Mechanical Properties of Friction Stir Welded Aluminum Alloy with Butt and Lap Cases

Dr. Nadhim M. Faleh
Email:Abo.mohomod@yahoo.com
Engineering College, University of Al-mustansiriyah /Baghdad

Received on: 4/11/2012 & Accepted on: 7/3/2013

ABSTRACT

Mechanical properties were investigated in base and friction stir linear welds of 7075 aluminum alloy. Welding tools consist of a shoulder with a pin and with-out pin. This work addresses the effects of tool geometry on tensile stress and shear strength of butt and lap welds, and comparing with base material. Also, the effects of process condition on the strength of friction stir processed material are quantitatively characterized. Compared to the butt case, the friction stir lap linear welds, with pin, leads to a 20% increase in optimized weld strength with 1000 rpm of tool revolutions and 200 mm/min of tool speed. The optimizing of operating conditions primarily leads to a 15% increase in optimized weld shear strength, with 1000 rpm of tool revolutions and 200 mm/min of tool speed.

Keywords: Frictions stir lap welding, Fatigue, Crack propagation, Aluminum 7075

الخصائص الميكانيكية للحام الدمج الاحتكاكي لسبيكة المنيوم لوصلة تراكبية وتجانبية

الخلاصة

المواصفات الميكانيكية قد درست للحام الدمج الاحتكاكي لسبيكة المنيوم ٧٠٧٥. عدة اللحام تكونت من حامل بوجود بروز اسطواني، وبدون بروز. هذا العمل تحرى تاثير شكل العدة على جهد المقاومة وجهد القص لحالتي اللحام التجانبي والتراكبي، والمقارنة مع المعدن الاساس. كذلك، تاثير ظروف التشغيل على مقاومة لحام الدمج الاحتكاكي قد حددت كميا. استنادا الى مقاومة حالة اللحام الخطي التجانبي ، ان لحام الدمج الاحتكاكي الخطي التراكبي بعدة ذات بروز، قد حقق زيادة مفضلة حوالي ٢٠% في جهد المقاومة لمعدن اللحام. المفاضلة في ظروف التشغيل انتجت زيادة حوالي ١٥% في جهد القص لمنطقة اللحام وبدوران للعدة حوال ١٠٠٠ دورة بالدقيقة وسرعة للعدة حوالي ٢٠٠ مليمتر بالدقيقة.

NOTATIONS

FSW – Friction stir weld
TD – Transverse direction of welds
HAZ – Heat affected zone
TMAZ–Thermo-mechanically affected zone
NZ – The nugget zone

https://doi.org/10.30684/etj.31.11A2
2412-0758/University of Technology-Iraq, Baghdad, Iraq

INTRODUCTION

As a new solid-state joining technology, friction stir welding (FSW) owns many advantages, such as low stress, small distortion, no fusion welding defects, *etc*. Because the metal of weldment isn't melted during FSW, the material flow in weld of FSW is the key factor to influence the quality of weld. In order to thoroughly understand the mechanism of FSW, many researchers have made lots of scientific work on the metal plastic flow of weld in FSW[1].

Several methods on material flow have been published, including the steel ball tracing technology, the stop-action technology, the metallography method, the marker material method and the numerical simulation method. They showed that the material on the retreating front side is entrained and filled in the retreating side of the rotational tool. They used the thin copper as maker materials to study the material flow in the thickness of weld and then put forward the sucking-extruding theory.[3]

Some of researchers analyzed the effect of welding parameters on the flow behavior of metal in weld by FE method. For FSW, the tunnel defect and the hole defect may result from the pin of rotational tool when the welding parameters aren't reasonable. Therefore, using the rotational tool without pin can avoid the appearance of the tunnel defects or the hole defects. However, the researcher on the tool without pin are relatively few.[4]

They developed a new tool without pin for the friction stir spot welding. During FSW, the serious metal flow lies in the contact region of weldment with rotational tool shoulder [5].

Friction stir welding (FSW) is a solid-state process where joining of metal plates is achieved through a thermo-mechanical action exerted by a non-consumable welding tool onto metal plates. During welding, the synergy of tool rotation and tool translation along the butt line of aligned plates imparts severe plastic deformation to the materials (the absolute values of deformation strain and strain rate being up to one or two orders of magnitude) as well as induces flow of the plasticized materials around the welding tool.[6] FSW modifies the original microstructure to various extents in different locations of a weld. A stir zone where a recrystallized grain structure is generated, a thermo-mechanically affected zone, and a heat affected zone are encountered in sequence from the weld center towards the parent material. FSW has been extensively investigated on aluminum, titanium, steel, magnesium, and copper alloys [7].

The aim of this study is the comparison between the mechanical properties of aluminum alloy and the mechanical properties of stir welded aluminum alloy with butt and lap case. In addition of the pervious aim, there is another witch is finding optimal design for tool of FSW.

EXPERIMENTAL WORK

WORK PIECE PREPARATION

After the surface of 7075 (AA 7075) alloy with the thickness of 3 mm was simply burnished to wipe off the oxide layer, the joint configuration was jointed with two case; butt and lap, as shown in Figures (1) and (2) .

The material of plates, used in this study, is Aluminum Alloy 7075 (AA 7075) produced as extruded flat plate, with dimensions of 300 x 160 mm^2 (length x width). The chemical composition of aluminum alloy 7075 is given in Table (1).

Table (1) Chemical composition of AA 7075-(wt%)[12].

Zn	Cu	Fe	Cr	Mg	other	Al
5.70	1.80	0.15	0.04	2.40	0.55	Balance

FSW was carried out on 3 mm thick AA 7075 plates. Before FSW, the abutting faces of the plates were finely milled in order to avoid surface scaling intruded with the tool. Work piece consist of two plates, were joined with butt condition in case 1, and with lap condition type AZ31 in case 2.

TOOL PREPARATION

The butt and lap joints configuration was jointed by the rotational tool. During FSW, two types of tool were considered in this study, namely, the tool with shoulder with pin and the tool with shoulder and with-out pin. The structure of rotational tool is shown in Figure (1) and (2).

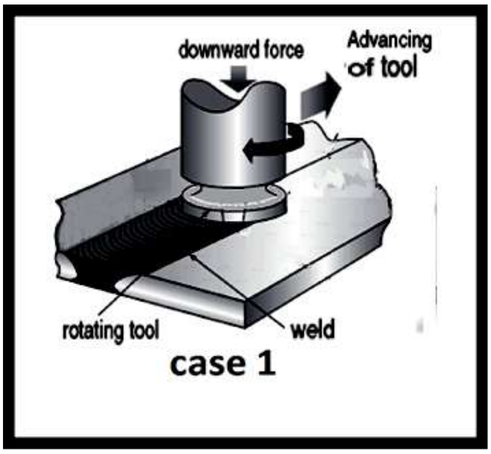

Figure (1) shows the friction stir butt welding (FSW).

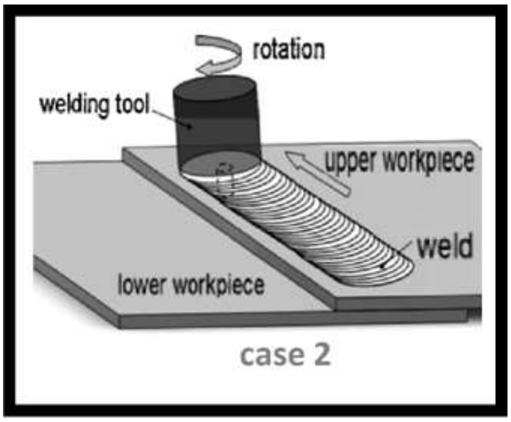

Figure (2) shows the friction stir lap welding (FSW) [2].

The FSW tool had a shoulder with pin diameter of 6 mm, a pin length of 5 mm. Table (2) shows the chemical composition of tool. Also, shoulder with-out pin was used in this work. Figures (3) to (4) show the two types of stirrer.

Table (2) Composition of FSW tool.

C	Si	Mn	P	Cr	Mo	Co
0.86	0.40	0.45	0.04	0.05	4.5	4.0

Tool rotation and welding speeds were taken as 1000 rpm 100 mm/min, respectively for first stage of welding, than, different tool revolutions and speed were used.

Figure (3) shows a sample of tool with pin.

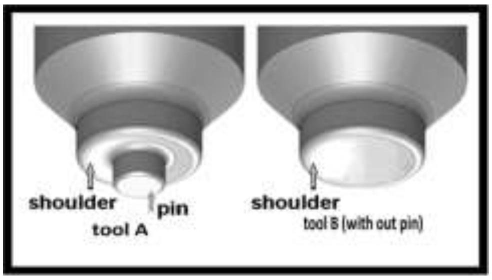

Figure (4) shows the tool with pin and without pin.

FSW Operations

Welding operation was carried out as specified above, with toe case of joining; butt case and lap case, as shown in Figures (1) to (2). The experimental work can be divided into the following steps:-

First stage: FSW operation used tool with pin, with tool rotation of 1000 rpm and welding speed was taken as 100 mm/min, were used to weld two groups of work pieces: (1) Butt type. (2) Lap type.

Second stage: FSW operation used tool with-out pin, with tool rotation of 1000 rpm and welding speed was taken as 100 mm/min, were used to weld two groups of work pieces: (1) Butt type. (2) Lap type.

Third stage: FSW operation used tool with pin, with tool rotation of 1000 rpm and welding speed was taken as 50, 100, 150, 200 mm/min respectively, used to weld two groups of work pieces: (1) Butt type. (2) Lap type.

Fourth stage: FSW operation used tool with-out pin, with tool rotation of 1000 rpm and welding speed was taken as 50, 100, 150, 200 mm/min respectively, used to weld two groups of work pieces: (1) Butt type. (2) Lap type.

TESTING PREPARATION

Groups of specimens were prepared to cover testing plan of this study as shown in Figure (5). Test specimens approximately 10 mm wide were cut from friction stir linear welds along the transverse direction (TD) of welds.

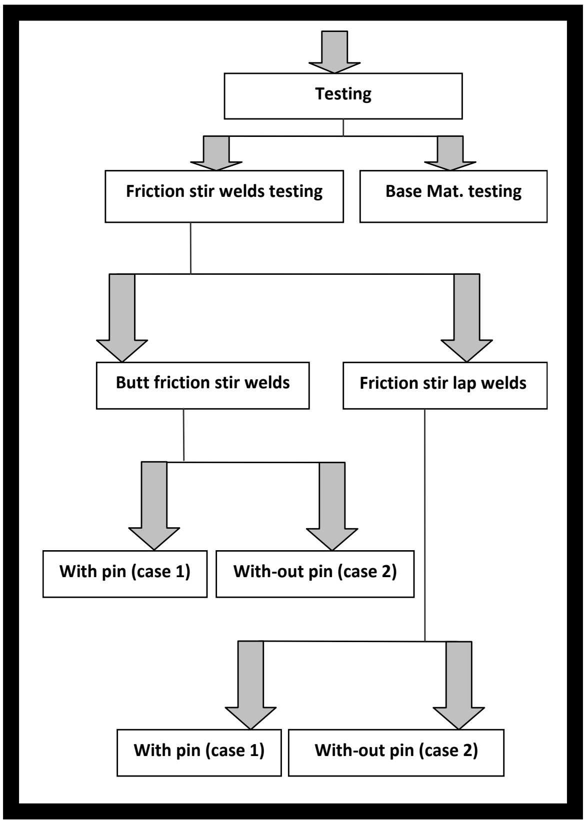

Figure (5) shows groups of specimens.

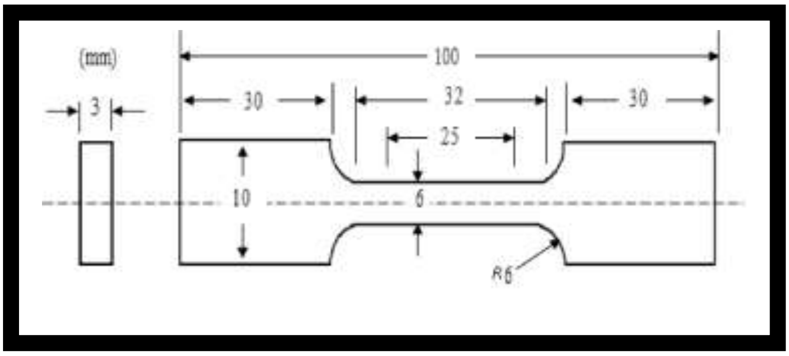

Figure (6) shows the specimens of tensile test details [13].

In case of lap weld, spacers were attached onto both ends of a specimen prior to testing to ensure that an initial pure shear load was applied to the interfacial plane as shown in Figure (7). Weld strength (also called 'lap shear strength') was computed as the ratio of load-at-failure to initial specimen width. No fewer than two specimens were tested to obtain average weld strength.

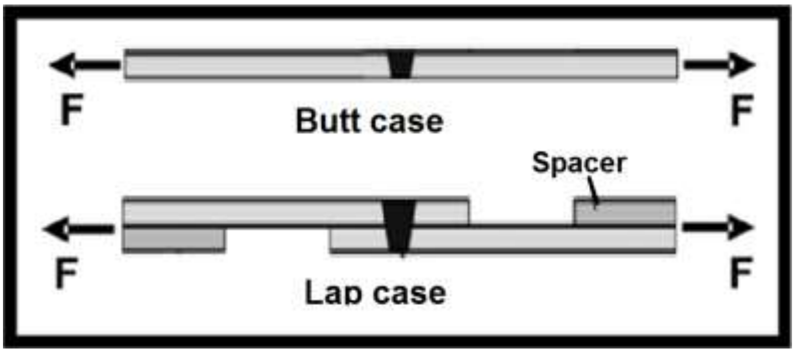

Figure (7) shows the method of tensile test.

RESULTS AND DISCUSSION

The effect of tool shape on lap tensile strength of welds as shown in Figure (8) compared with butt case of weld, with operating condition of stirrer; 1000 rpm and 100 mm/min feeding. Take the welding tool type A (butt joining) comparing with type B (lap joining). The tool shoulders have the same size, but with two case; with pin and without pin. The effect of the pin diameter is important; the pin leads to weld strength higher than 20% compared with case of shoulder with-out pin.

The effect of tool shape on lap tensile strength of welds as shown in Figure (9) compared with butt case of weld, with operating condition of stirrer; 1500 rpm and 100 mm/min feeding. Take the welding tool type A (butt joining) comparing with type B (lap joining). The tool shoulders have the same size, but with two case; with pin and without pin. The effect of the pin diameter is important; the pin leads to weld strength higher than 18% compared with case of shoulder with-out pin.

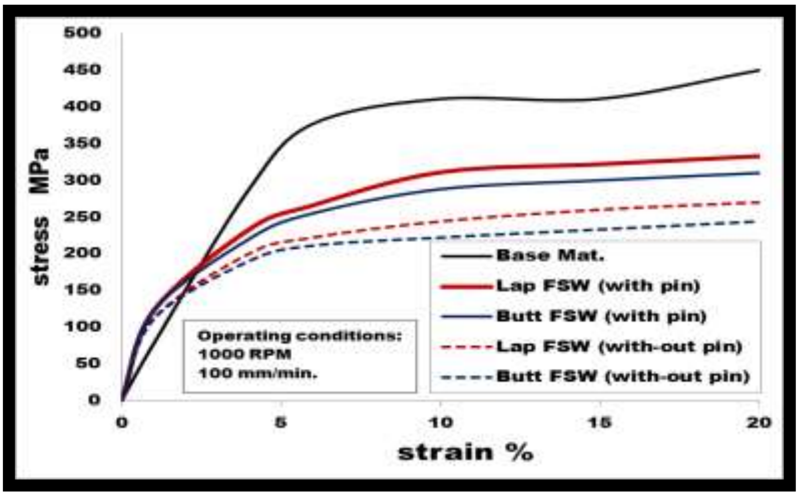

Figure (8) shows the results of tensile tests (1000 rpm).

The effect of tool shape on lap tensile strength of welds as shown in Figure (10) compared with butt case of weld, with operating condition of stirrer; 2000 rpm and 100 mm/min feeding. Take the welding tool type A (butt joining) comparing with type B (lap joining). The tool shoulders have the same size, but with two cases; with pin and without pin. The effect of the pin diameter is important; the pin leads to weld strength higher than 20% compared with case of shoulder with-out pin.

The method of joining between two plates, leads to a slight increase in weld strength at proper process conditions, but the magnitude of weld strength is less than that for the base material, which is about 390N/mm^2 as yield strength, and 480N/mm^2 as ultimate tensile strength. The lap method leads to a remarkable increase in weld strength when the tool travel speed is higher than 150mm/min as shown in figures mentioned above.

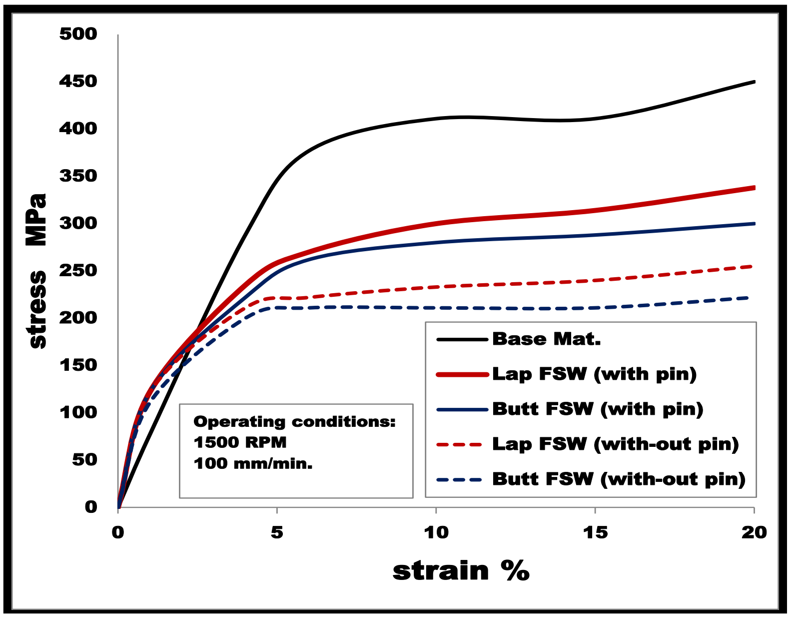

Figure (9) shows the results of tensile tests (1500 rpm).

In addition, high weld strengths around 300N/mm can be maintained, by lap joining, within a wide range of rotation speeds from 1000 rpm to 2000 rpm Compared to the peak weld strength given by the butt joining, with same geometry of tool, the peak weld strength given by the lap joining is increased by 15% as shown in Figures (8) to (10).

The tensile strength of base material in this study was compared with the results of a pervious study, which is done by Ç. Yeni[12]. The comparison showed that our experimental results coincident with the researcher's resultant, for about 80%. In addition of coincident, for about 70% in shear tensile tests.

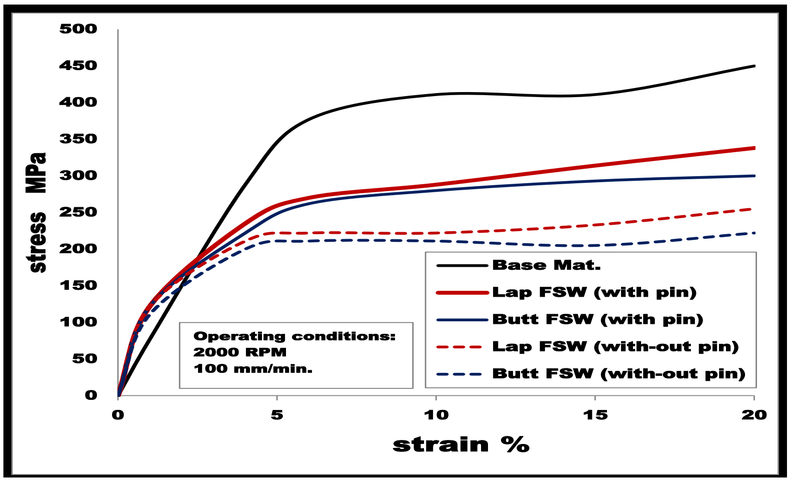

Figure (10) shows the results of tensile tests (2000 rpm).

The lap method of joining between two plates, leads to a slight increase in shear strength of weld at proper process conditions, but the magnitude of weld strength is less than base material. The lap method leads to a remarkable increase in shear strength of weld, when the tool travel speed is higher than 150mm/min as shown in Figure (11).

The microstructure of the welded joint is formally divided into four zones: base material, heat affected zone (HAZ), thermo mechanically affected zone (TMAZ) and the nugget zone (NZ). The nugget zone is composed of fine-equaled grains which are formed under high temperature and large deformation in the weld center due to the stirring process [8]. The TMAZ is the region surrounding the nugget on either side where there is less heat deformation compared to the weld center [9]. The simultaneous rotational and translational motion of the welding tool during the welding process creates a characteristic asymmetry between the adjoining sides. The side where the tool rotation coincides with the direction of the translation of the welding tool is called the advancing side (AS), while the other side, where the two motions, rotation and translation counteract is called the retreating side (RS) [10, 11].

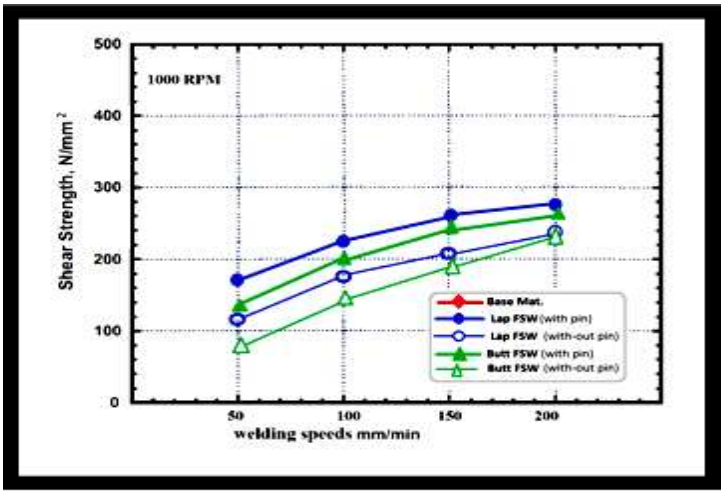

Figure (11) shows the results of shear tensile tests.

CONCLUSIONS

The strength of friction stir processed material is only 60–70% of the tensile strength of the base material.

The tested samples of FSW with lap joining showed good strength behavior, about 15% compared with FSW butt welds.

The samples of FSW by stirrer with pin, showed good strength behavior, about 20% compared with FSW butt welds.

The FSW samples machined with high revolutions for tool, about 2000 rpm, showed good strength behavior, about 15% compared with FSW of 1000 rpm.

REFERENCES

[1]. Liguo Zhang, Shude Ji, Guohong Luan, Chunlin Dong and Li Fu, "Friction Stir Welding of Al Alloy Thin Plate by Rotational Tool without Pin", J. Mater. Process. Technol.,2011, 27(7), 647-652.

[2]. Yang, Q. X. Li, K. Chen, Y.J. Shi, "Effect of tool geometry and process condition on static strength of a magnesium friction stir lap linear weld", Materials Science and Engineering A 528, pp2463–2478, 2011.

[3]. Costa ET. al., J. D. "Fatigue Behaviour of AA6080-T6 Aluminum Alloy Friction Stir Welds under Variable Amplitude Loading", 2009

[4]. Omar Hatamleh et. al.**,** “Fatigue Crack Growth of Peened Friction Stir-Welded 7075 Aluminum Alloy under Different Load Ratios” , Journal of materials Engineering and performance, 2009.

[5]. Booth snd I. Sinclair , D. “Fatigue of Friction Stir Welded Aluminium Alloy 2024-T351” , Material Research Group, University of Southampton, pp39-40,2000.

[6]. Jeff Horschel, “Fatigue of Friction Stir Processed 2024-T3 Aluminum for Aerospace Applications”, 2005.

[7]. Padmanaban and V. Balasubramamian,G. "An wxperimental investigation on friction stir welding of AZ31B magnesium alloy, Int. J. Adv. Manuf. Technol., vol.49, pp.111-121, 2010.

[8]. Zhou, C. X. Yang, G. Luan, "Investigation of microstructures and fatigue properties of friction stir welded Al-Mg alloy", Materials Chemistry and Physics 98 (2006) 285-290.

[9]. Tang,W. X. Guo, J.C. McClure, L.E. Murr, "Heat input and temperature distribution in friction stir welding", Journal of Materials Processing and Manufacturing Science 7 (1998) 163-172.

[10]. Zhou, C. X. Yang, G. Luan, "Fatigue properties of friction stir welds in Al 5083 alloy", Scripta Materialia 53 (2005) 1187-1191.

[11]. Czechowski,M. "Low cycle fatigue of friction stir welded Al-Mg alloys", Journal of Materials Processing Technology 164-165 (2005) 1001-1006.

[12]. Yeni a, Ç. S. Sayer, O. Ertuğrul, M. Pakdil, "Effect of post-weld aging on the mechanical and microstructural properties of friction stir welded aluminum alloy 7075", Materials Science and Engineering, Volume 34, pp 105-109, 2008.

[13] ASTM standard, “Standard Test Methods for Tension Testing of Metallic Materials [Metric]”, Volume 03.01, Section 03, 2005.