Int. J. Chem. Sci.: 14(4), 2016, 2958-2966
ISSN 0972-768X
www.sadgurupublications.com

MICROSTRUCTURAL AND MECHANICAL PROPERTIES OF SOLID STATE WELDED DISSIMILARALUMINUM ALLOY JOINTS

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ABSTRACT

The heat treatable aluminum alloy AA2024 is used extensively in the aircraft industry because of its high strength to weight ratio and good ductility. AA6061-T6 aluminum alloy (Al-Mg-Si alloy) has gathered wide acceptance in the fabrication of light weight structures requiring high strength to weight ratio and good corrosion resistance. In the present investigation, the high strength AA2024 and medium strength 6061-T6 were welded by the FSW process, to accertain the optimal mechanical properties by varying the rotational speed from 800 to 1200 rpm and welding speed between 20 to 80 mm/min. This work was aimed at studying the effect of advancing side materials on tensile. Microstructure and micro hardness properties in dissimilar aluminum alloy joints. The experimental results revealed that sound defect-free joints could be obtained when the high strength AA2024 was fixed at the advancing side. The tensile strength was improved at high heat input. The microstructure at AA2024 (Advancing side) shows elongated particles of Al_2Cu and MgSi in a matrix of aluminum solid solution and voids were also observed in a matrix.

Key words: Friction stir welding, Dissimilar joint, Tensile properties, Microstructure.

INTRODUCTION

Friction stir welding (FSW) is a relatively new and attractive joining technique which has already generated considerable interest in the aerospace sector as a potential replacement technique for riveting. In general the process is well established particularly for aluminum alloys[1-4]. The conventional fusion welding and its alloys has always been a great challenge for designers and technologists. The difficulties associated with this kind of joints and mainly related to the presence of a tenacious oxide layer, high thermal conductivity,

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high coefficient of thermal expansion, solidification shrinkage, and high solubility of hydrogen and other gases in molten state[5]. The fusion welding of aluminum alloys leads to the melting and re-solidification of the fusion zone, which results in the formation of brittle inter-dendritic structure and eutectic phases. The formation of brittle structure in the weld zone leads to the drastic decreases in the mechanical properties like lowers in hardness, strength and ductility[6,7].

Generally the 2000 series (Al-Cu alloy) series of aluminum alloys have poor weld ability because of the copper content, which causes hot cracking, poor solidification, microstructure and porosity in the fusion zone. Therefore, the fusion welding processes are not suitable for joining of these alloys. Among the 2000 series of aluminum alloy AA2024 is heat treatable, and it is used extensively in the aircraft industries for application such as Fuselage skines, fuselage frames, and wings due to its high strength to weight ratio and ductility[8-10]. The heat provided by the fusion welding processes is responsible for the decay of mechanical properties of AA2024 due to phase transformations softening is introduced in this alloy[11-14].

The aluminum alloys of 6000 series containing magnesium and silicon as major alloying elements, have attractive combination of properties such as medium strength, formability, fatigue resistance and relatively low cost and widely used in many structural manufacturing fields such as the aerospace, ship constructions, high speed train and automotive industries for high performance structural demanding applications.

Cavalieve et al. investigated the tensile behavior of dissimilar FS welded joints of aluminum alloy 2024-T3 and 7075-T6: and both the ultimate strength and elongation of the dissimilar joints are lower than both the base material. Amancio Filho et al.[15] determined the tensile strength of the dissimilar FS welded joints of aluminum alloys AA2024-T351 and AA6056 T4 as 56% of the AA2024 –T351 and 90% of the AA6056-T4. It is reported that the poor tensile strength observed in these joints are due to the thermal softening of the base materials; and the poor ductility observed in these joints is due to the stress concentration caused by the large difference in strength between base materials leading to confined plasticity and then failure.

However, very few systematic studies have been performed on dissimilar FS welding, and the relationships between the various welding parameters and the resulting weld properties have not been identified. Dissimilar welding of aluminum alloys is a core demand of the aircraft industries to substitute the traditional joining technologies with low costs and high efficiency ones such as friction stir welding in the future advanced design.

Hence, the present research work is aimed at understanding the microstructural changes brought about by friction stir welding process parameters on AA2024-AA6061dissimilar joints and their influence on mechanical properties especially hardness gradient and tensile properties, and also aimed at studying the effect of advancing side materials and microhardness properties in dissimilar aluminum alloy joints.

EXPERIMENTAL

The material used for dissimilar Friction stir Welding (FSW) were AA6061 and AA 2024 aluminum alloys. The aluminum alloys AA2024-T3 and AA6061-T6 are selected for the dissimilar FS welding process; where T6 heat treatment consists of solution heat treated and artificially aged at 190^{o}C for 12 hrs, and T3 denotes solution heat-treated and then cold worked. The chemical composition and mechanical properties of base metals are presented in Tables 1 and 2, respectively. FSW is perpendicular to the rolling direction of both the aluminum alloy plates. The side where the tool rotation is in same direction as translation of the welding tool is referred as the advancing side. However, when the direction of the tool rotation and translation motion of the tool is contacts with each other, it is referred as the retreating side. All the welds were butt welds and were carried out using tools made of High speed steel. The shoulder diameter of the tool was 18 mm; the probe had a diameter of 6 mm and a height of 5.7 mm. The tool travelled along the centerline of the weld. The welding condition and process parameters are given in Table 3. The photographs of fabricated joints are displayed in Fig. 1. The down ward force of stir tool, which could be controlled by FSW equipment during welding was set to be 10 KN and the forward tilt angle of stir tool was kept 2° during welding.

Table 1: Chemical composition (wt%) of the base metals

Alloy	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
AA6061-T6	0.567	0.173	0.212	0.031	0.92	0.066	0.021	0.018	Bal
AA2024-T3	0.50	0.50	4.9	0.9	1.8	0.10	0.25	0.15	Bal

Table 2: Mechanical properties of the base metals AA2024-T3 and AA6061-T6

Alloy	Yield strength (MPa)	Ultimate tensile strength (MPa)	Micro hardness (HV) @0.5 kg
AA6061-T6	276	310	107
AA2024-T3	324	469	137

Table 3: Welding conditions employed to join the AA6061-AA 2024 plates

Weld	Position	Rotational speed (rpm)	Welding speed (mm/min)
2024-6061	AS-RS	1200	35
6061-2024	AS-RS	1200	35

The tensile specimens are prepared as per the American society for Testing of Materials. (ASTM E 8M-04) standards whose geometry and dimensions are shown in Fig. 2. The tensile tests were carried out at room temperature using a Universal Testing Machine (Make:FIE, India). For the optical microscopy the samples were cut in a direction perpendicular to the welding direction. These samples were then grinded successively on Sic papers of grit 80 to 600. After which they were polished on a fine cloth using a 1 μm diamond paste to obtain a mirror finish. The samples were then etched using a solution of 1% HF. These were then used for optical microscopy.

The microhardness measurements were taken on the cross section perpendicular to the welding direction using an inventor with a load of 0.5 kg for a dwell period of 15 s.

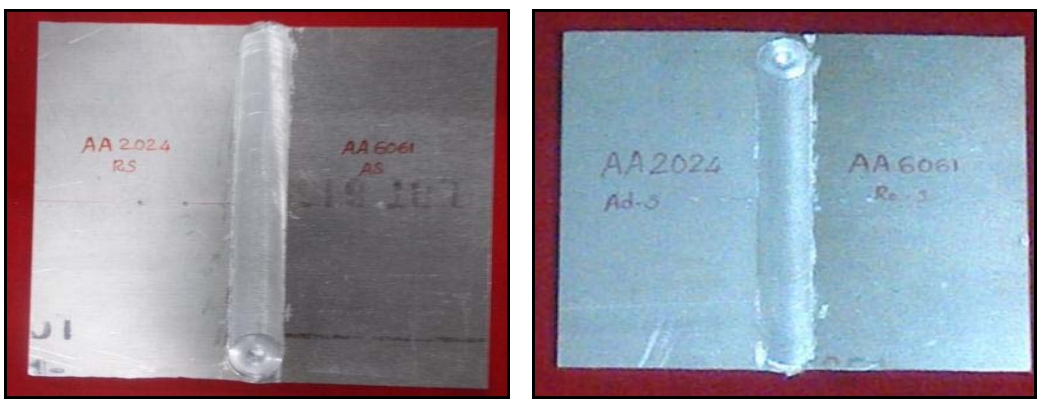

Fig. 1: Photographs of fabricated joints

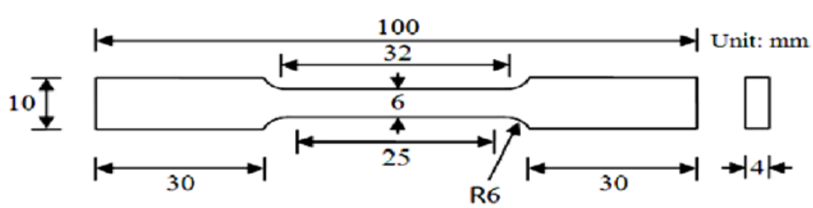

Fig. 2: Dimensions of the tensile specimen

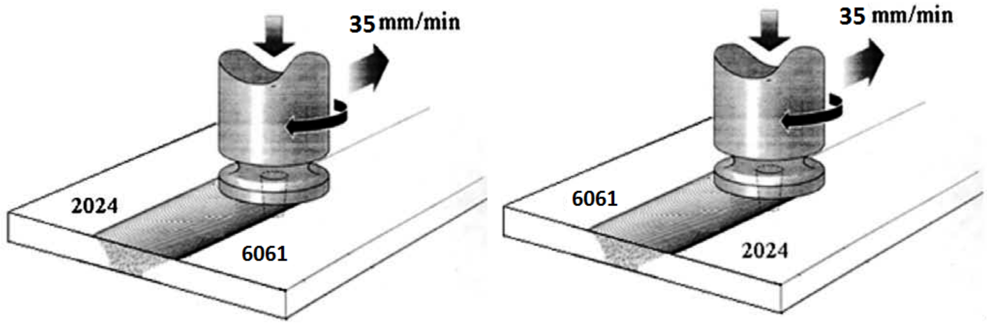

Fig. 3: Schematization of the produced welds in different conditions and with different positions of the alloy plates

RESULTS AND DISCUSSION

In this work, FSW dissimilar welds of AA 6061-AA2024 joints were successfully obtained by varying the processing parameters and the position of the of the different alloys on the advancing side of the tool (Fig. 3).

Tensile properties

In any welding, the heat input plays an important role on the tensile properties and hardness of the weldments. The specific weld input energy for FSW may be obtained by the ratio of the rotational speed to the welding speed. From the experimental results, it was found that the ultimate tensile strengths increased with increase in weld speed in the tested range.

Table 4: Mechanical properties obtained from tensile tests

Material	Welding speed (mm/min)	Tensile load (kN)	Ultimate tensile strength (MPa)	Fracture location
FSW 2024 (As)- 6061 (Rs)	35	14.50	170.67	Weld zone
FSW 2024 (Rs)-6061 (As)	35	7.03	83.96	Weld zone

The maximum tensile strength of the dissimilar friction stir welded joint was obtained under a welding speed of 35 mm/min for the tool rotation speed of 1200 rpm. All the joints failed in the weld region. Some previous report explained that FSW creates softened region at the nugget zone because the strengthening precipitates dissolved and grew during the weld thermal cycle, which results in the degradation of mechanical properties of the joints. It also observed from the test, the experimental results revealed that better tensile strength could be obtained when the high strength AA2024 was fixed at the advanced side.

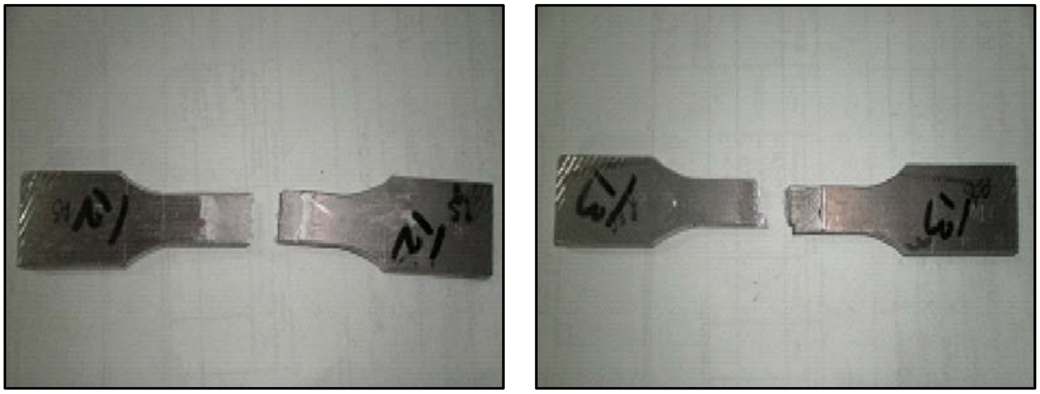

Fig. 4: Photographs of tensile tested specimens

Microhardness measurements

The average hardness of the nugget zone was found to be significantly higher than the outside the nugget (HAZ). In Harris and Norman work, it is suggested that the variation of the micro hardness values in the welded area and parent metal is due to the difference between the microstructure of the base alloy and weld zone. The highest values of micro hardness are reached in the case of dissimilar AA2024-AA6061, when the 2024 alloy is on the advancing side of the tool. Fig. 5 microhardness profiles of the studied joints in different conditions.

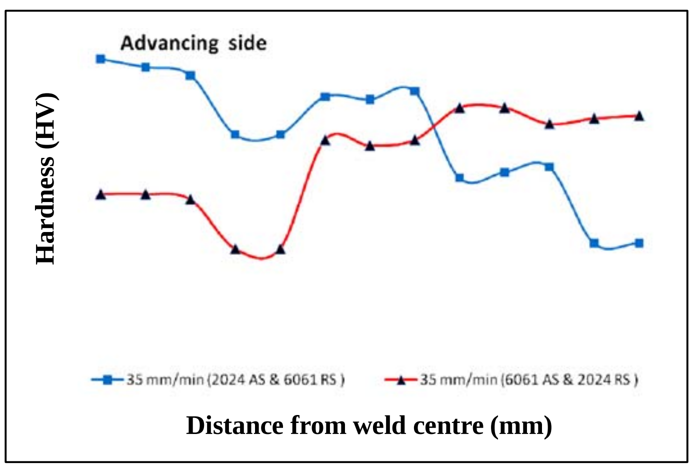

Fig. 5: Microhardness profiles of the studied joints in different conditions

Microstructural evolution

Fig. 6 shows the microstructure of the cross section area of welded joint observed at a welding speed of 35 mm/min and a tool rotation speed of 1200 rpm. The micro structure shows fusion between weld and base metals. The microstructure at Al 6061 (RS) base shows elongated particles of Al-Si and MgSi in a matrix of aluminum solid solution and Al 2024 (AS) base alloys elongated particles of Al_2 Cu and MgSi in a matrix of aluminum solid solution and voids also observed in a matrix.

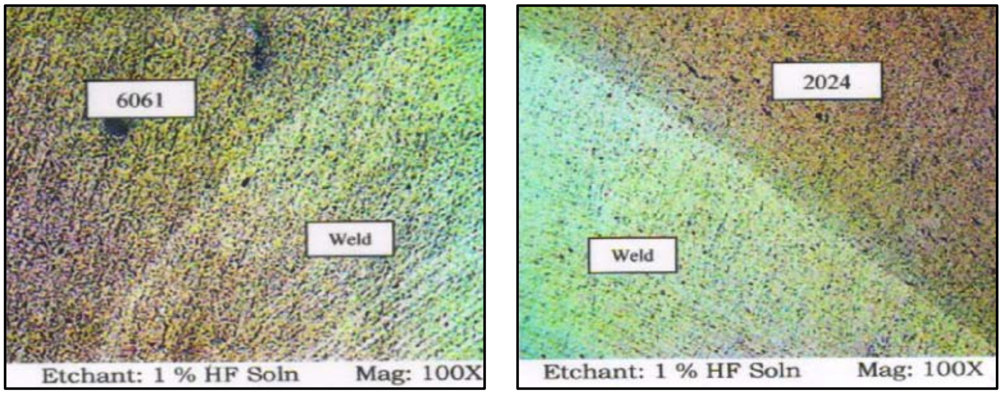

Fig. 6(a): Micro structure of the joint with AA6061 (AS) and AA2024 (RS) at the welding speed 35 mm/min

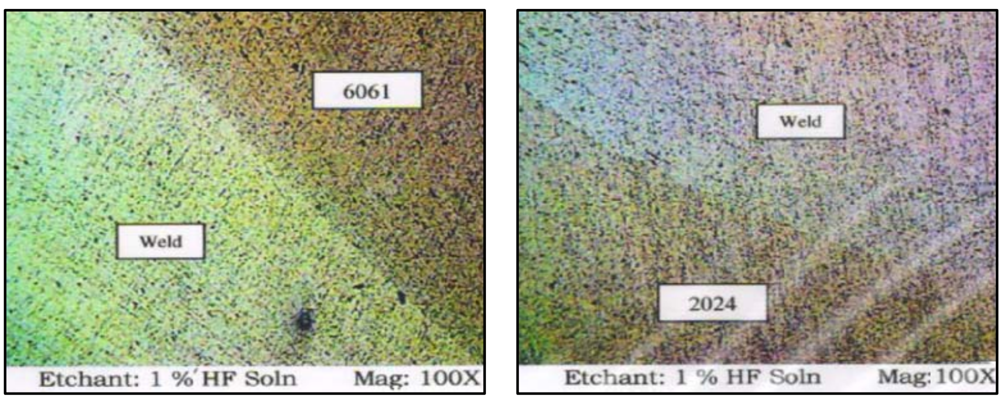

Fig. 6(b): Micro structure of the joint with AA6061 (RS) and AA2024 (RS) at the welding speed 35 mm/min

CONCLUSION

In summary, AA 2024 and AA 6061 aluminum alloys were friction stir welded at various welding parameters, and the effect on the microstructure and mechanical properties was investigated. The following conclusions are reached.

(i) Sound defect-free joint could be obtained only when the high strength AA2024 aluminum plate was fixed at the advancing side. Some defects was observed when the soft Aluminum 6061 was fixed at the advancing side. This is attributed that the hard material was hard to transport to the advancing side during FSW.

(ii) The maximum tensile strength of the dissimilar friction stir welded joint was obtained under a welding speed of 35 mm/min for the tool rotation speed of 1200 rpm.

(iii) A maximum ultimate tensile strength 170.67 MPa was obtained when the high strength AA2024 was fixed at the advanced side.

(iv) The micro structure shows fusion between weld and base metals. The microstructure at Al 6061 (RS) base shows elongated particles of Al-Si and MgSi in a matrix of aluminum solid solution and Al 2024 (AS) base alloys elongated particles of Al_2 Cu and MgSi in a matrix of aluminum solid solution and voids also observed in a matrix.

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Accepted : 31.10.2016