Lap Joint Carbon Steel ST 37 and Aluminum 6061 with Friction Stir Welding (FSW)

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Abstract

In this research, Aluminum 6061 and Carbon steel ST 37 sheet were lap joined by friction stir welding. A hardened medium carbonese steel (EMS 45) was used as rotary Probe. The microstructures of the joining inter-metallic compounds were observed by scanning electron microscopy, microstructure photograph, and micro-hardness tests. The joint strength was evaluated by shear stress tests. The experiment was performed with varied length of pin probe 6, 7, and 8 mm, equal rotational speed of 2500 rpm, and welding speed (15 mm/minutes). The Inter-metallic compounds of aluminums sheet was cut off the pin probe and the mixture on the Carbon steel ST 37. Intermetallic compounds were analyzed on its micro sructure in this region aluminum and carbon steel mixed, the value joint tensile shear 6.2KN.

Keywords: Friction Stir welding, Intermetallic compounds, Lap joint.

1. Introduction

Friction Stir Welding (FSW) is a solid phase joining technique on fabrication industry. Good quality single sided and double sided butt, "T", and lap joints. It was invented in 1991 and was originally used to produce butt joints of aluminum alloys[1]

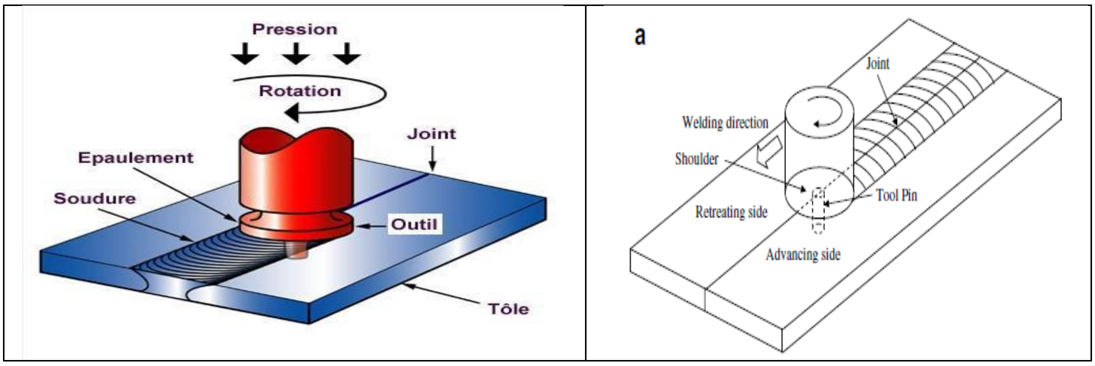

Fig. 1. : Friction Stir Welding Process [1a]

Friction stir welding (FSW) is a solid-state, hot-shear joining process in which a rotating tool with a shoulder and terminating in a threaded pin moves along the butting surfaces of two rigidly clamped plates placed on a backing plate as shown in Fig. 1. The shoulder makes firm contact with the top surface of the work-piece. Heat generated by friction at the shoulder and to a lesser extent at the pin surface softens the material being welded [1a]. During FSW, heat is generated by friction between the tool and the work-piece and via plastic deformation. A fraction of the plastic deformation energy is stored within the thermo mechanically processed region in the form of increased defect densities.[1a]

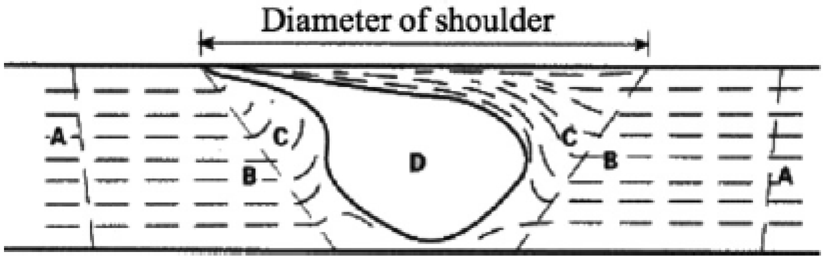

Fig. 2. Schematic cross-section a typical FSW weld: (A) base metal, (B) heat affected zone, (C) thermo mechanically affected zone, and (D) nugget Zone [1a]

Friction Stir Welding (FSW) is new technique for aluminum alloys joining. This technique utilizes non-consumable electrode and Heat generated from the rotating welding tool. It can trigger deformation at the welding zone, thereby affecting the joint formation of material that is in solid state [2].

The FSW has become an efficient option of welding method for the same or dissimilar aluminum alloys, especially those which are difficult or impossible to be welded by the conventional fusion welding without any hot crackings, blowholes or distortions [3,4].

Lap joints are widely used in the assembly of parts and products in the transportation industry. Common examples include ship decks, railway tankers and goods wagons, and stringer to skin in aircraft fuselages. For these applications, panels are often straightened with stringers and profiles, which are mechanically or fusion welded joined in a typical lap joint configuration [5].

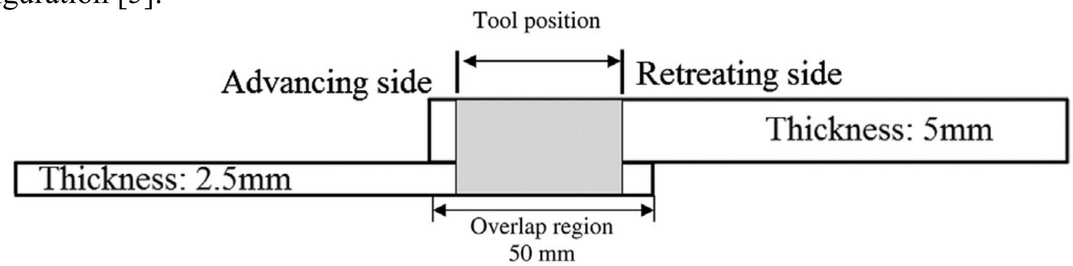

Fig. 3. Schematic of lap Joint [5]

Effect of pin geometry on the macrostructure and microstructure of FSW joint was presented in the Figure below

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Tools	Description of the pin	Big diameter of the pin (mm)	Small diameter of the pin (mm)	Pitch of the pin (mm)
T1	Conical screw thread pin	7	5	0.8
T2	Cylindrical–conical thread pin	7	5	0.8
T3	Stepped conical thread pin	7.5	4	0.8
T4	Neutral Flared-Triflute pin	7	5	0.8

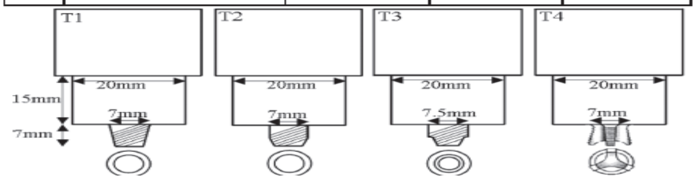

Fig. 4. Geometry and technical details of the investigated tools [5].

The base materials for welding were AA6063 (Al–0.7%Mg–0.4%Si) aluminum alloy and AA5052 (Al–2.5%Mg) aluminum alloy. The thicknesses of the AA6063 plate and the AA5052 plate were 4 mm and 2 mm, respectively. The plates were friction stir welded vertical to their rolling directions. The so-called lap–butt joint of dissimilar to AA6063/AA5052 aluminum alloys consisting of three plates [6].

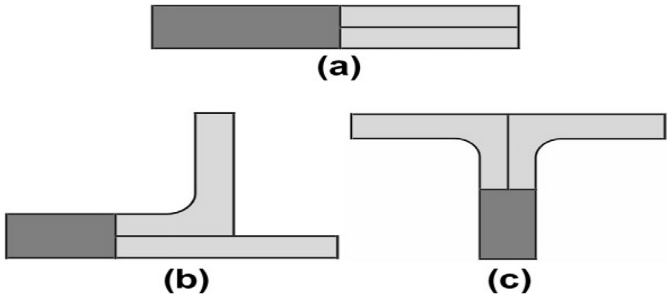

Fig. 5 . Sketches of the so-called lap–butt composite joint (a) and its applications on some engineering structures (b and c) [6].

The rolled plates of 1060 aluminum alloy and commercially pure copper were used as the top and bottom plates of the lap joints. Table 1 indicated chemical composition and thicknesses of these two materials. Both plates were cut to fit the samples of 20mm length and 10mm width and before welding, the samples were degreased using acetone. In order to make lap joints, a FSW adapted milling machine was used where the rotating tool was made of quenched and tempered steel. It had a 15 mm diameter shoulder and a left-hand threaded pin (5mm×6.5 mm). Some couple of samples were friction stir welded with the pin rotating clockwise at speed of 1180 rpm and welding speed of 30, 60, 95, 118, 190, 300, and 375 mm/min [7].

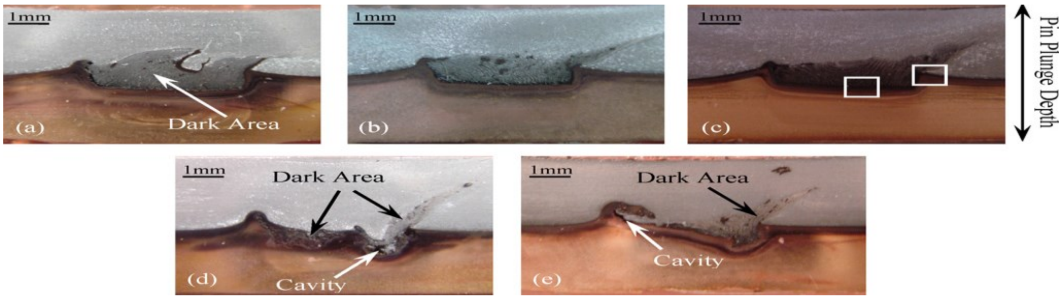

Fig.6. Macroscopic overviews of the FSW joint cross sections at constant tool rotational speed of 1180rpm and welding speeds of (a) 30, (b) 60, (c) 95, (d) 118, and (e) 190 mm/min [7].

The base materials examined during friction stir welding were Al 5754 alloy with a thickness of 2.1 mm, dual phase DP600 steel with a zinc coating and thickness of 3.0 mm, and 1.5 mm thick 22MnB5 alloy steel with a 9 lm coating of Al–12Si alloy [8].

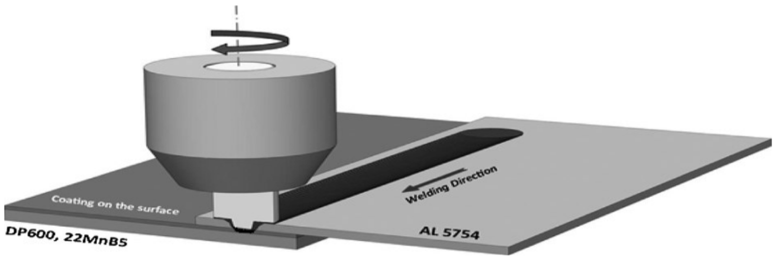

Fig. 7. Schematic illustration of FSW setup used in this study [8].

In this paper, Aluminum 6061 and Carbon steel ST 37 were joined by friction stir welding (FSW) with lap joint. The relationship welding parameters, some length of Pin Probes, micro hardness, micro structure and shear stress testing were previously investigated to evaluate the joint. The benefits of lap joint of dissimilar metal aluminum 6061 and Carbon steel ST 37 might be connected.

2. Experimental Procedures

In this research Aluminum 6061 and Carbon Steel ST 37 sheet were lap joined by friction stir welding. The material was initially received in the form of 100 long 50 mm wide, and 6 mm thickness. Table 1 showed the nominal chemical compositions of the materials. A hardened medium of Carbon steel (EMS 45) was used as rotary Probe. The experiment was performed with varied length of pin probe 6, 7, 8 mm, equal rotational speed 2500 rpm, and welding speed (15 mm/min). The process Friction Stir welding joints were cross sectioned perpendicular to the welding direction for the metallographic analysis to conduct shear stress tests.

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Fig. 8. Variation length pin probes

Fig. 9. The material research Aluminum 6061 and Carbon steel ST 37

Table 1
Chemical composition (wt%) of the materials used for this study.

Material	Chemical Compositions
Al 6061	0.9 Mg 0.6 Si 0.25 Cu 0.086 Mn 0.18 Fe 0.1Cr
0.192 Ti	0.01 ZnAl (bal)
Carbon	0.95 Fe 0.22 C 0.23 Si 0.41 Mn 0.057 P 0.018 S
Steel ST 37	0.058 Ni 0.198 Cr 0.055 Mo 0.102 Cu 0.001 Mg

Table 2
FSW Parameter used in this study

FSW parameters	
Rotation speed (rpm)	3000 rpm
Travel speed (mm/s)	15 mm/min
Pin diameter (mm)	6 mm
Tool shoulder diameter (mm)	15 mm
Pin length (mm)	5.5 mm 6 mm 7 mm 8mm

3. Results and Discussion

3.1 Micro structure

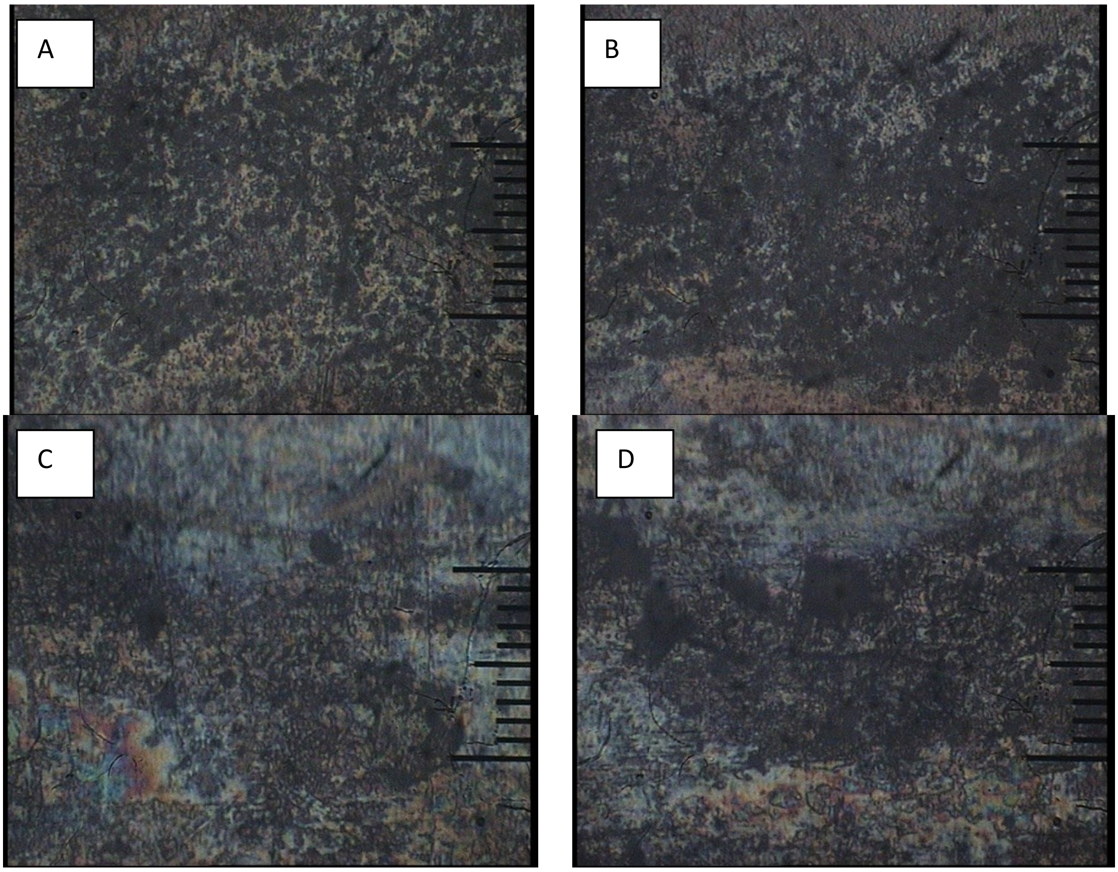

Fig. 10. Microstructure welding lap (A) 8 mm long pin, which is good weld, (B) 7 mm long pin, which is good weld, (C) 6 mm long pin, the welded joint is not good, (D) 5.5 mm long pin, welded joint very bad.

Fig. 10 showed the metallographic cross sections of welds produced by using different length of pin probes. Extremely good welding was presented in the work with 7 mm and 8 mm pin probe as it produced very good joining of intermetallic compounds. Also, it could be seen that long pressure pin had the tendency to produce good intermetallic compounds. On pin short, in order to produce intermetallic compounds welding was not achievable. The particular explanation was supported by Fig 11.

Length of pin	8mm	7mm	6mm	5.5mm
Microstructure				
SEM				

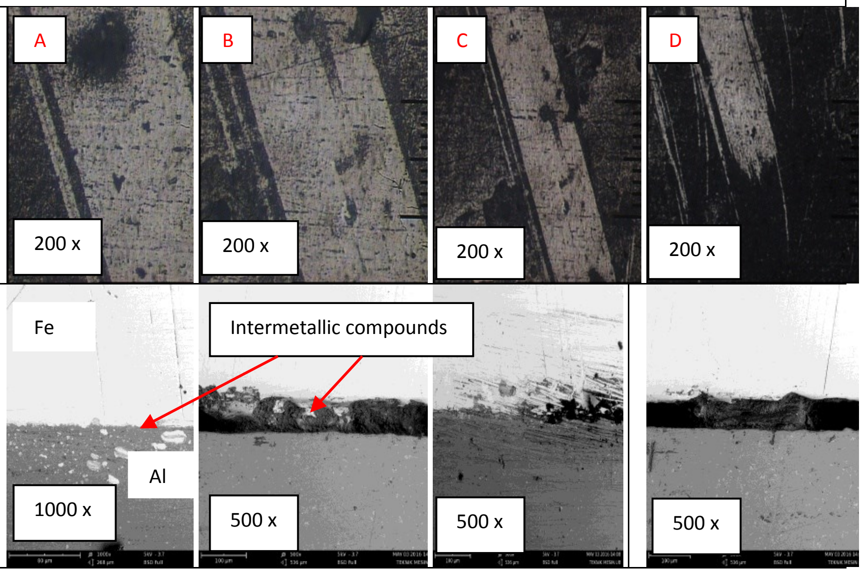

Fig. 11. The Microstructure Intermetallic compounds length of pin (A) 8 mm, (B) 7 mm , (C) 6 mm, (D) 5.5 mm

From Fig 11. we were able to be see the relationship of length of pin to metallic compounds of the welds aluminum 6061 and Carbon steel ST 37. This might be connected as pressure for the length of pin probe. In the picture of a microstructure, it could be seen that the length of aluminum pin was connected the surface Steel ST 37, as it was also indicated on the SEM.

3.2 Micro Hardness

The value of microhardness tests on the length of pin probe 5.5 mm could not be tested because it was unconnected. At length of 8, 7, 6 mm, the pin had high possibility for hardness tests on intermetallic compound. This was caused by the fact that aluminum 6061 plastic pressed on surface the Carbon steel ST 37. It was shown on Fig.12.

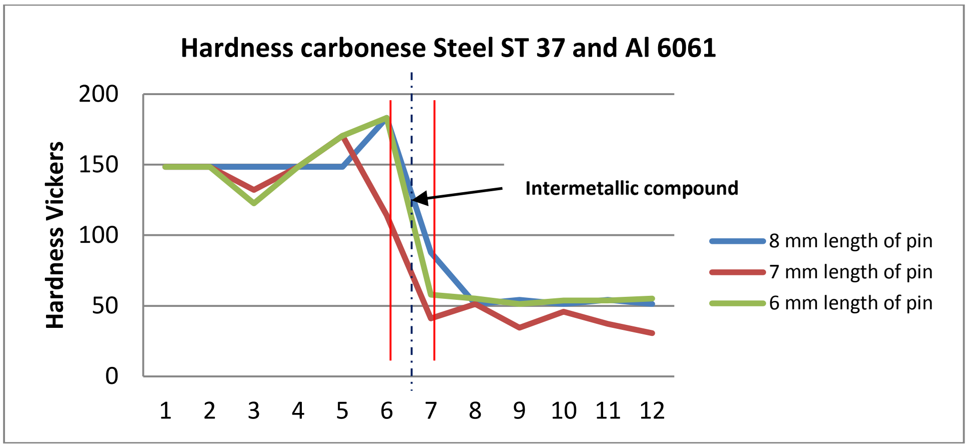

Fig. 12. Microhardness Vickers Number

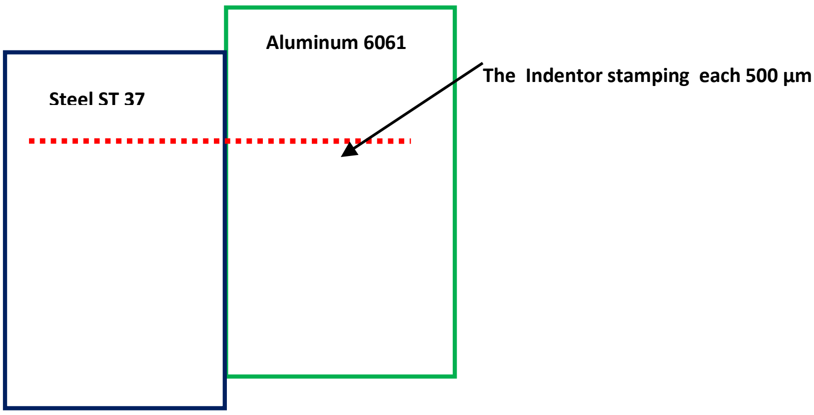

Fig. 13. Measuring Micro Hardness

For long pin probe of 6, 7, 8 mm on Carbon steel ST 37, the value hardness same was 150 HV, intermetallic compound value hardness was also almost the same which was between 40 – 150 HV, and on aluminum 6061 value hardness was 50 HV.

3.3 Shear Stress

The shear stress value of Friction Stir welded joints was measured. It was presented and was shown on Fig 14, and the result tensile tests Fig 15.

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Fig. 14. Shear Stress tests

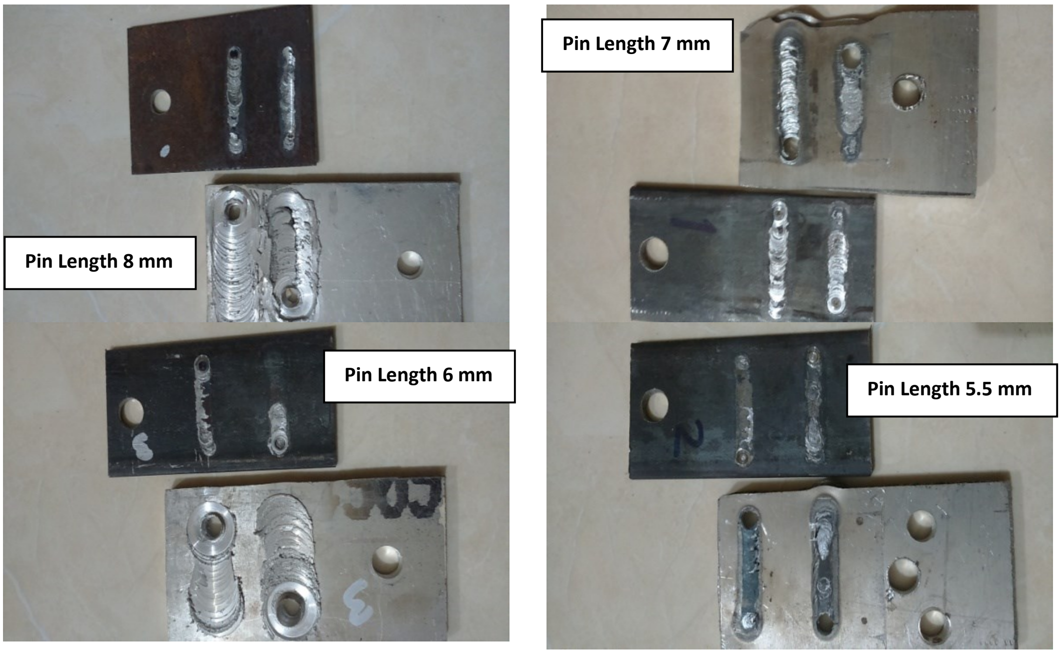

Fig. 15. Texture of Shear stress tests

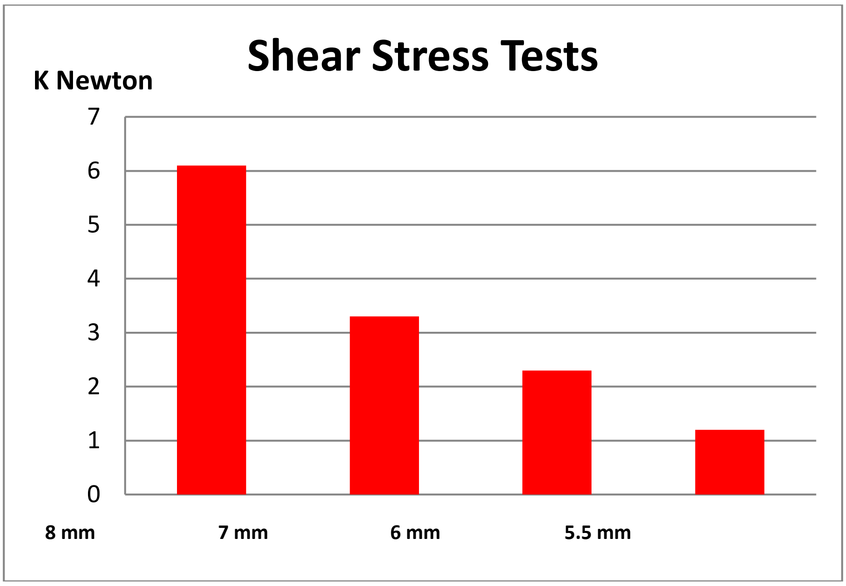

Fig. 15. Result Shear stress tests

It was found that the Shear Stress value 6.1 KNewton at length pin was 8 mm; therefore, at length pin 7 mm value was 3.3 KNewton. The average value Shear stress was 3.225K Newton. The highest stress shear was on the longest pin, which was 8 mm supported microstructure Fig. 10 and Fig. 11 because aluminum plastic pressed onto the surface of the metal in the 3000 rpm. The evidence on Ferro could be welded to Aluminum with solid welding (FSW), which was shown on Fig 10 and Fig. 11.

4. Conclusions

From the experiment of new surface preparation on Friction Stir welding, it could be summarized that:

1. Carbonize Steel ST 37 and Aluminum 6061 can welded with solid welding
2. On pin long connection produced was strong and the inter-metallic compounds were thick.
3. The ShearStress value 6.1 KNewton at pin length was 8 mm, and the average Shear stress was 3.225 KNewton.

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