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The New Purpose of Friction Stir Welding Corner Design to Increase the Strength of the Joint Running Title: The New Purpose of Friction Stir Welding

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Abstract: Aluminum 6061 plate was joined by Friction Stir Welding (FSW) with new purpose of friction stir welding corner was designed to increase the strength of the joint. The corner-joint micro structure distribution depends on welding tool rotation (rpm) and travel speed (mm/min) analyzed and with two position welded observed. The welding parameters were observed, i.e., tensile strength, microstructure, heat input and micro hardness. The microstructure results are homogen and plastic homogen. The new surface joining gave higher tensile (σ) than that in the previously published papers. The benefit of the new surface preparation is the Highest Force (F) = σ×A. The tensile stress average is 206.75 MPa on the welding Position 1 and 221.4 MPa: on the welding Position 2. It was more than 160 MPa in all Aluminum alloy caused by homogeneity of microstructure, microhardness, small kissing and large plastic area.

Key words: Aluminum, friction, heat input, microstructure, tensile, welding, alloy

INTRODUCTION

In prepare Friction Stir Welding (FSW) is a solid phase joining technique on fabrication industry. The good quality single sided and double sided butt "T" and lap joints. It was invented in 1991 and originally used to produce aluminum alloy butt joint (Thomas *et al*., 1991).

The Friction Stir Welding (FSW) is a solid-state, hot-shear joining process which a rotating tool with a shoulder and terminating in a threaded pin. It moves along the butt surfaces of two rigidly clamped plates placed on a backing plate as shown in Fig. 1.

The shoulder position is firm contact with top surface of the work-piece. The heat generated by friction on the shoulder and lesser extent on the pin surface softens the material being welded (Nandan *et al*., 2008) (Fig. 2).

During FSW, heat is generated by friction between the tool and the work-piece through plastic deformation. The fraction of the plastic deformation energy is stored within the thermomechanical processed region in the form defect densities increment (Nandan *et al*., 2008).

Friction Stir Welding (FSW) is new technique for joining aluminum alloys. This technique is non-consumable electrode. The heat was generated from welding tool rotation. It can deform at the welding zone which affect the joint formation material is solid state (Padgett *et al*., 2003).

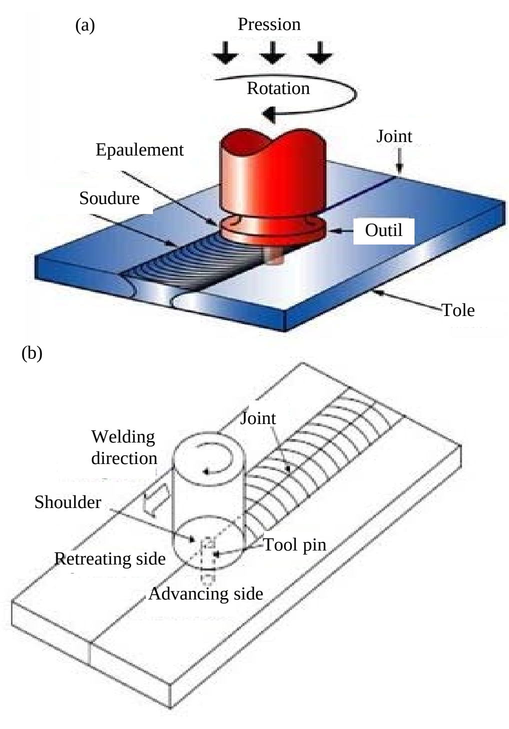

Fig. 1: a, b) Friction stir welding process (Nandan *et al*., 2008; Wang *et al*., 2015)

The FSW has become an efficient option of welding method for the same or dissimilar aluminum alloys.

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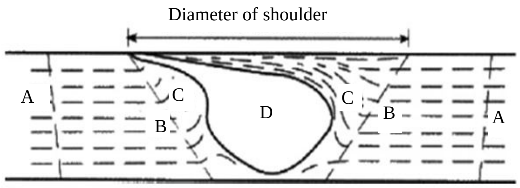

Fig. 2: Schematic cross-section a typical FSW weld: a) Metal base; b) Heat affected zone; c) Thermomechanical affected zone and d) Nugget zone (Nandan *et al*., 2008)

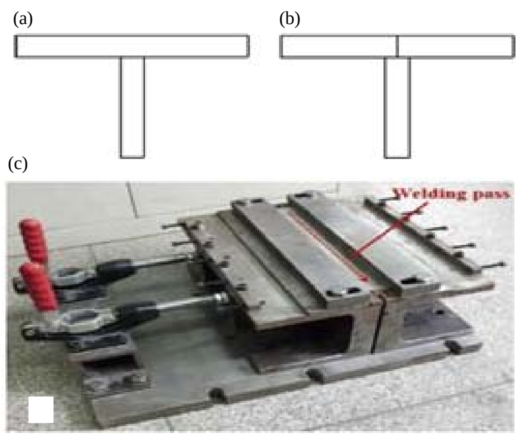

Fig. 3: a) T-lap; b) T-Butt-lap joints and c) Special clamping fixture (Zhao *et al*., 2014)

Particularly in those which are difficult or impossible to be welded by the conventional fusion welding without any hot cracks, blowholes or distortions (Jata *et al*., 2001; McNelley *et al*., 2008).

In the journal friction stir welded t-joints optimization (Silva *et al*., 2015). The one of the conclusion said, the joint improvisation may be achieved by using 1000 rpm, 3.90 mm of probe depth and a shoulder/probe 2.5 diameters ratio. The welding does not speed in a significant effect on the joint mechanical behavior using the optimized parameters as shown in Table 1.

Conducted experiment with two combinations modes T-lap and T-butt-lap joints, special clamping joint was used (Zhao *et al*., 2014) (Fig. 3).

The same experiment with three combinations modes T-lap, T-butt-lap and T-double butt joints is listed in Fig. 4 (Cui *et al*., 2012).

T-welded joint using FSW is generally comprised of a skin and a stringer. T-joint welds are extensively used in supporting frames for pressure vessels, bridge structures, etc. In fusion-welded T-joints of aluminum alloys, high residual stress and significant distortion are difficult to avoid. Although, welding distortion could be mitigated

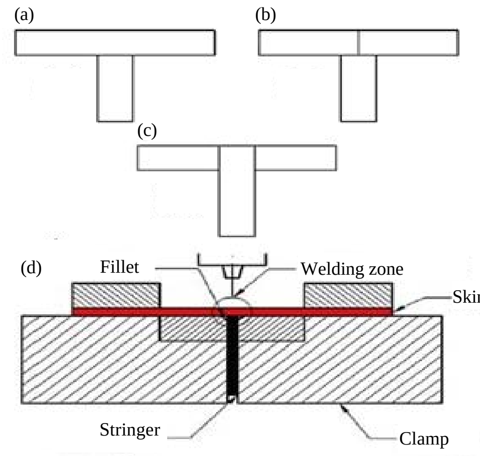

Fig. 4: a) T-lap; b) T-butt-lap; c) T-double butt and d) FSW process (Cui *et al*., 2012)

Table 1: List of selected paramater level (Silva *et al*., 2015)

Parameters	Units	Level 1	Level 2	Level 3
Toot rotational speed	rpm	490	1000	1500
Welding speed	mm/min	76	216	360
Shoulder/probe diameters ratio (D/d)	-	2 (12/6)	2.5 (15/6)	3 (18/6)
Probe depth	mm	3.50	3.70	3.90

by using pre-deformation, thermal tensioning or optimized welding sequences but these methods are time-consuming and costly (Cui *et al*., 2012).

The Nugget Zone (NZ) of microstructure was characterized by fine grains. Grains in NZ could become larger as the welding tool rotational speed increased or the traverse speed decreased. In Thermo Mechanically Affected Zone (TMAZ) of both skin and stringer, grains with highly deformed structure was obtained. The extent of deformation of grains in TMAZ was found to be more severe with the rising of tool rotational speed or declining the traverse speed (Cui *et al*., 2012).

Aluminum alloys weldments with T-configurations are increasingly important in transport area. The especially in aerospace and airplane, ship building and car body, etc. For example, T-lap joints are extensively used in back supported cars seats, bridge structures and supported frames for pressured vessels. Some of special features of T-joints are stiffness and tensile strength of the skin which can be remarkably reinforced by the stringer without significant weight gain. Now a days, T-joints are fabricated by fusion welding, extrusion and rivet connection (Hou *et al*., 2014).

Figure 5 shows the effect of different rotational speeds on the recorded welding thermal cycles. The thermocouples were placed at themed-plane of the plate on the Advancing Side (AS), 10 mm away from the weld center. It can be seen that the peak temperature raises

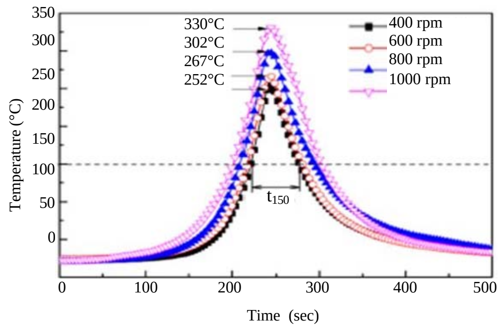

Fig. 5: The welding thermal cycle of the joint produce (Wang *et al*., 2015)

Fig. 6: FSW experimental with thermocouple (Wang *et al*., 2015)

Table 2: FSW parameters (Wang *et al*., 2015)

Identification	Shoulder diameter (mm)	Rotational speed (rpm)	Welding speed (mm/min)	Tool tilt angle (*)
D10	10	-	-	-
D12	12	-	-	-
D14	14	514	98	1.5
D16	16	-	-	-

from 252-330°C with the rotational speed increasing from 400-1000 rpm. Moreover, a typical elevated-temperature over 150°C exposure time t 150 chronologically increases from 57-100 sec as the rotational speed rises from 400-1000 rpm (Wang *et al*., 2015).

During welding, thermal cycles were acquired using two k-type thermocouples. The thermocouples were positioned at 1 and 2 mm from the edge of the weld bead, respectively TC1 and TC2, the advancing side of the joint and near of the half length of the specimen with a distance between them of 5 mm as is seen in Fig. 6. The thermocouples were placed in machined holes at 1 mm in diameter and 1.5 mm in deep (Wang *et al*., 2015). It is shown on Table 2, Fig. 7 and 8.

In this study, Aluminum 6061 were joined by Friction Stir Welding (FSW) with new purpose of friction stir welding corner was designed to increase the strength of the joint. The relationship among welding parameters, heat input, microhardness, micro structure and tensile properties are investigated to evaluate the quality of the joint. The benefits of new surface preparation for corner

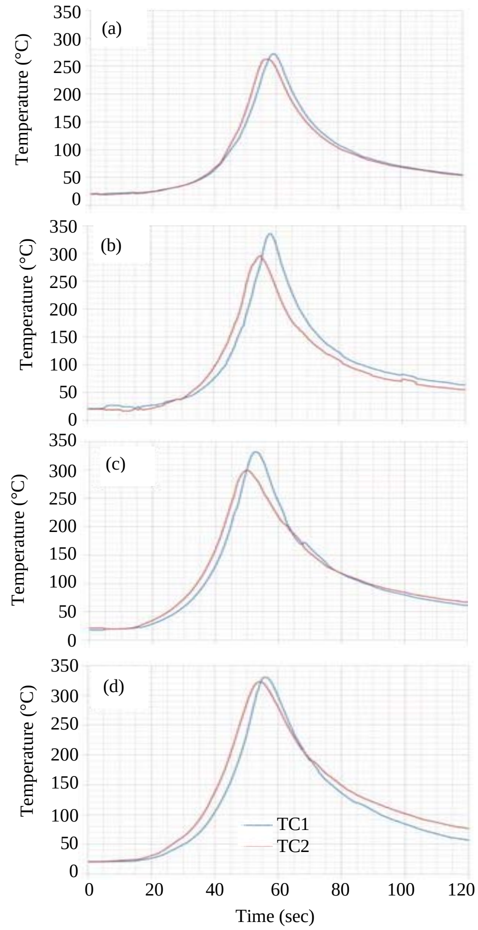

Fig.7: Thermal cycle of FSW welded: a) D10; b) D12; c) D14 and d) D16 (Wang *et al*., 2015)

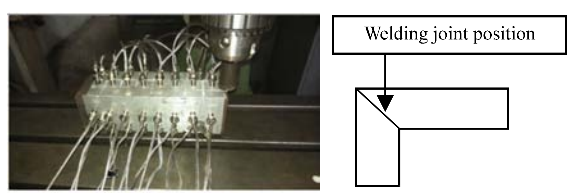

Fig. 8: The material research with thermocouple

joint design is strengthen the force. It can be more suitable than traditional surface preparation. The micro structures, microhardness, heat input and tensile of strength the new surface joining are evaluated and compared with previously published papers.

MATERIALS AND METHODS

The used materials in the experiment was 6061 aluminum alloy with 10 mm thickness, 100 mm width

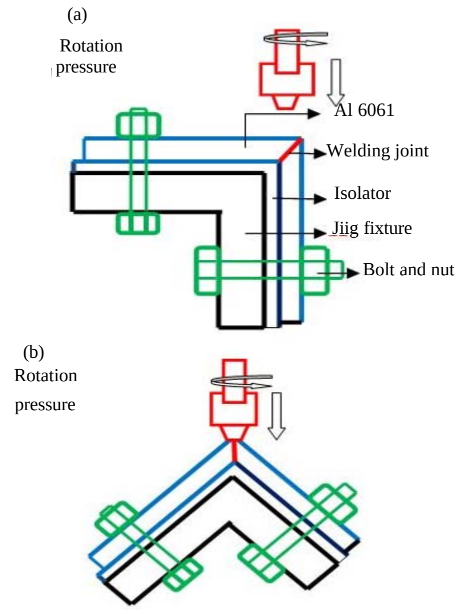

Fig. 9: Drawing jig fixture and probe position WFS: a) Welding Position 1 and b) Welding Position 2

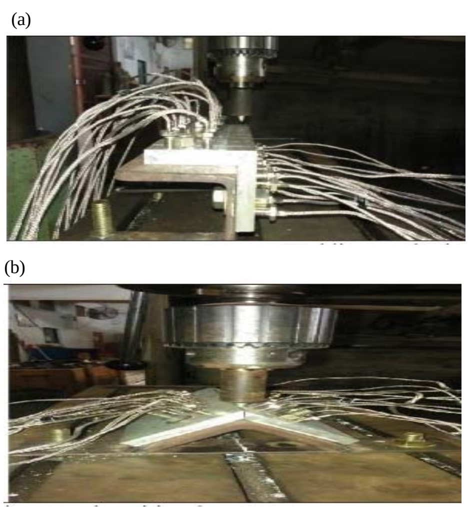

Fig. 10: a) Welding method Position 1 and and b) Position 2

and 200 mm length. The chemical composition of 6061 is listed in Table 3 and shown on Fig. 8. The tensile of the base material was 160 MPa before the welding experiment. The sheet surfaces were milling in 45° dimensional. It made holes with 7 mm diameter every 20 mm length and 20 mm width to be put 32 thermocouple. The probe was made of hardened carbonize steel EMS 45.

A jig fixture for special clamping the corner joint new surface design was designed and fabricated. They are shown in Fig. 9-11.

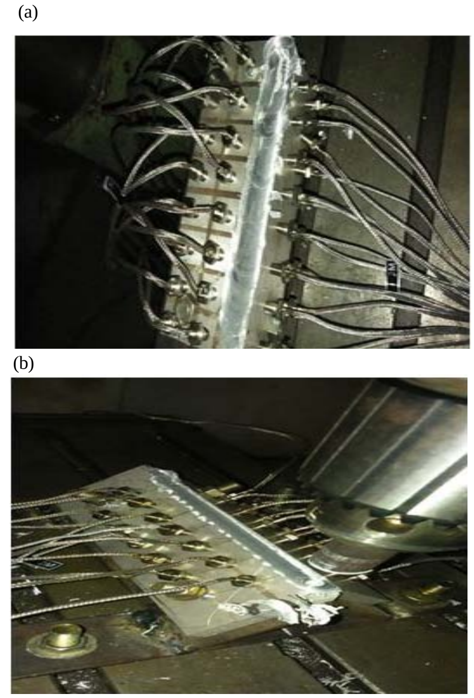

Fig. 11: a) Welding result Position 1 and b) Position 2

Table 3: Chemical composition of 6061 aluminum alloy (wt. %)

Compositions	Mg	Si	Cu	Mn	Fe	Cr	Ti	Zn	Al
Content	0.9	0.6	0.25	0.086	0.18	0.1	0.19	20.01	Bal.

RESULTS AND DISCUSSION

Microstructure: Friction stir welding joint at the 1500 rpm and welding speed 15 mm/min are resulting of the weld on NZ, TMAZ, HAZ and parent metal. Metal flow from the rotating probe are shown in Fig. 12 and 13.

Figure showing the FSW process on the NZ of (A) here show ramming metal neat, so picture showing flow process joining region TMAZ on metal (Fig. 12b). Figure 12a-c have shown flow metal pictures on HAZ and TMAZ regions. These areas were far from center pin connection and not affected by heat. The defect is found on the surface of the weld shown Fig. 10d it is due to the heat was produced in lower temperature and lower probe pressure. During FSW, heat was generated by friction between the tool and work-piece via. plastic deformation. A plastic deformation fraction energy is stored within the thermomechanically processed region in the form of increased defect densities (Nandan *et al*., 2008). Figure 13e and f showed a connection FSW is good because the heat produced probe is enough 0.8 melting point (Tang *et al*., 1998) also 18.7 Newton pressure (Lienert *et al*., 2003).

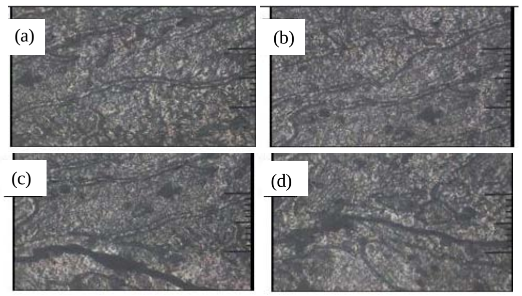

Fig. 12: Microstructure welding Position 1, flow metal Nugget Zone (NZ): a) Well welded flow metal Thermo Mechanichally Affected Zone (TMAZ); b) Well welded; c and d) Flow metal Heat Affected Zone (HAZ) weld are rough

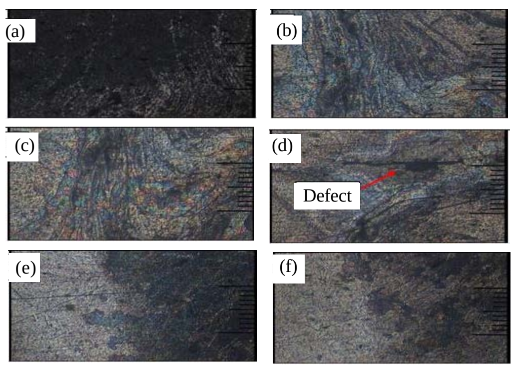

Fig. 13: The welding Position 2: a) Flow metal NZ; b) Flow metal TMAZ joining process; c) Flow metal HAZ joining process; d) Flow metal HAZ is rough; e and f) Flow metal HAZ is well welded

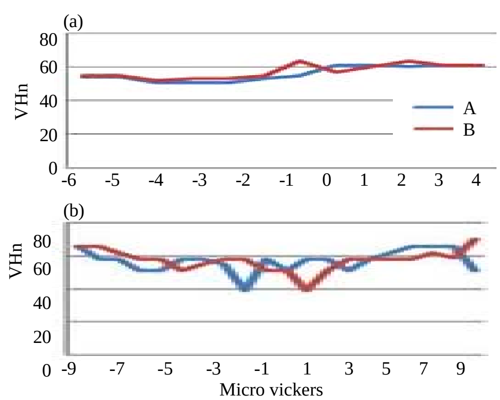

Fig. 14: Micro hardness vickers number: a) Position 1and b) Positions

Macrohardness: Microhardness result on the NZ, TMZ, HAZ and the parent metal had similar value for the two experiments. The hardness was measured two crosssections are shown in Fig. 14 and 15.

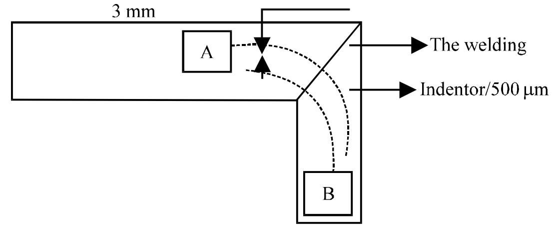

Fig. 15: Measuring microhardness

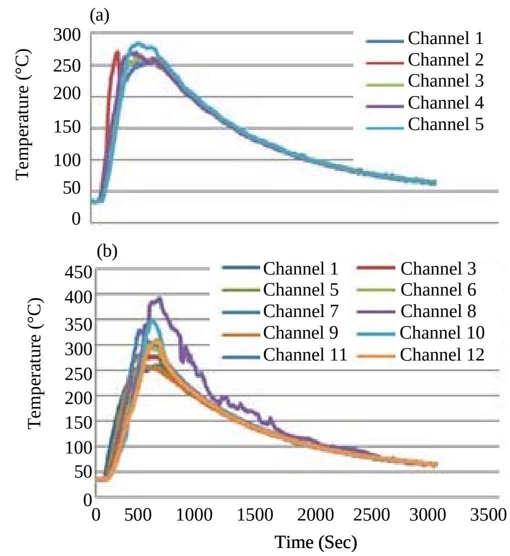

Fig. 16: a) and b) Heat input FSW welding Position 1 and Channel 11 heat was produced in 400°C

The microhardness welding Position 1 has same value on experiment A and B but there is a hardness value increased at NZ. This is caused plastic areas (nugget) and pressure shoulder probes plastic areas. Microhardness value in welding Position 2 is fluctuated. Because the contact pressure and elastic area are small. Resulting in fluctuated elastic region which distributed uniform strength.

Heat input: Heat input production depends on greatly from rotational and travelling of the probe diameter. The heat input produce similar is 300°C (Channel 1-9) on the welding Position 1 as shown in Fig. 16.

One of the effects the result welded joint was good on plastics region. At welding temperature 300°C generated welding connection was not good on elastics region. This phenomenon has correlation with Fig. 11d that caused by probes rotations had reached plastic temperature. The hardness and tensile on plastic region is higher than those on elastic region (Fig. 17).

Heat input measurement welding Position 2 and 1 has same value (Channel 1-6). Heat input in channel 10 at

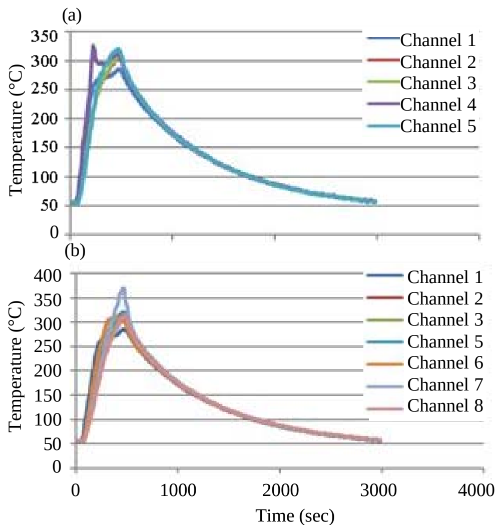

Fig. 17: a and b) Heat input FSW welding Position 2

Fig. 18: Jig fixture of tensile tests

400°C is higher than Channel 1 and 6 up to 50°C. It caused by probes rotation that have reached plastic temperature. The hardness of plastic region is higher than that of elastic region.

Tensile: The tensile value stress friction stir welding and the process tensile test using jig fixture as shown Fig. 18 and 19.

The average tensile value is 206.75 MPa on welding position 1 and the average tensile value is 221.4 MPa on welding Position 2. The highest of all kinds of alumnum alloy is 160 MPa because the area friction is small on round probe. It is better of the new surface joining with FSW. Two factors that cause high stress tensile are the presence of fine, prefect without any defect in microstructures are important to get a relatively higher tensile strength. The presence of fine, prefect without

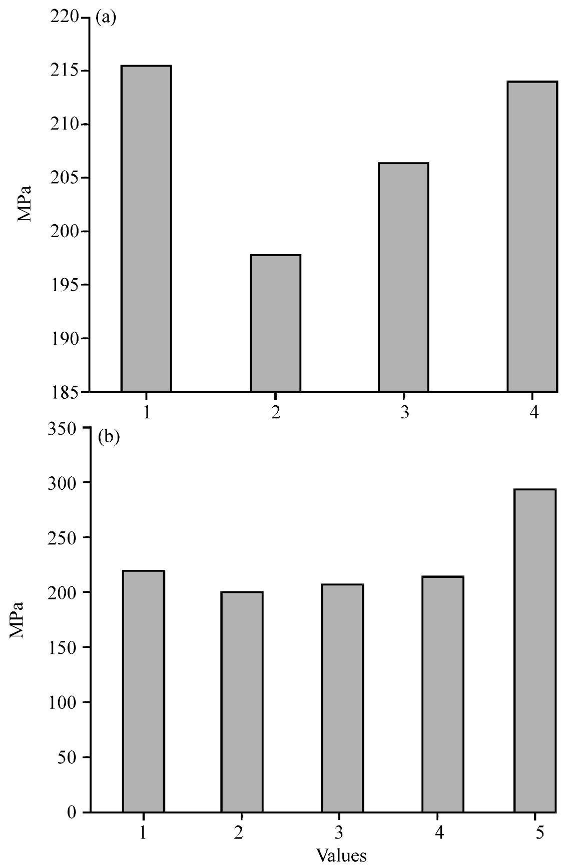

Fig. 19: a) Result tensile tests welding Position 1 and b) Position 2

any defect in microstructure. They are essential to enhance the strength of the weld zone and the plastic area.

CONCLUSION

From the experiment of new surface preparation on FSW can be summarized. The new surface joining gave higher tensile (σ) than that in the previously published papers; the benefit of the new surface preparation is the: Highest Force (F) = σ×A, the tensile stress average is 206.75 MPa on the welding Position 1 and 221.4 MPa on the welding Position 2. It was than 160 MPa in all Aluminum alloy caused by homogeneity of microstructure, microhardness, small kissing and large plastic area.

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