Effects of Friction stir Welding Parameters on Microstructure and Mechanical Behavior of Dissimilar Joint of 7075-T6 Aluminum and Alpha Brass

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Abstract— This study examines the microstructure and mechanical properties of dissimilar joints of 7075-T6 aluminum and brass alloy fabricated by friction stir welding. Effects of travel speed and pin offset on microstructure, microhardness, and tensile strength of the welded joints were investigated. Results of different tests indicate that there was a longitudinal crack in samples welded at the low tool offset, on the other hand in the offsets higher than 0.8, the welding quality decreases due to the mechanical forge reduction. The maximum tensile strength obtained for the joint was equal to %72 of the tensile strength of the brass base alloy which was fabricated at travel speed and offset of 12.5 mm.min-1 and 0.8 mm respectively. Microstructure of the samples was observed by the optical microscopy. Thickness and chemical composition of the intermediate layer was examined by scanning electron microscopy (SEM) equipped with an EDS unit. Specimens were then characterized by X-ray diffraction (XRD) to investigate the phase constituent of the intermediate layer. It was found that an increase in the thickness of the intermediate layer could decrease the tensile strength of the joint.

Keywords- *friction stir welding; dissimilar joint; 7075-T6 Aluminum; alpha brass*

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I. INTRODUCTION

Friction stir welding (FSW) is a relatively new technique developed by The Welding Institute (TWI), UK in 1991 [1-4]. FSW is a solid state welding technique for joining the similar and dissimilar casted and wrought aluminum, steels, titanium, copper and magnesium alloys, as well as dissimilar metallic alloys and metallic matrix composites. The technique can be used to produce butt, corner, lap, T, spot and fillet joints as well as to weld hollow objects, such as tanks and tube/pipe, and parts with three-dimensional contours [5]. Application of FSW has attracted much interest as capable method especially for joining of dissimilar alloys due to the combination of unique properties such as high strength, high process speed, non-consumable welding tool, low energy consumption and no need for shielding gas. Welding of dissimilar materials by using FSW resulted in its widespread use in the nuclear industry, aerospace and shipbuilding [6]. Moreover, in this welding method, the material experiences a plastic deformation but doesn't reach the melting point and oxidation and hot fracture hence, don't occur in the welding zone [7].

Friction stir welding is a solid state welding process whereby non-consumable rotating welding tool, with shoulder and probe (pin), is plunged into adjoining parent materials. Frictional heat generated by the rotation of the tool during this process causes the materials to transform into plastic state. The softened material is stirred together by the rotating tool pin and yields solid state bond. Welding speed, rotation speed and location of the tool are the most important parameters in joining through friction stir welding [1, 8].

Due to the low temperature in FSW, the amount of distortion produced by shrinkage is very slight. Severe plastic deformation and heat evolution resulted from tool movement on working surface, form new equiaxed grains via recrystallization process [1,9]. In the recent years, several researches have been done to join some dissimilar alloys such as aluminum to magnesium, aluminum to titanium and aluminum to copper through FSW [10, 11]. Friction stir welding of brass to aluminum however, is less reported in the literature. Both of the brass and 7075-T6 aluminum alloy show high thermal and electrical conductivity and good corrosion resistance which make them desired materials in many engineering applications like aerospace. In addition, the brass/aluminum joints are being used in heat transfer systems and electrical applications. In the present study, 7075-T6 aluminum and alpha brass alloy are successfully welded via FSW and the effect of fixed location of base metals (pin offset) and tool travel speed on microstructure, tensile strength and welding hardness have been studied.

EXPERIMENTAL PROCEDURE

The materials used in this study were plates of alpha brass and 7075-T6 aluminum, both 4 mm in thickness. Chemical composition and mechanical- thermal properties of these alloys are presented in table 1, 2 and 3 respectively. The plates have been cut into the required size (140mm×80mm). The edges of the plates were prepared by machining. The plates were fixed in butt joint configuration to fabricate FSW joints. To perform the welding process a Universal milling machine was used. The fixture set up was made from CK45 steel. Fig. 1 shows the welding machine and fixture set up. For making the butt weld in 7075-T6 aluminum and brass joining, the alpha brass was laid as advancing side and Aluminum as retreating side. One of the most important factors to get a sound joint is known as "offset" that shows the position of pin center. In other words, a significant part of the tool should move towards brass side. A scrobiculated conical welding tool was made of high speed steel (HSS) with a shoulder of 18 mm in diameter was used in this study. Welding process has carried out at the speeds of 8, 10, 12.5 and 22 mm.min^{-1}, and the offsets of 0, 0.5, 0.8 and 1 mm towards brass, were applied. To achieve the best mechanical properties and quality of joint, the tool should be moved towards softer material. Fig. 2 (a) indicates the schematic view of offset parameter.

Welding tilt angle, depth of sinking pin and rotating speed of tool were selected as 2°, 0.2 mm and 900 rpm respectively. The tensile specimens were prepared by wirecut according to the ASTM E8M standard (fig. 2 (b)). Also, the Vickers microhardness tests was performed, by the load of 100 g and dwell time of 10 seconds on the cross section of joints and perpendicular to the welding direction.

To make better estimation of the compositional region of the joint, microhardness test was taken from multiple points. Specimens were prepared by ASTM E3-01 for microstructural investigation. Prepared samples were etched according to ASTM E883-02. The applied etchants for the aluminum side and brass side were HCl+HNO3+HF and FeCl2+HCl+H2O respectively. Microstructure of the specimens was examined by optical microscopy. Also, scanning electron microscopy, energy dispersive spectroscopy (EDS) and X-ray diffraction analysis were used to determine the thickness and chemical composition of phase constituent in the intermediate layer.

TABLE 1- CHEMICAL COMPOSITION OF BRASS

Material	Cu	Zn	Ni	Si	Sn	Mg	Fe	Al
CuZn30	69	30.23	0.3	0.25	0.1	0.05	0.05	0.02

TABLE 2- CHEMICAL COMPOSITION OF 7075 ALUMINUM

Material	Al	Zn	Mg	Mn	Cu	Si	Ti
Al 7075 – T6	Balance	5.1	2.1	2.02	1.21	0.4	0.02

TABLE 3- MECHANICAL AND THERMAL PROPERTIES OF MATERIALS

Material (HV)	Tensile Strength (Mpa)	Yield Strength (Mpa)	Elongation (%)	Melting point(Co)	Hardness
Al 7075 – T6	553	482	12	640	170
CuZn30	381	220	65	930	92

Fig.1. A view of applied welding machine and fixture

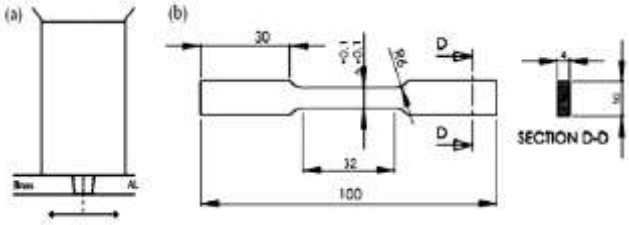

Fig.2. Schematic illustration of (a) offset parameter (b) tensile test sample

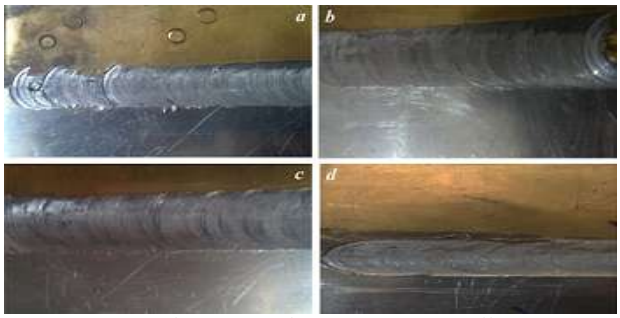

Fig.3. Surface quality of welded samples in different

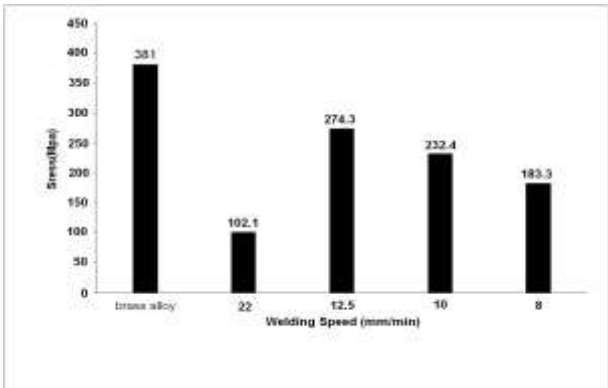

Fig.4. Tensile strength of joint at different welding speeds

RESULTS AND DISCUSSION

Fig.3 shows the surface quality of welded samples in different welding speeds. In high welding speeds, the amount of heat generated by the friction and plastic deformation decreased due to faster movement of the tool. Holes formed due to the insufficient heat are distinguishable in fig. 3 (a). As illustrated in fig.4, these holes have reduced the tensile strength of joint. At the welding
speed of 12.5 mm.min-1, the best surface quality with the maximum tensile strength (equal with 72% of the tensile strength of the brass base alloy) was obtained due to sufficient heat and suitable material flow (fig. 3(b)). Also fig. 3 (c) and (d) show that the surface quality of the joint has decreased as a result of more heat generation in the travel speed of lower than 12.5 mm.min^{-1}. This probably is because of the grain growth and formation of big flashes at the weld surface which finally results in a decline in tensile strength of the joint.
As shown in fig. 5 in all of the welded samples an intermediate layer has formed and it is easy to detect that raising the temperature (reduction of welding speed) increases the thickness of the brittle intermediate layer which provides the brittleness of the joint and consequently diminishes the tensile strength.

In fact at very high welding speeds the joint doesn't have desirable mechanical properties due to insufficient heat and a decrease in the travel speed increases the tensile strength.
In order to identify the produced compounds in the interfacial, the joint fabricated at the travel speed of 12.5 mm. min-1 was studied using XRD analysis. Fig. 6 shows the XRD patterns for cross-section examination of the aluminum side and brass side of the joint. As can be seen detected compounds at the welding line includes Al2Cu, Al4Cu9, Al and brass (fig. 6 (a)). CuZn, Al2Cu, Al4Cu9 and brass are detectable formed at the aluminum side (fig. 6 (b) and (c)). In fact, due to shorter diffusion distances, finer brass particles faster and more

welding speeds a) 22 b) 12.5, c) 10, d) 8 mm/min

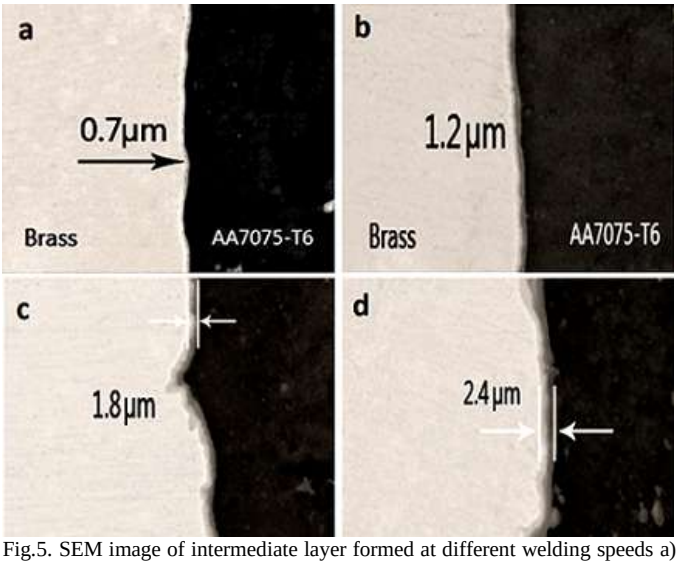

Fig.5. SEM image of intermediate layer formed at different welding speeds a) 22 b) 12.5, c) 10, d) 8 mm/min

compounds at the brass side and Al2Cu, Al4Cu9, and Al are easily transformed into the intermetallic compounds. Also, lower welding speeds could accelerate formation of intermetallic compounds on the surface of brass particles in the stirred zone by means of providing higher temperatures.
Weight ratio curves of different elements obtained by EDS analyses are shown in Fig. 6 (d). The first point belongs to aluminum side of the weld and the second one is for brass side. From this curve, Cu/Al weight percent ratio is 1.29 next to the aluminum side which corresponds to Cu/Al weight percent ratio in Al2Cu compound. On the other hand weight percent ratio for Cu/Zn near the brass is 1.14 that is in accordance with Cu/Zn weight percent ratio in compound CuZn. Therefore it can be concluded that

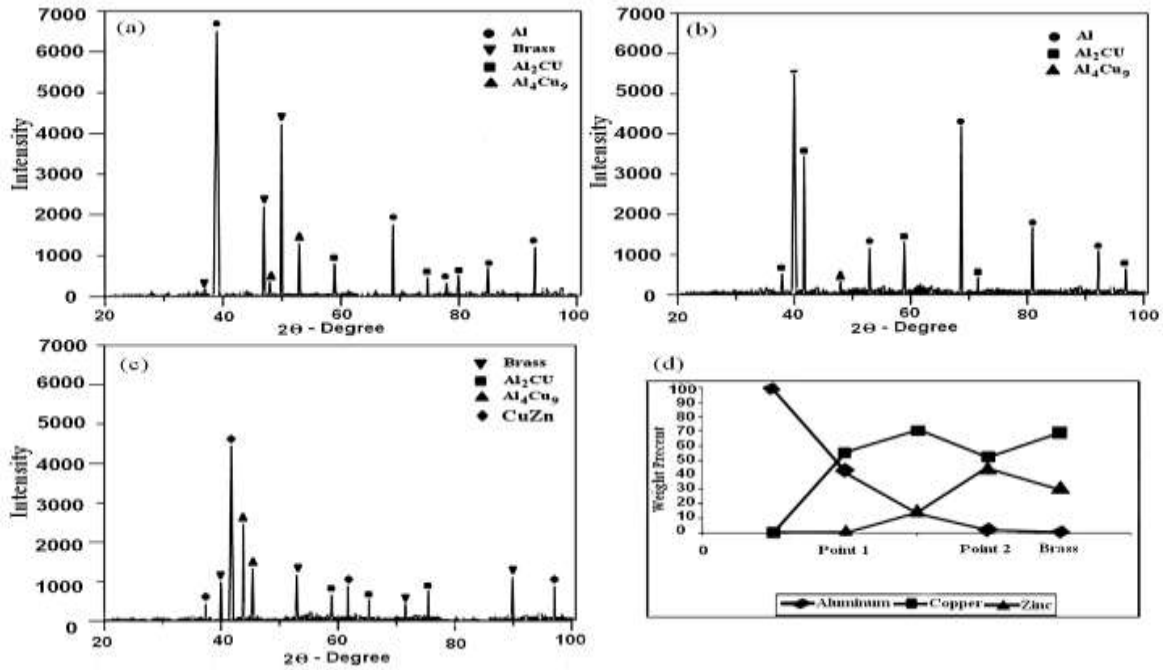

Fig.6. XRD patterns of a) cross-section of weld, b) aluminum side and c) brass side of the joint d) Weight ratio curves of elements at different points of joint

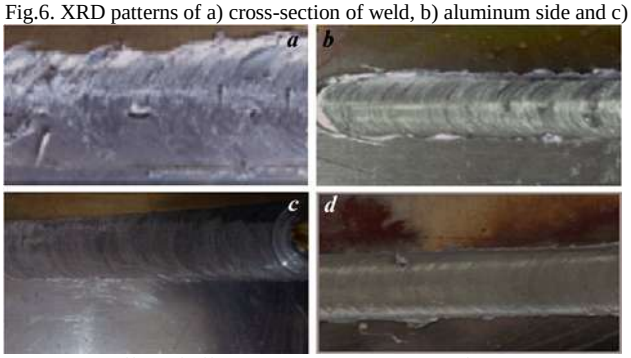

Fig.7.effect of offset parameter on the joint surface quality

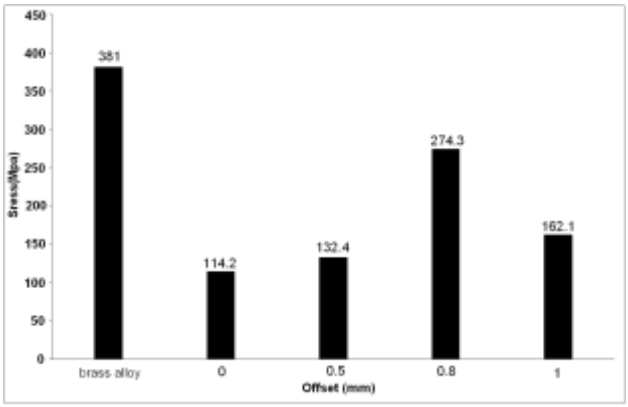

Fig.8. Tensile strength of joint at different offsets

insufficient heat for joining in the high welding speed, and formation of intermetallics and thickening of intermediate layer in low welding speeds are responsible for reduction of the tensile strength. So there is an optimum value for the travel speed which produces maximum tensile strength for the joint that is equal with 12.5 mm. min-1 in our experiment. Effect of the offset parameter on the joint surface quality is shown in Fig. 7. As illustrated, without any Offset, surface quality of the produced weld is too low and the weld metal has numerous cracks and holes (fig. 7 (a)). Applying the offset of 0.5 mm (moving of the tool towards brass) improves the surface quality of the weld; however the surface still contains cracks and flashes (fig. 7 (b)). As shown in fig. 7 (c) the best quality of the weld is achieved when the offset 0.8 is applied. Increasing the offset parameter to 1 mm reduces the weld quality and tensile strength. This is due to the reduced contact surface area between the pin and aluminum (fig. 7 (d)). Results of the tensile test for joints produced at different offsets are illustrated in Fig. 8. Significant effect of the offset parameter on tensile strength of the joints is easy to detect from this chart.

These results are in good agreement with the surface quality of joints so that maximum tensile strength is obtained when the offset of 0.8 mm is applied. As it can be found, the best joint with maximum tensile strength was obtained at rotation speed of 900 rpm, travel speed of 12.5 mm.min-1 and the offset of 0.8 mm (optimum condition). Results of the tensile test revealed that fraction occurs in the interface of the aluminum and brass joint in all of the welded samples, which show the brittleness of the joint in the interface. Fig. 9 indicates the fracture location on the welded sample in optimum condition. Microstructure of different parts of the

Fig.9. Fracture location in the welded sample

Fig.10. (a) Microstructure of sound weld fabricated at optimum condition. Microstructures of (b) aluminum base metal, (c) brass base metal, (d) the stir zone (SZ) , (e) onion rings in the stir zone (SZ), (f) TMAZ of brass, (g) TMAZ of aluminum, (h) HAZ of brass side

aluminum and brass joint welded in optimum condition are illustrated in Fig. 10 (a). Five distinct zones including stir zone (SZ), thermomechanically affected zone (TMAZ), heat affected zone (HAZ), base metal of brass alloy and base metal of aluminum alloy can be observed in this figure. By comparing fig. 10 (b) and fig. 10 (g), it can be found that the grains of aluminum alloy at the thermomechanically affected zone elongated upward due to the plastic deformation and heat evolution. The effect of plastic deformation and heat evolution in thermomechanically affected zone of the brass appeared as mechanical grain refinement at this zone (Fig. 10 (f)). Also regarding the Fig. 10 (h) it can be recognized that the HAZ zone of the brass has the coarser grain than the TMAZ one which can be attributed to the more heat generated in HAZ zone and subsequent recrystallization of the structure. Onion rings which are produced by an appropriate material flow during rotation of the tool in stir zone as well as the composite structure with fine grains both produced at the optimum condition can be observed in fig. 10 (d) and (e) respectively.

The cross sectional microhardness profile obtained from top and bottom regions of the weld fabricated at optimum condition is illustrated in fig. 11. Due to more heat generation and consequently better material flow under the tool shoulder, the hardness of top region is higher than bottom. Microhardness profile is plotted from brass side. By moving away from brass area and getting close to stirred zone, the microhardness decreases, this is because the HAZ zone affected by heat of process and grain size therefore becomes larger, leading to a decline in hardness. Approaching the weld line, the hardness increases. The increase in brass side is due to reaching TMAZ zone which experienced a severe plastic deformation. Further increase of the hardness can be detected in the center of the weld where is the stirring zone of aluminum and brass. The increase of hardness in stirred zone is thanks to the recrystallization process, refining of grain size, transferring of brass particles into aluminum matrix and also formation of reinforced composite structure. Maximum hardness obtained in this region is 157 HV. Also it should be mentioned that the composite structure generated at stirred zone leads to penetration of microhardness indenter into the aluminum matrix in addition to combination of fine intermetallic particles and brass fragments. Precise hardness of intermetallic particles therefore, cannot be measured. As a result, the observed hardness peaks in the stir zone associated with fine intermetallic particles/brass fragments combination will not reach the real hardness of intermetallic.

Moreover, microhardness results of the bottom region do not show this hardness variation which comes from lack of distributed particles within the lower regions of the stir zone. The microhardness decreases by moving from stirred zone towards aluminum. This decrease in hardness is probably due to dissolving of hard precipitates which exists in 7075 T6 aluminum alloy matrix. In the HAZ zone minimum hardness can be observed at the aluminum side, because there is no deformation in this area and only coarsening of the grains occurs due to the heat of process. The hardness increases by passing the HAZ zone and finally it reaches the hardness of base aluminum alloy.

CONCLUSIONS

Dissimilar friction stir welding of 7075-T6 aluminum and alpha brass was successfully performed and the following important conclusions were driven:

1. The best surface quality and maximum tensile strength were obtained at welding tilt angle of 2°, tool rotating speed of 900 rpm, travel speed of 12.5 mm.min-1 and the offset of 0.8 mm.
2. Insufficient heat for joining in the high welding speed, and formation of intermetallics and thickening of intermediate layer in low welding speeds are responsible for reduction of the tensile strength. The optimum travel speed value which

produced maximum tensile strength is equal with 12.5 mm. min-1.

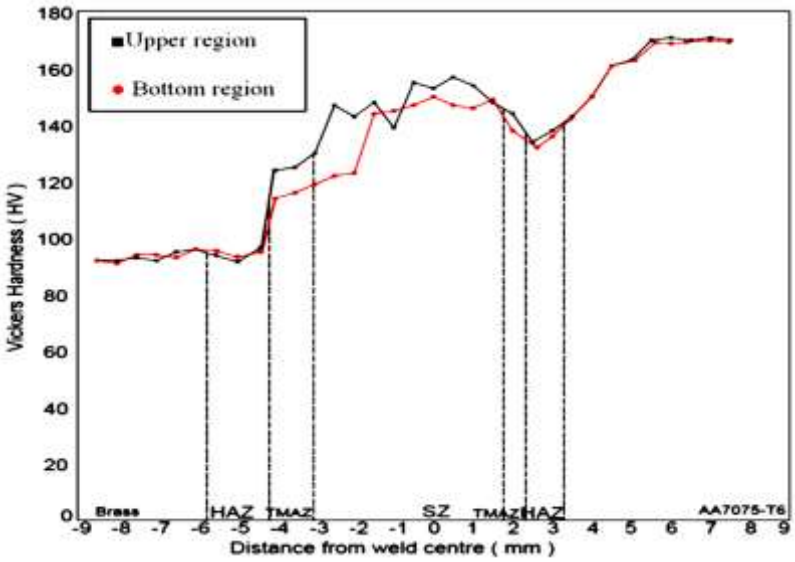

Fig.11. Cross sectional microhardness profile of the weld fabricated at optimum condition

3. Formation of composite structure results in different hardness values in the stir zone. Also hardness of the upper side of the weld was higher than the lower side that is due to the more heat generation and consequently better flow of the material in this region.
4. Maximum hardness was 157 HV that is obtained in the stir zone next to the base aluminum alloy.
5. Formation of cracks in the weld metal for the offsets lower than 0.8, and reduced contact surface between pin and aluminum for the offsets upper than 0.8, are reasons for the lower surface quality and tensile strength and consequently weaker joints.

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