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Research paper

A comparative investigation of different cooling media on the FSW joints of AA6061-T651 alloy

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Abstract

The present work aims to compare the effect of different cooling media namely, air, water and oil on the characteristics of the welded part of the AA606-T651 alloy using friction stir welding. The results showed that the welded part quality is much improved using the proposed immersed media (oil). However, the tensile strength and the ductility of the joined parts significantly increase using oil submerged friction stir welding process. Whereas, the impact energy was slightly more than that of the air submerged friction stir welding and slightly less than that of the conventional friction stir welding.

Keywords: *Friction stir welding, Submerged friction stir welding, Tensile strength, Welding efficiency.*

1. Introduction

Welding of aluminum and its alloys still seem to be problematic due to its high thermal conductivity and relatively low melting temperature. So many of welding methods were developed throughout the years for joining aluminum alloys. Friction stir welding (FSW, which was developed firstly by the welding institute of UK [1]), is a new welding method used to join parts through forming bonding between them due to severe plastic deformation of mating surfaces under condition of hydrostatic pressure [2].

FSW is a more suitable alternative method for joining aluminum alloys which are used in different industrial applications due to some of its outstanding qualities such as, better dimensional stability, preservation of base material properties, and resistance to hot cracking etc. Nowadays,there are some ofindustrial applications require the welding to be carried out in submerged state, such as repairing underwater pipelines, marine platforms, ships and other marine engineering projects. Such works may be done using the arc welding techniques, but it is also considered a very difficult and dangerous technique as it requires the welder to work with electric equipment underwater. The most suitable solution for such problematic welding cases can be achieved using the newly developed welding technique called submerged friction stir welding (SFSW) [3]. Nowadays, SFW becomes applicable to join parts under water without need for further processing In SFSW, the welding process is performed under a liquid such as water or others using a permanent metallic tool with a special geometry, consisting of a pin and a shoulder. The pin is plunging into the welded metal, whereas the shoulder touches the workpiece surface of the mating surfaces. The required heat for welding is generated from the rotational speed of the tool due to the friction between the tool shoulder and the work piece. The main Factors governing the welding process are Tool rotational speed, travel speed, and pin geometry effect the quality of the welded parts. These parameters are responsible for generating the frictional heat and creating the stirring mechanism that joins the materials effectively [4, 5].In last years, the particular interest is to improve the joint characteristics by controlling the temperature developing during the welding process and so the whole welded parts are immersed in the liquid which is called submerged friction stir welding (SFSW) [6,7]. Many of researchers investigated the SFSW technique through studying the effect of the submerged conditions on the welded parts characteristics. Fu et al. [8] investigated the influence of submerging conditions on the characteristics of FSW AA7050 alloy using conventional and submerged with cold and hot water conditions. theydemonstrated that hot water was the optimal choice since it improved the ultimate tensile strength and elongation. In similar manner, the tensile strength of the under-water welded AA2219 alloy seems to be higher as compared to that of air FSW [9]. Zhang et al. [10] carried out an experimental study using SFSW of AA2219-T6. Their results showed that the tensile strength was very sensitive to the rotational speed and increasing the rotational speed above 1400 rpm caused void defect to form in the stir zone. Upadhyay and Reynolds [11], investigated the FSWprocess using sheets of 7050-T7 Al alloy. They focused on studying the effect of thermal boundaries on friction and hencethey observed that the surface convection in water SFSW is higher, thus resulting in a decrease in the tool temperature and an increase in the torque required and in consequence the power consumption. The main findings from their study is that the hardness of water SFSW is higher than that of conventional air FSW.

Hofmann and Vecchio [12], used the submerging friction stir processing (SFSP) on AA 6061-T6. They investigated the relation between the SFSW and the grain size of the welded parts. They clarified that that more grain refinement was attained under submerging conditions due to faster cooling rate. The studies have been conducted in the field of SFSW especially, in another cooling media such as oil are scanty, which consider an important gab in this field. Moreover, some of marine application required the welding under similar condition. The current work presents an experimental investigation on SFSW of AA6061-T651 alloy using air, sea water, and for the first time using oil as emerged media. The effect of these different submerging media as well as other process parameters such as rotational speed, pin shape, and translation speed on welded part mechanical properties were conducted.

2. Materials and Experimental Details

Base metal used in this work is AA6061-T6 alloy. The rolled AA6061-T652 was received in the form of a plate of dimensions 100 x 50 x 6 mm. Tools were manufactured from a low alloy steel to perform the welding of the aluminum alloy plates. Tool was consists of two geometries, one of them called the shoulder and the other called the probe or pin. The chemical composition for the base metal plate and the tool were performed, and also the mechanical properties for the base metal was tested as shown in “Table 1”. The tool shoulder dimensions were 18 mm, which is the source of heat input to the welding zone. In this investigation three pin geometries have been used, namely the round pin (R), conical pin (C), and the threaded pin shape (T) as shown in “Fig.1”. FSW experiments were carried out in air and submersed welding conditions. In order to measure the temperature during the welding process, the K Type thermocouple is the most suitable one. The temperature was reading using an industrial data logger, which records the temperature at an interval of one second.

For the convenience of statement, friction stir welding performed in air is defined as conventional FSW, while the one performed under water and oil is defined as submerged FSW (SFSW). The FSW experiments were carried out on CNC milling machine, and for the SFSW processes a special setup was prepared see “Fig. 2”. All the experiments were carried out along the longitudinal direction of the specimens. After cleaned by acetone, the specimens were clamped to the backing plate in a container, and then the water or oil at room temperature was poured into the container to immerse the top surface of the specimens.

In this study, a three experimental factors three levels array was used for investigating the effects of process parameters on welded part properties for each cooling media used. The range of each process parameter levels were selected based on trial welds and process parameters such as travel speed (TS) of (42, 60, and 90 mm/s), pin shape (Ps) of (C, R, and T), and wire feed speed (WFS) with levels for FSW different from SFSW.

Table 1: Chemical composition of the base plate and the tool and mechanical properties of AA6061-T651 alloy

Element	**Si**	**Mg**	**Cu**	**Mn**	**Zn**	**Ni**	**rC**	**C**	**Fe**	**Pb**	**Al**
AA6061 plate wt%	0.361	3.1	2.1	0.002	5.72	0.04	0.372	0.0001	0.001	0.012	Bal.
Tool wt%	0.36	3.1	0.002	1.8	5.72	0.004	0.373	0.68	Bal.	0.02	0.002
Mechanical Properties of AA6061-T651											
Ultimate tensile strength MPa		Yield Strength MPa			Elongation %			Impact Energy J			
325		237			12			46			

For FSW (710, 960, and 1400 rpm) and for SFSW (1080, 1460, 2050 rpm), Transverse tensile tests were carried out on the sub size sheet specimens prepared according to the American Society for Testing of Materials (ASTM E8M-04) standards [13] with a gauge length of 25 mm, and cross-section within the gauge length of 6.25x6 mm^2 See “Fig.3”. Tests were performed using testing machine with displacement rate of 1 $mm.min^{-1}$. Three trial of experiments were performed for assessing the tensile properties of the welded material. Theimpact tests were performed on welded processed specimens using an instrumented pendulum machine (FIT-300N). According to ASTM E23, Sub-size charpy V specimens (10 x 5 x 55) mm, with 2 mm deep V- notch.

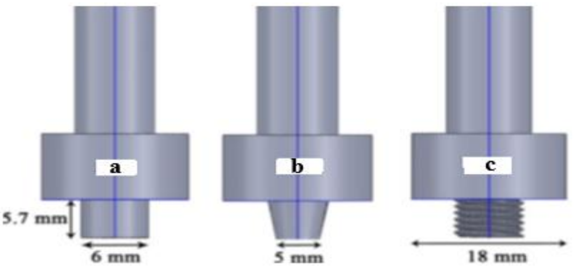

Fig. 1. Tool pin shape (a) round pin (R); (b) conical pin (C); and (c) thread pin (T).

Fig. 2. SFSW set up, (a) the milling machine, and (b) close up shows the submerged FSW.

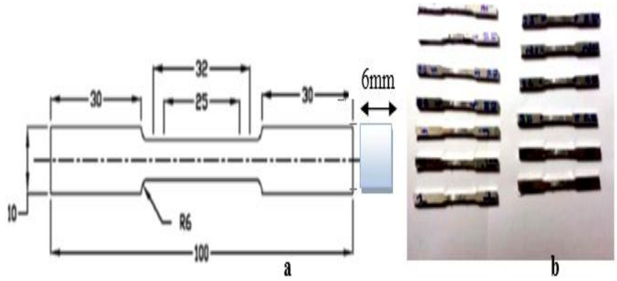

Fig. 3. (a) ASTM Sub-Size specimen for tensile test [13]; and (b) photograph illustrates the prepared tensile specimens.

3. Results and Discussions

The influence of the tool traveling speed (TS) on the tensile behavior for friction stir-welded aluminum alloys specimens was investigated with respect to the ultimate tensile strength (UTS) and tensile elongation (El %) for the three cooling media. “Fig.4” presents the enhancement in the welded part tensile strength with SFSW using sea water. It obvious that the oil media is more effective than sea water in improving the tensile strength. In similar manner the relation between the welding elongation and the interaction effects between the cooling media and both the pin shape and travelling speed as can be seen in “Fig.5”. It is clear that the TS effects on the tensile strength and the ductility but its effects is not significant see “Fig.4”, and “Fig.5b”. In the oil SFSW process, the travel speed of 60 mm/s is the most effective. The overall welding efficiency was measured for the experiments and so found that the high welding efficiency can be achieved using oil SFSW.

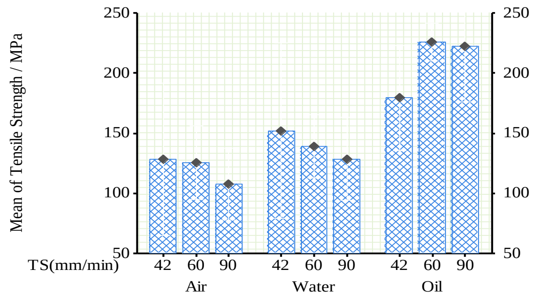

Fig. 4: Plots illustrate the interactions between cooling media and travel speed versus tensile strength.

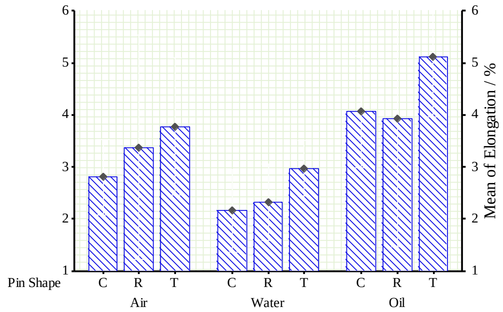

Fig.5a: Plots illustrate the interactions between cooling media and pin shape versus the welding ductility.

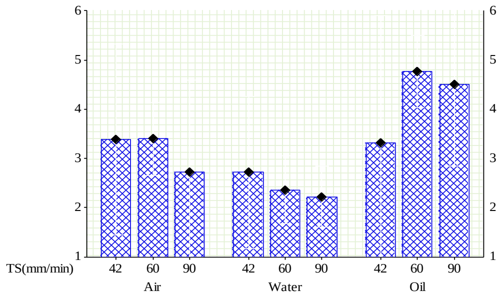

Fig.5b: Plots illustrate the interactions between cooling media and travel speed versus the welding ductility.

It is clear that the pin shapes play a vital role in the welded parts characteristics. “Fig.5a” and figure “Fig.6a” shows the effects of the pin shape on the elongation and the impact energy respectively. The threaded pin has the major effect on the welded parts ductility and also on the notched energy. The Charpy toughness for the oil SFSW process is slightly large than that of sea water SFSW but it is less than that of the conventional FSW see “Fig.6” and“Fig.7”represents the overall amount of the impact energy results for the three processes, it appears that the conventional FSW process behave with high toughness compared to other SFSW processes.

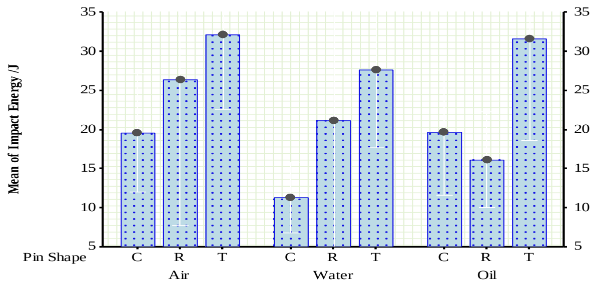

Fig.6a: Plots illustrate the interactions between cooling media and pin shape versus impact energy.

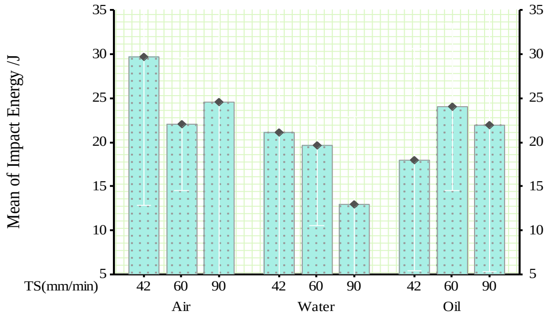

Fig.6b: Plots illustrate the interactions between cooling media and travel speed versus impact energy.

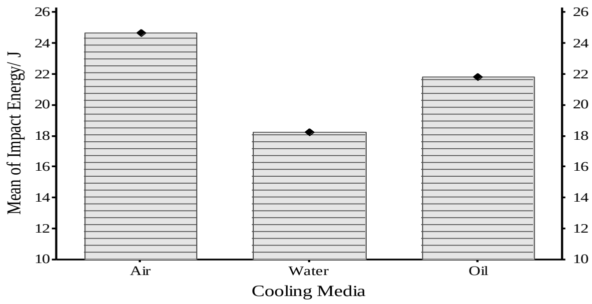

Fig.7. The effect of cooling media on the impact energy.

It is obvious form the figure 4, figure 5b and figure 6b that The highest mechanical properties are associated with travelling speed of (60 mm/s) in case of oil SFSW. Whereas, the low travelling speed (42 mm/s) is more suitable for the FSW and water SFSW processes. This may be attributed to the developed temperature during welding process. Where, the temperatures generated in the oil SFSW process is more than that for both air FSW and see water SFSW processes (see figure 8). This attributes to the thermal conductivity properties for the three cooling media. The oil seems to be less conductivity than the see water and hence acts as thermal surrounding for the work piece, which leads finally to increase the generated temperature.

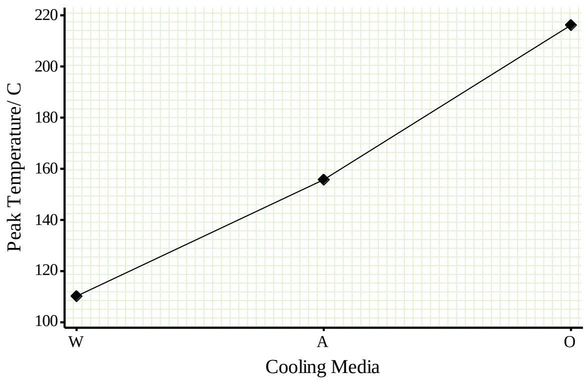

Fig.8. The effect of the cooling media on the peak temperature of the welded parts.

Figure 9 refers to the microstructure of the welded specimens at the nugget zone (NZ). It is obvious that the grains seems to be finer in the see water condition (see Fig. 9b) due to rapid cooling. It is also clear that there are some of welding defect like un-welded zones which may be the main reason to deterioration of mechanical specifications (see Fig. 5 and Fig. 6). The structure of the oil SFSW specimens reveals a uniform grains without flows in the stirred zone (see Fig. 9c).

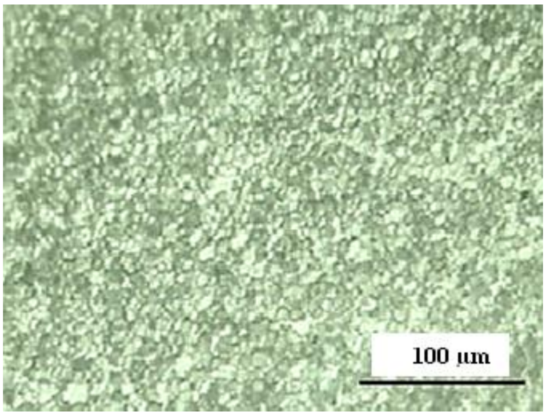

Fig. 9a: Microphotograph illustrates the microstructure of NZ for CFSW (1460 rpm, and 60 m/min)

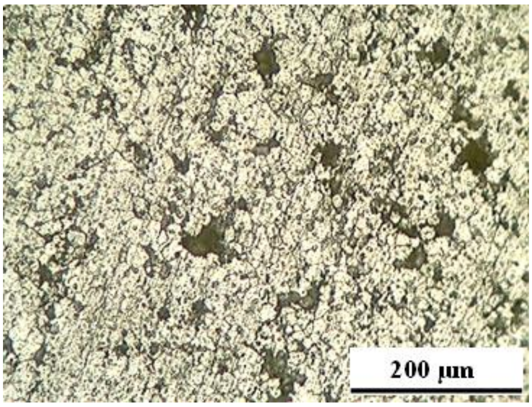

Fig. 9b: Microphotograph illustrates the microstructure of NZ for see water SFSW (1460 rpm, and 60 m/min)

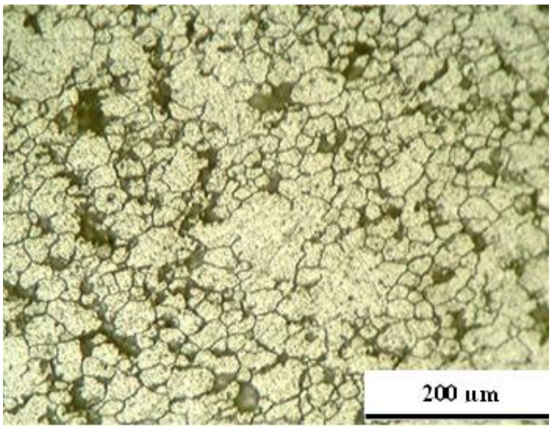

Fig. 9c: Microphotograph illustrates the microstructure of NZ for oil SFSW (1460 rpm, and 60 m/min)

4. Conclusions

In the presentstudy, AA6061-T651 alloy was successfully welded under SFSW conditions and compare the results with conventional FSW process. The main findings can be summarized as following:

- The results indicate that the best welding quality can be obtained using oil SFSW process and so this welding process can be used in join or repair ship parts and any submerged component made of the aluminum 6061 alloy without any risk.
- High welding efficiency achieved using SFSW process (about 61.34 %) compared to the conventional FSW (about 37.38).
- Oil SFSW process produce aluminum components with average tensile strength (about 198.95 MPa) higher than that gained using conventional FSW (about 121.5 MPa).

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