EFFECT OF PENTAGON TOOL PIN PROFILE ON FRICTION STIR WELDING OF DISSIMILAR ALUMINUM ALLOY AA6061 AND AA7075

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Abstract - Friction Stir Welding a variant of Friction Welding has parameters namely tool material, tool geometry, tool pin profile, tool tilt angle, axial force, tool rotational speed and tool transverse speed. Here in the present investigation the effect of pentagon tool pin profile is been studied on joining of dissimilar aluminum alloys AA6061 and AA7075. Tool transverse feed is kept as 31.5 mm/min; tool rotational speed is kept as 765 rpm and tool tilt angle as 2 degrees forward. Mechanical properties, Microstructure, Macrostructure and Temperature profile analysis is been done. Microstructure analysis has been done with the help of Keller's Reagent. Temperature measurement is carried out by K-type thermocouple, embedded at different depths (1.5mm, 3mm and 4.5mm) and at different positions along the longitudinal axis. Aluminum alloy AA6061 is kept on advancing side and AA7075 is on retreating side.

Index Terms - Friction Stir welding (FSW), pentagon tool pin profile, AA6061, AA7075

I. INTRODUCTION

Aluminum is the most challenging in terms of welding and it is also the most demanded and used material in the market now-a-days[1-3]. The applications of aluminum are increasing at a rapid rate due the properties of aluminum such as higher strength to weight ratio and also upto some extent a corrosive resistant oxide layer. AA2XXX and AA7XXX series are the most difficult to weld materials with the help of the conventional fusion welding processes [4-8]. The reason behind the difficulty in AA7075 welding is the sensitiveness of AA7075 towards solidification cracking due to the presence of copper[9] and also oxidation and vaporization of zinc causes several problems. The other major setback of arc welding is the distortion and residual stresses due to rapid heating and cooling. Friction Stir Welding (FSW) variant of Friction Welding (FW) was invented in 1991 by Wayne Thomas and his team at The Welding Institute at Cambridge[10]. This process is termed as solid state welding process as the materials to be welded are not melted. Here the temperature for the process is 60 to 80% of the melting temperature. In this process the rotating tool as shown in Fig.1 is been plunged with the application of axial force into the line of joining of material. Due to this rotation and with the help of the frictional heat generated between the shoulder face and the top surface of the plates the plastic deformation of the materials takes place and also the proper movement of material from one plate to another is been assured. The other major advantage is similar[9, 11-14] and dissimilar materials[15, 16] both can be welded easily with some small changes in arrangements.

There are various parameters in friction stir welding which are to be given proper attention , they are tool rotation speed, tool transverse speed , tool tilt angle , tool material , tool pin profile , axial force and also the arrangement of advancing and retreating side. There is lot of research done on optimization of parameters [9, 12, 14, 16-18] but less light is been focused on variation of tool pin profile and its effect on various properties. Infact , tool pin profile plays a major role in mixing of material and ensuring better quality of welded specimen[11].The effects of pentagon tool pin profile on mechanical properties, microstructure analysis and temperature profiles are been studied. Also the arrangements of materials on advancing and retreating side plays an important role[16]. Advancing side is termed as the side where the tool rotation direction and the tool transverse feed direction are same whereas for retreating side the direction of tool rotation and the transverse feed direction are opposite. During dissimilar materials welding the softer material is placed on retreating side and the harder material on the advancing side. From the previous studies[16], AA6061(softer material) is placed on the advancing side whereas AA7075(harder material) is placed on the retreating side which is opposite to which is generally seen. The other thing different from the fusion welding processes is the different zones in the Friction welded specimen , they are Nugget Zone (NZ), Heat affected zone (HAZ) and Thermo-Mechanically affected zone (TMAZ). Nugget zone is the region where tool pin rotation takes place whereas in the Thermo-Mechanically affected zone the material is affected thermally and mechanically both [19].

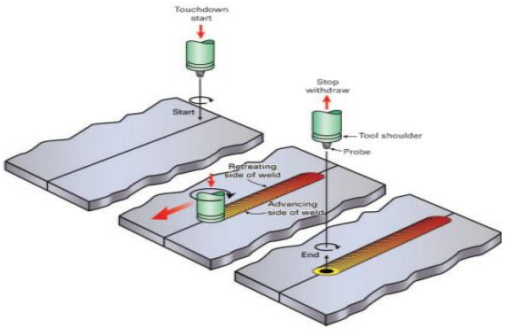


Fig.1 Friction stir welding process [20]

Large amount of research work is done in the field of FSW of AA6061 Aluminum grade[4, 5, 21] as it has many applications and lesser work is done in the field of FSW of AA7075 material[9, 13, 22, 23], and also less focus is been raised in the FSW of AA6061 and AA7075 dissimilar materials joining[15, 16] till now according to the best of the author's knowledge.

In the present investigation the novel approach FSW is done for the dissimilar aluminum grade materials (AA6061 and AA7075) with the help of the pentagon pin profile and to obtain the variation in the mechanical properties , micro and macrostructure analysis along with the temperature profiles at three different depths is been carried out .

II. EXPERIMENTAL SETUP

Rolled plates of 6mm thickness of Aluminum alloy AA6061 and AA7075 were used as base materials. Plates were machined to dimensions of 100 mm * 50 mm each. The chemical composition of AA6061 and AA7075 is shown in Table I and Table II respectively whereas the mechanical properties are shown in Table III. After cutting the holes were drilled on the face to fix thermocouple into the plate. The diameter of drilled hole was taken as 2 mm and with different depths such as 1.5mm, 3mm and 4.5mm. This holes were drilled at every 25mm distance from the top on the longitudinal axis. The tool rotational speed was kept as 765 rpm and the transverse feed as 31.5 mm/min with 2 degrees forward tilt with no offset provided.

Mg	Zn	Cu	Si	Fe	Cr	Al
0.11	0.2	0.27	0.56	0.56	0.18	Balance

Table I
Chemical composition of AA6061(wt%)

Mg	Zn	Cu	Si	Fe	Cr	Al
2.5	5.67	1.5	0.35	0.61	0.24	Balance

Table II
Chemical composition of AA7075(wt%)

Mechanical property	AA6061	AA7075
Ultimate tensile strength	288 MPa	572 MPa
Brinell hardness(BHN)	95	150
Thermal Conductivity	170 W/m.K	130 W/m.K
Melting point(Celsius)	582-652	477-635

Table III
Mechanical properties of base metals

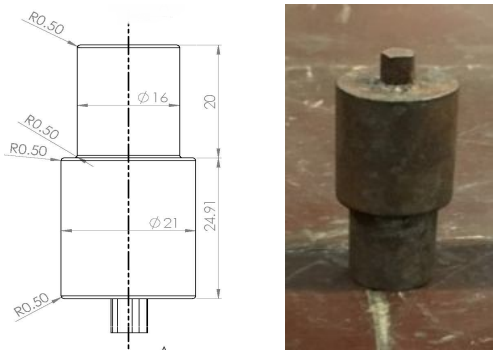


Fig.2 Dimensions of pentagon tool

The tool pin profile selected is the pentagon tool pin profile which has a side length as 2.35 mm , other dimensions of the tool are shown in Fig.2 .

The microstructure specimen were made in the transverse direction , 10mm away from the exit hole and having 10 mm width . The etchent used was Keller's reagent. Tensile specimen was taken perpendicular to the weld joint with the help of the wire cut EDM , the specimen is shown in Fig.5. Three different samples were taken into consideration and the simple average is been done for the same. For the temperature measurement K-type thermocouple were used and thus temperature profile was obtained at different depths .

III. RESULTS AND DISCUSSIONS

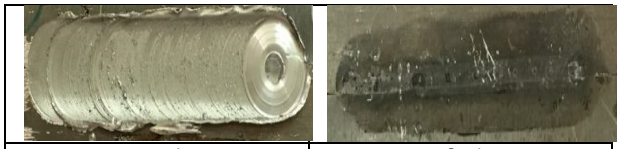
The mechanical properties of AA6061 and AA7075 are listed in the Table III. Since the mechanical characteristics of the base materials are very different , it is necessary to determine the processing condition for successful solid state joining. Various parameters like rotational speed of tool ,feed rate affects the material flow patterns and intermixing capacity of the materials and which ultimately determine the macro and microstructure.

Improper material flow as well as heat input leads to pin hole ,tunnel defect, piping defect, zigzag lines, inappropriate onion rings, kissing bond in Friction Stir welded joints. Thus FSW was performed with various processing parameters like rotational speed as 765 rpm & feed rate as 31.5 mm/min aiming to determine a suitable working condition to attain sound weldments.

A. VISUAL INSPECTION

Visually we inspected the front and back full penetration as shown in Fig.3 with almost no defect.

Onion rings were formed on the top of the surface which can be clearly seen in the Fig.3 . The specimen then was cut in the transverse direction and observed that there was no tunneling defect. The other notable fact is the amount of aluminum got stuck on the pin after the completion of process as shown in Fig.4, due to which proper finishing is to be done for further use. After longer usage the shape of the pentagon tool pin loses its edges and thus it becomes similar to the cylindrical pin profile.



Front view	Back view

Fig.3 Front and back view of welded specimen



Fig.4 Aluminum on the pentagon pin

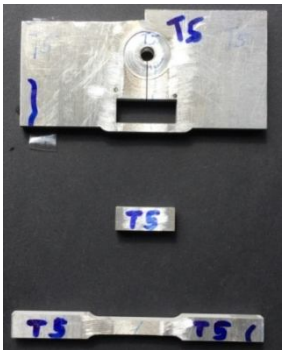


Fig.5 Tensile and microstructure analysis specimen.

B. TENSILE PROPERTIES

The tensile specimen is shown in Fig.5 , Table IV shows the tensile properties of the base AA6061 alloy and the properties of welded specimen of AA6061 and AA7075 alloys. In Table IV the joint efficiency is also been shown which represents the strength of welded specimen to the strength of the softer base metal which is found to be almost around 60% (Here UTS stands for the Ultimate tensile strength and number in the bracket suggests the number of samples , as in base metal only two samples were taken and in welded specimen three samples were taken, sample 2 in welded specimen shows lower tensile strength as it consisted of the hole which was made for the thermocouple and specimen got fractured from that point). Only the tensile properties of AA6061 alloy are shown in the table because all joints failed on the AA6061 side at positions in HAZ regions where the hardness minima are located.

	UTS 1(MPa)	UTS 2(MPa)	UTS 3(Mpa)	Average UTS(Mpa)	Joint efficiency (%)
AA6061	290.18	286.27		288.225	
Welded specimen	177.41	158.63	179.49	171.8433	59.621

Table IV
Tensile properties for three different samples

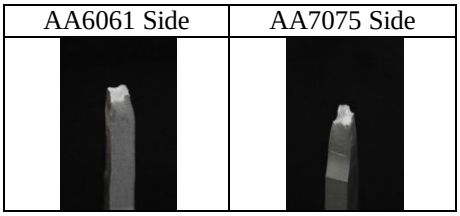


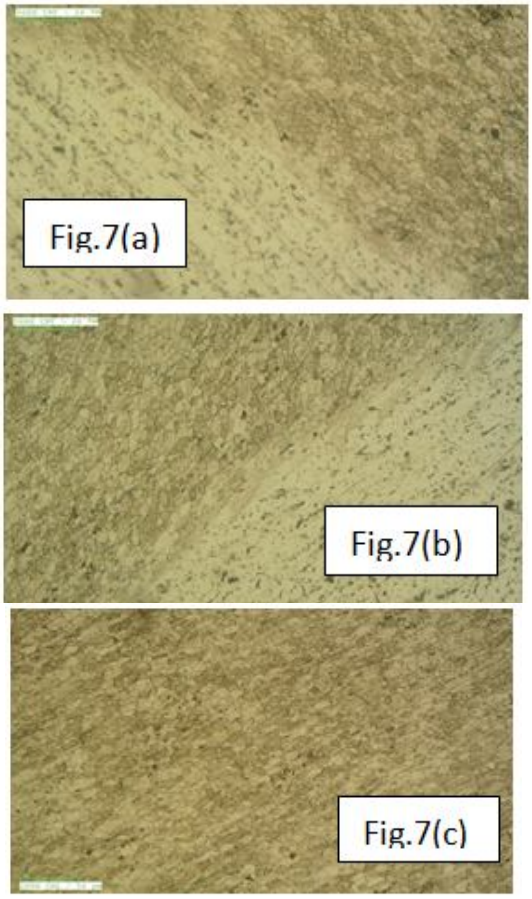
Fig.6 Welded specimen after fracture

As reported previously in dissimilar FSW of other Al alloys, the friction stir welded joints usually fractured at locations in HAZ on the weaker material side. The failure locations in HAZ also indicate seamless bonding has been achieved between dissimilar AA6061 and AA7075 alloys under all investigated welding conditions. The reason is advancing side induced less heat input and thus less severe precipitate coarsening in the HAZ. The pictorial view of the tensile specimen after the breakage is shown in Fig.6 it would prove that the failure of aluminum materials is ductile in nature.

C. MICROSTRUCTURE AND MACROSTRUCTURE STUDIES

Grain structures of different location and zones are studied using optical microscopy. The grain structures of different locations and zones across the Base metal(BM), Heat affected zone(HAZ), Thermo-Mechanically affected zone (TMAZ), Nugget zone (NZ).

Three different regions where microstructure is been obtained they are, left interference zone (Fig.7(a),interference between nugget zone and base metal AA6061), right interference (Fig.7(b), interference between nugget zone and base metal AA7075) and the nugget zone(Fig.7(c)).The interface zones are which differentiates the nugget zone from the base metal. The differentiation is done by looking at the grain structures. The zone in the middle is called weld pool/stir zone/nugget zone(Fig.7(c)). It is the zone where dissimilar materials are mixed and joining takes place. The amount of heat input , mixing of materials & rate of cooling decides the size of grains which in turn decides the strength of the nugget zone.



The microstructure in the nugget zone is characterized by a typical feature of fine equiaxed grains, which is due to dynamic recrystallization during FSW. The pentagon pin is asymmetric and will generate intense pulsating stirring action and generate additional frictional heat and higher plastic deformation which will result in poor material flow and weak stirring force which finally results in coarse grain structure but this is not coarser than the base material.[24-26] In the macrostructure view the pin can be clearly seen in the nugget zone as shown in Fig.8.

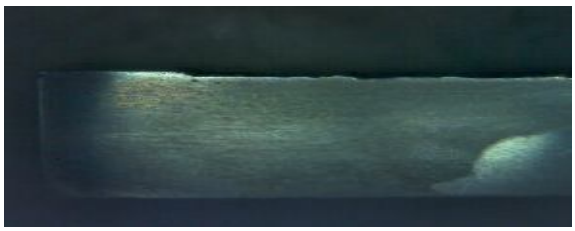


Fig.8 Macrostructure view

D. TEMPEARTURE PROFILE

Temperature at six different positions were measured , 3 on advancing side and 3 on retreating side, and that too at different depths. Here by the experiments it can be seen that the maximum temperature is found at retreating side on the third thermocouple on the longitudinal axis with the help of graph shown in Fig.9, (here 6061 represents aluminum grade AA6061 whereas 7075 represents aluminum grade AA7075 and the number in the bracket shows the position of thermocouple from the point where the welding is been started). The temperature generated is very high due to high frictional force. This is due to the asymmetrical nature of the tool pin profile.[27-29]

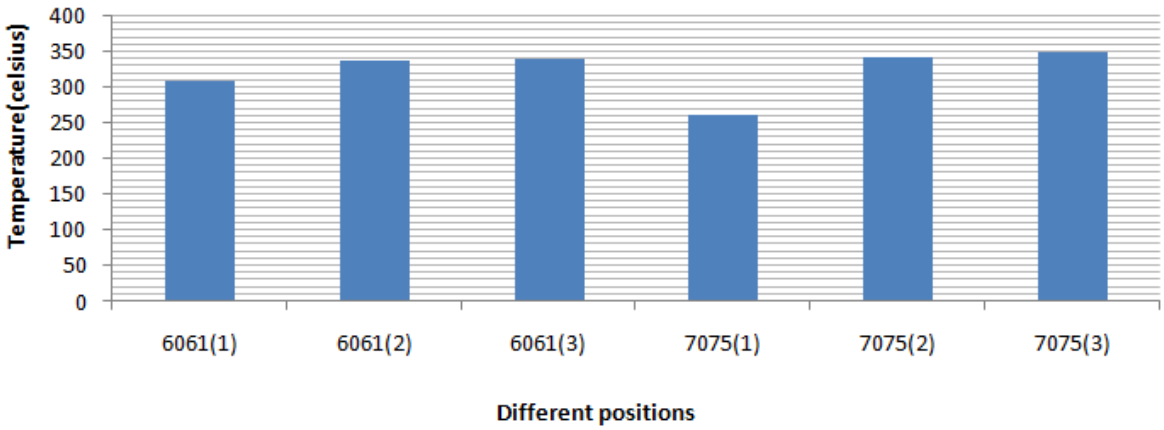


Fig.9 Temperature at different positions

CONCLUSIONS

Due to the use of the pentagon tool pin profile the microstructure obtained in the nugget zone is finer(as in Fig.7(c)) as compared to the original microstructure (as on left and right side of the interface line in Fig.7(a) and Fig.7(b) respectively).The major problem with the pentagon pin profile is the edges of the pin get blunt and almost become cylindrical in shape after 4 to 5 experiments.

From the temperature profile it can be seen that temperatures are almost similar at positions 2 and 3 but highest temperature is obtained at position 3 on the retreating side.

The failure of the welded specimen is ductile in nature as cup and cone like structure is obtained on

the broken pieces of the welded specimen during the tension testing.

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