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Study the weld Region by Friction Stir Welding of AA5086-H32 by Using a FillerAA6061-T6.

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Abstract

The friction stir welding (FSW) is a relatively modern joining technology process used for welding aluminium alloys such as 5xxx. In this work a 3-mm thick plate of aluminium (AA5086-H32) was welded by friction stir welding (FSW) method using four different values of rotating speed; N= 410, 510,680 and 920 RPM and three linear speed V= 25, 40 and 75 mm/min. Tensile test was used to determine the welding efficiency of the samples. The fatigue test was studied in the three regions welding metal (WM), welding metal by using a filler AA6061-T6 (WM1) and heating effect zone (HAZ), and then compared with base metal. The welding speed have an effect on the welding efficiency of the welded samples by using filler AA6061-T6 where the maximum welding efficiency (83.8%) was obtained at N= 920 and V= 40 mm/min. The maximum value of hardness was at the weld line and started to decrease away from it, hence the values of hardness at the advance side was higher compared to the retreating side. The tensile strength of the welded samples was less than the base metal. The fatigue and microstructure were studied for the welded sample which gave the highest tensile strength. The fatigue test was performed at room temperature (RT) to establish the S–N curve equations and endurance limits. It was calculated at 10^7 cycles. The fatigue endurance limit was decrease in weld metal and heat affected zone, also the reduction percentage in fatigue endurance limit which compared with base metal.

Keywords: Friction Stir and, nugget zone, joining, microstructure, fatigue limit, pseudo heat index.

INTRODUCTION

FSW was invented at the Welding Institute (UK). It is an energy efficient, environment friendly and versatile joining technique that has proved to be one of the most significant achievements in the field of joining aluminum alloys [1, 2, 3]. It has been widely used in the area of space, aircraft, marine, fuel tank and food saving industry for about a decade. It is used to bond aluminum alloys as well as Mg alloys, Cu alloys, Ti alloys and steel [4, 5].The aluminium alloys AA5xxx and AA6xxx used in the ship, aircraft and transport vehicle structure fabrications [6, 7].Welding of aluminium alloys (AA5xxx and AA6xxx) by TIG or MIG arc welding processes result in welding problems due difference in solidification modes for each type of alloy. So that the FSW process was considered as a good method to weld different aluminium alloys [8,9].The fatigue behaviour of friction stir welded of different series aluminium alloys (5083 and 6061) was investigated. The fatigue strengths of the welded joints were equal to or lower than those of the parent materials [10,11].The fatigue behavior of dissimilar FSW joints of different aluminum alloys (AA6082 and AA5754) was studied where the ratio was R=0.1 , it was observed that the fatigue strength of the welded sample was less than those of the base material. The improvement in the fatigue strength was observed for lower applied stress ranges [12]. The aluminum alloys type 5083-H111 and 6082-T651 were welded by FSW and tested by the bending fatigue. The results showed that the fatigue strength of weld joints were close to each other with small void effect [13]. The effect of FSW process parameters on the formation of welding defects of dissimilar aluminum alloys: AA5083-H116 and AA6063-T6 were investigated. The tunnel defects were found in the advanced side. The kissing bound were formed towards the retreating side [14]. The microstructure of FSW joints of AA6061 and AA5086 were studied. The microstructure in visitation indicates that the hardness of joints were improved due to brittle inter metallic phase formation and higher fraction of grain boundary [15]. A lap joint of AA 6082-T6 and AA5754-H22 was performed using FSW. They concluded that the hooking defects were the major factor that effect on the tensile strength of the welded joints [16]. FSW of different AA 2014-T6 and AA 6061-T6 were perfumed taking into account the effect of various welding process parameters. It was found that the percentage of each alloy in the stirred zone -SZ- effect on the metal flow, hardness, temperature distribution and the welding torque[17].The mechanical properties and microstructure of the FSW joints of aluminum alloys 6061 to 7050 were studied a similar hardness profile distribution was observed about the weld line. This was due to the distinct properties for both alloys. Increasing the rotating speed resulted in increase the joint strength. The first sets of welded specimens were failed in the SZ due to the inadequate material intermixing. The other was failed at the HAZ due to the material softening [18].The present work objective is to study the effect of the linear and rotational speeds of the welding machine on the tensile strength of friction stir welded aluminium alloys type AA5086-H32 by using a FillerAA6061-T6. The metallurgical and fatigue properties of the welded region which gave the highest tensile strength were analyzed.

EXPERIMENTAL WORK

Materials

The material use in the friction stir welding process are AA5086-H32 and the filler A6061-T. The measured chemical compositions using Olympus alpha 4000 and delta professional handheld XRFn, are listed in table (1).

Table 1. Chemical compositions of AA5086-H32 and AA6061-T6-(used a filler)

Element wt. %	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	Al
AA5086-H32	0.37	0.4	0.07	0.47	3.721	0.11	-	0.065	0.01	Rem
stander	0.4	0.5	0.1	0.45	3.6-4.5	-		0.02-0.26	-	Rem
AA6061-T6	0.67	0.7	0.32	0.07	0.276	0.22	-	0.121	0.017	Rem
stander	0.4-0.8	0.7	0.4-0.45	0.1	0.04-035	0.25	-	0.25		Rem

Welding Parameters

Tool rotation rate (ω, rpm) and tool traverse speed (ν, mm/min) along the line of joint are very important for FSW. The rotation of tool results in stirring and mixing of material around the rotating pin and the translation of tool moves the stirred material from the front to the back of the pin and finishes welding process. Higher tool rotation rates generate higher temperature because of higher friction heating and result in more intense stirring and mixing of material. However, it should be noted that frictional coupling of tool surface with work piece. A suitable tilt of the spindle towards trailing direction ensures that the shoulder of the tool holds the stirred material by pin and moves material efficiently from the front to the back of the pin .The other important parameter in FSW is the shoulder plunge depth. Plunge depth of the FSW tool can be defined as the position of the lowest point of the tool shoulder with respect to the surface of the welded plate as shown in Figure1. [19, 20, 21]. The general relationship between max T°C and FSW parameters can be calculated from the equation below [19]:

$$T/Tm = K\ (\omega 2\ /\nu * 10^4)^{\alpha} \quad (1)$$

Where α : exponent is reported to range from 0.04 to 0.06, K: constant is between 0.65 and 0.75,Tm°C is the melting point of the alloy. Also the shoulder plunge P can be calculated from the equation:

$$P = 0.5\ D \sin\theta \quad (2)$$

where P = shoulder plunge (mm), D = shoulder diameter (mm), θ = tilt angle (degree). FSW tool is of hardening tool steel -ASTM A681-94 O1 type, has 56 HRC. The tool had a featureless shoulder of 14 mm diameter and smooth pin of 4 mm diameter, 2.7 mm height and 2.5 cone angle. Fig (2-a, b) shows the tool that has been used in making all weld trails. The four different rotational speeds are 410,510,680 and 920 rpm and the linear speed are 25,40and74 mm/min was used in (FSW).

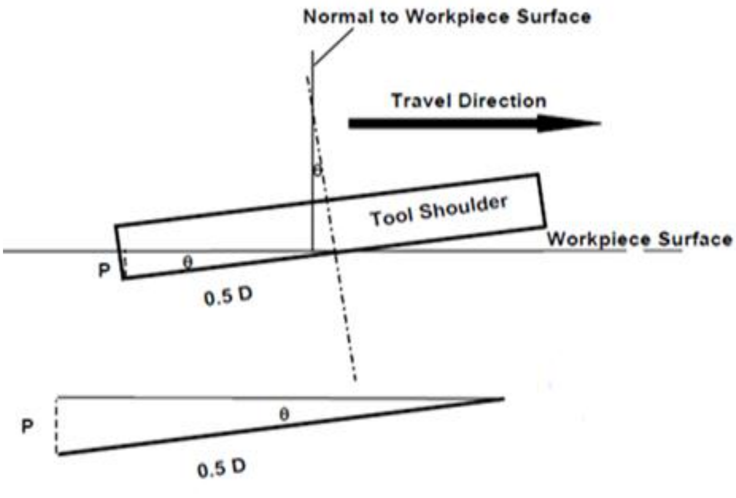


Figure (1) Schematic drawing of the shoulder plunge depth.

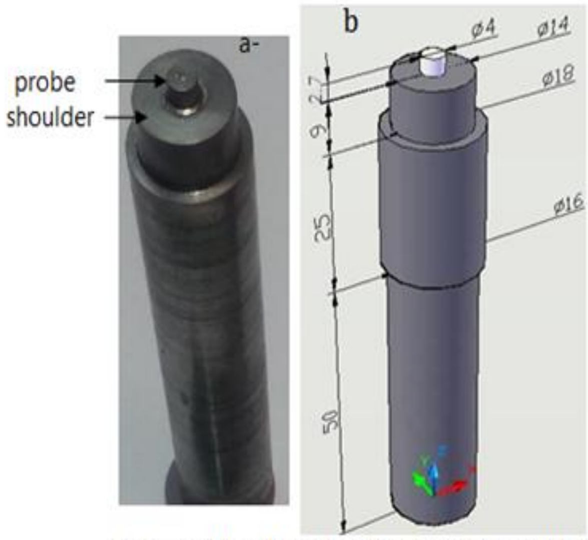


Figure -2-tool used in friction stir welding- **a**- photograph tool - **b**- schematic tool.

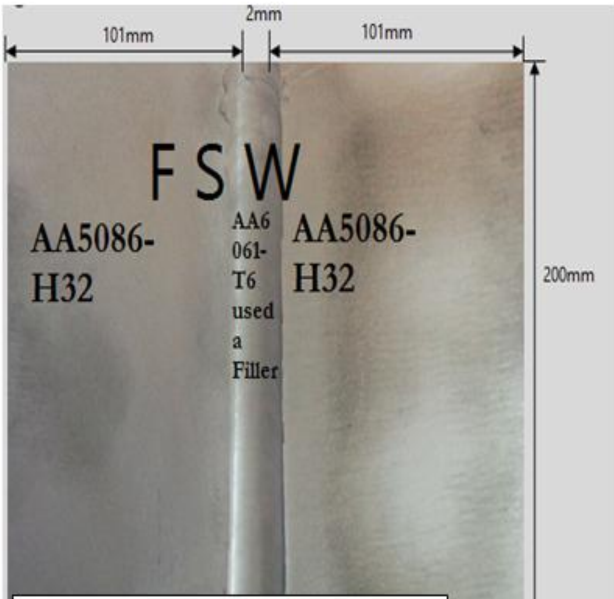


figure -3- shown tow plate welled

Figure -4-the milling machine(IWASHITA) used for welling process.

Preparation of welding process

The samples needed to weld the materials (AA5086-H32) was cut from a plate 3 mm thickness with dimensions-105x 205mm- and- 3 x 2 x105 mm dimensions of the filler metal(AA6061-T6) . The net work pieces welled by FSW as shown in Fig -3- Fig -4-the milling machine(IWASHITA) used for welling process.

Micro hardness Testing

Micro hardness testing of the welded joints was done by Zwick/Roell micro hardness machine. Micro hardness measurements were taken in vertical and horizontal axes using diamond pyramid indenter with a load of 50 g and loading within 15 sec according to ASTM-E384. The specimen surface was prepared by different grades of emery papers according ASTM- to provide a suitable flat surface.

Micro structural Evaluation of the Welded Area

The specimens were sectioned to the required size from the joint comprising the NZ, TMAZ, HAZ and BM for FSW. The specimens were mounted with polymeric material for easy preparing, according to ASTM E3, the specimens are prepared through a series of successive steps starting from grinding with 220, 320, 400, 600, 800, 1000, 1200 and 2000 emery paper, the specimens were rotated at 90° and polished to a mirror finish with different grades of alumina suspension by universal grinding and polishing machine for metallographic specimen preparation. Washing the specimens with distilled water between stages was necessary to prevent carryover of abrasive and contamination of preparing surfaces. Finally the specimens were etched in special chemical.

Tensile testing

The standard (ASTM B557M-02a)and the AWS D17.3/D17.3M:2010 are adopted for the manufacture of tensile test samples for the purpose of examining the mechanical properties of base material, HAZ and the welding line are located in the middle of the sample respectively as shown in Figure. -5 .The tensile tests were carried out at 25^{0}C and constant loading rate (2mm/min) by computerized universal testing machine (test center 600KN) .Figure.-5-show the Sample of tensile test -a- schematic for base, HAZ. -b- schematic for welded.

Fatigue test

The fatigue test used is the type of alternating bending test. Samples of this test were manufactured as shown in Figure. (6-a, b). The behavior of the highest fatigue bending stress was studied The weld conditions (linear and rotating speed) that gave the highest ultimate stress value in tensile testing were approved for the manufacture of fatigue test samples The fatigue behavior of the sample was studied in different regions, such as welding line, heat affected zone (HAZ),and the base material.

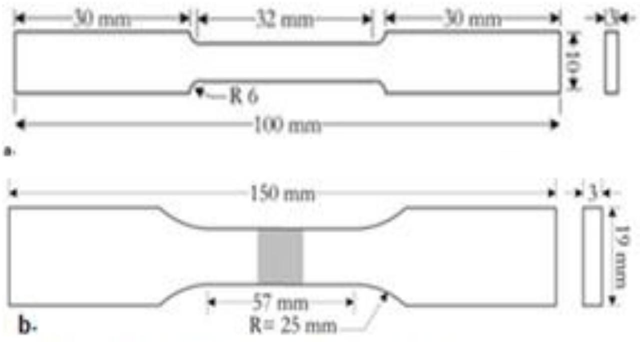
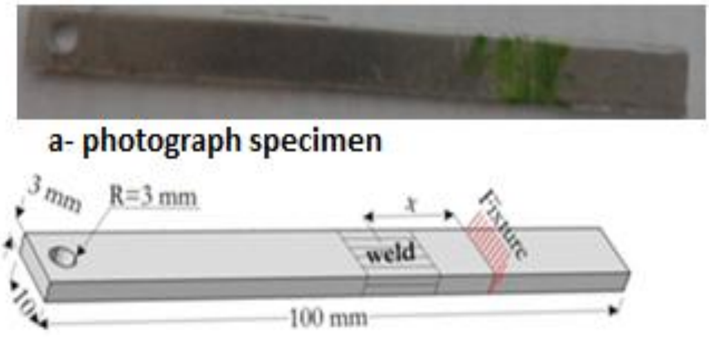


Fig.-5- the Sample of tensile test . -a- schematic for base , HAZ -b- schematic for welded



b-schematic specimen

Fig. 6- fatigue test specimet

EXPERIMENTAL RESULTS AND DISCUSSION

Microstructure

The microstructure of the welded sample at weld conditions (N=920 RPM, V= 40 mm/min.) which gave the highest tensile strength were illustrated in Fig -7-. This figure represents the welded joints AA5086-H32 and filler AA6061-T6. The microstructure of the base materials AA5086H32 and the filler AA6061-T6 are shown in Figure -6- a, f . In(b) and (c), there are seen that the microstructures of heat affected zone in the advancing and retreating sides are approximately similar to base materials without any significant grain coarsening , in the same figure-e- represents the welded joints for AA5086-H32- and in (h), (i) there are seen that the microstructures of heat affected zone in the advancing and retreating sides there is a clear and significant bent and elongation in grains at the advanced side witch compared with the retreating side. This can be attributed to the fact that the plastic flow direction from the advance side to the retreating side produces fiber structure pattern during the welding process. In addition, the direction of the plasticized materials on the advanced side of the weld is the opposite of the base material, which leads to make the deformation and elongation of the grain is relatively large in that side.

The hardness Results

The amount of high heat generated during the friction stir welding process leads to refinement grain size and the occurrence of thermal changes in the weld zone, which in turn lead to a clear variation in the hardness as shown in figure 8. It's noticeable from the figure that the highest value of the hardness was found at the center of weld region and decreases in the HAZ through the parent material of AA5086-H32 when using AA6061-T6 fillers and without use**.** In general the hardness values of the weldments were higher as compared with the HAZ and base alloy. Hardness value was increased in the weld metal which was about (108 HV0.05) and that conforms to the Hardness distribution in two axes was recorded. Fig (8) shows hardness test result, while hardness value in the HAZ was recorded to be about 75 HV0.05, this value is less than in the weld metal, the base alloy which is about 76 HV0.05. Figure 8 shows the hardness distribution along the line weld, the base alloy and heat affect zone (HAZ) in the y-axis direction. From this figure it can be seen that the largest reduction in hardness at the affect heat zone about 75 HV0.05 due to heat input and grain growth in this region. Fig. 8- shows the hardness of welding section of AA5086-H32 H32 when use AA6061-T6 a filler under using the optimal welding conditions at rotational speed of 900 rpm and travel speed of 40 mm/min.

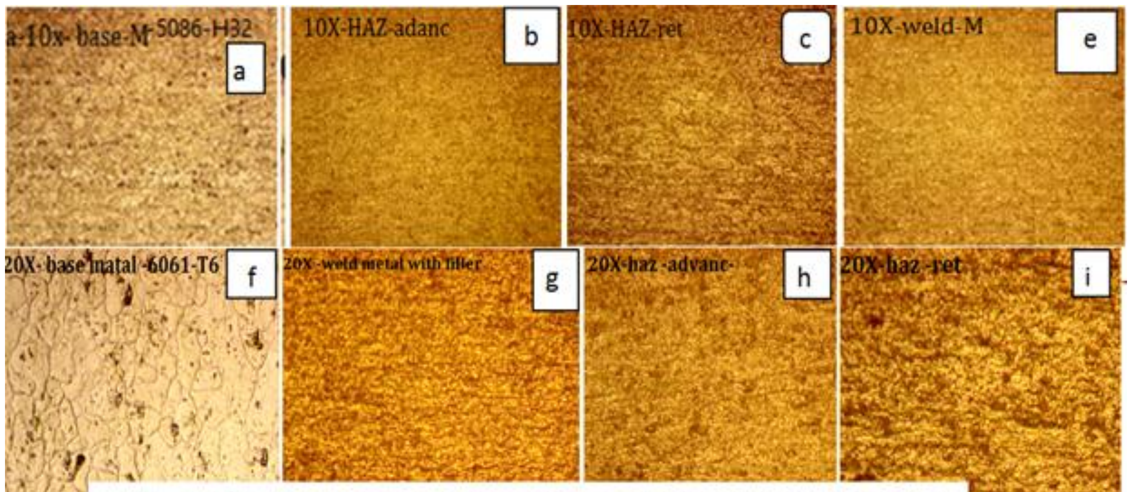


Fig.-7- The microstructure of the welded sample under welding conditions.

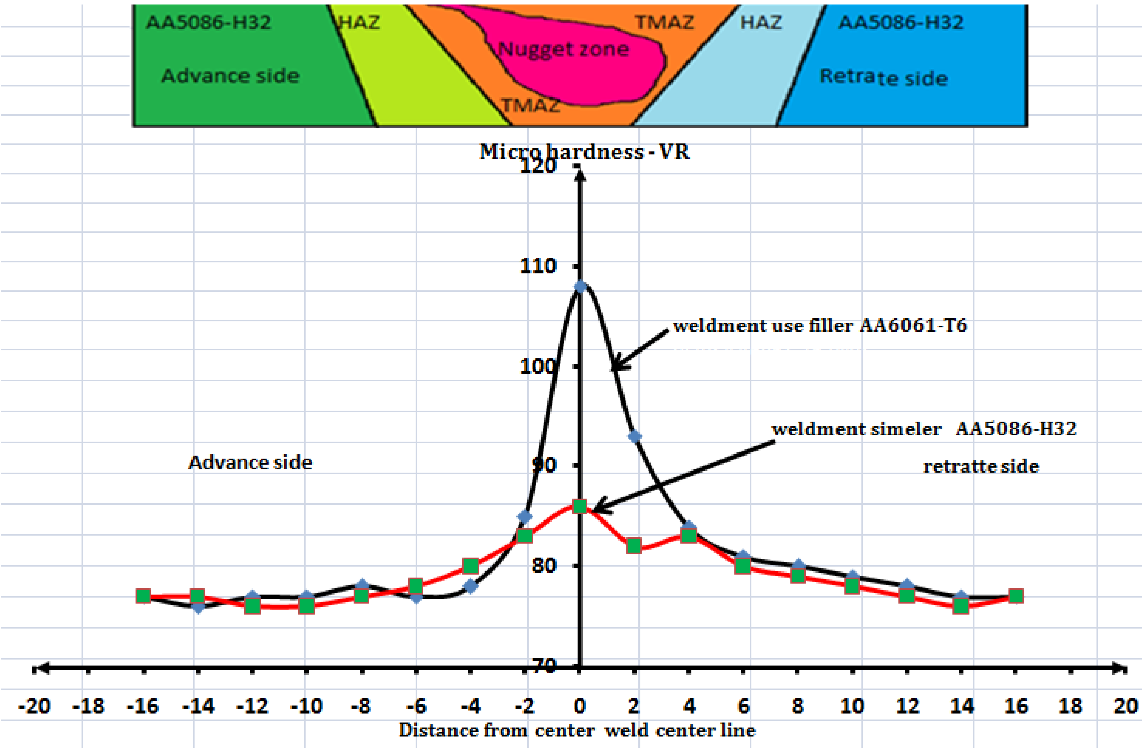


Fig.-8- the hardness for tow region similar weld -AA5086 -H32 and use AA6061-T6 a Filler.

Tensile testing

The tensile test results showed that all welded samples had failed in the welding region. This can be attributed to the change in the mechanical and metallurgical properties of both metals during the welding process.The pseudo heat index , ultimate stress σu, yield Stress σy, elongation e%, and welding efficiency which can be calculated from equation[22]:

$$\sigma u = \text{Force fracture/Area} = p/Ao \quad (3)$$

$$\sigma y = \text{Force/Area} = P/A\text{--- Offset method} \quad (4)$$

$$E\% = (L_f - L_o / L_o) \times 100 \quad (5)$$

$$\text{pseudo heat index} = \omega^2/v*10^4 \quad (6)$$

$$\text{Welding efficiency} = \sigma f/\sigma u\ \% \quad (7)$$

Figure-9-A- curve A,B show the both variable welding efficiency and T/Tm% in the welding region of AA5086-H32 similar welding (WM) at the different conditions of rotational speed and travel speed. The highest values of tensile strength , efficiency and T/Tm% were 257 MPa ,80% and 79.67% respectively, and observed at rotational speed(N= 920 RPM) and Leaner speed (V=40 mm/min).The lowest values of the tensile strength and the welding efficiency were(193 MPa ,60.14%) and observed at rotational N= 510 RPM and leaner speed V=25mm/min . Also the Fig - curve c, d show the variable of welding efficiency and T/Tm% in the welding region of AA5086-H32 use AA6061-T6 a filler (WM1) at the different conditions of rotational and travel speed. The higher value for tensile strength ,welding efficiency and T/Tm% were(269 MPa ,83.8% and 79.66% respectively) and observed at rotational speed(N= 920 RPM) and Leaner speed (V=40 mm/min) .The lowest values of tensile strength was 191 MPa and welding efficiency was 59.5% and observed at rotational speed N= 510 RPM and leaner speed V=25mm/min Fig -10- explain the variation welding efficiency and variable pseudo heat index in the welding region at the different conditions of rotational and travel speed. The highest values of tensile strength, weld efficiency and T/Tm% were observed at 2.11 R2/min.mm2 of pseudo heat index. But the highest value is 3.38 R2/min.mm2 which is give a tensile strength(248 MPa) , welding efficiency (77%) and T/Tm% (81.9 %) . Fig -11- explain the variation welding efficiency and elongation e%1for welding region(WM1)and elongation e% in the welding region(WM) at the different conditions rotational and travel speed. the highest values of tensile strength , efficiency and T/Tm% were observed at 5.4% ,5% for the tow region . But the highest value of pseudo heat index give 4.35% and 4.15% elongation% for the test specimens of AA5086-H32 similar welding (WM) and AA5086-H32 use AA6061-T6 a filler (WM1)respectively.

Table 3. Tensile test results of AA5086-H32 and AA6061-T6 (used a filler).

Material	yield Stress σy(MPa)	u(MPa) σ Tensile stress	Elongation (%)
AA5086-H32	224	321	8.9
AA6061-T6	281	345	8.3

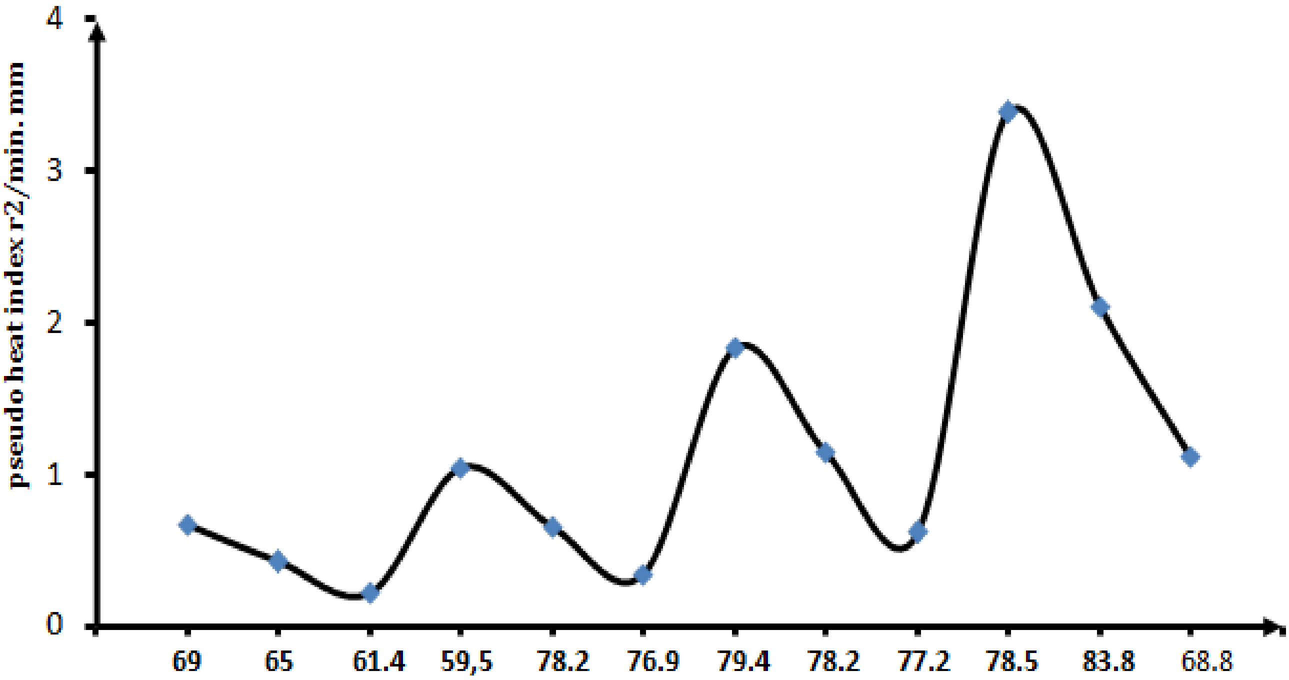


Fig.10- Welding efficiency % against pseudo heat index r2/min. mm

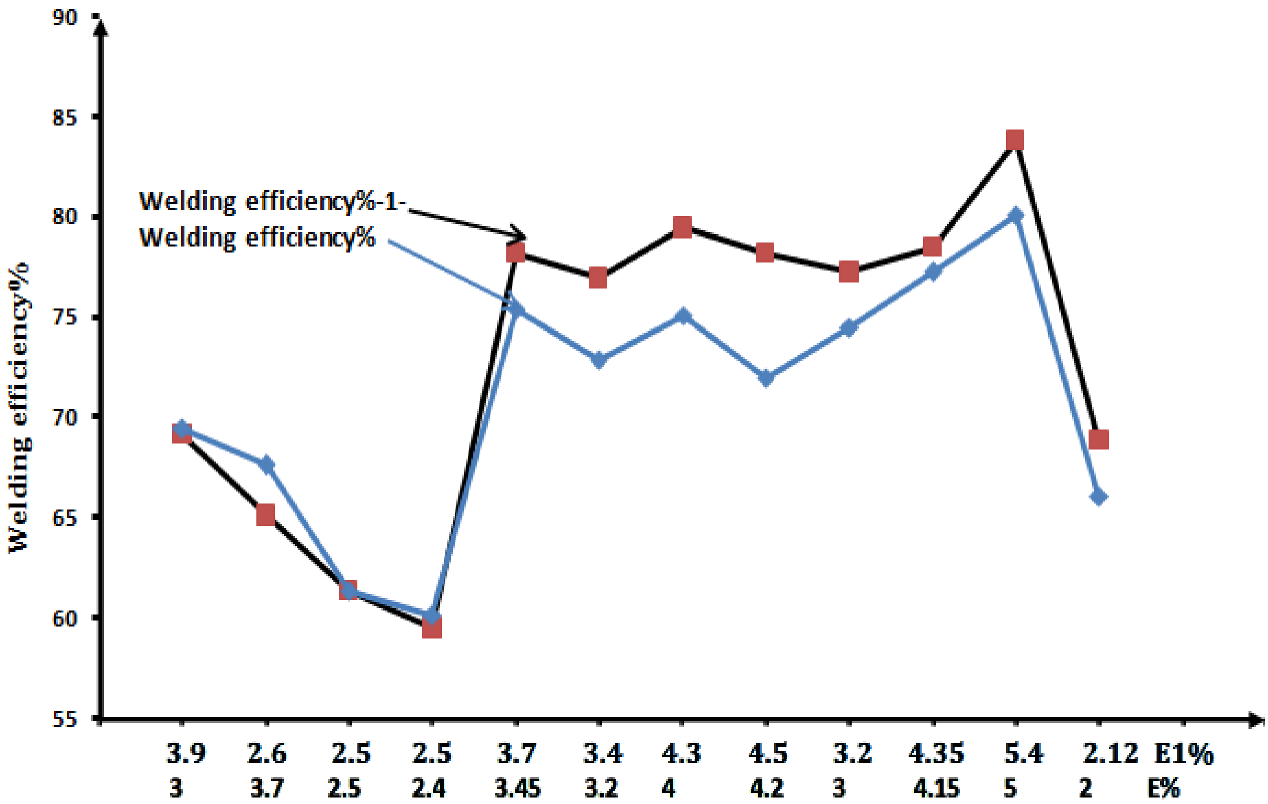


Fig. 11 - Welding efficiency against elongation % at different rotating and leaner speed.

Fatigue test

The fatigue test was study the mechanical and metallurgical properties of weldments represent. The tow weld conditions (linear and rotating speed) that gave the highest ultimate stress value in tensile testing were approved for the manufacture of fatigue test samples. The fatigue behavior of the sample was studied in different regions, such as weld metal (wm), weld metal used filler (wm1), heat affected zone (HAZ) and the base metal (BS).The fatigue test is the type of alternating bending test. All fatigue S-N curves of the four regions can be analyzed based on Basque equation follows:

$\sigma_{b=}$ M.Y/ I (8)

σ_b maximum applied bending stress, M: the maximum moment calculated from equation below:

M = F * L (9)

Where M in N.mm and L is the moment arm = 100 mm, y is the distance from the tip to centre X- axis section of the specimen = h /2 mm, I: is the second moment of inertia of the specimen calculated from equation below [23]:

$I=bh^3/12$ (10)

Fatigue curve of material is obtained by many constant amplitude fatigue tests can be presented by [24]:

σ_f = A. N_f (11)

σ_f : applied stress at fierier due to applied stress at $\sigma_{f,}$ N_f : number of cycle, A and α are material constants that can be evaluated by linearizing the curve by rewriting equation (11) in logarithmic form as following :

$\text{Log}\sigma_f = \log.A + \alpha\ .\log N_{f.}$ (12)

A and α can be determined by using the fitting and the least square method.

$$\alpha = \left(\frac{H\ \sum_{i=1}^{h} \text{Log}\sigma_{fi}\,.\text{Log}\ N_{fi} - \sum_{i=1}^{h} \text{Log}\sigma_{fi}.\ \sum_{i=1}^{h} \text{Log}N_{fi}}{\left(h \sum_{i}^{h} (\text{Log}N_{fi}\right)^2 - \left(\sum_{i=1}^{h} \text{Log}N_{fi}\right)^2} \right) \quad (13)$$

$$\text{Log}\,A = \left(\sum_{i=1}^{h} \text{Log}\,\sigma_{fi}\,. - \alpha \sum_{i=1}^{h} .\ \sum_{i=1}^{h} \text{Log}N_{fi}\right)/h \quad (14)$$

Where I is number of test or -i = 1, 2, 3...h, and h is total factor of test. The f Fig endurance limit for (wm),(wm1), (HAZ)and (BS)under higher tensile stress were carried out at variable cyclic stresses in pure bending tests Fatigue curve of material is obtained by many constant amplitude fatigue tests and can be presented by the equation-8- [26]. Figure- 12- illustrates the fatigue behaviour of (wm) , (wm1), (HAZ)and (BS) and give the S-N curve equations for them. Table(6)show the endurance limits at 10^7 cycles at different weld regions for AA5086.

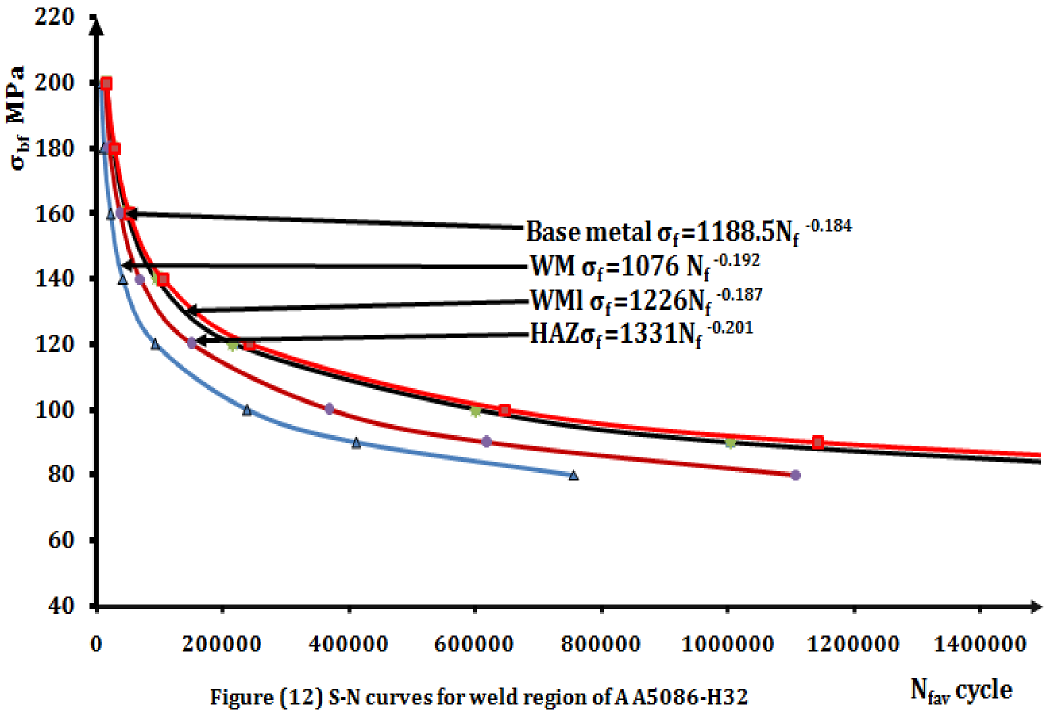


Figure (12) S-N curves for weld region of A A5086-H32

Table 6. Fatigue endurance limits at 10^7 cycles			
Base metal	Weld metal	Heat metal zone	Weld metal
61.2	48.73	52.14	60.185
Reduction % in endurance limit			
	12.47	9	1.029

CONCLUSIONS

From the results which were obtained from the experimental can be summarized:

1) The fracture of the tensile test specimens welded by FSW occurred in the weld region.
2) The optimal conditions of the friction stir welding were 920 rpm rotation speed and 40 mm/min travel speed for a 3mm thick plate of AA5086-H32 by using AA6061-T6 fillers and similar welding were gave the higher strength 269 MPa and 257 MPa respectively and producing the welding efficiency 83.8% and 80% respectively, achieved when the welding temperature about0.79.66% Tm and pseudo heat index 2.11 r^2/min.mm.
3) The hardness results showed that the stir zone has higher value than other welding zones in all welded joints and the variation in hardness has range from 108-85 HV0.05 for NZ and HAZ respectively.
4) From fatigue test at constant amplitude bending was found the number of cycles (Nf) or fatigue life increasing from stir zone (N Z)for weld metal, an affected heat zone(HAZ) and weld metal by using AA6061-T6 fillers..
5) The fatigue life and fatigue limit for weld joints by using AA6061-T6 fillers was higher than that of similar weld joints.
6) The reduction percentage in fatigue endurance limit of (WM1,HAZand WM)was 1.023%,9%,12.47% respectively as compared with base metal (AA5086-H32).

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