An Overview of Friction Stir Welding of Metal Matrix Composites

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***Abstract* –**Metal matrix composites comprises of a metal having low density, such as aluminum, magnesium etc. having reinforcements in the form of fibers and particles of a material like silicon carbide or graphite. Metal composites have good specific strength, stiffness, operating temperature and good wear resistance than the unreinforced metals. They have wide range of applications especially at places where saving weight is an important factor like aerospace, automobiles etc. Friction stir welding (FSW) is a promising technique of welding used for joining various metal composites. The present paper gives an overview of friction stir welding of metal composites explored through various research studies and experiments in a systematic and chronological order. It also gives the impact of different process parameters on the microstructure and mechanical properties of the FSW joints of metal composites in comparison to the base metal.

Key words - Friction Stir Welding, Metal Matrix Composites, Base Metal, Mechanical Properties, Microstructure.

I.INTRODUCTION

Two or more materials that have different chemical and physical properties combine to form a composite, whose characteristics are different from the individual constituents. In metal composites one part is necessarily a metal and other material can be a metal or another material, such as organic compound or a ceramic. Metal-matrix composites have improved physical, thermal and mechanical properties i.e. low density, good specific strength, stiffness, high thermal conductivity, better fatigue resistance, thermal expansion control, and good wear resistance which makes these materials suitable for structural, aerospace, automotive, electronic, thermal and wear applications[1]. Due to wide range of applications of metal composites efforts are being made to develop technology that can enhance the performance of the metal composites. Friction stir welding has been an emerging technology used for welding of various metals and its alloys especially aluminum and magnesium. But how effectively FSW can be used for joining of metal composites is yet to be explored.

II. FRICTION STIR WELDING

The Friction Stir Welding (FSW) was evolved in 1991 at The Welding Institute [2]. This process can be used to weld aluminum, magnesium, titanium, copper alloys [3]. FSW is a process in which welding state remains in solid state. In this process a special tool having shoulder and a pin is rotating with tilt angle. Tool is inserted between the edges of the plates to be joined in such a manner that shoulder meets the top surface of the plates. Tool moves along the interface with some welding speed [4]. Friction produced due to movement of shoulder and work piece increases the temperature of the material which results in heating which causes the plastic deformation [5]. On the other hand, pin causes the stirring action between the interfaces of the two plates and shoulder puts the force like forging which formulate the joint. Both the tool rotation and welding speed of the tool helps forming the joints. Figure 1 explains the working of FSW technique.

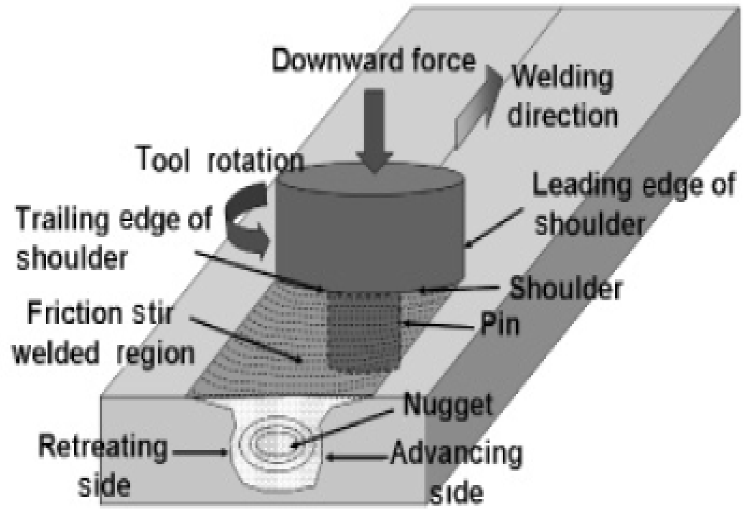

Figure 1. Schematic representation of FSW technique [6]

The friction of the tool with the work piece generate heat which makes the material elastic which gets moved from front of the tool to the rear side which is further joined by the shoulder of the tool to make a weld. The tool is used for three purposes i.e. generation of heat for the plates, stirring of the material for joint formulation and pressing of the material using tool shoulder. Friction that takes place between rotating pin of the tool and shoulder causes plastic deformation of the work piece results in heat generation. Material around the pin gets softened due to localized heating. The transverse movement of the tool moves the material from front to rear of the tool which fills the hole at the back end and tool shoulder helps in bonding the material together by putting pressure. As a result a solid joint is produced without melting. Different microstructure regions of the welded zone are given in figure 2.

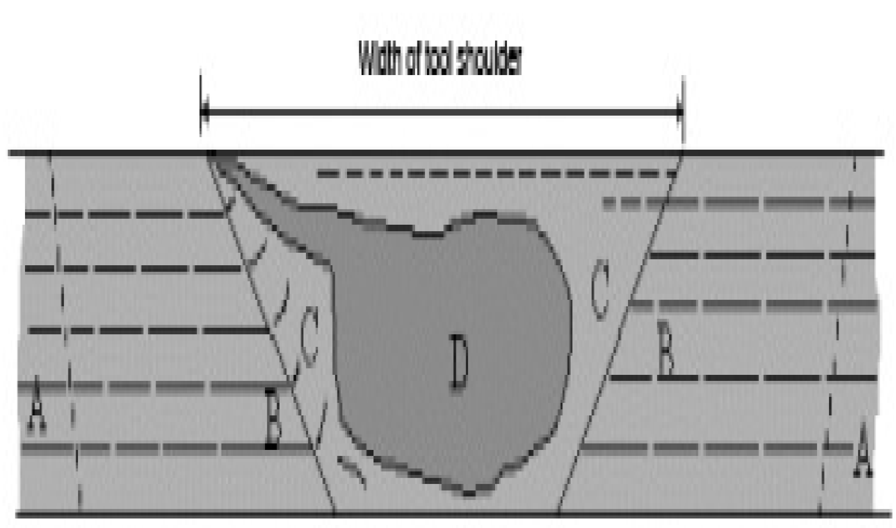

Figure 2. Welding regions [5]

A. Material which remained unaffected
B. Heat affected region (HAZ)
C. Thermo-mechanically affected region (TMAZ)
D. Nugget region (Part of TMAZ)

A. Material which remain unaffected

This is part of work piece goes under a thermal cycle but not directly affected by heat which changes microstructure and mechanical properties. It is basically that part which has not deformed due to heat.

B. Heat affected region (HAZ)

HAZ is very near to weld center where there is no plastic deformation. In this region the material has experienced a thermal cycle which resulted in change in the microstructure and the mechanical properties due to heat.

C. Thermo-mechanically affected region (TMAZ)

This region is deformed plastically due to tool used for welding, and the heat from the process also influences the material. Significant plastic strain without recrystallization in aluminum alloys forms a distinct boundary between the deformed zone and recrystallized zone. TMAZ in aluminum alloys is due to deformation at high temperature without recrystallization. In case of other materials, TMAZ is recrystallized but there is absence of nugget region.

D. Weld Nugget

Nugget is recrystallized area of TMAZ in aluminum alloys. This part is scientifically very important. A diagram representing regions of microstructure is shown in the above figure 2. This area is below the tool shoulder. It is part of TMAZ where grain structure is different. This area is also considered sub-zone of the TMAZ. Friction stir welding has many advantages as compared to conventional fusion welding techniques. There are different mechanical, metallurgical and environmental advantages. Better mechanical properties such as tensile strength, hardness etc. of the welded joints is obtained using this process. Structure having low distortion and good stability is obtained after welding. The joints are of high quality which is defect free. There is dynamic recrystallization of the grain structure which results in refinement of grains. There is less wastage of material, fuel and energy. The emission of gases during the welding is negligible as compared to other welding processes. Due to all these merits of the FSW process, lot of studies and experimentation is going to see the influence of the welding parameters on the welded joints of similar and dissimilar materials.

III. DIFFERENT PARAMETERS OF FSW

Friction stir welding have different parameters which can affect the mechanical properties and microstructure of the welded joints. Some of important welding parameters are given as:

1. Tool material: Tool material must have good shear strength, proper dimensional stability, wear resistance and oxidation resistance.
2. Tool shape: FSW tool has shoulder which is of concave shape to escape the material. It puts downward pressure which forges the material. Pin is of cylindrical shape which develops stirring and causes the plastic deformation. Tilting the tool at certain angles helps in better bonding of the material to be joined.
3. Tool rotation & Welding speed: Increasing the rotating speed causes the plastic deformation of material by increasing the temperature. Increasing the tool rotational speed after certain level, results in coarsening of grain structure. Lower feed rates results in more heat which helps in easy movement of the tool. Very high feed rate can cause voids and cracks in the weld due to low heat input.
4. Welding forces: Different types of forces act on the tool during welding process due to very high temperature and pressure. These forces should be kept low as possible for better joints. [6]

IV LITERATURE REVIEW

A thorough examination of the various online research studies was undertaken to find out the effectiveness of friction stir welding for metal composites. Table 1 summarizes the review studies with a brief detail:

TABLE 1

OVERVIEW OF THE STUDIES RELATED TO FSW OF METAL COMPOSITES

Sr. No.	Name of the Researcher	Year	Contribution	Workpiece material	Parameters & Properties selected	Major Findings
1.	Liu et al.	2005	To find out the wear characteristics of WC-Co tool used for FSW of AMC having 30 percent SiC.	Aluminum matrix composites	Tool wear	The initial welding had resulted in maximum wear and welding speed resulted in the wear of the pin.
2.	Amirizad et al.	2006	Study of microstructure and mechanical properties of FSW of AMC with 15 percent SiC particles.	A356 with 15% SiC_p	Tensile properties and Hardness	FSW can be easily used to join aluminum matrix composite castings.
3.	Lee et al.	2006	Study of microstructure and wear resistance of FSW of magnesium matrix composite containing SiC.	AZ91 Mg with SiC as particulate	Hardness and Wear	The hardness of the weld zone more and uniformly distributed. Wear resistance of welded zone was better than the base metal.
4.	Ceschini et al.	2007	Study of effect of FSW joints of AMC with 10 percent Al_2O_3 particles on the microstructure, tensile and fatigue properties.	AA7005 with 10 % Al_2O_3	Tensile Strength, Fatigue and Microstructure	Better joint efficiency of joints as compared to that of base metal.
5.	Uzun	2007	Study on Friction stir welding aluminium alloy matrix composite with SiC as particulate.	AA2124 with SiC_p	Microstructure and Microhardness	The weld nugget had homogeneous SiC particle distributions containing fine particles.
6.	Feng et al.	2008	Study of mechanical properties with microstructure of joints of alloy matrix composite with SiC as particulate formulated using FSW.	AA2009 with 15% SiCp	Hardness, Longitudinal and transverse strengths	Improvement in strength of the welded joints and grain growth was revealed in the microstructure.
7.	Pirondi & Collini	2009	Analysis of FSW butt joints of AMC with Al_2O_3 as particulate keeping in view resistance to crack propagation.	Al with Al_2O_3 as particulate	Fatigue crack propagation resistance	Welding affects fracture toughness and crack growth rate due to fatigue in different manner which depends upon the material.
8.	Minak et al.	2010	Study of fatigue properties of AMC welded using FSW.	AA6061 with 22 vol.% of Al_2O_{3p}	Ultimate tensile strength	FSW of composite using different welding parameters showed decrease in fatigue properties as compared to base composite.
9.	Vijay & Murugan	2010	Study of microstructure and mechanical properties of friction stir welded AMC with 10 percent TiB_2 keeping in view affect of tool pin shape.	Al with10 wt.% TiB_2	Tool pin profile	Joints welded using pin having square shape has improved mechanical properties than other pin shapes.
10.	Bozkurt et al.	2011	Study on Friction stir welding aluminium alloy matrix composite with SiC as particulate.	AA2124 with SiC	Microstructure ,Microhardness, and Tensile strength	Tensile strength of FSW butt joints was found to be less than that of the base composite.
11.	Gopalakrishnan & Murugan	2011	Study of tensile strength of friction stir welded aluminium matrix composite having TiC as particulate.	AA6061 with TiCp particulate	Axial force, Speed of welding, Tool speed, Percentage of TiC addition	FSW joints of high efficiency were obtained.

12.	Nami et al.	2011	Friction stir welding of aluminium matrix composite having 15 wt. % Mg_2Si as particulate and study of their mechanical properties and microstructure.	AMC with 15 .% Mg_2Si	Microhardness and Tensile strength	Friction stir welding can be applied to weld aluminium matrix composite having 15 wt. % Mg_2Si as particulate.
13.	Payganeh et al.	2011	Study of affect of FSW on the appearance and strength of polypropylene composite containing glass fiber.	Polypropylene composite plates having 30% glass fiber	Pin shape, Tool speed, linear speed and Tool tilt and strength	Tool pin shape significantly affected the weld quality. The tool speed and tilt angle had more affect on appearance of the weld as compared to linear speed.
14.	Dinaharan and Murugan	2012	Friction stir welding of aluminium matrix composite having ZrB_2 as particulate and Study of mechanical, microstructure and wear properties.	AA6061with 10 % ZrB_2	Hardness, Tensile strength and Wear resistance.	The weld zone had more hardness than the base material. The tensile strength of welds was same as that of parent composite. The wear resistance of the composites increased after FSW.
15.	Boromei et al.	2013	Friction stir welding of aluminium matrix composites having Al2O3 as particulate and Study of microstructure and impact strength.	AA6061 with 20% of Al2O3 and AA7005 with 10% of Al2O3 particles	Microstructure and Impact energy	The Impact energy of the FSW joints was more as compared to base materials.
16.	Cioffi et al.	2013	Friction stir welding of aluminium matrix composite reinforced with ceramic.	2124Al with 25 % SiC_p	Tensile strength	The size of TMAZ, increased at rotational speed.
17.	Periyasamy et al.	2013	Optimization of parameters of friction stir welding process parameters used to form joints of Al/SiCp metal matrix composites.	AA6061 with 20% SiC_p	Rotational speed, Traverse speed and Axial force / Tensile strength and hardness	The joints mechanical properties were affected by different welding parameters.
18.	Wang et al.	2013	Study of FSW of AMC with SiC_p.	AA2009 with SiC_p	Ultimate tensile strength	The SiC particles got homogenously distributed in the nugget zone as compared to base material.
19.	Ni et al.	2014	Study of strain-hardening and tensile properties of joints of AMC having SiC_p formed using FSW.	AA2009 with 17 % SiCp	Tensile properties and Work hardening	The FSW joint had higher strain hardening rate as compared to that of base material.

The welding speed had great impact on wear of the tool pin and maximum wear was generated during the initial part of welding in aluminum matrix composites (AMCs) composed of 30 % SiC particulates [7]. FSW can be used to join aluminum matrix composite having 15%SiC_p and gives better mechanical properties in the weld zone than the base composite [8]. The hardness near weld zone was more homogenous than the welded region while resistance to wear of the welded zone was more than the base metal in AZ91 Mg alloy with SiC [9]. Joint efficiency of the FSW joints of composite with 10 % of Al_2O_3 particles was more as compared to base composite [10]. Friction stir welding can be used to formulate joints of AA2124 having 25 % SiC_P [11]. FSW improved the hardness, longitudinal and transverse strengths of the welded composite joint having AA2009 as base metal and 15% SiCp [12]. Welding process affects the resistance to fracture and crack growth rate differently based upon the material in Al–Al_2O_3 particulate-reinforced composite [13]. FSW joints under different welding parameters showed improvement in fatigue behavior than that of the base composite of AA6061 with 22% of Al_2O_{3p} [14]. Joints of Al with 10% TiB_2 welded using square pin profile gave improved mechanical properties than other pin profiles [15]. Tensile strength of butt joints of composite of AA2124 with 25 % SiC_p was found less than that of the base composite [16]. The tool pin shape and the welding speed affect the tensile strength [17]. Friction stir welding can be used to formulate joints of aluminum matrix composite having 15% Mg_2Si [18]. Geometry of tool pin affects the quality of weld in polypropylene composite plates consisting of 30% glass fiber by weight. The tool rotation speed and tilt angle affects the appearance and strength more as compared to linear speed.

V. CONCLUSION

After thorough investigation of the studies related to friction welding of metal composites it can be concluded that FSW is a better method for joining metal composites as improved mechanical properties in terms of tensile strength, fatigue properties, wear resistance and hardness compared to base metal was obtained. But few studies have depicted negative effect too on the properties of metal matrix composites as compared to the base metal [14,16] which paves the way for further research in this area.

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