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A new method for measurement the residual stresses in friction stir welding

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ABSTRACT

Purpose: The residual stresses in different welding methods are fundemental problems to consider. Friction stir welding is one of a solid state joining process, it is economical in that it permits joining together different materials, the specimens in this method (FSW) have excellent properties of mechanical as proven by tensile, flextural and fatigue tests, also it is environmentally friendly process minimizes consumption of energy and generate no gasses or smoke. In friction stir welding , there are two kinds of generated residual stresses: tensile stress and compressive stress. So, this study measuring the residual stresses by using a new method for measuring residual stresses depends on tensile testing and stress concentration factor, this method is a simple, fast and low cost, also it is not need special device.

Design/methodology/approach: In previous studies, several techniques were used to predict the value of residual stress and its location, such as destructive, semi-destructive, and non-destructive methods. In this study, a simple, new, and inexpensive way was used based on the tensile test and stress concentration of the friction stir welding (FSW).

Findings: By comparing the results obtained with the previous studies using the X-ray method, with the current research, it was found that the results are good in detecting the location and value of the residual stress of friction stir welding. The value of discrepancy of the residual stress in the results between those obtained by the previous method and the current method was about 3 MPa.

Research limitations/implications: There are many rotational and linear feeding speeds used in this type of welding. This research used two plates from 6061 AA with 3mm thickness, 100 mm width, and 200 mm length. The rotational speed used in friction stir welding was 1400 rpm, and the feeding speed was 40 mm/min.

Practical implications: The residual stress obtained with the new method is 6.2 MPa, and this result approximates other known methods such as the X-ray method in previus studies.

Originality/value: Using a new simple method for measuring residual stresses of friction stir welding depends on stress concentration factor and tensile testing. This method is fast and low cost , also it is not need specialized device, compared to other methods such as x-ray or hole drilling methods.

Keywords: FSW, Residual stress, Tensile test, Stress concentration, AA 6061

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METHODOLOGY OF RESEARCH, ANALYSIS AND MODELLING

1. Introduction

Friction stir welding is a welding that has some advantages compared with fusion processes , FSW is a solid state joining process invented by Thomas at TWI in December 1991. FSW, does not involve exceeding the melting temperature of the metal that is to be processed. A rotating pin pierces a hole in the line of joint between the pieces of work to a depth of predetermined and moves forward in the weld direction [1]. The mechanical and thermal stresses that are caused by the welding process leads to the generation of residual stresses [2]. The residual stress formed at the region of welding was one of the most important variables to determine the mechanical properties of welds; various methods have been suggested to measure the residual stress of fusion and fusion welding processes to obtain reasonable valuations value [3]. These methods can be divided into three main categories: destroyed, semi-destroyed, and non-destructive [4]. In 2003 C.M. Chen, R. Kovacevic [5] studied the finite element modeling of FW and thermomechanical investigation of AA 6061-T6. X-ray diffraction technology is used to measure the residual stresses of the welded plate. The relationship between the calculated stresses of the welded and the influencing factors such as the tool's speed has been studied. Moreover, by studying these variables, an optimum relationship was obtained between the remaining stresses and those factors.

M. Iordachescu et al. [6] studied the use of X-rays to determine the value of the remaining stresses of the surface of the aluminum alloy type 6061 welded to frictional welding. The resulted wide HAZ, and the lower material rate of cooling produced the relatively low residual of compressive stresses in the zone. It was noticed the effect of the temperature generated as a result of welding on the values of residual stresses, which include a compression-type and tension-type (that causes danger).

Then, at 2014, A.A. Salman et. Al., [7], studied the mechanical properties for aluminium plate welding by using frication stir welding with effect of various frication stir processing parametris. There, the investigation included calculate the tensile strength and modulus of elasucity, in addition to, other properties for alumium alloy with various welsoing speeced and other parametris effect. Thus, the study used the experimental technique to calculate the mcechnaica properties for 7075-T73 Aluminum Alloys plated welding by frication stir welding.

Mohamed A. Mohamed et al. [8] investigated the transverse and longitudinal residual stress in the frictional stir welding of 6061 alloys using hole drilling technique using ESPI at different conditions. This method combined the traditional method with the electronic speckle pattern interferometry (ESPI) method, eliminating the application of a strain gauge through the stress profile of depth measurements by gradual drilling. Sergio Delijaicov et al. [9] studied the effect of varying the welding parameters on the resulted temperature, forces, Vickers microhardness, and residual stresses of dissimilar joints of AA7475-T761 and AA6061-T3 welded by (FSW). The tool feed rate, rotational speed, and tool angle of tilt were analyzed using DOE approach.

Also, at 2018, Kadhim K. Resan et. al., [10], studied the fatigue life for aluminum alloy with effect of temptaure by using frication stir welding processing. There, the studied included using for the experimental technique to calculate the fatigue life and strength for alloy by using fatigue device machine with different frication stir welding technique.

Then, at 2020, Akeel Z. Mahdi et. al, [11], presented investigation of mechanical properties for different aluminium alloy of welding point by using frication stir welding technique. There, the investigation included study the effect of refill stir welding on microstructure and mechnical properties for two aluminum alloy teypes, AA6061 and AA5052.

Friction stir welding is a technique of wleding and changing the a metal through intense properties , localized plastic deformation ,this technique mixes the materials without changing of phase, But this method, like the other different welding methods, generates a residual stress that must be measured . There are many ways to measure this stress., a new and easy method was used in the current study.

This study aims to use a new method for measuring residual stresses depends on tensile testing and stress concentration factor, this method is a simple , fast and low cost , also it is not need particular device. Also it is not need specialized device, compared to other methods such as x-ray or hole drilling methods.

2. Experimental procedure

2.1. Materials and chemical composition

In this study, AA6061 was used-plates of aluminium alloys of 180 mm length, 100 mm width, and 3 mm thickness. The chemical compositions of AA 6061 base metals are shown in Table 1.

Table 1.
Chemical composition of AA 6061 (weight %)

Element	Base metals	Standard
Mg	0.87	0.8-1.2
Si	0.63	0.4-0.8
Cu	0.32	0.15-0.4
Mn	0.095	Max 0.15
Ti	0.017	Max 0.15
Cr	0.21	0.04-0.35
Zn	0.12	Max 0.25
Fe	0.43	Max 0.7
Al	Balance	95.8-98.6

2.2. Mechanical properties

The tensile test was performed according to ASTM E-8 [12]. Tensile strengths of base metals and the welded joints were measured using various samples in direction to the direction of welding. Three samples for each specimen were made according to the dimension shown as in Figure 1. There, three samples were tested to calculate the average value for tensile mechanical properties [13-26].

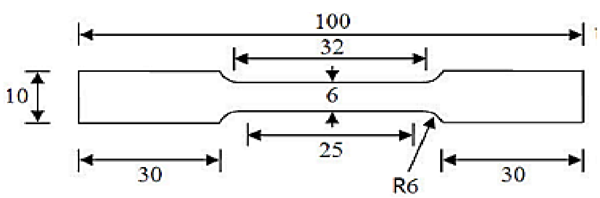

Fig. 1. Tensile specimen for AA 6061 aluminium alloy (all dimensions for specimen in millimeters)

2.3. Friction Stir Welding (FSW) method

It is economical to allow the welding of different materials, and it can be used for heterogeneous joints containing materials with entirely different mechanical, chemical, and thermal properties. One of them may be cheap, and it is ensuring the welding is happened with high quality. The welding cycle is needed to be short time and, thus, high production rates, so productivity is perfect. It has excellent mechanical properties, proven by tensile, fatigue, [27-41], and bend tests compared with other results were calculated by other techniques [42].

There are many rotational and linear feeding speeds used in this type of welding. This research used two plates from 6061 AA with 3 mm thickness, 100 mm width, and 200 mm length. The rotational speed used in friction stir welding was 1400 rpm, and the feeding speed was 40 mm/min. Some parts of the friction stir welding machine are shown in Figure 2.

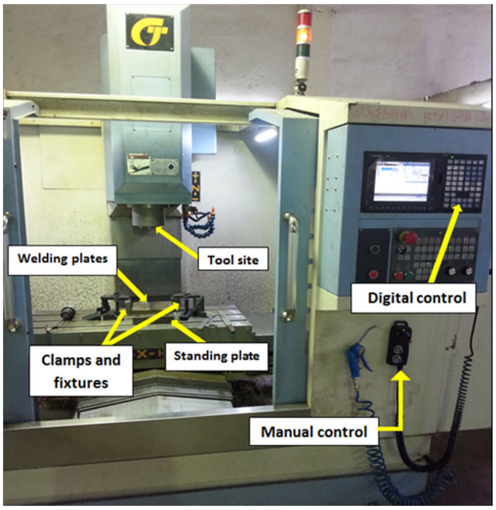

Fig. 2. The processes of aluminium alloy by friction stir welding

3. The new technique for measuring residual tensile stresses

Residual stresses are those stresses that remain in an structure (such as in a component of welded) until in the absence of loading of external or gradients of thermal. In some cases, residual stresses lead to large deformation of the materials, which leads to deformation and warping of the body. In other cases, they affect susceptibility to fatigue and fracure .

Residual stress measurements in aluminum alloy AA 6061 friction stir welds were achieved using the principle of stress concentration factor. There are some consecutive steps to calculate residual stresses, which are as follows,

1. Measuring the ultimate tensile stress of the base metal (AA 6061) without welding.
2. Measuring the friction stir welding specimen's maximum tensile stress and then the fracture zone position is determined.

3. Drilling a hole with 2 mm diameter on the base metal (AA6061) and calculate the ultimate tensile stress.
4. At the same position fracture zone in (2), drilling hole with (2mm) of friction stir welding; the stress concentration factor (Kt) was calculated by

$$K_t = \frac{\text{Ultimate tensile stress for base metal AA6061 without hole}}{\text{Ultimate tensile stress for base metal AA6061 with a hole}} \quad (1)$$

5. Finally, the tensile residual stresses are calculated by:

$$\text{Residual Stress} = \left(\begin{array}{l} K_t \times \text{ultimate tensile stress FSW with hole} - \\ \text{ultimate tensile stress FSW without hole} \end{array}\right) \quad (2)$$

To measure the residual stress using the proposed new method, there must be four groups, as shown in Table 2.

Table 2.
Four groups to determine the residual stress

Sample	Group
Without welding, without hole	A
Without welding, with a hole	B
With welding, without a hole	C
With welding, with a hole	D

4. Results and discussion

The tensile strength of friction stir welded and without weld specimens for AA 6061-T4 aluminum alloy are shown in Table 3 and Figure 3. The welding tool and other factors, such as feed rate and rotational speed, significantly affect the distribution of residual stresses since the tensile residual stress in the HAZ region is caused by heat generated by friction. The decrease in rotational speed means a relatively low heat generated rate, which contributes to the generation of residual compressive stress, which is less dangerous than the tensile residual stress. The fact that cracks and their propagation are caused by tension and that the compressive residual stresses can reduce the speed of crack propagation.

Table 3.
Ultimate tensile stress for all groups

Group	Average of ultimate stress, MPa
Group A, without welding, without a hole	367
Group B, without welding, with a hole	305
Group C, with welding, without a hole	133
Group D, with welding, with a hole	116

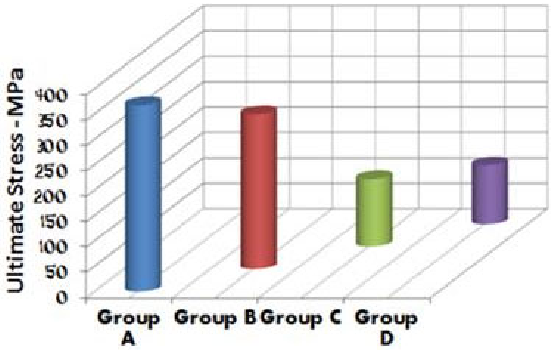

Fig. 3. Ultimate stress for different groups

According to Equation 2, the residual stress was calculated as, $(1.2 * 116 - 133) = +6.2$ MPa (residual stress type tension). The obtained residual stress by the new method is 6.2 MPa (tensile). The maximum residual stress by the X-ray technology is, according to reference [6], as shown in Figure 4 at a distance of about two millimeters from the welding line is 10 MPa.

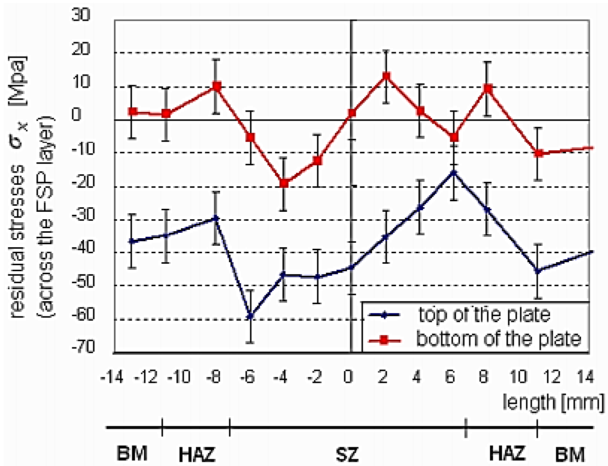

Fig. 4. Profile residual stresses of Friction Stir Welding of AA6061 by X-ray [3]

The stresses of residual of the tensile type has a more dangerous than those of compression type because the cracks are not allowed to propagate in the compression case. The new suggested method in this work approximates the residual roughly proved its effectiveness in identification the tensile residual values. Compared with the study in reference [6] and the residual stress value, the difference with the new method is about 3 MPa.

The friction zones are :

(a) Stir zone, the recrystallised area in thermo-mechanically affected zone (TMAZ) in metal alloys is generally called the stir. In such area, the subgrain boundaries and grain appear to be replaced with fine, recrystallized of grains of equiaxed characterized by a nominal dimension of small dimensionsscale.

(b) Affected of Heat region. In this zone the material is undergone a cycle of thermal which has modified the mechanical properties or the microstructure. add to that, no deformation occurred in this zone.

(c) Thermo-mechanically affected zone (TMAZ). In this zone, the material has been deformation by the pin, and the heat treatment flux has also some influence on the material. In the case of metal alloy , no recrystallization is observed in this area; on the extensive, contrary deformation is present.

(d) Base metal: no material deformation has occurred; such material of remote has not been affected by the heat transfer flux in terms of microstructure or mechanical properties, [7].

5. Conclusions

1. The new method was good in determining the value of tensile residual stresses than the x-ray method.
2. The current method can be used to find the most significant value of the tensile residual stress.
3. The disadvantage of a new method is that it determines the maximum value of residual stresses only.
4. In the current method, the distribution of residual stresses along the weld line can not be determined.

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