Investigation on Hardness Properties of Friction Stir welded AA 2024 Hybrid Metal Matrix Composite Plates

Sadashiva.M [1], H.K.Shivanand [2]

[1] Assistant Professor Department of Mechanical Engineering PESCE, Mandya, Karnataka, India,
[1]Research scholar, Department of Mechanical Engineering, JNTUA, A.P, India
[2] Associate Professor, Department of Mechanical Engineering, UVCE, Bangalore, Karnataka, India

Abstract- **In today's world, requirement of light, inexpensive and quickly processed materials has increased to a great extent. The Al 2024 is an alloy with copper as the primary alloying element and used in applications requiring light weight, wear resistance, high strength to weight ratio and high elastic modulus. The Aluminium metal matrix composites (MMCs) have applications in many industries specially in Aerospace domine, however to extend their applications limit, an appropriate effective joining methods needed for developing a robust structure. In the present research work, Aluminium based metal matrix hybrid composite plates are prepared using stir casting method using graphite crucible furnace, followed by joining is carried out by Novel Solid state Friction stir welding (FSW) process using non consumable cylindrical tapered tool with the welding parameters like rotational speed and traverse feed, and the impetus given on the effects of torque, normal force, traverse force that acts on the plates during welding. The specimens made were tested on vickers hardness tester. The effect of different weight percentages of SiC particulates and E-glass fiber reinforcement in hybrid MMC plates on hardness was studied. The main objective is to evaluate and compare the hardness of Hybrid Aluminium metal matrix composite plates with basic material and weld zone. The results show that, the hardness increases with the reinforcement of SiC and E-glass fibers with AA 2024 alloy also weld zone exhibits excellent hardness compare to base.**

Keywords: Friction stir welding, Metal matrix composites, Stir casting, Hardness..

I. INTRODUCTION

Hybrid MMCs are made by dispersing two or more reinforcing materials into a metal matrix. They have received considerable research and trials by many research institutes in the early 1980s. Hybrid metal matrix composites are a relatively new class of materials and have many advantages over monolithic metals characterized by lighter weight, greater strength, high wear resistance, good fatigue properties, good hardness properties and dimensional stability at elevated temperatures than those of conventional composites. Because of these attributes metal matrix composites (MMCs) are under consideration for a wide range of applications. Automobile, Aeronautical industry or ship building industry are associated with continuous searching for material with low density, low specific gravity, high stiffness and specific strength, materials which preserve relatively high hardness property.[1]

The aluminium metal matrix composite materials is combination of two or more constituents in which one is matrix and other is filler materials (reinforcements). Aluminium metal matrix may be laminated, fibers or particulates composites. These materials are usually processed through powder metallurgy route, liquid cast metal technology or by using special manufacturing Process.

The modern development in the field of science and technology demands the developments of advanced engineering materials for various engineering applications, Specially in the field of transportation, aerospace and military engineering related areas.

S. Balasivanandha prabhu. Et al, [2006] has studied high silicon content aluminium alloy-silicon carbide metal matrix composites were successfully synthesized, using different stirring speeds and stirring times. The present research work is fascinated about the work carried out by the researcher by studying the methods adopted by them in fabrication of AMMCs and the same is adopted in the present research work. [2]

Manoj single. D. et al., (2009), has studied to develop an aluminium based silicon carbide particulate MMCs with an objective to develop a conventional low cost method of producing MMCs and to obtain ahomogenious dispersion of reinforcement by stir casting technique. it is decided in the present work to fabricate the Aluminium based metal matrix composites using a Silicon carbide and E-glass fiber reinforcements.[3]

Literature depicts that a considerable amount of work has been carried out by previous Investigators to prepare the mechanical properties of Al 2024/sic/E-glass fiber composite. The main challenge in the development and processing of a Engineering materials is to control the microstructure mechanical properties and cost of the product through chemical composition, processing method and. This requires the sound theoretical and practical knowledge of the materials engineers. This made to adopt stir casting method to get sound cast.

Friction stir welding (FSW) was invented and patented by W. M Thomas et al. of the Welding Institute in Cambridge, UK.,[4] it is energy efficient, environmental friendly solid state welding process. Since there is no dendrite structure, porosity distortion and residual stresses, provide controlled and modified micro structures in metallic materials. this process can be used for joining most of the aluminium alloy.
FSW uses a rotating cylindrical tool having a shoulder and a pin (tip) which is pressed against the work material to be processed and moved along the welding direction. The local heating due to friction and forging action of the tool deform and process the work material at high temperature. Since the material flows at high temperatures, the process offers the possibility of redistributing the particles in AMCs [5-8].
In friction stir welding material is subjected to plastic deformation at elevated temperature due to stirring action of the rotating tool friction stir welding achieves solid phase joining by locally introducing frictional heat and plastic flow by rotation of the welding tool with resulting local microstructure change in aluminium alloys the welding temperature in friction stir welding ranges between 425-480 degree Celsius.
Usually the welding temperature not exceeds 80% of melting point and does not cause melting but it's enough to cause dissolution of strengthening particles in heat affected zone, thermo-mechanically affected zone and the nugget zone which leads to the formation of softened with degraded mechanical properties in heat effected zone .friction stir welding also cause s the grain refinement in the weld zone due to which the tensile strength of the joint increases with little loss of ductility

The potential applications of FSW in Aerospace, marine, automobiles and land transport domains are as mentioned below: Engine and chassis cradles, Wheel rims, Truck bodies, Tail lifts for Lorries, Mobile cranes, Fuel tanks. [9]

II. EXPERIMENTAL WORK

The present work carried with the fabrication and hardness characterisation of a hybrid composite with the following constituents.
*Aluminium 2024 matrix
Aluminium silicon magnesium alloys – commonly known as AA2024 series alloys.

Table 2.1 chemical composition of Al 2024

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	others
0. 50	0. 50	3.8- 4.9	0.30- 0.9	1.2- 1.8	0. 10	0.25	0. 15	0.15

The composites of above materials varied in the following proportions:
90% Aluminium 2024+3% E-glass +7% SiC particulates

The experimental procedure adopted in the present research work consists of three phases mentioned as below:

Phase: 1 Fabrication
Cast Aluminium 2024 ingots for a particular composition were placed inside a graphite crucible and melted in a coke fire open furnace, the temperature of a furnace was made to reach 800o C. Aluminium melts at around 660o C the superheat was given to ensure liquid state of aluminium 2024 during mixing and pouring. Molten aluminium 2024 is taken in a ladle and it is poured in to a mould set up contains mould cavity of require shape of plates and produce null percentage of reinforcement in aluminium 2024 specimen followed by varying percentage of sic and E-glass. But preparation of hybrid composite is contains following steps preheat the furnace, placing ingots and heated up to 800 o c separately weigh the 7% and 3% weight fraction of fine greenish silicon carbide particulates preheated up to700o C (preheat leads proper wettabality and prevent sudden cooling of the melt which causes the brittleness) and short chopped E-glass fiber preheated to 500 0C respectively. Before this preheated ingredients added to the mixture, some of the molten state aluminum 2024 is taken out of the furnace, Poured after adding preheated reinforcement in furnace. Immediately the mixture of crucible was stirred with the help of electric stirrer at the speed of 500 rpm for 10 minutes to get homogeneous distribution of reinforce in matrix maintain pouring temperature before poured into the cope and drag box setup, allowed to solidifies up to 1 hour after takeout the cast specimen. After allowing the mould to cool at room temperature, the cast material (fig4.8) is taken out, by opening the mould halves

Fig: 1, Al 2024 Ingot


Fig: 2, Sic

Fig: 3, E-glass fiber


Fig: 4, open type crucible


Fig: 5, mixing of Sic and

Furnace *E-glass fiber mixture(preheated)*

Fig: 6, Stirring with Electrical Stirrer

Fig: 7, prepared mould cavity

Fig:8, pouring of molten AMMC

Fig:9, Solidified Cast product

Phase 2: Machining

The cast specimen had to be machined for to get standard weld specimen. The dimensions are in accordance with the ASTM standards. The specimens dimension is 100mm*50mm*6mm.

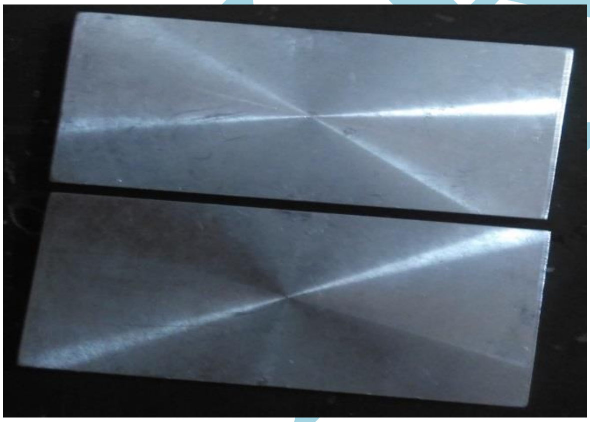


Fig: 10, Machined plates according to ASTM standards

Phase: 3 Friction stir welding

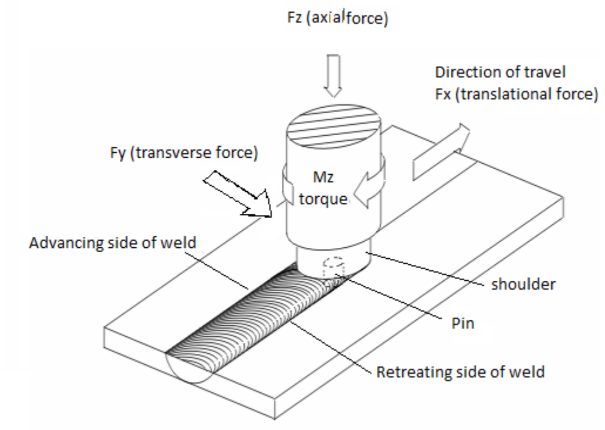


Fig: 11, friction stir welding

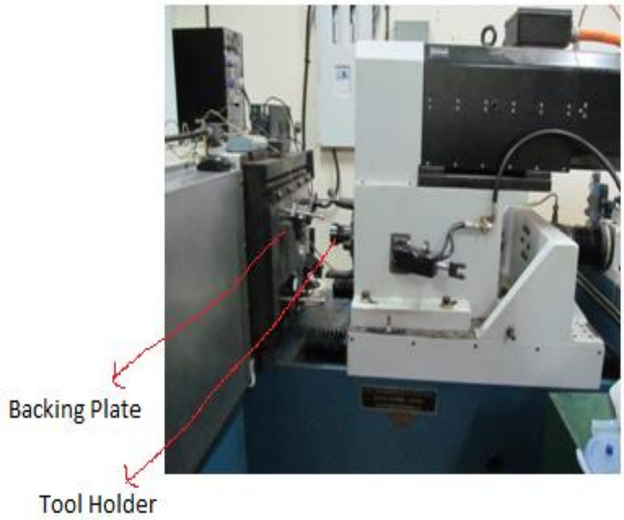


Fig: 12, FSW Machine

In this phase, the ASTM standard plates of size 100mm*50mm*6 mm are brought to butt join using Friction stir welding. The welding is carried out using an indigenously built robust Friction Stir Welding machine, with the shoulder pin of the tool plunging in between plates. Friction stir welding parameters are set considering the tool rotational speed as 600 rpm, 800 rpm and 1200 rpm, tool traverse feed rate as 40 mm per min. with a single pass and tilt angle as zero[12] [13] [14] [15]

The Tool considered in current research is having a shoulder diameter of 25 mm and a tapered pin of 5 mm length, Initially the two plates of aluminium are fixed firmly on the backing plate of versatile FSW machine in the vertical position and a compressive load is applied on the plates in order to prevent the formation of gap between two work plates, the bolt and nuts are tightened by using an allen key firmly to further enhance the compressive load acting on the plates. The machine is switched on and the hydraulic system is actuated, the spindle is operated and the parameters are fed to the FSW machine making use of a data interface setup and the welding is done on plates, the weld length is input in the data interface as 70 mm and tool penetration as 5.2 mm. [16]

Fig: 13, friction stir welding tool

The FSW process uses a cylindrical tapered tool having shoulder and tip whose dimensions are as follows,
Tool material-HcHr
Tool pin length-5mm
Pin top diameter-4.5mm
Pin bottom diameter-6mm
Tool shoulder diameter-25mm
Hardness-58-60 HRC

Processing parameters in FSW Process for specimen-1
Table no: 1, (Al 2024+0%E-glass+0%Sic)

Spindle speed	600 rpm
Traverse speed	40 mm/min
Plunger depth	5.2 mm
Pre heating time	10 sec.
Tool tilt angle	0

Processing parameters in FSW Process for specimen-2
Table no:2, (Al 2024+3%E-glass+7%Sic)

Spindle speed	600 rpm
Traverse speed	40 mm/min
Plunger depth	5.2 mm
Pre heating time	10 sec.
Tool tilt angle	0

Processing parameters in FSW Process for specimen-3
Table no:3, (Al 2024+3%E-glass+7%Sic)

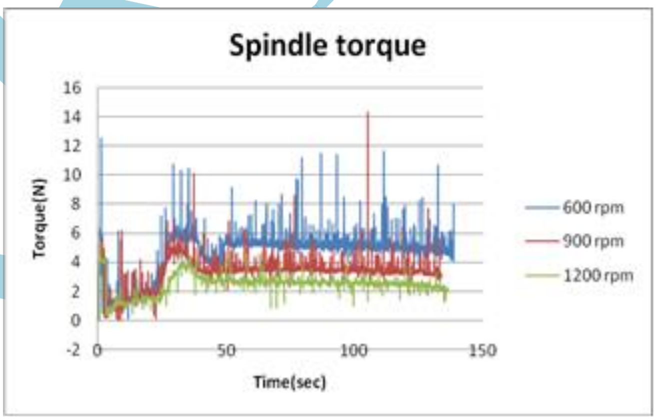
Spindle speed	900rpm
Traverse speed	40 mm/min
Plunger depth	5.2 mm
Pre heating time	10 sec.
Tool tilt angle	0

Processing parameters in FSW Process for specimen-4
Table no:4, (Al 2024+3%E-glass+7%Sic)

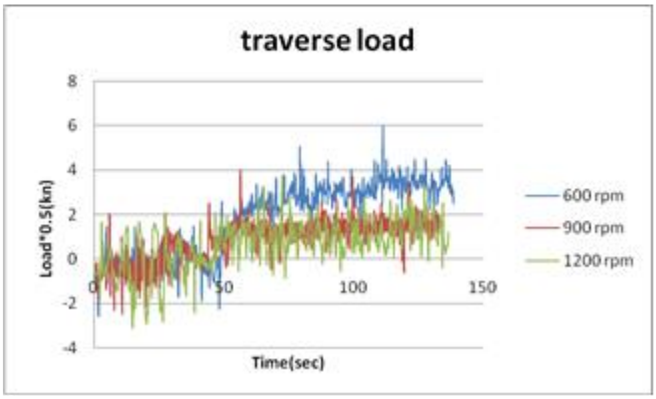
Spindle speed	1200rpm
Traverse speed	40 mm/min
Plunger depth	5.2 mm
Pre heating time	10 sec.
Tool tilt angle	0

Fig: 14, Friction stir welded plates.

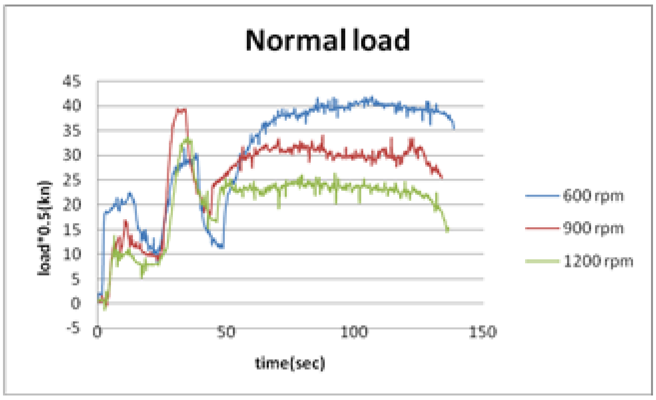
RESULTS AND DISCUSSIONS OF FSW PROCESS OF AA 2024 ALUMINIUM ALLOY



Graph no: 1 Comparision of Spindle torque for Various speeds with constant feed40 mm/min.



Graph no: 2, Comparison of Traverse load for Various speeds with constant feed 40mm/min.



Graph no: 3, Comparison of Normal load for various speeds with constant feed 40mm/min.

The graphs are plotted for Normal load vs time in seconds, Spindle torque vs time in seconds, Transverse load vs time in seconds for Aluminium 2024 specimens (base material) as well as Aluminium 2024 /3% E Glass /7% SiC specimens, It is distinct form the graph of normal load versus time, that the normal load varies between 0 k N to 20 k N for an initial duration of 50 seconds (i.e., the time interval for plunging) to further become at 21 k N(Peak value) and constant load on weld during 60-130 sec for remaining , finally drop down at the end of the process.

From the graph of spindle torque vs time, clear inferences can be drawn from the fact that the spindle torque varies from zero to a peak value of 14N-m during the initial interval of 40 - 130seconds inherently described as the time taken for plunging, and then remain constant until the end to further drop down at the completion stage of the process.
The graph of transverse load vs time is indicative of the fact that the transverse load varies from (-3*0.5 k N = - 1.5 k N to +4*0.5 k N = 2k N) throughout the time duration consumed for friction stir welding the component. i.e., Negative sign indicates that the transverse load component is considered in negative X – axis.

IV. HARDNESS TEST

Followed by Friction Stir Welding the Hardness is carried out with Vickers Hardness testing method for hybrid metal matrix composites plates for varying compositions and also with varying FSW parameters. And the results have been compared with basic material.

Fig: 15,Dimond cone impression on weld zone of FSW sample.

In Vickers method constant range of light loads applied using a diamond indenter to make an indentation which is measured and converted to a hardness value.
A square base pyramid shaped diamond is employed in the present work for testing in the Vickers scale and 50Kgf is applied on the work samples to make an indentation on base of the specimen and also on the weld zone. Furthur the indentation dimensions are measured using tool makers microscope to avoid the errors as much as possible and finally Vickers pyramid number is calculated by the given formula. Test trials mentioned below

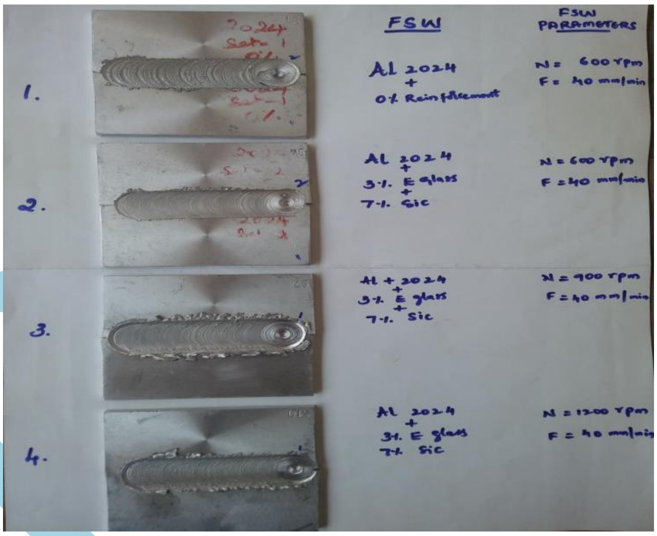


Fig: 16, Friction stir welded plates subjected to indentation

RESULTS AND DISCUSSIONS FORMULATION

VHN= (1.854*P)/L^2
Where P= Load applied for indentation to occur.
L= Average length of the indent (Rhombus)

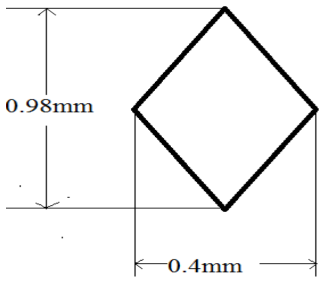


Table no:5, Vickers Hardness Number

Sample	Al+ 0% E-glass +0% Sic		Al+ 3% E-glass +7% Sic		Al+ 3% E-glass +7% Sic		Al+ 3% E-glass +7% Sic	
Location	ob	ow	ob	ow	-	ow	-	ow
Speed rpm	-	600	-	600	-	900	-	1200
Feed mm/min	-	40	-	40	-	40	-	40
Impression -1(HV)	85.7	102.82	97.0	118.75	-	114.57	-	136.0

Impression -2(HV)	86.6	113.81	87.3	113.43	-	187.57	-	99.73
Impression -3(HV)	84.8	110.0	103	111.69	-	115.59	-	116.6
Average (HV)	84.8	108.87	96.0	114.62	-	139.24	-	117.4

Ow: on weld spot of FSW
Ob: on base material

CONCLUSION

In this investigation an attempt has been made to study the effect of Normal load, Traverse load and Spindle torque on the formation of friction stir processing zone in a single sided friction stir weld on al 2024 hybrid metal matrix composite plates. And hardnes test have been carried out for the hybrid samples and compared with the basic material by taking in to an account of Friction stir speed as a main parameter, From this investigation, the following important conclusions are derived:

Table no: 6, Vickers Hardness Number

Sample	Al+ 0% E-glass +0% Sic		Al+ 3% E-glass +7% Sic		Al+ 3% E-glass +7% Sic		Al+ 3% E-glass +7% Sic	
Location	ob	ow	ob	ow	-	ow	-	ow
Speed rpm	-	600	-	600	-	900	-	1200
Feed mm/min	-	40	-	40	-	40	-	40
Average (HV)	84.8	108.87	96.0	114.62	-	139.24	-	117.4

The increasing in hardness have been observed in Al+ 3% E-glass+7% than Al+0% E-glass+0%Sic this shows the Hybrid metal matrix composites have higher hardness property than the basic material.

The joints fabricated by single pass weld have shown higher hardness number for Vickers hardness is at 1200 rpm. at feed rate of 40mm/min. than 600 rpm and 900 rpm, the hardness had increasing gradually with increasing speed.

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