Tensile strength Characteristics on Dissimilar Metal Friction Welding of Ti-6Al-4V & SS304L

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Abstract: *In this research, the method of friction welding joints in Titanium and Stainless Steel with aluminium interlayer coating is created. The friction welding process is a solid-state joining process of dissimilar or similar materials. This friction welding process needs high rotational speed and high forging pressure. Titanium and stainless steel materials melting temperatures are around 1600^{O}C. Welding process which needed high-pressure, temperature and good velocity regions. Titanium and stainless steels are coated 300^{O}C ranges to applied aluminium spray coating method with constant pressure. The source of the aluminium coating is strong titanium and stainless steel adhesive strength. In this experimental project, four different trials of titanium and stainless steel joints have been performed at different speeds and constant forging pressures. Trial 4 connections of titanium and stainless steel made of 2100^{O}C temperature and forging pressure of 60 MPa, friction time of 5 sec and friction pressure of 70 MPa. Friction welding experiments were completed with the help of friction time, forging pressure, rotational speed and friction pressure. Tensile load stress results are calculated by the UTM machine and evaluated the results of design experts with ANOVA table and RSM.*

Key Words: *Titanium, Stainless Steel, Friction Welding, ANOVA, RSM*

1. INTRODUCTION

The structural strength of titanium and stainless steel welded materials are found in this inspection process. (Ram babu, G. et al., 2015 [1]) Dissimilar materials are acts three stages of heat loss under the friction welding process. Friction welding processes are mainly used to connect two solid-state materials with constant pressure and temperatures (Senthil Kumar, G. et al., 2017 [2]). For specific dissimilar or identical joints, auto industries use the friction welding method. This method helps to connect the dissimilar materials with temperature losses constraints for different rotation speed (Kumar, R.et al., 2015 [3]). Titanium and aluminium materials compositions are very high saturated. Titanium compositions are iron (Fe) 0.40%, aluminium (Al) 6.19%, vanadium (V) 4.04% and remaining 89.37% titanium material particulars are in titanium (Ramesh Kumar, R et al., 2018 [4]). These mechanical compositions are taken from ASME GRADE-5 standards. Normally titanium is a good heat absorption material. This may not affect natural energy (Abhinand. (2017) [5]). This process could be saving more energy from the other welding process. Titanium is a strong resistance alloy to corrosion, which saves natural energy (Skamura, M. et al., 2017 [6]). Good collaborations to mixing aluminium and titanium joining process which makes the improved energy saves and heat dissipation of atmospheric temperature. Stainless steel compositions are titanium (Ti) 0.019%, nickel (Ni) 8.11%, Molybdenum (Mo) 0.197%, Magnesium (Mn) 1.77%, chromium (Cr) 19.10%, Vanadium (V) 0.0587%, iron (Fe) 70.75% particulars are mixed with high temperature heated materials. Stainless steel and aluminium materials compositions are good in nature (Praneeth, J. (2017) [7]). The solid performance conditions are good for the fictionally welded material. In aerospace industries, non-corrosion steels are present with high bonding strengths. Aluminium compositions are iron (Fe) 0.3%, chromium (Cr) 0.05%, Magnesium (Mn) 0.10%, titanium (Ti) 0.05-0.30%, nickel 0.05% with high heat treatment energy absorption and good corrosion resistance (DU, B. (2017) [8]). These three combination welded materials are a high-temperature and good stability of the successful heating process (Lin, Y., & Zheng, Z. (2017) [9]). Constant pressure and changing the speed of welded parameters is shown god bonding connections. Friction welding process needs better joint and less heat generation parameters with standard formulations (W. Ratanathavorn, & A. Melander, (2017) [10]).

Fig. 1 Titanium and Stainless steel

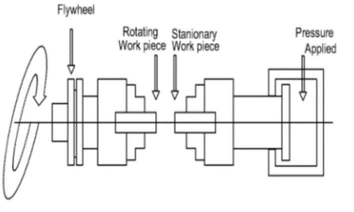

Fig. 2 Schematic setup for the friction welding process

The fig 1&2 schematic diagrams help to find the methodology of friction joining process. Pressure and speeds are constant with different trials. In these parameters are calculated with theoretical results. Dissimilar joints applications are used in Aerospace engine blocks.

2. EXPERIMENTAL SETUP

Titanium and stainless steel welded diameter are 16 mm and the length of the material is 50 mm. All sample trial materials are the same diameter and length. Both material compositions are tested and verified successfully. Specific temperatures for friction soldering are tested and the temperature for the melting of two different materials is determined. Titanium and stainless steel friction welding parameters are needed very high endurance and less time consumption for the welding process.

Fig. 3 Experimental setup

Fig. 4 Initial Fire point of the frictional welding process

The friction welding process is a good method as compared to other weld joining process. Initially, joint 1 was connected between titanium and aluminium materials with a standard temperature of 500-600 ^{O}C. The welded materials are placed into the cold liquid formation after successful completion. The setup works are shown in fig. 3 &4.

Then aluminium material end side removed 2mm long and joint 2 were connected between aluminium and stainless steel with a high-temperature gradient of 800-900 ^{O}C. After completion of trails, it's followed the cold liquid formation.

Now calculated the temperature variance between titanium and aluminium temperatures are 200-500 ^{O}C. The basically titanium and aluminium melding temperatures are 1500-1600^{O}C. This temperature is obtained high strength of materials and saves more energy of the welding process. But we are connected less temperature of 500-600 ^{O}C. These experimental setup results are shown the temperature and pressure variance from the other material joining stages.

2.1 Friction Welding Process

Friction welding processes are connecting two dissimilar materials with constant pressure variances. This pressure variance controls heat dissipation and non-corrosion resistance. Heat energy is transfer from solid to the liquid formation.

It happens materials are joined successfully and temperatures are reduced from material characteristics. All materials are having different properties and different melding temperatures. Maximum power is calculated from the titanium and stainless steel joined results are 5Kw and high endurance limits are very high.

Fig. 5 Welded dissimilar materials of titanium and stainless steel with an aluminium coating

Fig. 6 Heat treatment welded samples of Ti-6Al-4V and SS304L

Two dissimilar materials are connected with the help of varying speed and constant forging pressure. This rotational velocity is acted in XY-direction and heat escape in YZ- direction. With forging pressure, this process can be managed at a constant speed and increasing friction times. Thermal heat rejection process could control the limited pressure and material characteristics for dissimilar alloys. Joined dissimilar materials are shown in fig. 5 & 6.

3. RESULTS AND DISCUSSIONS

Experimental work results are successfully calculated with the help of joint one to joint 4. In this research work saved 38% of energy loss from the friction welding process. These process parameters are studied in friction welding standards. The tests of frictional heat generation were compared with international friction welding requirements. This result, welded with friction, is closest to international standards. The fig. 6 results are verified, dissimilar materials cannot able to connect directly without any interaction materials. Third material of aluminium added between Ti-6Al-4V and SS304L. Aluminium spray coating is painted with the help of thermal spray method of industrial formulation and verified along with all formation results.

The coated manner is never escaping the energy losses in frictional welding constraints. In this reason added the aluminium spray coatings. Welded all four samples successfully and verified the friction time, forging pressure, rotational speed and friction pressure. These results are shown in Table 1.

Table1. Setup parameters of Different trials

S. No	Friction Pressure	Friction Time	Forging Pressure	Forging Time	Speed (RPM)
1	40	5	45	5	1800
2	45	4	40	4	1600
3	50	5	55	5	2100
4	55	4	70	5	2300
5	60	4	80	4	2500

This energy loss is not affected by any material characteristics. Forging pressure and friction time parameter results are verified the table 1 and different testing process of dissimilar welds. This energy loss is not affected by any material characteristics. Different trials are tested after the machining process with the help of Universal Testing Machine. Tensile stress and strain results are listed below fig. 7 & 8.

Fig. 7 Tensile test setup of UTM

Fig. 8 Tensile broken area view

The tensile load's results are evaluated with the high speed universal testing machine. Different strength results are predicted and shown in table 2.

Table 2. Tensile test results of different samples

Sample	Friction pressure (MPa)	Friction time (sec)	Rotation speed (rpm)	Tensile strength (Mpa)
S1	150	10	1400	380.7
S2	160	10	1400	618.57
S3	170	10	1400	202.1
S4	180	10	1400	136.32
S5	190	10	1400	143.39

Friction time and friction speeds are maintained at constant for different samples. The tensile strength results vary from sample 1 and sample 2. The main joined parameters are varied from the experimental setup.

As compared with all samples results, sample 4 results are shown better strength of the experimental setup.

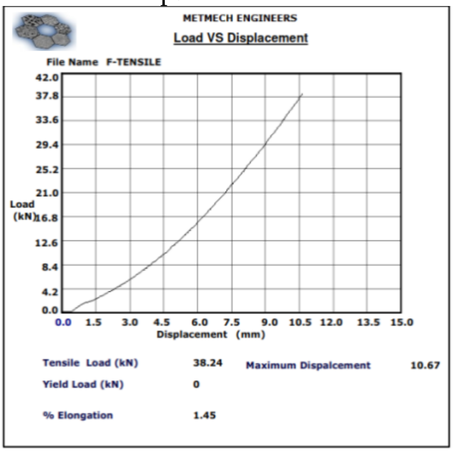

Fig. 9 Sample 1 Load vs. Displacement results

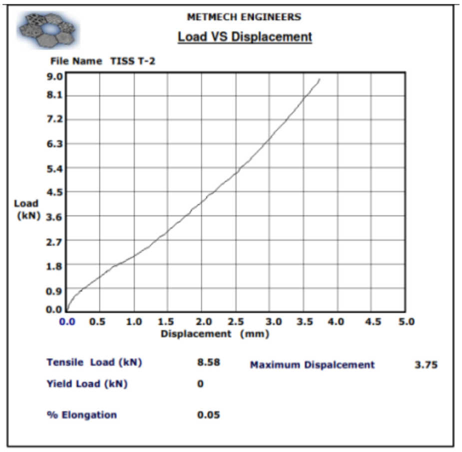

Fig. 10 Sample 2 Load Vs. Displacement results

Sample 1 results predict the displacement and load result values are shown the elongation is 1.45 and the tensile load is 38.24 kN.

Sample 2 results predict the Displacement and Load result values are shown the elongation is 0.05 and the tensile load is 8.58 kN. It is shown low strength of joined the materials.

Sample results are shown in fig. 9, 10, 11, 12. Sample 4 is not bonded with the initial parameters.

The reason, Sample 4 speeds are very high and pressure is very low.

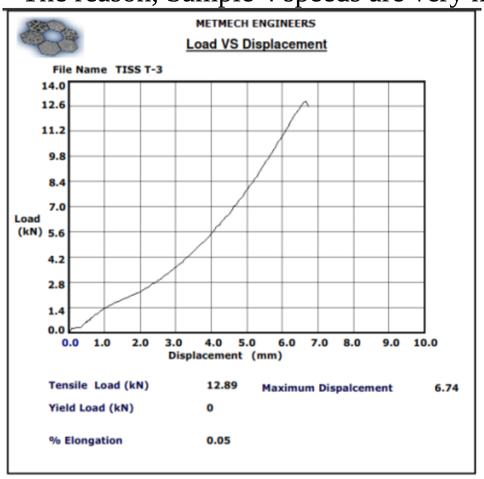

Fig. 11 Sample 3 Load Vs. Displacement results

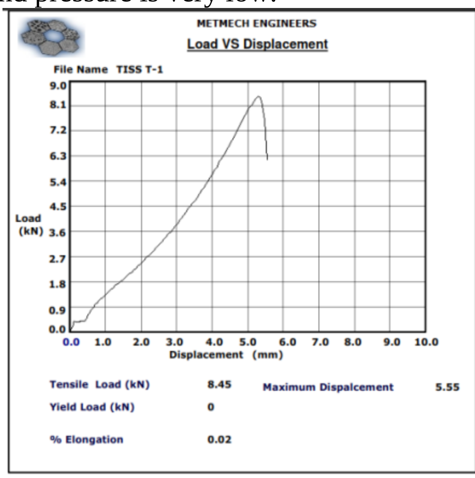

Fig. 12 Sample 4 Load Vs. Displacement results

Sample 3 results predict the displacement and load result values are shown the elongation is 0.05 and the tensile load is 12.89 kN.

It is shown low strength of joined the materials. Sample 4 results predict the Displacement and Load result values are shown the elongation is 0.02 and the tensile load is 8.45 kN and Maximum Displacement is 5.55.

It is shown good strength of joined the materials. Maximum and minimum results are shown in fig. 13, 14.

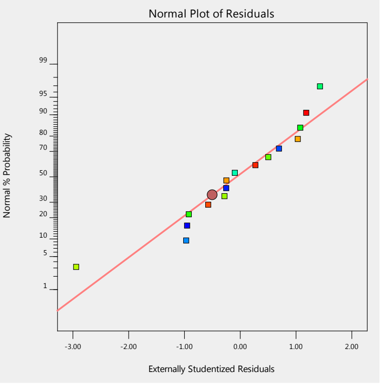

Fig. 13 Residuals and normal % probability results of Sample 1

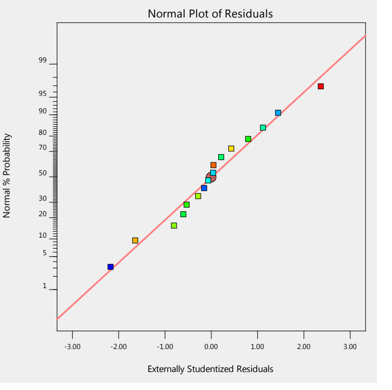

Fig. 14 Residuals and normal % probability results of Sample 2

Tensile results are evaluated in design experts. The normal plot residuals are predicted the good contact of the bonding strength of materials. External residuals results provide the good contact bonding strength of normal load and displacement regions. In the case, parameters consist of blue colour indicated accurate values from theoretical to optimized results. Orange colours are predicted the pressure variance from the optimized parameters. These parameters are shows a better strength from the friction time. Table 3, 4, 5 represents the ANOVA model.

3.1 ANOVA for Quadratic model of Coded Coefficients

ANOVA results are performing the co-efficient values and standard deviations. Mostly Anova tables are verified the residual values as experimental values. Residual values are indicated by 9.8.

Table 3. ANOVA Quadratic Model

Term	**Coef**	**SE Coef**	**T-Value**	**P-Value**	**VIF**
Constant	427.3	28.3	15.07	0.000	
Friction pressure	-110.4	17.4	-6.36	0.001	1.00
Friction time	25.7	17.4	1.48	0.198	1.00
Rotational speed	45.7	17.4	2.63	0.047	1.00
Friction pressure*Friction pressure	-46.8	25.6	-1.83	0.126	1.01
Friction time*Friction time	-64.3	25.6	-2.52	0.053	1.01
Rotational speed*Rotational speed	5.0	25.6	0.19	0.854	1.01
Friction pressure*Friction time	13.5	24.6	0.55	0.606	1.00
Friction pressure*Rotational speed	-24.9	24.6	-1.02	0.357	1.00
Friction time*Rotational speed	17.0	24.6	0.69	0.519	1.00

Residual calculations are compared with analytical results. Our experimental and analytical residual values are closely accurate. Analytical residual values are 9.86.

3.2 Analysis of Variance

Table 5. Two-way interaction Variance Results

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Model	9	146312	16256.9	6.74	0.025
Linear	3	119533	39844.3	16.53	0.005
Friction pressure	1	97558	97558.3	40.46	0.001
Friction time	1	5294	5294.2	2.20	0.198

Rotational speed	1	16681	16680.5	6.92	0.047
Square	3	22409	7469.8	3.10	0.128
Friction pressure*Friction pressure	1	8103	8102.6	3.36	0.126
Friction time*Friction time	1	15268	15268.2	6.33	0.053
Rotational speed*Rotational speed	1	91	90.7	0.04	0.854
2-Way Interaction	3	4370	1456.7	0.60	0.640
Friction pressure*Friction time	1	729	729.0	0.30	0.606
Friction pressure*Rotational speed	1	2485	2485.0	1.03	0.357
Friction time*Rotational speed	1	1156	1156.0	0.48	0.519
Error	5	12055	2411.0		
Lack-of-Fit	3	12055	4018.3	*	*
Pure Error	2	0	0.0		
Total	14	158367			

3.3 Regression Equation in Uncoded Units

Tensile strength = -3303 + 45.0 Friction pressure + 14.5 Friction time + 0.43 Rotational speed - 0.1171 Friction pressure*Friction pressure - 2.57 Friction time*Friction time + 0.00050 Rotational speed*Rotational speed + 0.135 Friction pressure*Friction time -0.0125 Friction pressure*Rotational speed + 0.0340 Friction time*Rotational speed

3.4 Fits and Diagnostics for Unusual Observations

Table 6. Fits Standard Residuals comparison

Obs	Tensile strength	Fit	Resid	Std Resid	
1	202.1	254.2	-52.1	-2.12	R
14	618.6	566.4	52.1	2.12	R

R Large residual

From the ANOVA table, it shows the results are listed in the above table. All residual values are predicted with standard deviations.

The minimum strength of the tensile value shown 202.1 MPa and the maximum strength of tensile value had shown 618.6 MPa. Fits and diagnostics results are in table 6.

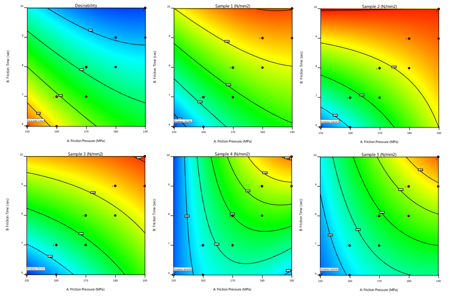

Fig. 15 Minimum Stress-induced area variation

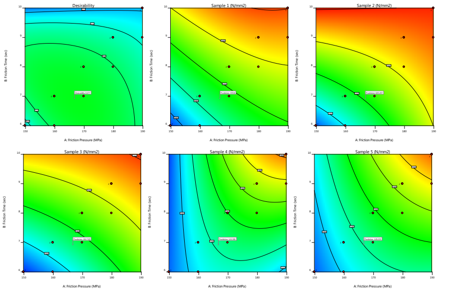

Fig. 16 Maximum Stress-induced area

Surface area variation predicts the better joining process parameters and good even joints. This process could be changed the normal variation of the timing process.

The highest stress-induced surface variance results predicted that this diagram would increase the pressure formation and friction rate. Minimum and maximum stress results are shown in fig. 15 & 16.

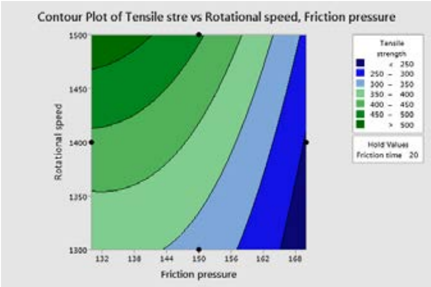

Fig. 17 Contour plot results of Tensile strength vs. rotational speed at friction time 20 sec

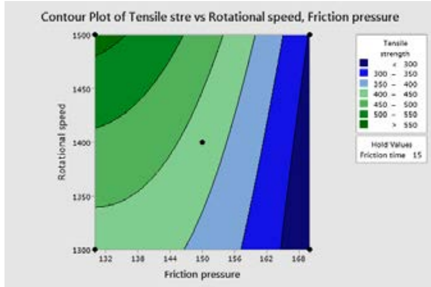

Fig. 18 Contour plot results of Tensile strength vs. rotational speed at friction time 15 sec

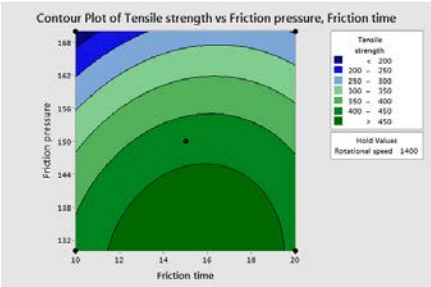

Fig. 19 Contour plot results of Tensile strength vs. Friction Time at 1400 speed

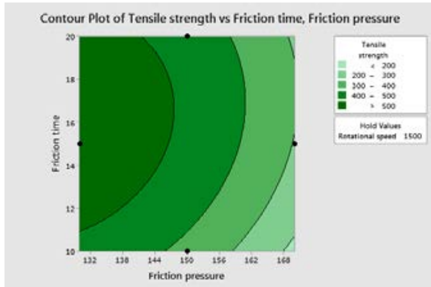

Fig. 20 Contour plot Results of Tensile strength vs. rotational speed at 1500 speed

Contour plot results represent the boundary conditions of rotation speed is 1500 rpm. In this constant speed values are shown the friction time and friction pressure plots. The same methods to be followed in fig. 24 results and the rotation speed had been changed from 1500 to 1400 RPM.

Now in this process changed the friction time and friction pressure with a constant rotational speed of 1500 rpm. This indicates the stronger difference between the initial parameters. Good bonding joints have appeared in this parameter setup. Contour results are shown in fig. 17-20.

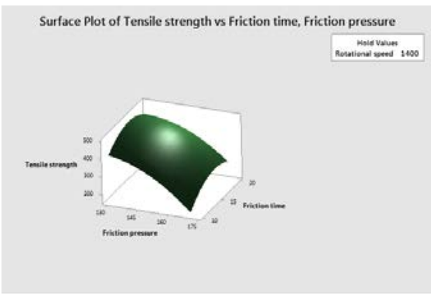

Fig. 21 SEM images for welded dissimilar joints

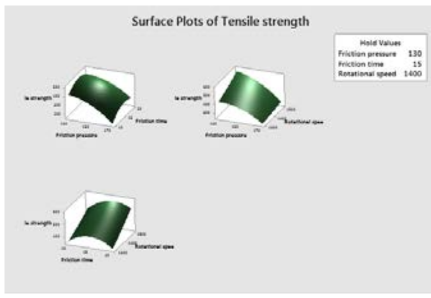

Fig. 22 Microstructures for dissimilar joints

Surface response method predicts the good parameters with significant. These parameters are provided three combination results. It contains friction time, friction pressure and tensile strength of materials. Fig. 21 & 23 shows the Rotational speed of 1500 rpm results are provided with a better joint of the strength of materials. As per the combination of results 1400 rpm joints are not in good bonding regions. Friction time as 10 sec at the point 160 MPa friction pressure only had shown good combination. Remaining trails are poor combination joints. When we are increased in the friction time as 15 sec and maintained 1400 rpm results are predicted poor combination results and less tensile strength results are analyzed. SEM and Microstructures results are shown in fig. 25 & 26.

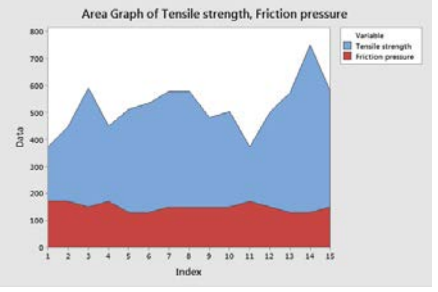

Fig. 23 Area Graph of Tensile vs. friction pressure

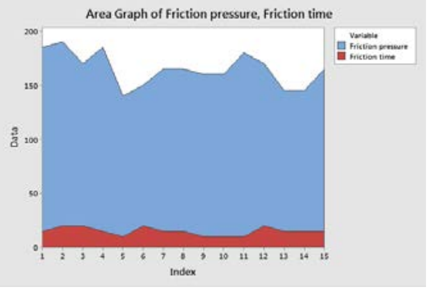

Fig. 24 Area Graph of friction pressure vs. friction time

Fig. 23 shows a comparison of tensile strength and friction pressure ranges. Finally, we concluded from this graph constant pressure and constant tensile results are predicted good bonding joints for the friction welding process. From the graph 24, we identified the results of less friction time and high rotation speed and high forging pressure are suitable for the friction welding joining. Area graph results are shown in fig. 24.

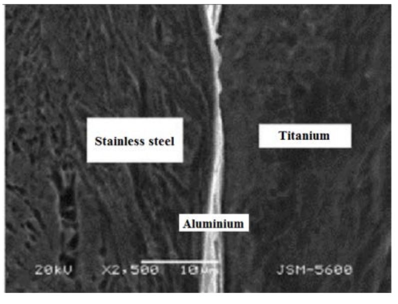

Fig. 25 SEM images for welded dissimilar joints

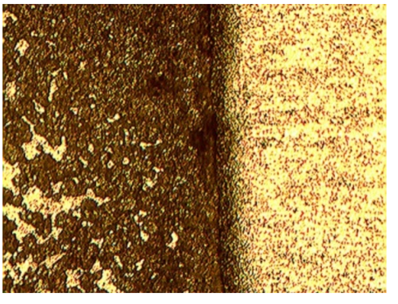

Fig. 26 Microstructures for dissimilar joints

SEM and Microstructural images are performed the identical ranges of dissimilar joints. Aluminium, stainless steel and titanium bonded structures are shown in fig. 25, 26. Figures of high-bonded frameworks with different materials reveal microstructure images.

Standard measurements are performed in ANOVA standard. Many sample methods are used in experimental procedures. But ANOVA standard method is provided good quality of results.

4. CONCLUSIONS

These tests have shown that titanium and stainless steel have a good common relation. The maximum principal stress friction welding results are provided degrees of freedom suitable working conditions. These results have evaluated a range of friction pressure is 70MPa, friction time is 5 sec, forging pressure is 60MPa, Forging time is 5 sec, speed is 2100 (RPM). Titanium and stainless steel friction welding forging pressures are 1.5 times higher than friction pressure.

Sliced materials deformation results are shows good mechanical strength in between titanium and stainless steel. In this report, it is proposed that 14% of energy in the natural area be joined between titanium and stainless steel saved. Energy parts must be stress dismissed in exhausting suitable heat handling method. We have established the effects of reduced friction time, high rotational speed and low forging pressure for friction welding joining. Dissimilar Quantification is 15% reduction in process time, a 20% increase in rotational speed and a 13% increase in forging pressure.

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