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Friction Stir Welding for Joining of Dissimilar Materials

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Abstract: *The findings of experimental study of welds completed between Al-steels that differ in chromium content. Analysis of the micro-structural evolution during the application of pre and post weld heat treatments is reported in dissimilar materials. Particular attention was paid for three different parameters as rotational speed, tilt angle and travel speed were used during this process with two values for each. The finest and bad samples from eight samples were studied using the for microstructure test before and after heating. In-welded condition there is a noticeable change in the hardness and strength of the aluminum alloy in the joint section. This can be credited to over-aging of the aluminum alloy due to the heat produced by the joining procedure. Standard T6 heat treatment develops the mechanical characteristics of the aluminum-steel joint. It showed the ability of friction-stir welding for joining dissimilar metals.*

Keywords: *dissimilar materials; friction-stir welding; rotational speeds; tilt angle; travel speed*

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I. Introduction

Friction stir welding is a kind of solid-state joining procedure which makes welds of high-quality [1]. It was firstly designed to weld aluminum alloys. It is illustrated by joining frictional heating and mechanical disintegration beginning from the rotating apparatus. It brings plastic unshaped of work piece material although the material is in a solid phase, following in complex mixing across the joint. It is imposed to push into the plates to be welded and moved along their contact line with rotating cylindrical pin machinery [2]. Fiction Stir Welding (FSW) can link simply the aluminum alloys and further materials which are soft than the apparatus used in the procedure as the tool which is rigid than the materials to be joined, mainly stir the material at the joint for producing heat-up by the friction and axial strength make course the objects to weld [3-5]. Mechanical goods and microstructure of FSW copper joints over a broad range of welding limits, including rotational speed (from 750 to 1200 rpm) and welding speed (from 200 to 800 mm/min) [6]. Unalike joints are presently immense concern in industrial uses, due to their industrial and fiscal benefits [7]. Hardness changes happen in the FSW joint a cause of the stirring effect caused by the tool action [8,9]. Because of the heat contribution into the base material during welding procedure, there is an alteration in the microstructure of the base material in a zone near the weld [10, 11]. In the vehicles and aerospace manufacturing, several hybrid parts are prepared from lightweight unlike materials such as aluminum alloys and fiber-reinforced polymers [12-17].

II. Materials And Method

Two materials were choosing in this research: Stainless steel and aluminum. The intention was to get better the mechanical properties of the welded joints by controlling the friction stir welding variables. All plates are 6.0 mm thick and the dimensions for the sheets were 101.6 x 50.8 x 6.35 millimeters. The edge of the steel plate is former machined while the Al plates are coarse edge. The chemical composition, physical properties and mechanical properties of the Al and Stainless steel used in this research are shows in table no 1-3 [18-21].

Table no 1: Chemical compositions of Steel -1018 and Al (6061 – T6)

Steel -1018	P		C		Mn	S		Fe
	<0.04		0.14-0.2		0.6-0.9	<0.05		Bal
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 no 2: Physical Properties of AA6061-T6

Materials	Density (kg/m^3)	Melting Point (ºC)	Poisson's Ratio
AA6061-T6	2700	580	0.33

Table no 3: Mechanical properties of Al (6061-T6)

Materials	Yield stress (MPa)	UTS* (MPa)	Modulus of Elasticity (MPa)	Elongation %
Al (6061-T6)	276	310	69.0	12
Steel -1018	370	440	205	15

* 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.

III. Results and discussion

3.1 Al/steel welds

Macro-segment of the Al-steel joints welded with a traverse speed of 25-30 mm/min does not show any noticeable defects like macro-cracks or voids (Fig. 2). The macroscopic interface between the steel and the aluminum plate looks sharp without any significant roughness or particles. There is no visible mixing of the two materials. This feature is attributed to the specific experimental conditions since the pin of the tool was fully located in the aluminum plate.

3.2 Friction Stir Welding between Aluminum (6061-T6) and steel (1018)

FSW between two dissimilar 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. The friction stir welding process was carried out by fixing the 1018 steel on the advancing side while the aluminum on the retreating side. The base metal hardness for 1018 steel was high, reaching 102 HRF so a heat treatment process was done. An annealing process was done to decrease the high hardness by holding the sample in the furnace from 870 to 910 Cº. All the procedures done with Al (6061-T6) sample were also done with this type of dissimilar welding. Table no 4 shows the various test conditions used to join aluminum and steel sheet. The different mechanical properties of the aluminum to steel joint are given in table no 5.

Table no 4: FSW parameters for aluminum to steel joint

S.No	Rotational speed (rpm)	Tilt angle (degree)	Travel speed setting (mm/min)
1	750	0	12
2	750	0	15
3	1000	0	12
4	1000	0	15
5	750	1.5	12
6	750	1.5	15
7	1000	1.5	12
8	1000	1.5	15

Table no 5: Mechanical properties of the aluminum to steel joint

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
S-1	AS-0-750-12	135	20.5	4.2	0.8	47.6	82.4	12.5	7.5	412.6	166.5
S-2	AS -0-750-15	111	49.2	4.8	1.5	54.2	78.2	8.0	6.5	276.0	273.0
S-3	AS-0-1000-12	94.3	20	3.5	0.8	53.5	86.3	7.2	9.5	268.4	246.2
S-4	AS-0-1000-15	98.8	53.5	3.4	1.6	48.5	88.0	6.5	3.9	265.6	158.4
S-5	AS-1.5-750-12	176	52.2	4.5	1.2	45.8	82.2	0.86	9.5	231.5	166.2

S-6	AS-1.5-750-15	157.5	24.5	4.5	1.0	50.2	78.6	6.0	6.0	220.8	125.3
S-7	AS-1.5-1000-12	138.5	36.2	4.2	1.7	49.0	83.2	3.0	6.9	330.2	135.2
S-8	AS-1.5-1000-15	109	37.4	4.0	1.8	58.6	88	6.40	5.8	284.2	154.2

B= Before, A= After

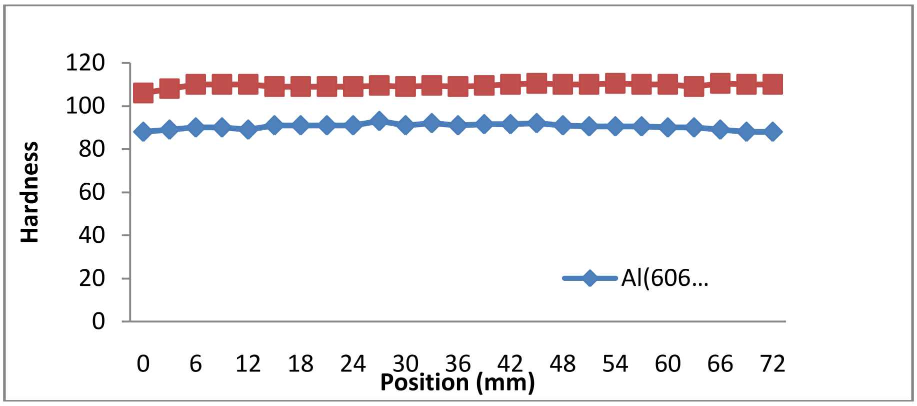

Figure1: Base metal Hardness Comparison between Aluminum and steel.

The hardness of the starting base metal of steel and aluminum are shown in figure 1 for comparison. After FSW, the friction stir welded zone is softer than the base metal because the metal in the heated FSW zone softens during the welding process. Hardness tests were conducted for welded material and the heat-treated conditions for it. Figures-2 shows typical variations in hardness over the friction stir welded zone. Heat treatment restores the strength in the welded zone, and the hardness is higher across the entire welded region than before heat treatment. These figures show the hardness comparison between two samples (S-3 & S-4), before and after the heat treating process, which have same the welding parameters. The welding parameters are tilt angle, rotation speed and travel speed, which were used for the welding of aluminum to steel joints. All the graphs show that the joint before the heat treating process was softer. However, there was an increase in joint hardness after the heat treating process and it showed variations.

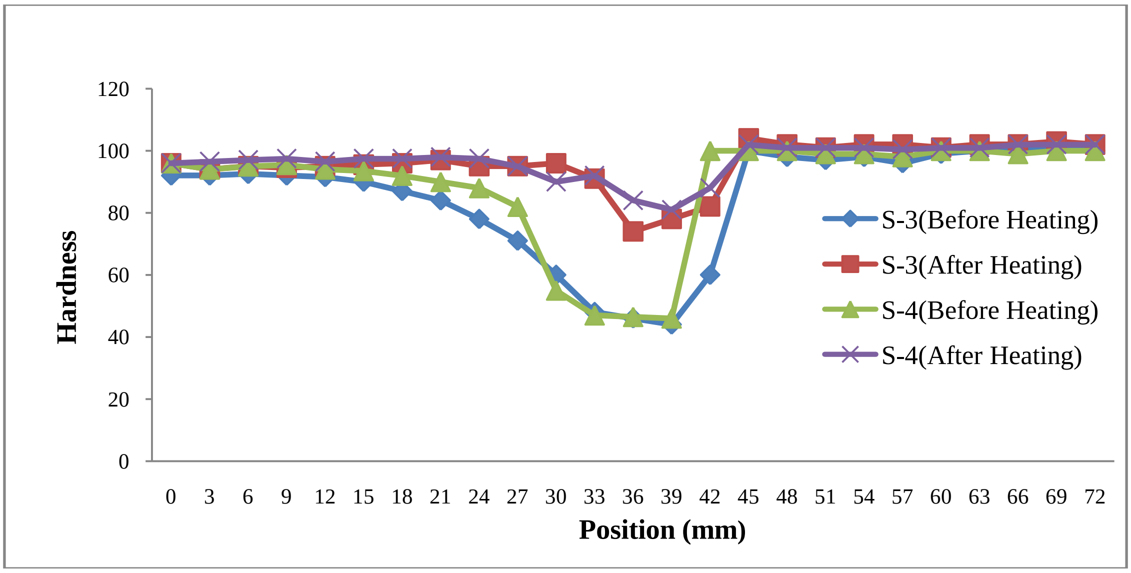

Figure 2: Welded samples hardness Comparison between S-3 and S-4 before and after heat treatment

The base metal hardness of aluminum and steel sides before and after the heat treating process was higher than the reference base metal of aluminum, as seen in figure 2. As declare before, the improvement in joint hardness after the heat treating process is because heat treating process restores the joint to its original properties. This means that the variations in temperature during friction stir welding process affect the mechanical properties, such as the hardness. From above figure, it is clear that base metal steel has higher hardness as compare to aluminum base metal.

3.3 Comparison of Tension Test before and after Heat Treatment

Tension tests were carried out for all samples which showed typical variations in strength over the friction stir welded zone. The figure-3 represents the comparison of curves before and after the heat treating process for S-5. As represented in graph, the sample before heat treating is stronger than the sample after heat treating. Normally, the graphs behavior is brittle, which means fractures occurred suddenly without any indication. The main reason that the aluminum–steel joints before the heat treating process are stronger than after the heat treating process is during the heat treating process, the atoms that exist in the joint area revert back to their original alloy, such as aluminum atoms to aluminum and steel to steel. This means that the different atoms, like the aluminum and steel in the welded zone, do not accept each other during the heat treating process.

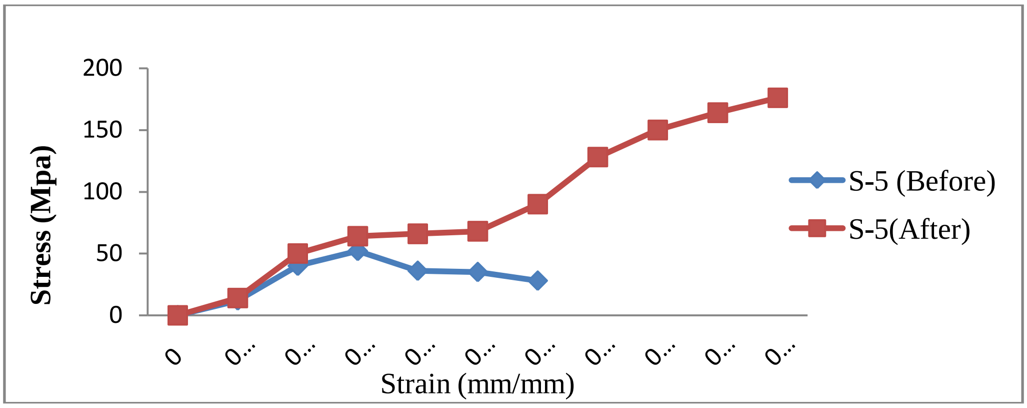

Figure 3: Stress-strain curve for Al - steel joint (S-5) before and after heat treatment

3.4 Effect of welding parameters before and after heat treatment

3.4.1 Effect of varying tilt angle before and after heat treatment

Figure 4 compare the variation in tension strength before heat for samples S-1 and S-5. The samples were welded using the same rotation and travel speeds, but S-1 was welded with a tilt angle of 0º and S-5 was welded with a tilt angle of 1.5º. There is a considerable difference between the two strength profiles, indicating the variation in tilt angle over the range of 0º to 1.5º had a significant effect on the strength of the welded samples. the graph show that the sample at a tilt angle equal to 1.5º were stronger than the sample at a tilt angle equal to zeroº. The effect of tilt angle on the strength of the same samples during the tension test was random. Figure 5 shows opposite result, that the sample, S-1 has a tilt angle equal to 0º is stronger than the S-5 at a tilt angle equal to 1.5º. It is due to the thermal cycles of friction stir welding and as the atoms for aluminum and steel do not accept each other in the joint area.

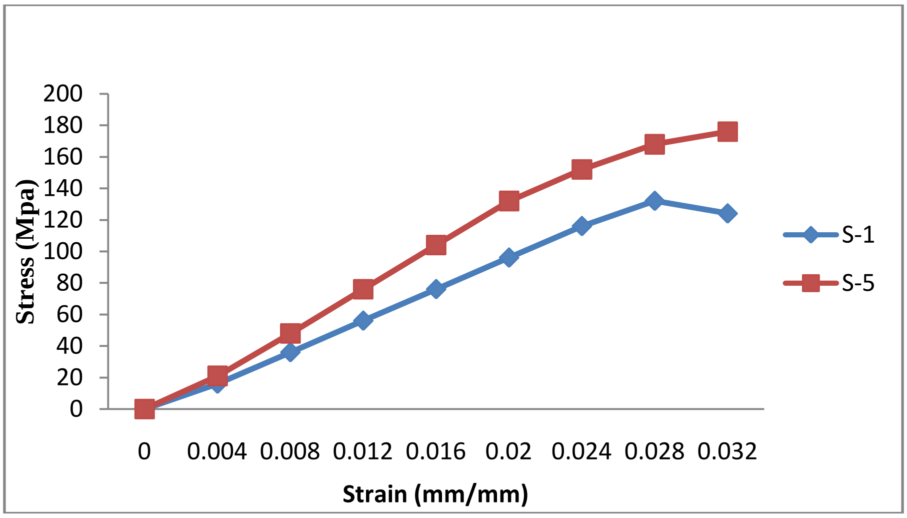

Figure 4: Stress - strain curve for Al - steel joint for varying tilt angle before heat treatment

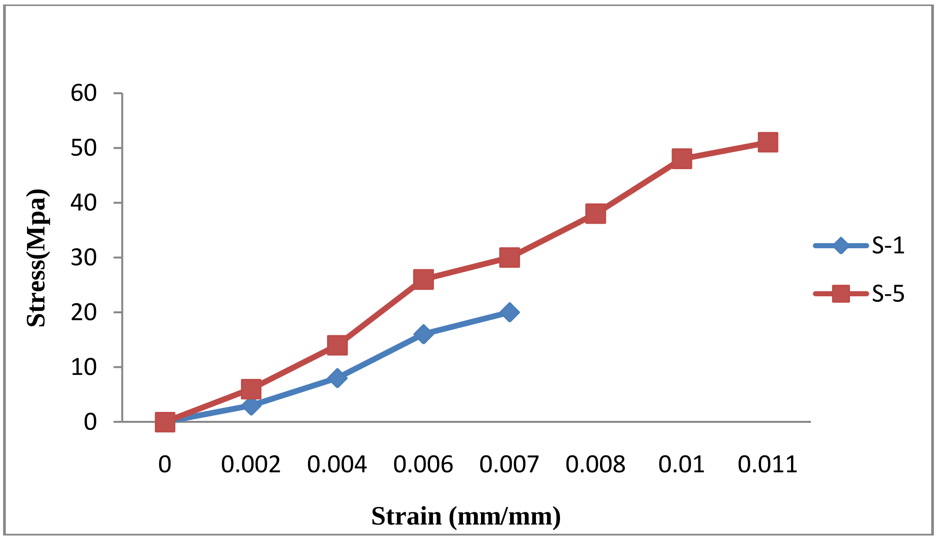

Figure 5: Stress - strain curve for Al - steel joint for varying tilt angle after heat treatment

3.4.2 Effect of Varying Travel Speed before Heat Treatment

Figure 6 showed the comparison of the variation in strength between S-5 and S-6. The samples were welded using the same rotation speed and tilt angle. The difference was that the travel speed when welding S-5 was 12 mm/min and when welding S-6 was 15 mm/min. The considerable difference between the two strength profiles, indicating the variation in travel speed over the range of 12 to 15 mm/min has a significant effect on the strength of the welded samples. The entire samples which have a travel speed equal to 12 mm/min are stronger than the sample at a travel speed equal to 15 mm/min. So, travel speed affects the mechanical properties before the heat treating process. The figure 7 shows that the samples with a higher travel speed (15 mm/min) were stronger than the samples with a lower travel speed (12 mm/min) after the heat treating process.

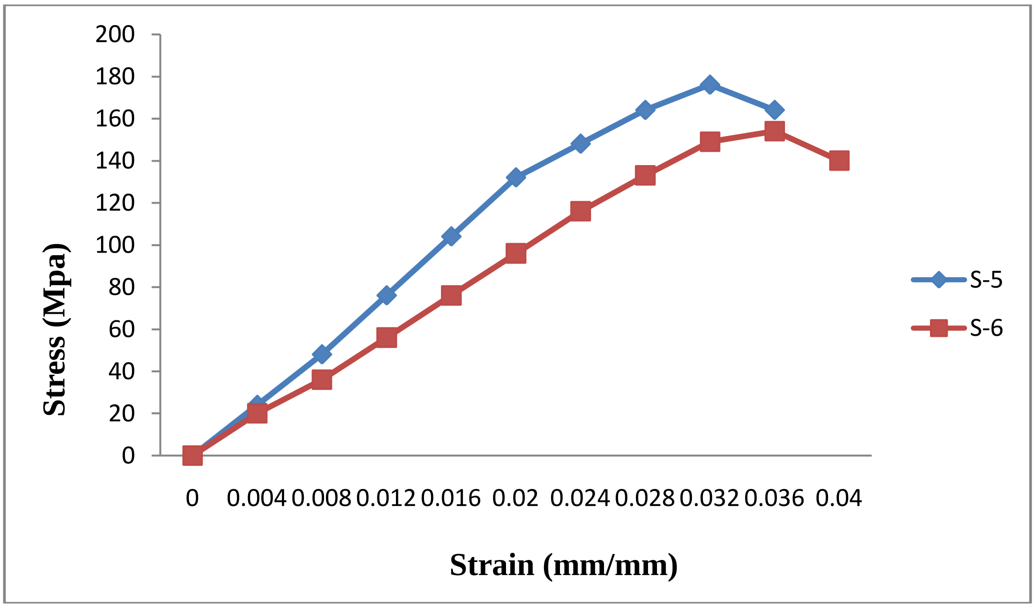

Figure 6: Stress - strain curve for Al - steel joint for varying travel speed before heat treatment

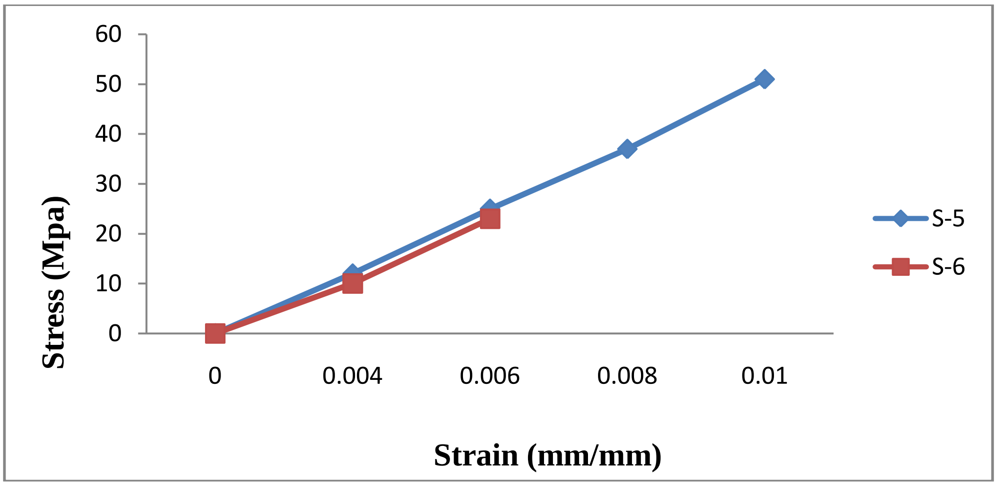

Figure 7: Stress - strain curve for Al - steel joint for varying travel speed after heat treatment

3.4.3 Effect of varying rotation speed before and after heat treatment

Figure 8 compares the variation in strength for S-6, and S-8. The sample were welded using the same travel speed and tilt angle. The difference was that the rotations speed when welding sample S-6 was 750 rpm and when welding the S-8 was 1000 rpm. The considerable difference between the two strength profiles, indicating the variation in rotation speed over the range of 750 to 1000 rpm has a significant effect on the tension strength of the welded sample. The samples that have a rotation speed equal to the 750 rpm are stronger than the sample at 1000 rpm. Effect of varying rotation speed after heat treatment (figure-9) was found opposite i.e the sample that have a higher rotation speed were stronger than the sample with a lower rotation speed. A similar observation was made for other combinations of welding conditions in which only the rotation speed was varied.

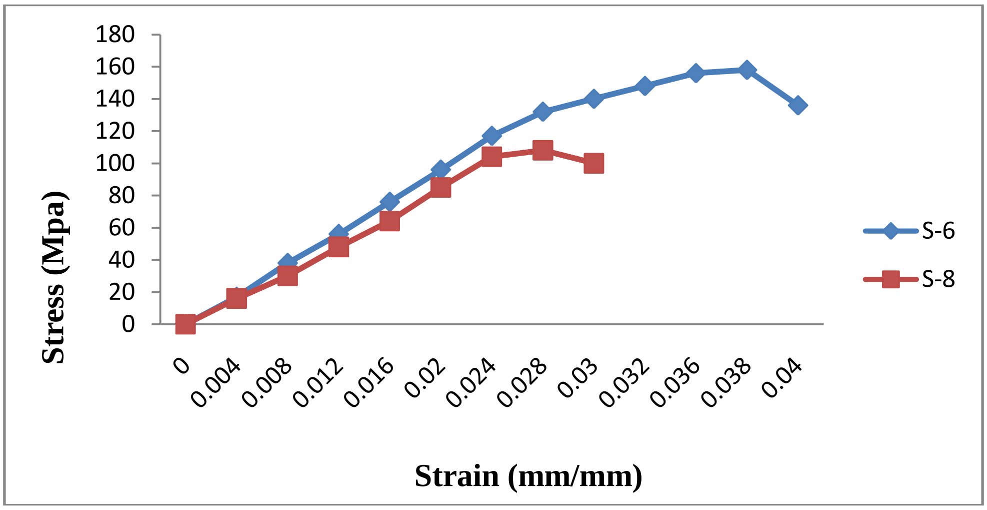

Figure 8: Stress - strain curve for Al - steel joint before heat treatment

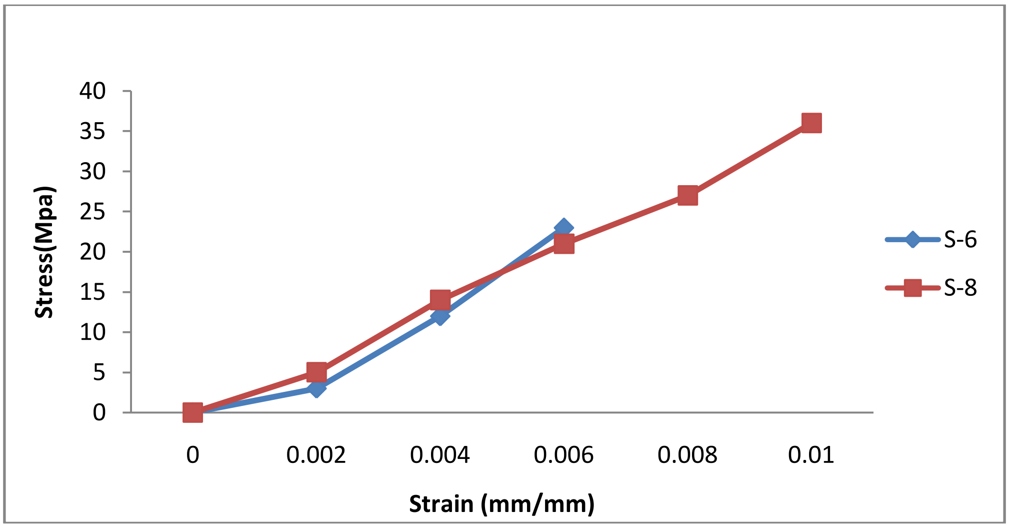

Figure 9: Stress - strain curve for Al - steel joint after heat treatment

IV. Conclusion

FSW practice was effectively implemented for joining of aluminum alloy and steel. The optimum operating conditions of FSW have been obtained for the plates of aluminum alloy and steel welded joint. The method consideration of friction stir welding i.e. Tilt angle, rotation speed, and travel speed of tool are higher controlling features affecting on weld quality. From the literature review, it can be observed that friction stir welding process has been successfully applied for joining dissimilar materials. Different effective methods can be utilized to improve welding procedure parameter. As a result we conclude that pre-heating of material get better the quality of weld. The tension test for the Al-steel joint illustrated that all the samples before the heat treatment were stronger than the samples after heat-treatment. It is concluded that during the heat treating process, the different atoms that exist in the joint region could come again to its original material. In this work for all joints, the outcomes of altering one of the three welding parameters perform arbitrarily, before and after heat treating.

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