



COMPARATIVE STUDY OF MECHANICAL PROPERTIES ALUMINUM ALLOY 5052-O WELDED BY TIG AND FS PROCESSES

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ABSTRACT

The TIG process is very versatile and may be used to weld any metal or alloy system over a wide range of thicknesses, but is usually restricted to 10mm and under for economic reasons. 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 aluminum alloy (5052-O) is welded in two welding processes TIG and FSW to evaluate some mechanical properties to determine the optimal welding conditions, and then compare the results between tow welding processes. According to commonly adopted standards. Welding in TIG process is carried out at 140 Amp welding current, 15 V welding voltage, 16 L/min gas flow rate, Arc length (3) mm and Velocity feed (70) cm/min. For FSP four different rotational speeds are used; 450, 620, 720 and 900 rpm with three different travel speeds 25, 40 and 75 mm/min. The experimental results for TIG welding showed that the weldments have 140 MPa ultimate tensile strength and 7.1 % elongation and the hardness values ranging 32-35 HV0.05 for the weld metal and heat affected zone. On the other hand, the experimental results for FSP showed that the weldments have 170 MPa ultimate tensile strength and 7.4% elongation, the hardness values ranging 47-49 HV0.05 for the weld metal and heat nugget zone under the optimal welding conditions at rotational speed of 900 rpm and travel speed of 40 mm/min. The studying of microstructure showed different distinct for the TIG welding and for the FSW. A large difference of grain size can be observed between two welding processes. The grain size in the heat affected zone for the TIG welding was about 56 μm and 37 μm for the weld metal zone, while the grain size in the heat affected zone for FSW process was about 18 μm and 12 μm for the nugget zone as compared with 32 μm for the base metal. From the experimental results the welding efficiency can be concluded for TIG and FSW processes was 68% and 81.6% respectively, this large difference is attributed to the low heat input in FSW as compared with TIG welding process. The fatigue endurance limit for AA5052-O was carried out in pure bending test. The fatigue test was performed at RT to establish the S-N curve equations. The fatigue endurance limits was calculated at 10^7 cycles from the empirical S-N curve equations. It was found that the fatigue endurance limit decrease in weld metal, heat affected zone, nugget zone for

both methods. Also the reduction percentage in fatigue endurance limit compared with base metal.

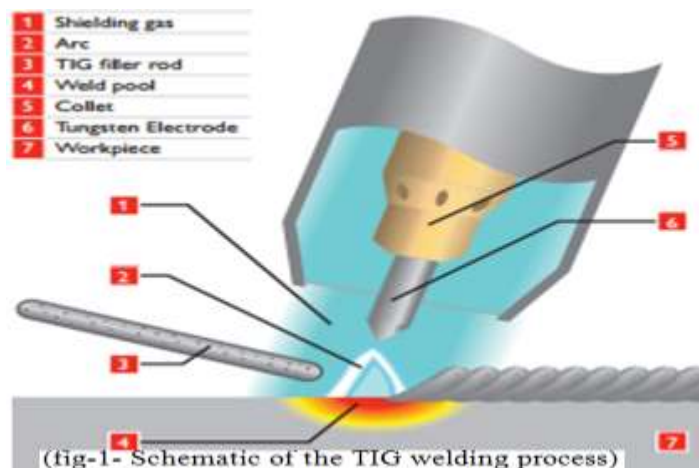
Keywords: Tungsten inert gas welding (TIG), Friction Stir Welding and Processing (FSW and FSP, Frictions stir welding or stir zone (SZ), joining, microstructure, fatigue.

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1. INTRODUCTION

Aluminium are low specific weight and low melting point, excellent corrosion resistance, high strength and stiffness to weight ratio, good formability, and high electrical and heat conductivity of aluminium alloys are among the most popular materials for structural components in engineering industry [1, 2]. Aluminium may be welded by either gas or arc processes, thermal conductivity of it is high being five times greater than that of steel, and hence with arc welding distortion and any tendency to crack are reduced.[3] Aluminum alloys are typically welded on AC with the gas tungsten arc welding (GTAW) process.[4] The TIG process can be run on DC-, DC+, or AC and AC be run on aluminium and its alloys. The most commonly used gas for TIG welding is argon which can be used on all metals. [5] Schematic of the TIG welding process in fig.1. Aluminium alloys have properties such as good strength, light weight and corrosion resistance that make it used in most parts of structures [6]. The aluminium alloys AA5xxx and AA6xxx used in the ship, aircraft and transport vehicle structure fabrications, 5052 -O, -H34, form ability, corrosion resistance, and low cost (roll forms, auto, trailers, truck trailer sheeting) [7,8, 9]. Welding of these grades of aluminium alloys by means gas tungsten arc welding or gas metal arc welding processes result in welding problems due difference in solidification modes for each type of alloy, and therefore the FSW process was considered as a good method to weld different aluminium alloys [10,11]. This process is a solid state welding technique [12,13].The fatigue behavior of gas tungsten arc welding (GTAW) process and friction stir welded of different series aluminium alloys (1050, 5083, 6061 and 7075) was investigated. They concluded that the fatigue behavior was sensitive to the microstructures of the welding zones. The fatigue strengths of the welded samples were equal to or lower than those of the parent materials [14]. The fatigue behavior of dissimilar FSW joints of different aluminium alloys (AA6082 and AA5754) was studied. They concluded that the fatigue behavior was sensitive to the microstructures of the welding zones. The fatigue strengths of the welded samples were equal to or lower than those of the parent materials [14]. The present work objective is to study the effect of the Welding in TIG process is carried out at 140 Amp welding current, 15 V welding voltage, 16 L/min gas flow rate, Arc length (3) mm and Velocity feed (70) cm/min and the linear and rotational speeds of the welding machine on the tensile strength of friction stir welded type AA5052-O. The metallurgical and fatigue properties of the welded region which gave the highest tensile strength were analyzed.



2. EXPERIMENTAL WORK

2.1. Material and specimen

The measured Chemical compositions of material and some properties and Electrode wilding feller are listed in table (1).

Table. 1. Chemical compositions and some properties of AA5052-O and Electrode wilding feller

Element	Fe%	Si%	Cu%	Mn%	Mg%	Cr%	Zn%	Al%	
Wight	0.4	0.25	0.1	0.1	2.5 -2.8	0.15-0.35	0.1	Rem	Standard
Wight	0.4	0.23	0.13	0.12	2.55	0.18	0.11	Rem	Experimental

Physical properties of AA5052-O

ou MPa	σy MPa	Milting point	Density
195	90	649°C	2.69 g/cm ³

chemical composition of Electrode

Element	Fe%	Si%	Cu%	Mn%	Mg%	Cr%	Zn%	Al%	
Wight	0.4	0.25	0.05	0.05	2.6-3.4	0.3	0.2	Rem	Experimental

2.2. Tinsel tests

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 for both welding processes respectively .The tensile tests were carried out at constant loading rate (2mm/min) by computerized universal testing machine (testcenter 600KN) .Fig. 2.show the Sample of tensile test -a- schematic for base, HAZ-b- schematic for welded.

2.3. Fatigue test

The fatigue test used is the type of alternating bending test. Samples of this test were manufactured as shown in Fig.6-a, b. The behavior of the highest fatigue bending stress was studied. The weld conditions 40 mm/min linear speed and 900 rotating speed respectively 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 welding line and the base material.

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Fig.2. the simple tensile test. a- schematic . b - photograph.

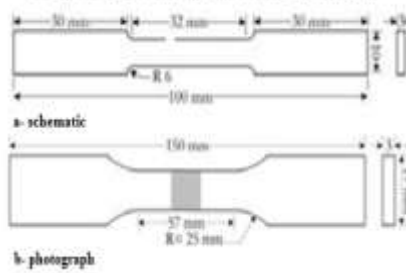
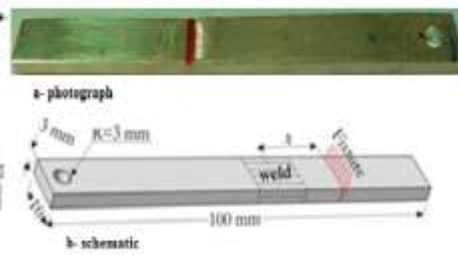


Fig.3. the sample fatigue test . a- photograph. - b- schematic



2.4. 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.

2.5. Grain Size Measurement

Grain Size is often preferred to measure the grain size by lineal intercept technique. In this technique, lines are drawn on a photomicrograph, and the number of grain boundary intercepts, "N" along this line is counted. The mean lineal intercept is [16].

$$(1) \quad I=L/NM$$

Where L: the length of line (μm), M: the magnification in the photomicrograph of the material and N: the number of intersections.

$$\text{or} \quad i=2/ \quad (2)$$

Where, D is the average grain diameter.

This is the most correct way to express the grain size from lineal intercept measurements. The microstructure of the welded sample at the optimal welding conditions of TIG and FSW which gave the highest tensile strength were illustrated in figure (4, 5) respectively.

Fig. 4. the microstructure of specimens weld in TIG welding method



Fif.5. the microstrucure the specimens welding in FWS of welding method.



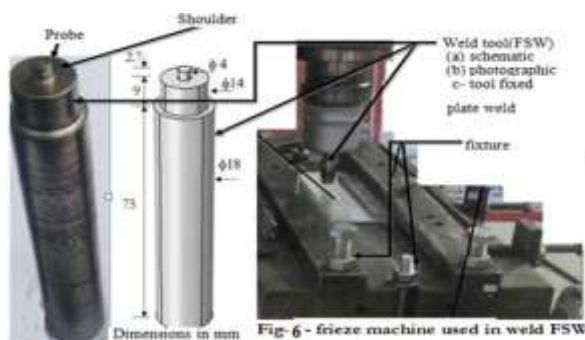
2.6. Preparation of welding process TIG

2.6.1. Tinstone inert gas welding process

The welding machine type -Murex-Transtig AC/DC-255EQUARE WAVE used in TIG welding .The parameters of the welding machine which can be manually controlled include(welding current , welding voltage , gas flow rate (argon), Arc length and Velocity feed, welding wire). These parameters have a significant effect on the quality of the final product of the welded samples.

2.6.2. FSW process.

The samples needed to weld the two plates with thickness 3mm and dimensions 100*200 mm. The tool used in friction stir welding is of type oil hardening tool steel (ASTM A681-94 O1 type). The tool consists of two cylindrical parts, the first the pin and the second is the shoulder. Before starting the welding process, the samples were fixed using fixture and backing plate tied to the base of the milling process machine as shown in figure (6).



3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1. tensile tests

In table -2- show the tensile properties test with the standard values of the alloy at room temperature.

Table 2 Mechanical properties of the base metal of AA5052-O

	σ_u MPa	σ_y MPa	E %	HB
standard values	195	105	14	48
Experimental values	205	107	13.7	51

All tensile test results for the Tinstone inert gas welding (TIG) and Friction Stir Welding (FSW) had failed in the welding region. This can be attributed to the change in the mechanical and metallurgical properties of both methods during the welding process. The pseudo heat index, ultimate stress σ_u , yield Stress σ_y , elongation $e\%$, and welding efficiency which can be calculated from equation. [17]

$$\sigma_u = \text{Force fracture} / \text{Area} = p / A_o \text{ MPa} \quad (3)$$

$$\sigma_y = \text{Force} / \text{Area} = P / A \text{ MPa Offset method} \quad (4)$$

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

$$\text{pseudo heat index} = \omega^2 / v \cdot 104 \quad (6)$$

$$\text{Welding efficiency} = \sigma_f / \sigma_u \% \quad (7)$$

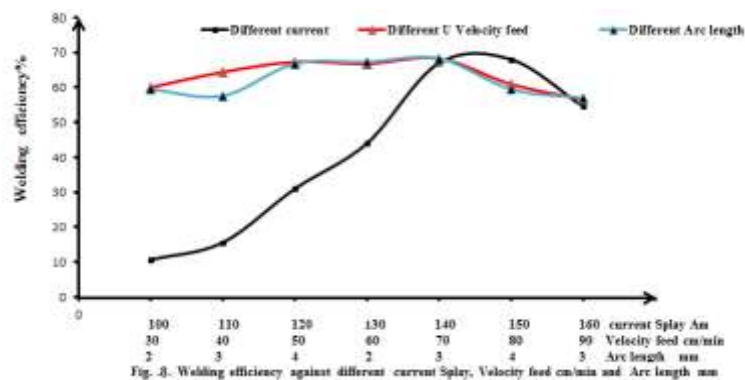
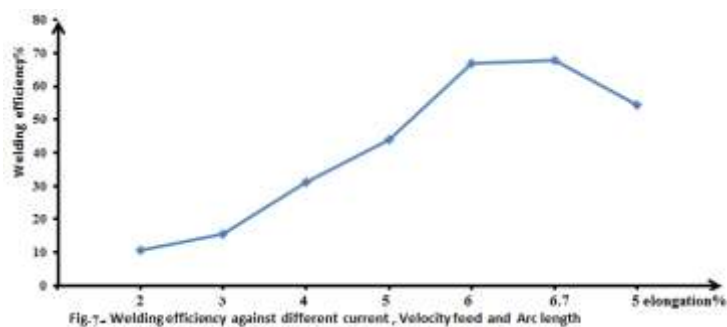
All results are an average of three readings.

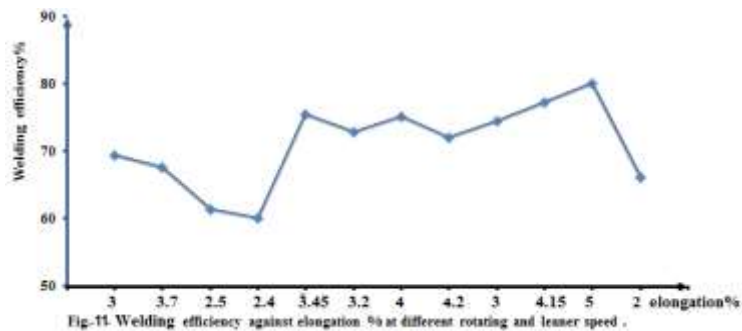
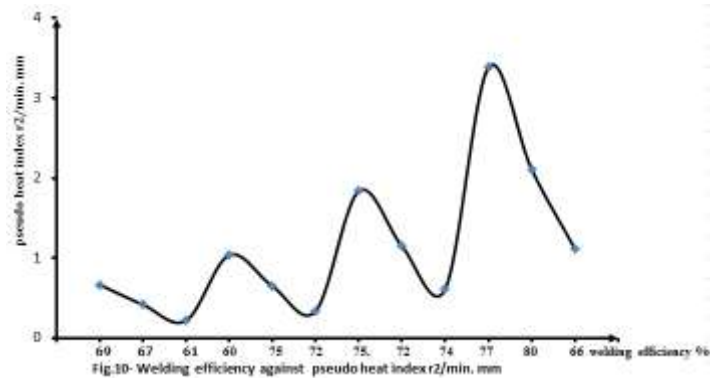
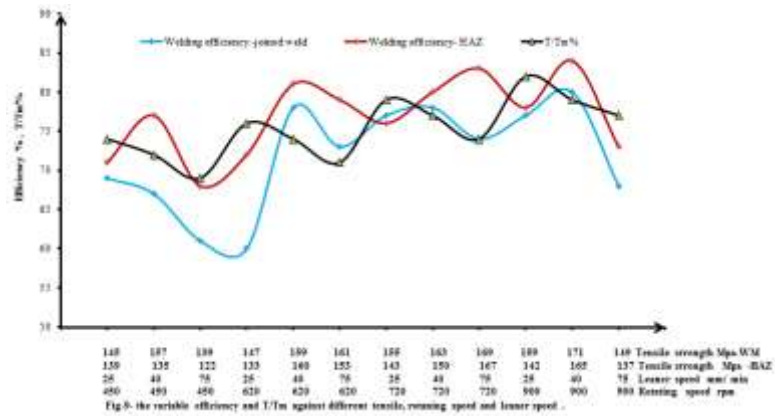
3.1.1. The tensile test results for the tinstone inert gas welding (TIG)

Figure-7- show the highest values of elongation from 6 - 6.5 give highest efficiency and the lowest value observed at 2% elongation. Figure-8- show the highest values of efficiency were 68% and observed at current =140Am, Arc length =3mm, velocity feed=70cm/min .The lowest values observed at current =100Am, Arc length =3mm and velocity feed=30cm/min.

3.1.2. The tensile test results for the FSW

Figure-9- show the highest values of tensile strength, efficiency and T/Tm% were 171 MPa, 80% and 79% respectively and observed at rotational speed (N= 920 RPM) and Leaner speed (V=40 mm/min) and the lowest values of the tensile strength, the welding efficiency and were 139 MPa, 61% and 69% respectively and observed at rotational N= 510 RPM and leaner speed V=25mm/min, but in HAZ The highest values of tensile strength and efficiency were 165 MPa and 84 respectively and observed at rotational speed (N= 920 RPM) and Leaner speed (V=40 mm/min) and the lowest values of the tensile strength and the welding efficiency were 139 MPa and 68% respectively and observed at rotational N= 450 RPM and leaner speed V=75mm/min. Also the Fig-10 show the highest values of pseudo heat index was $3.02 \text{ r}^2/\text{min.mm}$ gives highest welding efficiency in the welding region observed at rotational speed (N= 920 RPM) and Leaner speed (V=40 mm/min) and the lowest values of pseudo heat index was $0.22 \text{ r}^2/\text{min.mm}$ gives 61% welding efficiency and observed at rotational speed N= 450 RPM and leaner speed V=75mm/min. Fig -11- show the highest values of elongation from 5give highest efficiency and the lowest value observed at 2.4%.





3.2. Fatigue test

Fatigue of welded samples was tested at optimum welding conditions, which gave the highest value for tensile strength. The fatigue test was study the mechanical and metallurgical properties of weldments represent. The tow method welding TIG and FSW 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), 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 three regions can be analyzed based on Basque equation follows:-

$$\sigma_b = M.Y/I \quad (8).$$

σ_b is maximum applied bending stress.

Y is the distance from the tip to center X- axis section of the specimen = h /2 mm,

I is the second moment of inertia of the specimen can be calculated from equation .

I: is the second moment of inertia of the specimen calculated from equation [18].

$$I = bh^3/12 \quad (9).$$

M is the maximum moment calculated from equation.

$$M = F * L \quad (10). [19]$$

Where M in N.mm and L is the moment arm = 100 mm.

Fatigue curve of material is obtained by many constant amplitude fatigue tests can be presented by

$$\sigma f = A. Nf^\alpha \quad (11)$$

σf : applied stress at fierier due to applied stress at σf .

Nf: 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 :

$$\text{Log}\sigma f = \log A + \alpha. \log Nf. \quad (12)$$

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

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

$$\text{Log } A = (\sum_{i=1}^h \text{Log } \sigma_{fi} - \alpha \sum_{i=1}^h \text{Log } N_{fi}) / h \quad (14) [19]$$

Where i is number of test or -i = 1, 2, 3...h, and h is total factor of test. The Fig-12, 13- endurance limit for (wm), 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 much constant amplitude, fatigue tests and can be presented by the equation-11- Figure - 12, 13 - illustrates the fatigue behavior of (wm), (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 AA5052-0

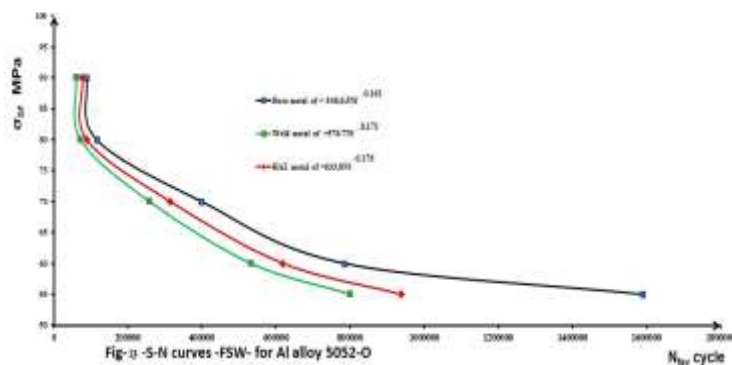
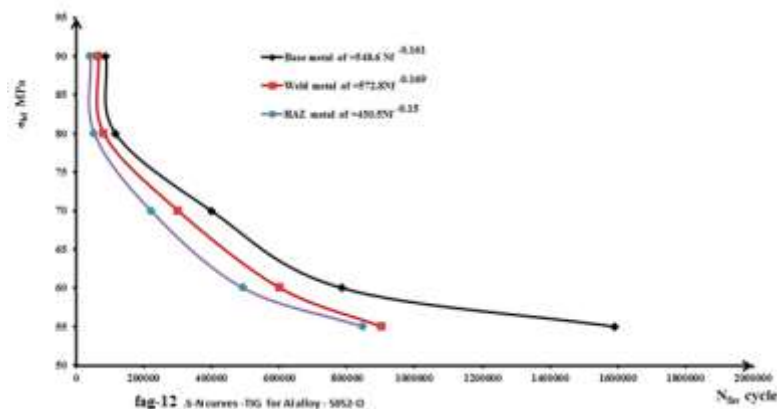


Table 3 Fatigue endurance limits at 10^7 cycles

FSW			TIG	
Base metal	Heat metal zone	Weld metal	Weld metal	Heat metal zone
40.94	36.64	37.6	37.6	38.3
Reduction % in endurance limit			Reduction % in endurance limit	
-	4.3	3.31	3.34	2.64

4. COMPARISON BETWEEN FSW AND TIG WELDING OF ALUMINUM ALLOY- 5052-O

From the results which were obtained from the experimental work and after discussing and comparing them, the FSW and TIG welding for a 3mm thick plate of aluminum alloy 5052-O, it can be concluded that:-

1. FSW optimal conditions were giving 84% welding efficiency at 900 rpm rotation speed and 40mm/min travel speed. while the best conditions for TIG welding were giving 68% welding efficiency at 140 Amp welding current , 15 V welding voltage ,16 L/min gas flow rate, Arc length(3) mm and Velocity feed(70)cm/min .
2. In TIG welding the maximum ultimate tensile strength of the welded joint is 140MPa compared to 205 MPa of the base alloy, the loss in strength of about 31.8%, while in FSW the maximum ultimate tensile strength obtained was 171 MPa, there is a loss in strength of about 16.6%, which means that the FSW produces a high ultimate tensile strength compared with TIG.
3. The fracture of the tensile test specimens welded by FSW and TIG welding occurred in the WM region.
4. The studying of microstructure showed different distinct zones for the TIG welding,(BM),(HAZ) and (WM), and for the FSW microstructure zones, (BM),(HAZ) and nugget zone, a large difference of grain size can be observed between two welding processes, the grain size in the heat affected zone for the TIG welding was about 56 μm and 37 μm for the weld metal, while the grain size in the heat affected zone for FSW process was about 18 μm and 12 μm for the nugget zone as compared with 32 μm for the base metal.
5. FSW is a solid state welding and does not need filler metal so that the chemical composition of the weld zone does not change as compared with TIG welding that needs filler metal leading to change in the chemical composition of the weld zone relative to the base metal.
6. In table -3- gives the experimental Fatigue endurance limits at 10^7 cycles for metal weld nugget zone and heat metal zone, for both weldedment temperatures embrittles the TIG welding, this embrittlement is due to superficial deformation of the specimens.
7. The reduction percentage in fatigue endurance limit of FSW was higher than that of TIG of AA 5052-O.

5. CONCLUSIONS

It can be concluded that:

1. The fatigue endurance limit for TIG welding decreases compared with FSW.
2. The reduction percentage in fatigue endurance limit of FWS was higher than that of TIG.

3. The fracture of the tensile test specimens welded by FSW occurred in the weld metal region, also the TIG welding, the reason may be that FSW is a solid state welding does not need filler metal so that the chemical composition of the weld metal does not change as compared with TIG welding that needs filler metal leading to change in the chemical composition of the weld metal relative to the base metal.

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