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Effect of Welding parameters on properties of Friction Stir Welded joints of Aluminum 6106 alloy with and without SiC reinforced particles

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ABSTRACT: *Aluminum 6106 as a light weight structural material with high specific strength, good damping capability and machine ability, is one of the most attractive materials in applications of transportation and mobile electronics for effectively reducing weight. The selected material was Friction Stir Welded by doping Silicon carbide micro powder. Welding parameters like tool rotational speed of 1450 rpm and varying welding speed of 40 mm/min, 60 mm/min and 80 mm/min with single and double pass welding was selected for the study. A cylindrical left hand threaded tool with 20 mm tool shoulder diameter and 7 mm pin diameter was employed for welding. After that the effect of reinforced Silicon carbide particles on the mechanical and metallurgical properties of single and double passes Friction stir Welded joints of Aluminum 6106 alloy was examined by employing Tensile test, micro hardness test and microstructure tests. It was examined that highest value of micro hardness at the rate of 122 Hv at stir zone achieved with double pass friction stir welding by doping SiC particles. Doping of SiC particles makes the FSW joints harder as compared to Friction Stir welded joints welded without doping SiC particles. Tensile strength increases with increase in welding speed from 40 mm/min to 60 mm/min and with double pass friction stir welding due to homogeneous dispersion of SiC particles.*

I. INTRODUCTION

Friction stir welding is a solid state joining process in which a specially designed rotating tool, which is inserted into an adjoining edge of the sheets to be welded and the tool, is moved across the length of the joint [1]. The tool is producing the frictional heating and plastic deformation heating in the welding zone along the joining of the work piece length basis for welding. The friction stir welding is a solid state joining process means no melting of a material take place during the process. In FSW, a specially designed rotating pin is first inserted into the material to be welded with or without a proper tool tilt angle and then move along the interfaces of specimen to be joined [2]. The pin with help of shoulder produces frictional heat due to pressure and plastic deformation around the pin within the welding zone. As the tool pin moves, material is swept around the tool pin and retreating side of the tool (where the local motion due to rotation opposes the forward motion) and the surrounding un-deformed material [3]. The extruded material is deposited to form a solid phase behind the tool.

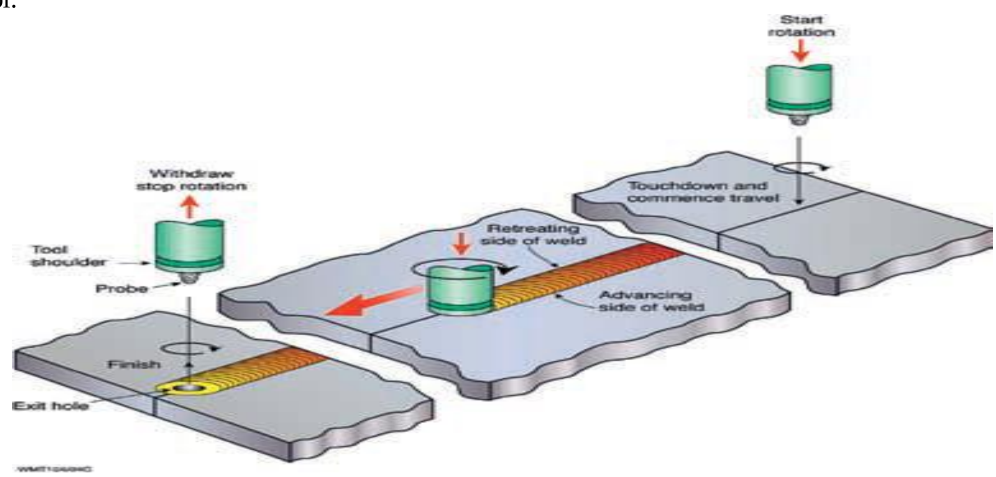

Fig. 1 Friction Stir Welding operation

II. LITERATURE REVIEW

Soron and **Kalaykov** ***(2006)*** studied that significant force is needed for FSW and at the same time position precision has to be kept, the control problems become complicated [4]. **Kisset** and **Czigang** ***(2007)*** found that the seam has undergone embrittlement, as a result of non-satisfactory homogenization. By analyzing the flow circumstances, during welding on seams produced by proper tool geometries it has been demonstrated that homogenization and, consequently the joint strength can be substantially improved [5]. **Kumbhar and Bhanumurthy** ***(2008)*** observed that, during the friction stir welding, extensive deformation is experienced at the nugget zone and the evolved microstructure strongly affects the mechanical properties of the joint [6]. ***Hamilton et al., (2010)*** utilizes the different characteristic curves and successfully predict the maximum weld temperatures at the lower energy weld conditions, i.e., 225 and 250 rev/min, but for the high-energy welds, 300 and 400 rev/min, and the curves over predict the maximum weld temperatures. Despite this discrepancy, the characteristic curves demonstrate that it is feasible to predict the maximum FSW temperature in an alloy if the thermal diffusivity, welding parameters, and tool geometry are known [7]. **Muruganandam** ***et al., (2011) c***oncluded that Friction stir welding was performed for four different tool rotation Speeds namely 600, 800, 1000 and1200. Defects were analyzed using radiography. It was found that defect concentration was maximum for the 600 RPM tool rotation. It was a little lesser for the 800 RPM parameter and even lesser for the 1000 RPM speed rotation. Minimum defects were observed for the highest tool rotation speed, namely 1200 RPM. An analysis of defects is given in this paper. Tensile Test values and bend test values were also reported [8]. **Singh** ***et al, (2011)*** revealed that micro hardness profile is obtained on welded zone indicate uniform distribution of grains in the stir zone. The maximum tensile strength obtained is 263 MPa which is about 85% of that of base metal. Scanning electron microscope was used to show the fractured surfaces of tensile tested specimens [9]. **Rana** ***et al., (2012)*** stated that conventional welding method FSW consumes considerably less energy. No cover gas or flux is used, thereby making the process environmentally friendly. The joining does not involve any use of filler metal and therefore any aluminium alloy can be joined without concern for the compatibility of composition, Which is an issue in fusion welding .When desirable ,dissimilar aluminium alloys and composites can also be joined with equal ease [10]. **Karthikeyan** ***et al., (2012)*** observed that welding strength of Aluminium AA 2011 and AA 6063 alloys improves with increased tool rotation speed. Optimum tool rotational speed for defect free nugget zone was found to be 1400 rpm and tool feed was found to be 60 mm/min [11]. **Kumar** and **Kamat** ***(2013)*** found that tensile strength and hardness of FSW is more than that of TIG welding. The mechanical properties of both welding specimen has been compared and with base metal strength [12]. **Prasad** and **Kumar** ***(2013)*** showed that tool rotation speed is dominant factor affecting tensile strength and hardness. Increase in tool rotation speed showed a decrease in hardness in HAZ. The effect of process parameters on tensile strength and hardness is evaluated and the optimum welding condition for maximizing the tensile strength and hardness is determined [13]. **Lal** ***et al., (2013)*** that micro hardness and tensile properties increases with increases the rotational speed of the tool. Micro hardness and tensile properties are superior with ST tool pin profile than SC tool pin profile. Grains of Microstructure of specimen at Thermo-Mechanical Affected Zone (TAMZ) becomes more fine as increases the speed of tool but ST pin profile have more fine grains than SC pin profile with same speed [14]. **Leon** and **kumar** ***(2014)*** revealed that parameters such as tool rotational speed and welding speed play a major role in deciding the joint characteristics. This paper focuses on optimization of all these parameters. From this investigation it was found that the joint made from the FSW yielded superior tensile properties and impact strength due to the higher hardness and fine microstructure [15]. **Marathe** ***et al., (2014)*** found that the threaded tool geometry gives the better weld strength and also the surface finish compare to the tapered tool geometry Testing of the specimens is carried out by ASME –SEC-IX and the weld strengths are compared [16]. **Abdullahet** and **Beithou** ***(2014)*** concluded that good surface finish is achieved at low burnishing speed and transverse stroke with burnishing force around200 N, high micro-hardness and high bending strength can be obtained at low burnishing speeds and low transverse stroke, with high burnishing force where as a high tensile strength is obtained at high burnishing speeds due to directional deformation of grains and the orientation of residual stresses [17].

III. EXPERIMENTAL WORK

The material under investigation was a 6106 Aluminium alloy under the form of rolled plates of 6 mm thickness. Six specimens of size 152 mm x 77 mm with grooves of 2 mm diameter and depth of 4.9 mm were welded together perpendicular to the rolling direction with single and double pass Friction Stir Welded doping SiC particles of size approximate 4 µm. The other six specimens were friction stir welded by adopted same parameters but without doping SiC particles. The employed tool rotational speeds of the cylindrical threaded tool and welding speeds was 1450 rpm and 40 mm/min, 60 mm/min and 80 mm/min respectively. A welding tool made up of High chrome high carbon steel with 20 mm tool shoulder diameter, 7 mm pin diameter and 5.8 mm long was used for present research work. For Friction stir welding edges are finished with milling operation so that interfaces can be properly matched. The machine used for the production of joints was fully automated vertical milling machine. Fixture was first fixed on the machine bed with help of clamps and then plates were held in the fixture properly for Friction Stir Welding as shown in Figure 3.

Figure 2. Work piece set up during FSW

Table no. 1 Parametric design adopted for Friction stir welding in current research work

Specimen no	Welding speed (mm/min)	Type of welding	SiC particles (used/ not used)
S1	40	Single Pass	yes
S2	60	Single Pass	yes
S3	80	Single Pass	yes
S4	40	Double Pass	yes
S5	60	Double Pass	yes
S6	80	Double Pass	yes
S7	40	Single Pass	no
S8	60	Single Pass	no
S9	80	Single Pass	no
S10	40	Double Pass	no
S11	60	Double Pass	no
S12	80	Double Pass	no

Specimens for the tensile strength analysis cut perpendicular to the weld line Tensile test specimens were prepared from the Friction Stir Welded plate in accordance with ASTM specifications, E-8M-08, having specimen of 50 mm gauge length and 12.5 mm width [1] [24]. Tensile test was carried out at a constant speed of 2 mm/min at 16 KN load. The load was applied until the necking was there and specimen failed. Servo Control Universal testing machine. Tensile test specimens before and after tensile testing are shown in Figure 3.

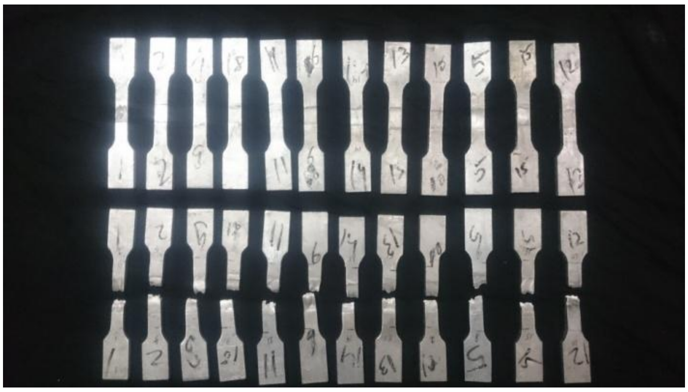

Figure 3. Specimens before and after testing

Visual inspection was performed on all welded samples in order to verify the presence of macroscopic external defects such as surface irregularities, excessive flash, and lack of penetration, voids and surface open tunnel defects. It was observed in the visual inspection that specimens welded with tool rotational speed 1450 rpm, welding speed 60 mm/min with tool shoulder diameter of 20 mm shows better surface texture. Hence no surface defects were observed on the welded as well as on the welded joint.

IV.RESULTS AND DISCUSSION

FSW has become a very effective tool in solving the joining problems of profiled sheets with material continuity, without using different joining methods; particularly in case of aerospace industry, where high ductility and tensile strength are required. In the present work, different FSW butt welds were processed with Friction Stir Processing.

A. Effect of welding speed and double pass FSW on the Tensile properties:

Tensile strength at constant rotational speed of 1450 rpm with doped Silicon carbide Particle increases from 40 mm/ min to 60 mm/min due to sufficient heat generation and proper distribution of SiC particles in the welded zone because of double pass Friction stir welding. At welding speed of 80 mm/min, a lower value of UTS is achieved due to low heat generation [18]. Improper interaction of tool shoulder and work piece surface causes less friction resulted in low heat generation and stirring action.

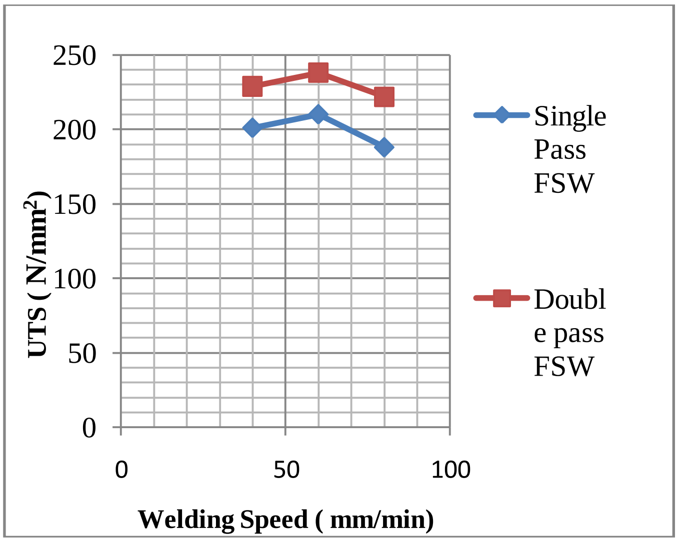

Figure 4. Effect of welding speed and no. of FSW passes on UTS

As shown in Figure 5 High values of UTS were observed in double pass Friction stir welded joints as compared to single pass. Double pass friction stir welding causes homogeneous dispersion of Silicon carbide particle and grain refinement because of dynamic recrystallization.

B. Effect of Silicon Carbide particle on UTS

The presence of SiC particles is considered for more effective formation of fine grain structure due to the restrain of grain boundary and the enhancement of the induced strain [19]. Doping of SiC particles increases the interface area between the SiC particles and aluminum matrix; due to low inter particles space area causes the agglomeration of SiC particle which results in low tensile properties. SiC particles increase could restrict the grain boundary sliding, dislocations and also the weak interfacial bond between the reinforcement particles and the matrix, finally leading to deterioration of the tensile properties during single pass FSW.

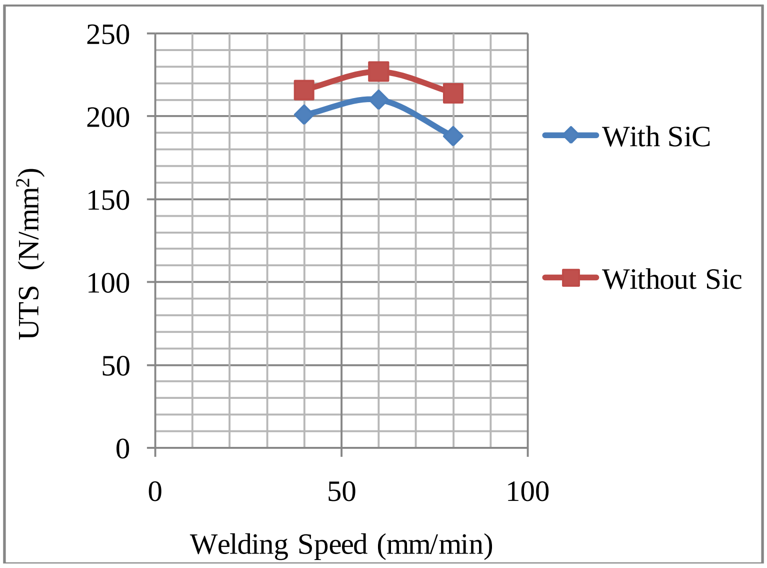

Figure 5. Effect of SiC particle on UTS with Single pass FSW

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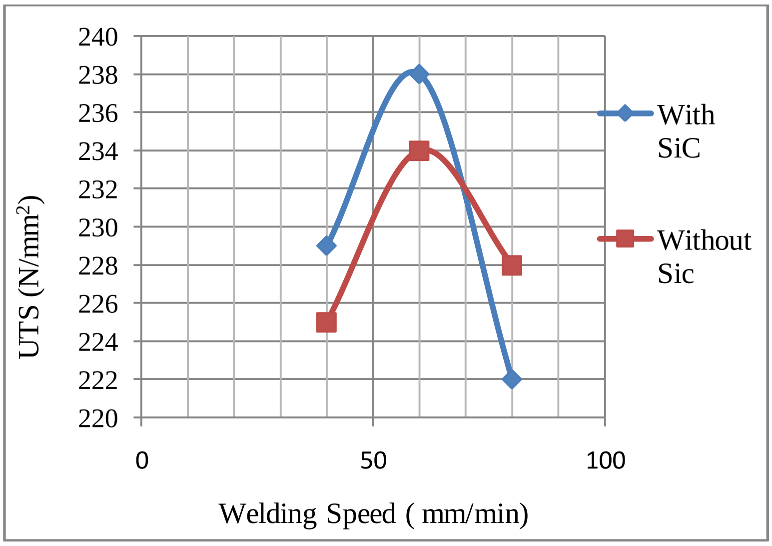

Figure 6. Effect of SiC particle on UTS with Double pass FSW

Double pass Friction Stir welding causes homogeneous dispersion of SiC particles in Stir Zone as compared with Single pass FSW, which further decreases the interface area between the SiC particles and aluminum matrix. Finally improvement in tensile properties was observed.

C. Effect of FSW Process Parameters on Micro Hardness

The Vickers hardness profile of the welded specimens was measured at a distance 2.5 mm from the top surface of the specimen thickness at Stir Zone on a cross-section perpendicular to the welding direction using Vickers hardness tester with 300 gf loads for 10 seconds. The Vickers hardness of the base metal was 75 Hv. The results of Micro hardness at SZ shown in Table 2.

Table no. 2 Micro hardness at Stir zone

Specimen no	Welding speed (mm/min)	Type of welding	Micro hardness (Hv)
S1	40	Single Pass	102
S2	60	Single Pass	107.4
S3	80	Single Pass	105
S4	40	Double Pass	112
S5	60	Double Pass	122
S6	80	Double Pass	117.6
S7	40	Single Pass	85.4
S8	60	Single Pass	88.3
S9	80	Single Pass	94.6
S10	40	Double Pass	79
S11	60	Double Pass	86.2
S12	80	Double Pass	90

D. Effect of welding speed and number of passes on micro hardness at Stir Zone

Micro hardness is a function of grain size i.e. smaller the grain size higher will be the micro hardness value [21] [22]. The grain boundaries become the main obstacle to the slip of dislocations and the material with smaller grain size would have higher micro hardness or tensile strength as it would impose restriction to the dislocation movement [1]. Thus with increase in the welding speed heat generation decreases which further decreases the grain size due to fast cooling rate, resulted in high micro hardness value. Same trend is followed in case of double pass Friction stir welding process except the micro hardness values were less as compared to single pass FSW process.

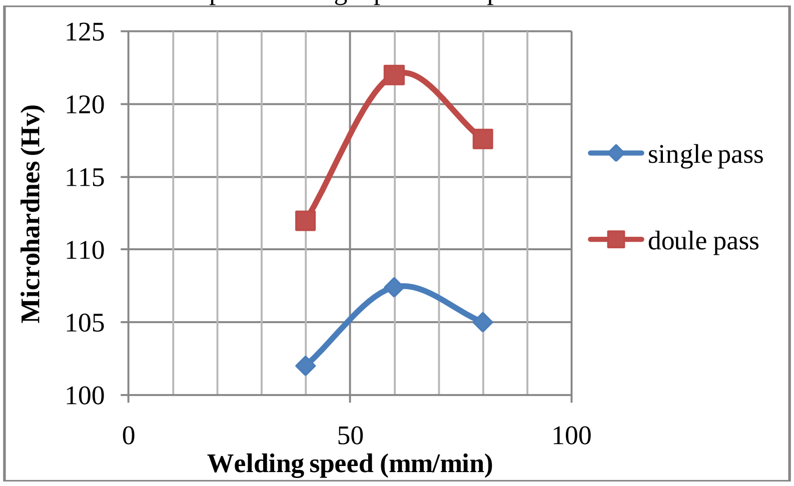

Figure 7. Effect of welding speed and double pass FSW with SiC particles

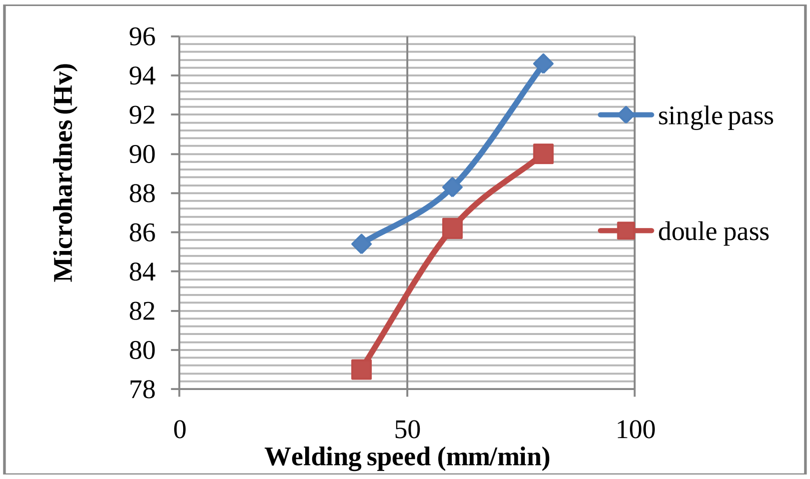

Figure 8.Effect of welding speed and double pass FSW without SiC particles

Micro hardness of SZ increases with increase in number of passes. The major contributions to the micro hardness of SZ due to the fine dispersion of SiC particles and good bonding to matrix alloy. The peak hardness is observed with double pass Friction stir welding because of homogeneous dispersion of SiC particles in the Stir Zones shown in figure 8. From Figure 9 decrease in micro hardness value is observed in double pass. Double pass causes material softening at SZ because of grain growth due to heat input in second pass.

E. Effect of reinforced Sic particles on micro hardness of Stir Zone

Micro hardness at optimum condition increases due to presence and pining effect of hard SiC particles as compared to the joints those Friction Stir Welded without doping SiC particles. The presence of SiC particles is considered for more effective formation of fine grain structure due to the restrain of grain boundary and the enhancement of the induced strain [19]. However the higher hardness is achieved by the SiC particles at the Stir Zone. Dispersion of SiC particles affects the micro hardness of SZ. It is revealed from the Figure8 that doping of SiC alters the effect of welding speed on the micro hardness of SZ. Micro hardness increases with increase in welding speed from 40 mm/min to 60 mm/min because of homogeneous dispersion of Sic particles. At welding speed of 60 mm/min proper stirring action of tool pin allows proper material flow from advancing side to retreating side further improves the dispersion of SiC particles in the aluminum matrix.

F. Microstrucrural characteristics of FSW joints

Figure 9. shows the microstructure of Aluminium 6106 alloy as received from supplier.

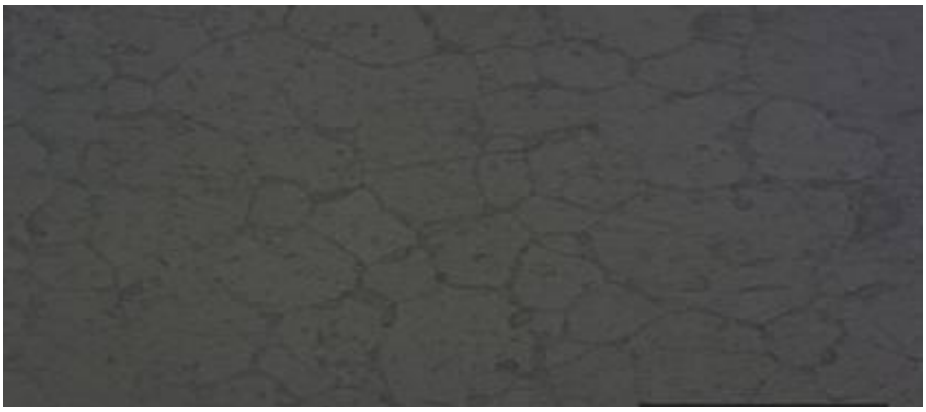

Figure 9. Microstructure of Aluminium 6106

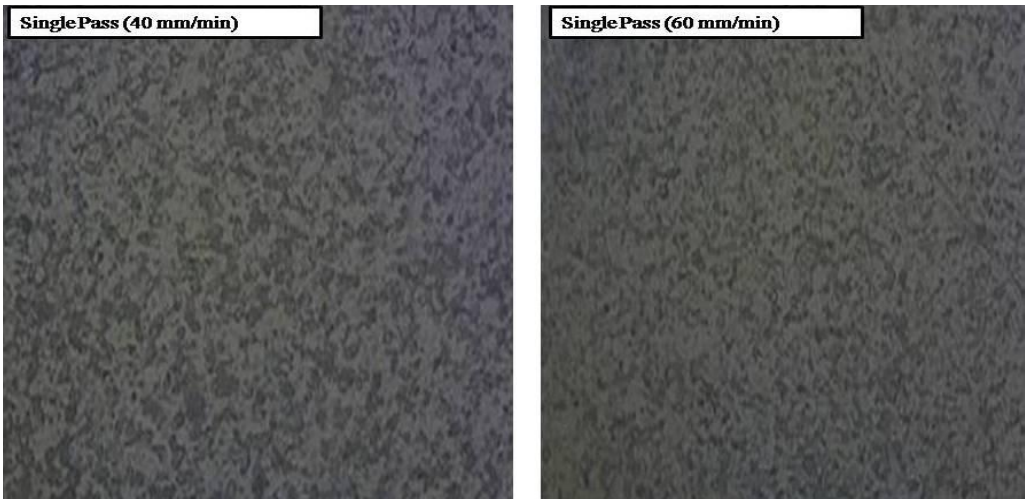

Figure 10. Effect of welding speed on microstructure with reinforced SiC single pass FSW

Figure 10 shows the effect of welding speed on microstructure of Stir Zone of specimen welded at a constant tool rotational speed of 1450 rpm with doping Silicon Carbide micro particles. It is observed that the grain size of Stir Zone of Friction Stir Welded joint was the function of welding speed, it decreases with increase in welding speed due to low heat input which reduces time for grains to grow [23]. Due to material deformation caused by tool shoulder and pin, the mixing of material flows associated with pin and shoulder leads to grain refinement [24].

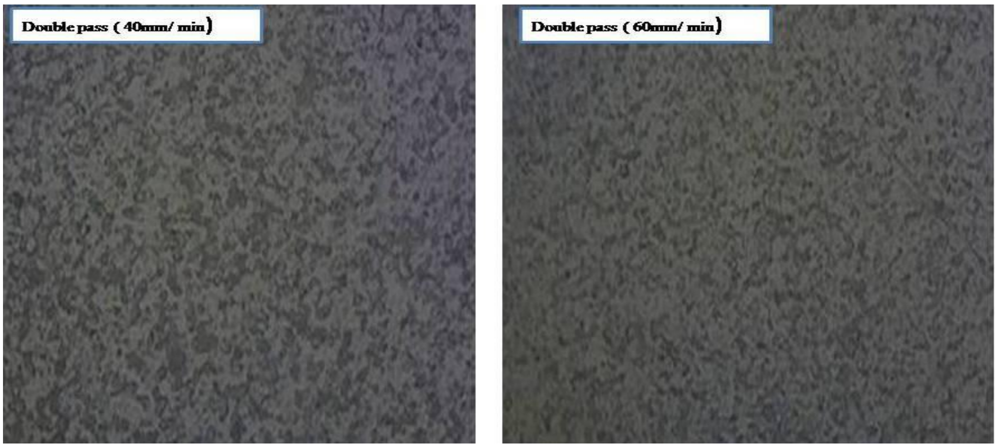

Figure 11. Effect of welding speed on microstructure with reinforced SiC double pass FSW

Figure 11 shows the dispersion of Silicon particles in the stir zone at welding speed of 40 mm/min and 60 mm/min during single and double pass FSW. It is revealed that double pass Friction Stir Welding cause more intense stirring of the welded zone resulted in more dispersion of reinforcement particles in the SZ. As shown in Figure 4.12 homogeneous dispersion of SiC particles in SZ during double pass friction Stir Welding improves micro hardness properties as well as tensile properties

V. CONCLUSIONS AND SCOPE OF FUTURE

In this work, a study of three welding speeds along with double pass FSW has been carried out on Friction stir welded joints with and without reinforced Sic micro sized particles. Analysis has been carried out on AA 6106 alloy of 6 mm thick plates. The welding process was carried out at a constant tool rotational speed of 1450 rpm with 20 mm tool shoulder diameter. The following are the conclusions drawn from the present research:

- The process parameters consisting of welding speed (40 mm/min, 60 mm/min and 60 mm/min), number of passes (Single and double pass FSW) and doping of micro sized SiC particles affect the micro hardness and tensile strength significantly.
- Tensile strength increases with increase in welding speed from 40 mm/min to 60 mm/min due to proper material flow from retreating side to advancing side.
- Doping of SiC particles decreases tensile strength of Single pass friction Stir welded joints. Double pass Friction stir welding causes homogeneous dispersion of SiC particles thus increases the tensile strength.
- Highest value of Micro hardness at the rate of 122 Hv at Stir Zone is achieved with doubles pass Friction stir welding by doping SiC particles. Doping of SiC makes the matrix harder as compared to Friction stir welded joints without SiC particles.
- Refinement of grain structure is achieved at Stir Zone in Single pass FSW as well as in Double pass FSW.

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