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To Study the Joining of Similar and Dissimilar Materials Using the Friction Stir Welding Method

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ABSTRACT: *Friction Stir Welding is applied in several industrial uses as automobile, biomedical, aerospace, fabrication, nuclear and robotics. In this procedure a non-consumable instrument is applied to join two facing work-pieces with no melting the alloys. Heat is created by friction between rotating tool and work-piece material, which soften the material in region near the tool. Tool is travels the length of the joint and strengthen solid-phase joint is produced. The main welding parameters which considered in this research are Tilt angle, rotation speed, and travel speed. Data represent that in welded circumstance there is a noticeable reduce strength and hardness of the aluminum alloy in the joint region. This can be recognized to over-aging of the aluminum alloy because of the heat created by the joining procedure. Still, standard T6 heating actions re-establish the mechanical characters of the aluminum -aluminum joint. This demonstrated the feasibility of FSW for joining both similar and dissimilar metals. This work is focused on the fabrication of high-quality welds and mechanical properties of the weld.*

KEYWORDS: *Friction stir welding, welding parameters, Tilt angle, rotation speed, and travel speed.*

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I. INTRODUCTION

Friction stir welding is a solid state joining method used for purposes where the unique melt properties must stay unaffected as far as achievable. The friction stir welding method is solid-state amalgamation that applies a non-consumable instrument to join two facings of materials without melting [1]. The heat created by friction guides to the softening of the metals, particularly by the friction stir welding instrument [2]. The friction stir welding thought is a specific design of an instrument which has shank, shoulder, and pin. The pin can be introduced into a butt joint or even lap joint and then revolving onward along the joint line. There are some benefits of friction stir welding instrument; these benefits contain heating the surfaces of the work section, making plastic bend, stirring and addition the materials about the pin to make the joint, flow the material, and limiting the heat below the shoulder [3]. Friction stir welding (FSW) take place by rotary instrument “Fig.1” with various speeds and the value of the weld joint and utmost potential welding speed is better by selecting the proper material of the instrument [4]. Commonly, instrument materials of friction stir welding should contain there characteristics: fracture hardiness, power, heating conductivity, thermal expansion coefficient, and reactivity of instrument material with oxygen from the atmosphere and with work pieces [5]. High cross speeds or low rotation speeds produce deficient weld temperatures and that makes the material incapable to contain wide bend during the welding method [6]. There are no protecting gases, porosity, spatter, arcs or vapors and no filler materials are mandatory throughout the friction stir welding process [7]. Friction stir welding with special tool designs, shapes, dimensions, and materials improves many mechanical and physical properties including creep, ductility, strength, fatigue, eliminating casting defects, grain microstructure and corrosion resistance [9]. FSW is supposed chief expansion in metal union in a decennium and is an eco-friendly due to its energy effectiveness, environment friendliness and flexibility [10]. Friction stir welding is a solid-state union method that can be used on aluminium alloys or other materials such as copper, steel and titanium [11-13]. The hotness of aluminium alloys is less than 500°C during the FSW method [14, 15]. In this paper we recognize the weld-ability of similar and dissimilar Al-alloys using the friction stir welding procedure and to estimate the mechanical belongings of like and unlike joints of Al-alloys. Here three combination were used as; Ti- 6Al-4V and 304 stainless steel; aluminum 6061 and copper 110; and aluminum with aluminium (6061-T6).

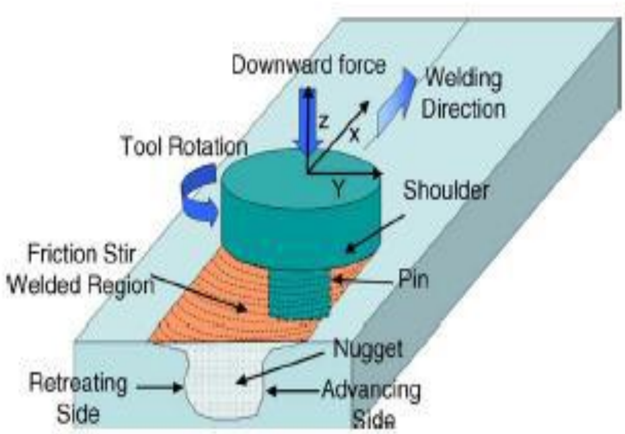

Figure1: Schematic diagram of friction stir welding [8]

II. MATERIALS AND METHOD

Three materials were considered in the present study: Titanium Alloy (Ti-6Al-4V), stainless steel and aluminum. The objective was to improve the mechanical properties of the welded joints by controlling the friction stir welding variables. All plates are 6.0 mm thick. The border of the steel plate is earlier machined while the Al plates are coarse border. The chemical composition, Physical Properties and Mechanical properties of the Titanium Alloy, Al and SS-304 used in this work are given in "Table 1-3" [16-18].

Table: 1 Chemical compositions (wt %) of Ti-6Al-4V, SS-304 and Al (6061 – T6)

Ti-6Al- 4V	Al	Fe	V	C	H	O	Ti	Others
	6.21	0.14	3.9	0.01	0.0045	0.2	Bal	<0.40
SS-304	P	Ni	Cr	C	Mn	Si	Fe	N
	0.03	8.15	18.4	0.08	1.6	0.42	Bal	0.05
Al (6061–T6)	Mg	Fe	Cr	Mn	Cu	Si	Al	Others
	0.8-1.2	<0.7	0.04-0.35	<0.15	0.15-0.4	0.4-0.8	Bal	-

Table: **2** Physical Properties of AA6061-T6

Density (kg/m^3)	Melting Point (ºC)	Modulus of Elasticity (MPa)	Poisson's Ratio
2700	580	69.0	0.33

Table: 3 Mechanical properties of Al (6061-T6)

Yield stress (MPa)	UTS* (MPa)	Hardness Number BHN	Elongation %
276	310	95	12

* Ultimate Tensile Strength

Friction stir welding testing were carried out using a Computed Numerically Command (CNC) grinding machine prohibited in position with a support arrangement. The tool dimensions were pin diameter 0.25 inch, pin length 0.2 inch, and shoulder diameter 1 inch. The rotational speed is ~750-1000 rpm and the traverse speed is 20 or 100 mm/min. These parameters are satisfactory to make certain close contact between the two substances (without porosity), which is necessary for distribution between bonding. In all testing: the welding direction corresponded with the rolling way of the material plates, Al was situated in the retreating surface; tool pin was situated in the Al plate so that it was peripheral to the steel plate with a precision of 0.05 mm. The plates are hold tightly on top of a backing plate and held together with dominant fittings.

Three different parameters (Rotational speed, Tilt angle and Travel speed) were used during this process with two values for each. By using these parameters, eight samples were welded and investigated with different tests, such as the hardness test, the tensile test, and the bending test, both before and after the heating process. The finest and bad samples from those eight samples also were studied using the for microstructure test before and after heating. The comparison was conducted by changing one of the parameters and keeping the other two as constants. The HRF scale was applied to determine the hardness for both the joint and base metal. The mechanical properties of the welds were explained by tensile tests achieved on transverse samples at 25 ºC and at 1 mm/min.

III. RESULTS AND DISCUSSION

FSW between titanium alloy and Stainless steel

FSW between these two dissimilar metals was not successful because of the high hardness and strength of the Ti-6Al-4V. The milling machine did not have the power and force required to join these two metals. The cause is that the machine which we used for welding was not perfect for it.

Friction Stir Welding between Two Sheets of Aluminum (6061-T6)

Friction stir welding between two similar materials joint was successful. The aluminum sheet dimensions used in this welding were 4 inches in length, 2 inches wide, and 0.25 inch thick. "Table 4" shows the various test conditions used to join the two pieces of aluminum (6061-T6) sheet.

Table: 4 FSW parameters for aluminum to aluminum joint

S.No	Rotational speed (rpm)	Tilt angle (degree)	Travel speed setting (mm/min)
1	750	0	25
2	750	0	30
3	1000	0	25
4	1000	0	30
5	750	1.5	25
6	750	1.5	30
7	1000	1.5	25
8	1000	1.5	30

The rotation speed was anticlockwise during the friction stir welding method. This means the tool rotation moved in anticlockwise direction and not clockwise along the joint line. Rectangular tension test samples were taken from the welded samples. Mechanical properties like hardness, fracture stress, ultimate tensile strength, and ductility were measured on all eight samples and represented in "Table 5".

Table: 5 Mechanical properties of the aluminum to aluminum joints

S.No	Sample Conditions	Tensile test (UTS) MPa		Tensile test Elongation %		Joint Hardness (HRF)		Standard deviation		Bending Test (MPa)	
		B	A	B	A	B	A	B	A	B	A
1	AA-0-750-25	118	262	4.5	6.3	50	113	5.25	1.98	246	410
2	AA-0-750-30	46	105	1.8	3.7	56	111	18.6	1.50	354.5	473
3	AA-0-1000-25	113	307	6.0	8.6	46.8	90	5.95	1.0	353	566
4	AA-0-1000-30	160	292	7.0	7.4	48	93.1	4.22	0.68	421	523.7
5	AA-1.5-750-25	179	290	10.4	6.8	51	94.5	3.10	0.52	372	493.5
6	AA-1.5-750-30	166.5	302	8.8	7.6	52	94	4.20	0.45	345.8	483.8
7	AA-1.5-1000-25	142	293	8.2	7.8	50.5	93	6.58	0.92	320	448
8	AA-1.5-1000-30	128	222	6.3	7.3	51	88	6.20	3.37	413	493.6

B= Before, A= After

Tensile Strength and Hardness Test

The comparative study was performed before and after the heating method for the samples. Another comparison was made when two of the three parameters were constant and the third one was varied. Hardness was considered in both the conditions-welded and heat treated circumstances. Hardness tests were performed in both the as-welded and the heat-treated conditions. After FSW, the friction stir welded zone is softer than the base metal as the metal in the heated FSW zone softens due to over aging. Heat treatment restores the strength in the welded zone, and the hardness is almost constant across the entire welded region. The hardness of the starting base metal is included for comparison. The hardness of welded metal after heat treatment is restored to the original hardness of the starting 6061-T6 alloy. The hardness for all the joints after the heating process are constant and higher than before the heating process as shown in the above figures. This means that the friction stir welding conditions and testing procedures method were reliable. A similar observation was made for other combinations of welding conditions between the other samples before and after heating method. The bending results showed that all the samples tested did not break completely. This means that the samples behaved as a ductile material rather than a brittle material. The samples were welded using the same rotation and travel speeds, but tilt angle was changed from 0 to 1.5º. There is no considerable difference between the hardness of two samples; this indicated that the change in tilt angle has no considerable outcome on the hardness of the samples. Similar assessment was detected for additional samples in which only the tilt angle was varied.

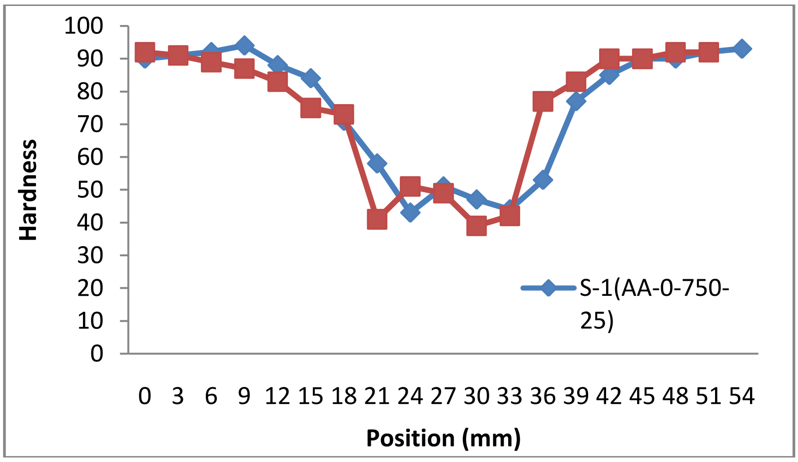

Figure: 2 The Hardness – position curve before heating
(A and T are constant while R is varied)

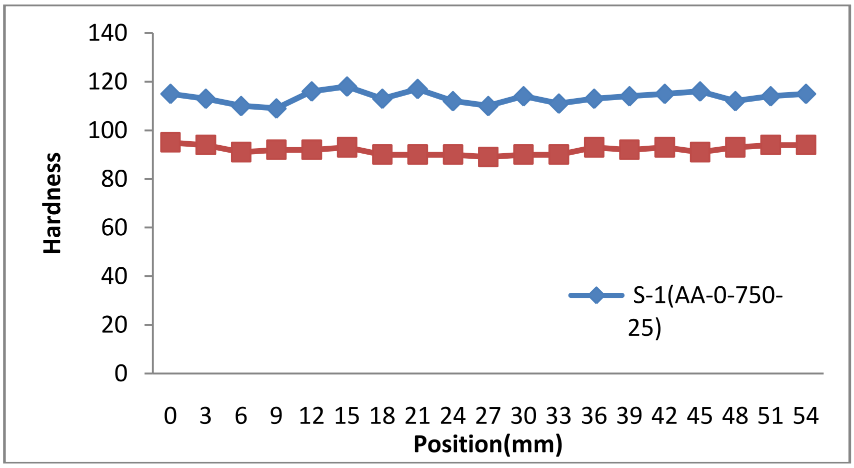

Figure: 3 The Hardness – position curve after heating
(A and T are constant while R is varied)

"Fig. 2 and 3" explain the variation in hardness for sample condition 1 and 3. The samples were welded using the same travel speed and tilt angle. The difference was that the rotation speed when welding sample 1 was 750 rpm and that when welding sample 3 was 1000 rpm. According to these curves, there is no substantial difference between the two hardness profiles, indicating the variation in rotation speed over the range from 750 to 1000 rpm has no significant effect on the hardness of the welded samples. It means there is no effect of welding parameters on mechanical characteristics such as the hardness before heating method. A similar observation was made for other combinations of welding conditions in which only the rotation speed was varied. Hence, FSW of two samples that have equal tilt angle and travel speed but with different rotational speed provides hardness close to each other.

After welding all samples were heated and noticed to T6 circumstance. The welding parameters did not play a significant role in the hardness profiles after welding and before heat treatment, it can be expected that after heat treatment, all hardness profiles will be similar for all welding conditions. The hardness variation with position falls within a narrow band in the range of 80 to 115 HRF for all the FSW tests conducted. This comparison shows that the hardness for the samples with same the rotational and travel speeds but a different tilt angle are constant after heating method. Furthermore, the sample's hardness at tilt angle equal to zero degrees is higher than at a tilt angle equal to 1.5 degrees. "Fig. 4 and 5" clarify the variation in tilt angle for sample condition 1 and 5. This explains that heat action re-establishes the strength in the welded zone, and the hardness is approximately stable across the whole welded region.

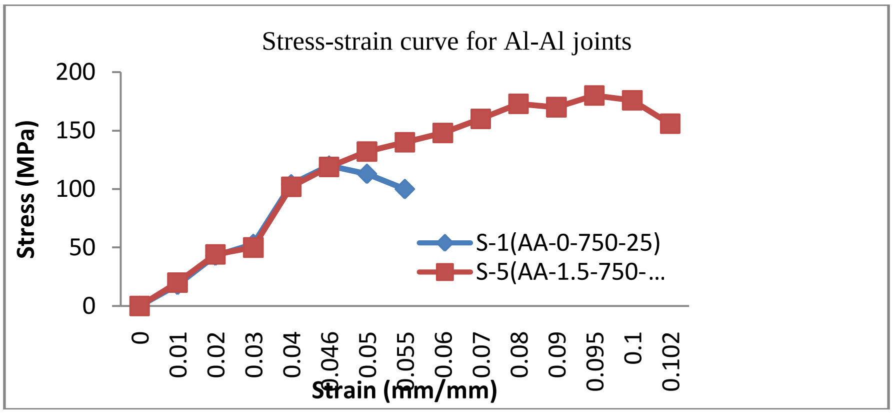

Figure: 4 Stress-strain curve for tension test before heating Conditions (T and R constant, A is varied)

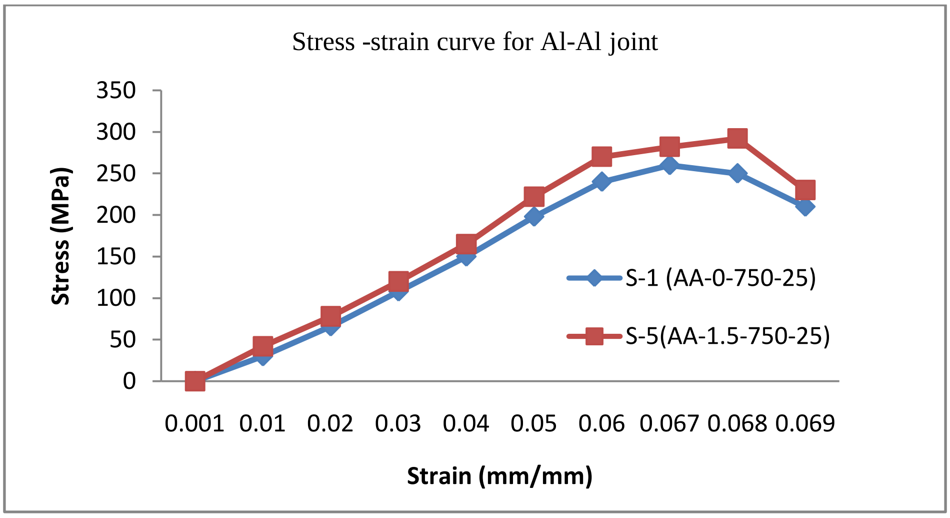

Figure: 5 Stress-strain curve for tension test after heating Conditions (T and R constant, A is varied)

The samples were welded with the similar rotation speed and tilt angle. The changes in travel speed for sample condition 3 and 4 have been given in "Fig. 6 and 7". The variation was the travel speed when welding the samples assorted between 25 and 30 mm/min. There is no substantial difference between the two hardness profiles, indicating the variation in travel speed over the range from 25 to 30 mm/min has no significant effect on the hardness of the welded samples. A similar observation was made for other combinations of welding conditions in which only the travel speed was varied as shown in the appendix. Data show that the hardness looks similar, even though the values do not match with each other one hundred percent. On the basis of data the hardness of the samples that have two of the parameters as constant while the third one is varied, is the same before the heating method.

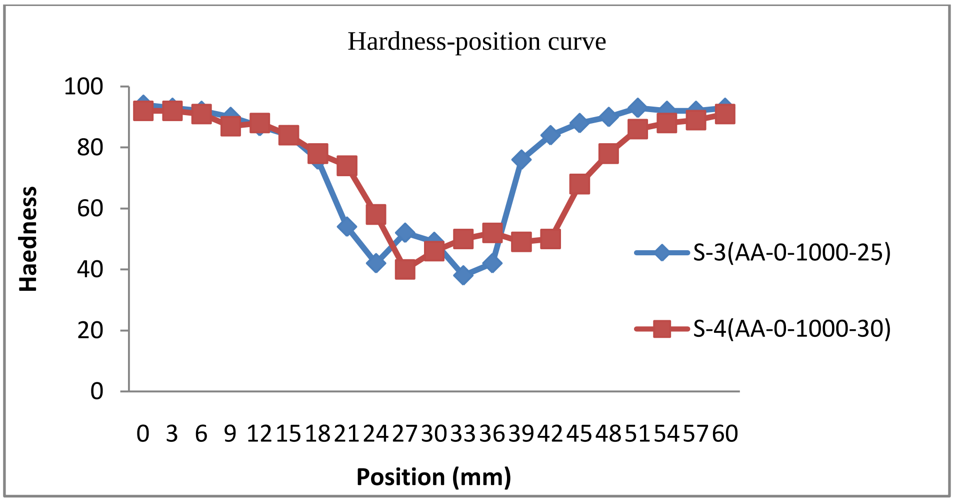

Figure: 6 Hardness position curve before heating
Conditions (A and R constant, T is varied)

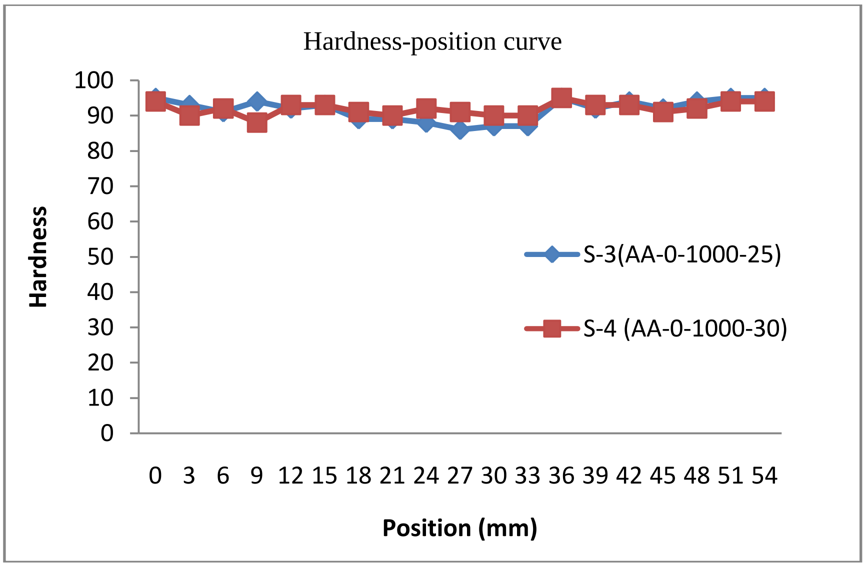

Figure:7 Hardness position curve after heating
Conditions (A and R constant, T is varied)

IV. CONCLUSION

FSW practice was successfully carried out for joining of aluminum alloy. The optimum operating conditions of FSW have been obtained for two plates of aluminum alloy welded joint. The method consideration of friction stir welding i.e. Tilt angle, rotation speed, and travel speed of tool are higher influencing factors affecting on weld quality. From the literature review, it can be observed that friction stir welding process has been successfully applied for joining similar as well as dissimilar materials but in our study dissimilar materials welded joint was unsuccessful. Various optimization methods can be utilized to optimize welding process parameters. We find that preheating of material can improve the quality of weld.

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