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An Assessment of Microstructural and Mechanical Characterizations of 5083 Aluminum Alloy Welds Made By the Friction Stir Welding

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Abstract:- Friction stir welding (FSW) is a solid state technique to join metals. FSW has become the main technique in many sectors of industry especially in Marine Industry. As on date, this welding technique is the most popular method for a series of aluminum alloys which are difficult to weld by conventional welding methods. Aluminum is a strong and light weight material which has been used in ships. This paper presents a review of friction stir welding of 5083 aluminum alloy which involve the microstructural and mechanical characterizations of this alloy's welds. The main aim of this paper is to present the gaps identified from the published literature of FSW of 5083 aluminum alloy by focusing on microstructural and mechanical properties and also discussed the effect of welding parameters as welding speed and rotational speed on the mechanical properties and microstructure of the 5083 friction stir welds.

Keywords:- friction stir welding, 5083 aluminum alloy, microstructure, mechanical properties, dissimilar, similar.

I. INTRODUCTION

The difficulty of welding aluminum alloys by conventional welding methods which involve melting the joint lines encouraging the researchers to do more research and development work in this area. Some time back in 1991 Wayne Thomas and his colleagues in The Welding Institute (TWI) in UK invented the friction stir welding (FSW) method. Friction stir welding is a solid state technique to join metals with a simple process with good properties. Initially, the FSW method is regarded as a laboratory technique then found its way into industry. FSW is applied in many industry sectors such as automotive, aerospace and shipbuilding applications. FSW method gives a number of advantages when compared to other conventional welding processes. FSW process takes place at temperatures below the melting temperature and as a good result eliminate many defects which occur in fusion welding methods. Reducing the welding temperature in FSW leads automatically to lower distortion and residual stress and makes possible to weld both a thin and thick materials. There is no filler metal and this leads to absence of unwanted phases in the weld microstructure. In friction stir welding there is no gross melting so no cracks or porosity in the welds.The minimum surface cleaning, low noise and no fumes during the process make the FSW a green technology and environmental friendly method. Figure (1) shows a schematic of the friction stir welding process. In general, FSW run can be divided in three sub-procedures. They are (a) plung and dwell, (b) traverse and (c) retract [1]. In this method, a non-consumable rotating tool runs over the substrates which results into the generation of heat due to friction. This leads to plastic deformation and softening of substrates near the tool area [2].

There are four distinct regions in FSW joints explained by P. L. Threadgill [3] in figure (2) which include (a) base metal (BM), (b) heat affected zone (HAZ), (c) thermo-mechanically affected zone (TMAZ) and (d) weld nugget. FSW can be applied on all ferrous materials from theoretical view. To date FSW is considered the most effective welding method for aluminum alloys. Aluminum is difficult to weld by fusion welding method due to its high thermal conductivity and reflectivity [4]. 5083 aluminum alloy is a solid-solution strengthened and strain hardened/stabilized AL-Mg wrought alloy [5].

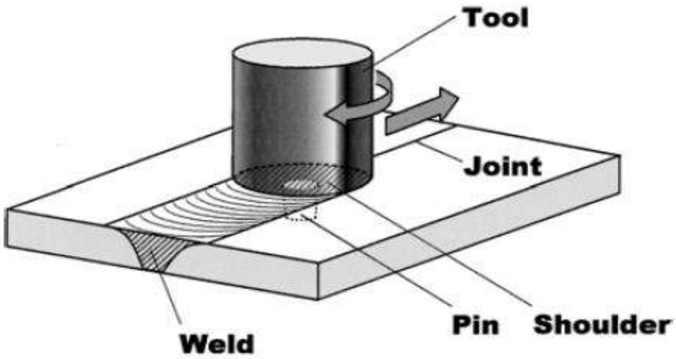

Fig.1: Schematic of the friction stir welding process [20].

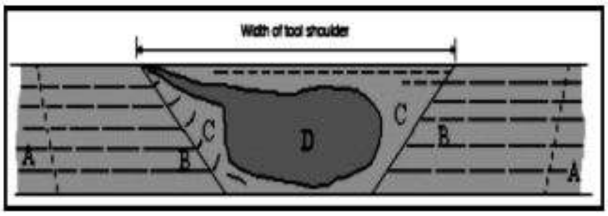

Fig. 2: Illustration of different microstructural regions in the transverse cross section of a friction stir welded material [3].

Good corrosion resistance, light weight and good mechanical properties make 5083 aluminum alloys widely used in transportation applications [18]. 5083 aluminum alloys are used for flat deck applications in ships [1].

Recently, many researches have been done to study and analyze the welding of 5083 aluminum alloy by FSW. There are many published review papers on FSW focused on FSW process and its variables [6], FSW of steels [7-8], FSW tools[9], flow mechanism and heat generation during FSW process[10], FSW of dissimilar material between aluminum alloys and copper[4] and dissimilar alloys [11]. There is no review paper focused on the FSW of 5083 aluminum alloy. So in this paper, a review of microstructural and mechanical properties of 5083 friction stir welds is presented.

II. FRICTION STIR WELDING OF SIMILAR 5083 ALUMINUM ALLOYS.

The experimental studies on the friction stir welding of aluminum alloys will provide an optimum parameters needed to produce a good joints which improve and develop the industry. T. Hirata el al [12] observed while welding rolled sheets of 5083-O aluminum alloy under all FSW conditions that the grain size in stir zone (SZ) was fine equiaxed and the grain size decreased with the decrease of rotational speed and increase of welding speed. They indicated in this study that the microstructure in stir zone is influenced by friction heat flow from the pin and shoulder. They summarized the relationship between the Rt/v (rotational speed / welding speed) and some mechanical properties as represented in figure (3). They observed that the decreasing of (rotational speed / welding speed) will lead to increase in the yield strength. They also have observed similar result for the elongation and dome height while the tensile strength was not changed with the change in Rt/V. Furthermore, the maximum hardness value was in stir zone. That is due to its fine grain size. The influence of force is not considered in their study. A. R. Yazidpour el al [13] successfully welded similar 5083-H321 aluminum alloys using FSW method. As the major observation in their study they concluded that the stir zone (SZ) in friction stir welds was fine equiaxed and the onion rings structure was observed in stir zone. They also have noticed that the down side of stir zone had finer grain structure rather than upper side. Furthermore, they examined the same material by using metal inert gas welding method for comparison purpose and found that the weld metal is composed of dendrites formed during solidification. They observed that there is an improvement in mechanical properties when using FSW welding method compared to MIG welding method under different welding conditions and that because the FSW process softens the material and makes the microstructure finer. Similar 5083 aluminum alloys were welded using FSW method by C. Zhou et al [14]. Neither porosity nor cracks was observed. As in [12] and [13] the stir zone in friction stir welds was fine equiaxed. They reported that the size of grains diminish gradually towards the weld center.

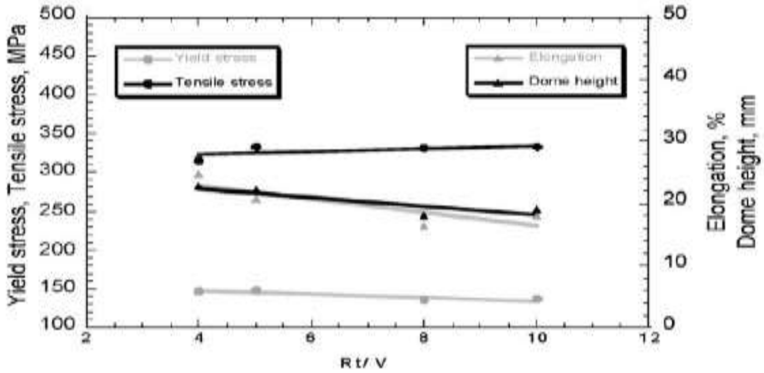

Fig. 3: Relationship between the (rotational speed / welding speed) and some mechanical properties [12].

S. Hong et al [15] studied the fatigue crack propagation (FCP) behavior of friction stir welding of similar 5083-H32 aluminum alloys at a tool rotating speed of 1600 rpm and welding speed of 0.25 m/min. They examined the microstructure of three zones. Dynamically recrystallized zone (DXZ), thermo-mechanically affected zone (TMAZ) and base metal (BM). Number of measurements of grain size in these zones showed that the DXZ has much finer grain structure compared to BM because of dynamic recrystallization during FSW process. They found that the (FCP) strongly influenced by grain refinement in the dynamically recrystallized zone (DXZ). They observed that the FCP rates in the DXZ tended to be lower than those in base metal. The presence of friction stir zone delay the FCP. S. Kasmanand and F. Kahraman,[16] have noticed that while using triangular pin in friction stir welding method of similar 5083-H111 aluminum alloys, by visual inspection that the nugget zone is formed in to circular or elliptical shape consisting of onion rings. They stated that the thermo-mechanically affected zone (TMAZ) consists of plastically deformed and elongated grains. They found that the maximum hardness values were measured in nugget zone and the hardness values of nugget zone and thermo-mechanically affected zone (TMAZ) are similar due to temperature reduction gradient from nugget zone to TMAZ while the hardness values of base metal and heat affected zone are almost similar. M.S. Han et al [17] studied the optimum friction stir welding conditions of similar 5083-O aluminum alloys by evaluating the mechanical characteristic. They found that the optimum FSW conditions are 124 mm/min as a welding speed with 800 r/min as a rotational speed. With these conditions the button shape at the end point was good and the stir zone had a soft appearance. D. Rao et al [18] in their study have found that during the welding of similar 5083 aluminum alloys that the microstructure variation from the stir zone (SZ) to the thermo-mechanically affected zone (TMAZ) was more drastic at the advancing side (AS) than the retreating side (RS). They noted that the onion ring structure was clear in SZ close to AS more than in the SZ which is close to RS. Additionally, the equiaxed grains was clear in SZ. The minimum hardness region was located near the heat affected zone (HAZ). The yield strength gradient in the HAZ at the AS was more than twice as that of at RS. Furthermore, they found that the 5083 AL alloy FSW joint fractured at the RS of the HAZ. B. Gungor et al [19] found during welding similar 5083-H111 aluminum alloys by FSW method that the nugget zone was free of onion rings and the thermo-mechanically affected zone (TMAZ) was completely recrystallized near the nugget zone. Moreover, the fracture surface appeared populated with very fine dimples. They observed that the weld performance of welded joints were 86% for 5083-H111 aluminum alloy. The micro-hardness of 5083-H111 weld joint was 84 $HV_{0.2}$ for nugget zone and 81 $HV_{0.2}$ for (TMAZ). I. Shigematsu et al [20] welded similar 5083 aluminum alloys by FSW method. They found that the microstructure of the joining zone is grain refinement. The strength of the joint was 97% of that of the original material. The hardness values were slightly higher than the values of original material. R. Miller [21] joined similar 5083 aluminum alloys. He observed that the boundary between the stir zone and TMAZ was clear while in the advancing side there are no macroscopic differences and TMAZ to HAZ cannot be defined. He found that there is no relation between the microscopic zones and micro-hardness profile. Based on tensile test results, he stated that the stir zone and HAZ material were weaker (40-60) % than the parent material.

III. Friction Stir Welding Between 5083 Aluminum Alloy and Other Metals.

Use of friction stir welding to join the dissimilar materials improve the mechanical properties and microstructure of the joints compared with other welding methods. H. Bisadi et al [22] successfully welded 5083 aluminum alloy and commercially pure copper using FSW method. They studied the effect of welding parameters including rotational and welding speeds on the microstructure and mechanical properties. They observed that a high welding temperature leads to higher aluminum particles diffusion to the copper sheet and as a result some cavities appear in the interface of these particles and copper material. Additionally, at low temperature of the welding process defects show up at a region near the sheets interface in the copper sheet.

Heat affected zone had the largest grain size. Moreover, the thermo-mechanically affected zone (TMAZ) at the aluminum side is larger than the one that of at the copper side. The hardness values of aluminum side weld areas are lower than parent material of aluminum. Heat affected zone had the minimum hardness among the other regions. The highest value of hardness was recorded near the stir zone of the copper side. They observed that increasing the rotational speed and decreasing the welding speed leads to decrease in hardness values of different areas of aluminum and copper joint. B. Gungor et al [19] joined 5083-H111 and 6082- T651 aluminum alloys by FSW method with 1250 rpm as rotational speed and 64 mm/min as welding speed. They noticed that the onion ring formed in the nugget zone. Heterogeneous mixing of pancake grains of 6082 and recrystallized fine grains of 5083 in nugget zone were clear. The micro-hardness of dissimilar weld joint was between 62.6-84 $HV_{0.2}$. Additionally, the joint efficiency was 65%. M. Movahedi et al [23] produced lap joints between 5083 aluminum alloy and St-12 using FSW method and they observed that at a constant rotational speed the weld zone defects such cavities decreased with reducing the travel speed and at travel speed of 7 cm/min there no defects are noticed. They found that the changing of rotational speed at constant travel speed does not have any effect on weld defects. They noted the formation of the ultra-fine grains in the ST-12 sheet near the interface. The maximum hardness values were in the layered structure than in ultra-fine grains region while the lowest values were noticed in 5083aluminum base metal. Reducing the travel speed and increasing the rotational speed leads to strengthening the joint. Additionally they stated that the effect of rotational speed on the joint strength is lower than that of the effect of travel speed. C. Shen et al [24] used 5083 and 6082 aluminum alloys and successfully joined them by FSW method. They stated that the microstructure of the welds consisted of finer grains in comparison with that of parent material. The average corrosion rate and corrosion current density of the welds were less than that of 5083 and 6082 parent metals while the polarization resistance was larger in values. I. Shigematsu et al [20] joined successfully 5083 and 6061 aluminum alloys. A complicated layer structure was observed in lower side while on the upper side the two aluminum alloys were clearly separated. They found that the hardness at interface of joints increased as the aging time increased. The strength of the joints was about 202 MPa. R. Palanivel et al [25] investigated the effect of welding speed on the microstructure and mechanical properties of weld joint between 5083-H111 and 6351-T6 aluminum alloys using FSW method. Three kinds of microstructure were found in weld zone. They are unmixed region, mechanically mixed region and mixed flow region. The top appearance was smooth without any voids or cracks. The minimum tensile strength was observed at the lowest (36 mm/min) and the highest (90 mm/min) welding speeds. The best tensile strength was at 63 mm/min welding speed. Based on the tensile test, at welding speed of 36 mm/min the failure was in the TMAZ side of 5083-H111 aluminum alloy and at 90mm/min the failure was in the TMAZ side of 6351-T6 aluminum alloy. Moreover, they noticed that the fracture surface was covered with a large population of microscopic voids which give the reason of the failure of the dissimilar joint. S. Jannet et al [26] compared the welding of 6061-T6 and 5083-O aluminum alloys using two welding methods, FSW and fusion welding. They observed that the FSW joints exhibited superior tensile properties performance compared to fusion weld joints. They found that the minimum hardness values were located at 8 mm from the weld center towards 5083-O side. The hardness values was high in weld regions compared to heat affected zone and base metal. The FSW joints showed excellent mechanical properties compared to fusion welding. The best strength and ductility were found in FSW joints due to grain refinement with a fine distribution of precipitates. Y. Fatoohi et al [27] connected dissimilar plates of 5083 aluminum alloy and copper by using FSW method. The microstructure examination showed some defects in samples without offset tool and reducing the defects in samples with offset tool. They observed that the compounds (AL_4CU_9 and AL_2CU) was found in the stir zone. They found that at high rotational speeds the use of offset tool decrease the strength and the use of offset tool in low rotational speed increase the strength. The greatest strength was found with rotational speed of 600 rpm, welding speed of 40 mm/min and 1 mm offset into the copper side. M. Ghaffarpour et al [28] evaluated the dissimilar joints properties of 5083-H12 and 6061-T6 aluminum alloys produced by FSW and tungsten inert gas welding method. They found that the joint obtained by FSW method had much quality than those obtained by tungsten inert gas welding method. They noted that the concavity took place on the weld surface and decreased the strength of the weld. They observed that the lowest amount of hardness was in the heat affected zone of the 6061 sheet. Additionally, the hardness values in stir zone of friction stir joint was higher than those in tungsten inert gas joint.

IV. CONCLUSIONS

The review of friction stir welding of 5083 aluminum alloys has been studied in this paper. FSW is considered a good alternative method for welding aluminum alloys compared with conventional welding method. FSW improves the mechanical properties and microstructure of aluminum alloys welds. Most of the above studies focused on the effect of rotational and welding speeds on the mechanical properties and microstructure of the welds. However, more studies should be done to study the effect of other welding parameters on the quality of joints made by friction stir welding.

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