengths are calculated by stud frictional rotation method. Speed variance is a very complicated structure in numerical simulations. Manufacturing materials samples are tested and verified successfully. Bonded structures and joint results are predicted better bonding strengths investigated by Sakamura, M., et al. (2018) [14].

2. EXPERIMENTAL SETUP

Dissimilar material composition

The dissimilar materials Ti-6Al-4V and SS304L samples are in the form of a circular rod size are 16mm diameter and 30mm length. The aluminum material is used to interface between Ti-6Al-4V & SS304L joints. The frictional welding and microstructure surface results have been analyzed with the help of a microscope. The friction welded UTM has examined samples of mechanical characteristics. The tensile test capacity of UTM Machine range is up to 30-tons. After successfully reviewing of the tensile test results are carried out by the hardness test.

Figure. 1 Experimental setup

Frictional welding experimental setup results are shown in Figure 1. The microstructural and hardness results are calculated from the starting edge heat zone to the ending edge heat zone. During the experiments 5 set of jointed materials have been tested. The optimized tool parameters and physical strengths have been evaluated with friction machines.

Sample Trials for frictional welding

In these experimental studies we have analyzed the frictional machine operations, and program setting controls for different joints. The machine spindle operates at a range of speeds like 1100, 1400, 2300, 3200rpm. We have examined the level of machine setting like upsetting time [UT], HEAT pressure [HP], feed rate upsetting pressure [UP], upset delay, heating time [HT], brake delay time. In this investigation, we obtained the following values: brake delay time [0.6sec], constant spindle speed [1600 rpm], upset delay [5sec], federate [0.60mm/s].

3. RESULTS AND DISCUSSIONS

Frictional welds joints of Ti-6AL-4V and SS304L

Titanium [Ti-6AL-4V] and stainless Steel [SS304L] welded samples are shown in figure 1. After welding, the samples' microstructure and mechanical properties were inspected and the test proved all joints were successful. The Frictional welding process generates high-temperature distribution parameters and less heat loss energy. The frictional heat dissipation effects act in mechanical, thermal properties. The joined structures gradient temperature effects have crossed the limitation of material behaviors. Microstructural joints have been observed, and frictional samples have been presented in figure 3. The observed heat affected zone and microstructural results have been investigated successfully. Clear heat-affected zones have been shown in figure 4. Frequently, it has been observed heat increased time and increased heat-affected area. Heating time continuously increased while changing speed. So, the material joints are widely grown. The microscopic evaluation and different parameter samples have been evaluated successfully. Scanning electron microscope and microstructural results were examined and shown in figure 4. Thermal and mechanical heat combined organic results have been obtained in these experiments. Constant thermo-mechanical deformation results have been shown in figure 3.

Tensile Test Results

Mechanical and metallurgical characteristics have been examined for frictional weld joints through tensile testing. Tool characteristics and weld joint strength results are displayed in figure 5. The welded materials have been tested on a hydraulically based tensile testing machine capable of 300kN. The tensile strength welded samples deformation elongation is 1.45%. The maximum displacement and deviation results of this investigation had shown 6.75 MPa. The titanium materials are presented with the non-deformed zone. The non-deformed region appeared from the bonded zone to approximately 1mm. The plasticized area emerged from the bonded zone to around 1.5-2.0mm. Stress-strain relationship results will show 0.02-1.45% of elongations. Maximum strain results display 9.38-26.68MPa. In this study investigation defined the maximum tensile parameters and brittle material conditions.

Hardness parameters

The hardness test performed is an essential characteristic of the joint for mechanical properties. Welded joints were polished with emery sheets and maintained at room temperature. The hardness values were taken from the titanium zone –aluminum zone –stainless steel zone with a distance of 0.2mm.

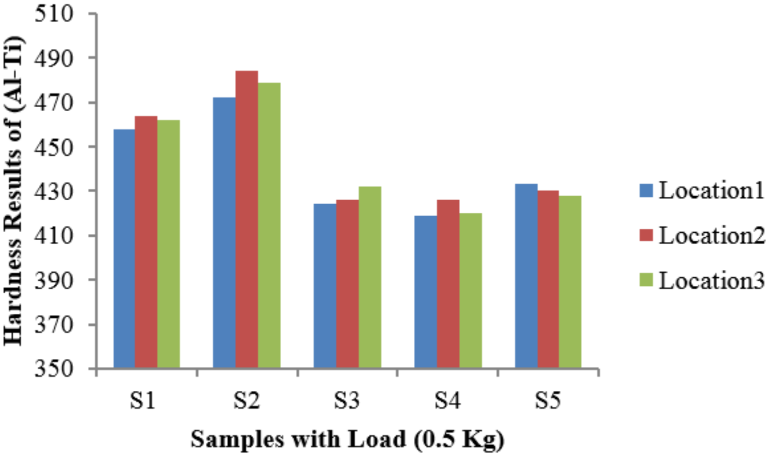

Figure 2. Aluminum - Titanium interfaced hardness results

SEM Analysis

Stainless Steel contains high molecules of chromium. This process converts mechanical energy into heat energy. Stainless steel, aluminum and titanium alloys joined bonding are shown in figure 4. Microstructural, morphology results are carried out with different zonal elongations. SEM image results are taken from 10µm and X-2500. Initially, location 1 scanned the Microstructure particles and displayed figure 4. The machine rotational speeds are fixed with 1200rpm.

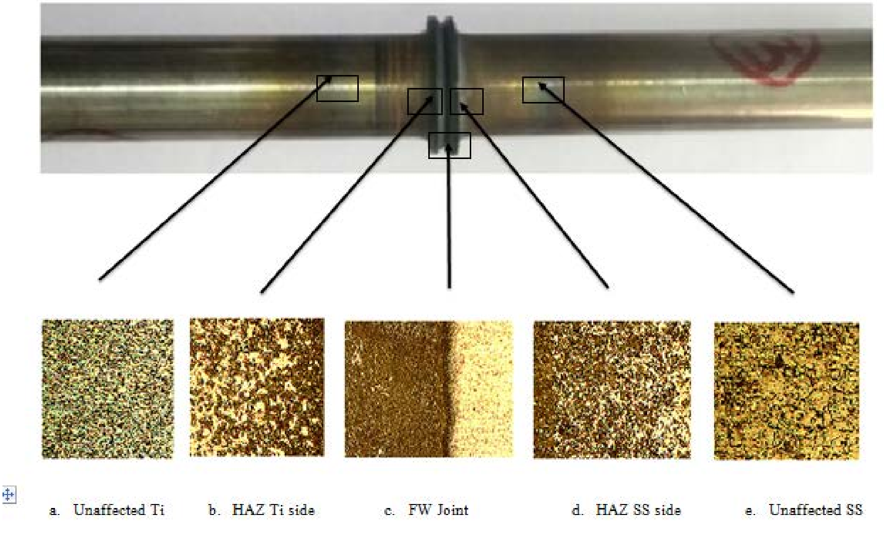

Figure 3. Optical Micrographs of friction welded joint

Two dissimilar samples of [Ti-6Al-4v] and stainless steel [SS304L] can be joined well by using a friction welded joint. We investigated from this study when heating time increased while the heat-affected zone also increased with proper bonding. Welded zones have been observed with a microscope; well-bonded interferences, shown in figure 3. Comparisons from figure 3 quickly identified the microstructures and heat-affected zones.

Microstructure Analysis

Four measurements results have been taken from all-welded samples. Figure 4 shows the test results. Titanium and stainless steel friction welded joints of stainless steel exhibit less hardness compared to titanium material. Lower toughness results have been obtained from the stainless steel samples. But higher toughness results were found in the welded zone. Elements joined performances are designed through micrographs.

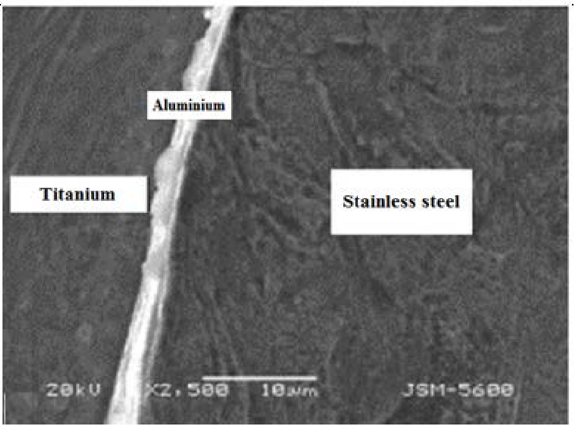

Figure 4. The connection between the width of HAZ and heating time

These test results have demonstrated that the friction-based joints temperatures are higher than the fusion welding joints temperatures. RSM successfully noted these temperature results. As per the ASTM standards, chirpy impact tests have been prepared.
Most friction welded models have low impact resistance results are provided. Temperature distribution test results are shown in figure 5.

ANOVA for Quadratic model

The Model F-value of 63.17 assumes that the model is significant. There is only a 0.01 % chance that an F-value this large could occur due to noise. P-values less than 0.0500 indicate that the model terms are significant. In this case, B is a considerable model term. Values higher than 0.1000 indicate that the model terms are not significant. The Lack of Fit F-value of 5.42 implies that the Lack of Fit is substantial. There is only a 2.62% chance that a Lack of Fit F-value this large could occur due to noise.

Table 1. Actual Vs predictable standard results

Run Order	Actual Value	Predicted Value	Residual	Internally Studentized Residuals	Externally Studentized Residuals	Cook's Distance	Influence on Fitted Value DFFITS	Standard Order
1	128.43	163.39	-34.96	-1.052	-1.058	0.094	-0.689	11
2	139.67	163.39	-23.72	-0.714	-0.697	0.043	-0.454	6
3	168.40	163.39	5.01	0.151	0.144	0.002	0.094	7
4	240.50	247.40	-6.90	-0.333	-0.319	0.059	-0.518	12
5	380.70	323.32	57.38	1.584	1.719	0.099	0.764	3
6	392.60	323.32	69.28	1.912	2.231	0.145	0.992	9
7	398.80	381.66	17.14	0.527	0.509	0.027	0.354	14

8	402.50	449.62	-47.12	-1.349	-1.408	0.105	-0.757	5
9	442.30	449.62	-7.32	-0.210	-0.200	0.003	-0.108	13
10	468.70	482.28	-13.58	-0.417	-0.401	0.017	-0.279	1
11	487.90	542.28	-54.38	-1.501	-1.605	0.089	-0.713	2
12	540.20	542.28	-2.08	-0.057	-0.055	0.000	-0.024	15
13	552.60	549.26	3.34	0.161	0.153	0.014	0.250	8
14	590.80	601.31	-10.51	-0.316	-0.303	0.008	-0.197	4
15	612.53	601.31	11.22	0.338	0.324	0.010	0.211	10
16	638.49	601.31	37.18	1.119	1.134	0.106	0.739	16

Quadratic model results are shown in Table 1. The Predicted R^2 of 0.9314 is in reasonable agreement with the Adjusted R^2 of 0.9431; i.e. the difference is less than 0.2. Model Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. This ratio of 19.758 indicates an adequate message.

Stress-strain relationship

All the sample results are compared and explained successfully. The Relationship matrix contains more tensile characteristics of entering parameters. As per the combination of effects, 1400 RPM joints are not in suitable bonding regions. Friction time as 10 Sec at the point 160 MPa friction pressure only had shown right combination. Remaining plots are represent the weak combination joints.

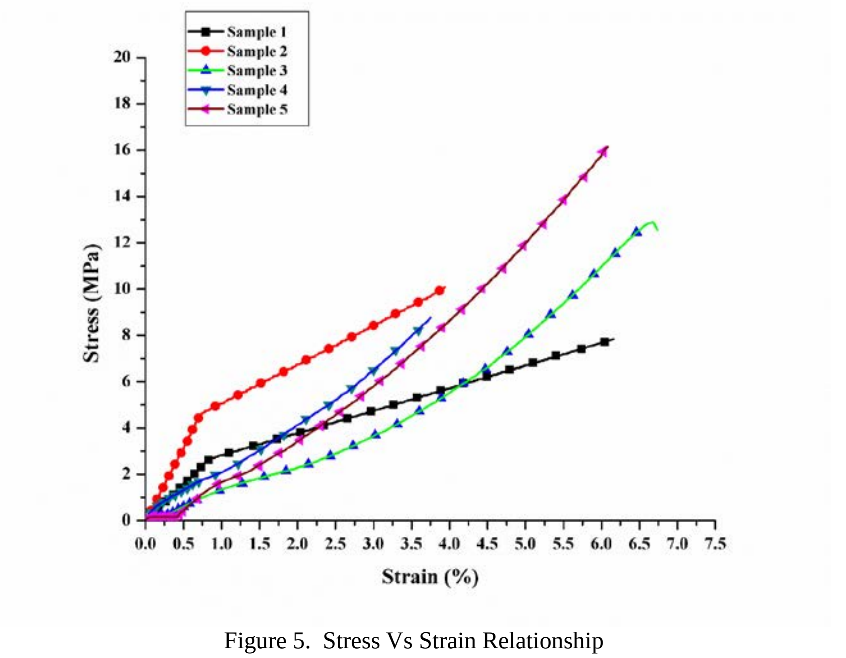

Figure 5. Stress Vs Strain Relationship

When we increased the friction time to15s and maintained 1400 rpm results predicted a poor combination results having less tensile strength.

Results are analyzed and shown in figure 5. The investigation of the overall main effects of the SN ratio and the plot of Means comparison is shown in table 1.

4. CONCLUSIONS

In this investigation, work results declared Frictional welded process could be necessary for industrial applications. Microstructural results are showing increased strength of material characteristics with frictional time. These joined samples used intermetallic on aluminum materials. Two solid-state bonding material characteristics provided more fusion welding characteristics. But in this investigation identified the stable bonding conditions are provided well in preheated treatments. Aluminum inter metallic diffusions have joined the samples successfully. This joint strength is examined with base materials and evaluated the results are shown higher by 96.62%. Friction welded collective toughness results provided higher revolution of the welded zone.

REFERENCES

[1] R. F. Hamade, T. R. Andari, A. H. Ammouri & I. S. Jawahir, Rotary Friction Welding versus Fusion Butt Welding of Plastic Pipes – Feasibility and Energy Perspective, *Procedia Manufacturing*, **33**, 693–700, doi:10.1016/j.promfg.2019.04.087, 2019.

[2] K.-S. Kho, A Study on the Proper Friction Welding Condition of Friction Welding for Similar Steel, *Korean Society of Technical Education and Training*, **23**(4), 109–114, doi:10.29279/kostet.2018.23.4.109, 2018.

[3] M. Kimura, M. Kusaka & K. Kaizu, Joint Strength Of Low Carbon Steel Joints And Its Selection Guide Of Friction Welding Conditions For Low Force Requirements Made By Friction Stud Welding Method, *Quarterly Journal Of The Japan Welding Society*, **36**(2), 135–144, Doi:10.2207/Qjjws.36.135, 2018.

[4] Y.-S. Kong, & Y. W. Park, Optimization of PWHT on Dissimilar Friction Welding for Piping Material of A105 to A312, *Journal of Welding and Joining*, **37**(2), 60–65, doi:10.5781/jwj.2019.37.2.9, 2019.

[5] C. Labesh Kumar, V. Jayakumar & G. Bharathiraja, Optimization of welding parameters for friction stir spot welding of AA6062 with similar and dissimilar thicknesses, *Materials Today: Proceedings*, doi:10.1016/j.matpr.2019.07.204, 2019.

[6] M. Lalwala & J. Menghani, Comparative Analysis of Metal Inert Gas Welding, Braze Welding and Friction Stir Welding for AA5083 Aluminium Alloy, *Materials Focus*, **7**(6), 851–856, doi:10.1166/mat.2018.1595, 2018.

[7] A. Łukaszewicz, Nonlinear Numerical Model of Friction Heating during Rotary Friction Welding, *Journal of Friction and Wear*, **39**(6), 476–482, doi:10.3103/s1068366618060089, 2018.

[8] K. Masaaki, K. Masahiro & K. Koichi, Effect of friction welding conditions on joint properties of austenitic stainless steel joints by friction stud welding, *Welding International*, **32**(4), 274–288, doi:10.1080/09507116.2017.1346854, 2018.

[9] D. Miara, J. Matusiak, A. Pietras, M. Krystian, M. Dyner, High speed friction welding of titanium alloys - structure and properties of joints, *The Paton Welding Journal*, **2018**(6), 40–42, doi:10.15407/tpwj2018.06.06, 2018.

[10] T. Miura, R. Ueji & H. Fujii, Optimization of microstructure at Ni-C steel joint by friction stir welding with CO2 cooling, *Welding International*, **32**(5), 338–344, doi:10.1080/09507116.2017.1346831, 2018.

[11] K. Nagatsuka, Dissimilar Materials Joining Of Metal/Cfrp Using Friction Stir Welding And Resistance Spot Welding Techniques, *Journal of the Japan Welding Society*, **87**(1), 33–38, Doi:10.2207/Jjws.87.33, 2018.

[12] A. G. Poklyatsky & S. I. Motrunich, Strength of welded joints of heat-hardenable aluminium alloys in TIG and friction stir welding, *The Paton Welding Journal*, **2019**(2), 13–18, doi:10.15407/tpwj2019.02.02, 2019.

[13] R. Adalarasan, A. Shanmuga Sundaram, Study of friction welding characteristics of Al/SiC composite and application of grey-based TOPSIS, *Journal of the Chinese Institute of Engineers,* **39**:4, pages 484-492, 2016.

[14] M. Sakamura, K. Ohishi, K. Ota, Y. Takeyasu & H. Fujii, Friction anchor welding between Al alloy and Zn-coated Steel using insert steel difference in the mechanism of friction anchor welding between the types of Zn coatings on Zn-coated Steel, *Welding International*, **32**(5), 363–376. doi:10.1080/09507116.2017.1346855, 2018.