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Properties of an Alluminium Metal Matrix and Hybrid Composites Reinforcement using Friction Stir Processing

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Abstract: *Aluminium metal matrix and hybrid composites (AMMHCs) are new materials used in recent time that have the capacity to meet the demand of advancement in processing applications. Several types of reinforcement have been used since the inception of friction stir processing (FSP). The most widely used reinforcing material is inorganic (metallic) powders such as silicon carbide, titanium alloy, graphene, iron , stainless steel, nitrides, oxides etc and fewer works have been reported on organic powders (i.e. bioprocessing using agro-wastes powders) such as fly ash, palm kernel shell ash, coconut shell ash, rice husk ash etc. Many researchers have established the roles of reinforcements in the modification of surface and texture of the reinforced metal matrix or hybrid composite material and how it enhanced the mechanical and metallurgical properties of the materials via intense, localized plastic deformation compare to the base material. FSP has advantages over other manufacturing processes in a way that it reduces defects and distortions in the material. FSP alters the physical properties of the base material without altering its physical state, this helps engineers develop attributes such as "high-state-rate superplasticity". The grain refinement occurs on the parent material which improves the properties of the first material while mixing with the second material (reinforcement). Subsequently, allows a variety of properties to be altered and this, in turn, improves its surface modification. The survey is aimed at reviewing different combination and diversified reinforcement particulates employed in the processing of composites of aluminium metal matrix and hybrid and how it enhanced the chemical, mechanical and metallurgical efficacy of the materials. It is very much needed to have a consolidated information about the different reinforcement phases, preparation of the microchannel (groove) that accommodates the reinforcements, its dimensions and various tools geometry that have been used in the past demonstrating the optimum processing results.*
Keywords*: Aluminium Metal Matrix, Hybrid Composites, Friction Stir Processing, Reinforcement Phases*

I. Introduction

Aluminium metal matrix and hybrid composites (AMMHCs) are widely used composites in the areas like aerospace, ballistic, electrical, aviation, tribological, space and air vehicle, automotive, thermal, structure, defensendustries, military, transportation, engineering and mineral processing applications because of their excellent and unbeatable combination of composites properties such as high strength-to-weight ratio, good corrosion, oxidation and wear resistance, high fatigue strength, low coefficient thermal expansion, high thermal and electrical conductivity, superior damping capacities, high specific stiffness and strength, creep resistance, and high plastic flow strength[1],[2].

Notwithstanding, aluminium alloys in isolation still suffer poor tribological properties and this can be overcome by the application of hard reinforcement phases in form of particles. Reinforcement particles provide AMMHCs materials a better strengthening at a lower cost, especially when using bioprocessing powder reinforcements. It has been established that favorable ductility in the metallic matrix materials would be maintained at the same time increased the modulus and the strength of the composites due to the reinforcement phase applied [3]. There two major categories of reinforcement; it can either be ex-situ or in situ. Ex situ is a way of synthesis route of adding reinforcement to the liquid or powdered metal, while the in situ method reinforcement compounds by reaction are formed during processing such as using reactivegases[4].

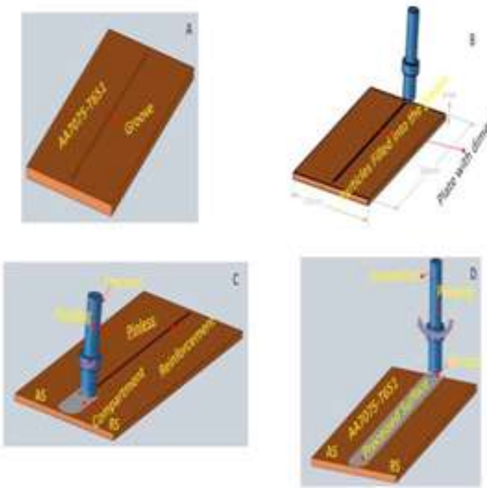
FSP is a novel processing technique derived from Friction Stir Welding (FSW) in which microchannel or groove that will accommodate the reinforcement phases may or may not be made on the matrix material[5]. FSP has become known across many industries for its potential to manufacture good AMMHCs in the solid state. It is facile, update and cost-effective to prepare AMMHCs using FSP [6]. Benefits of FSP include grain refinement, homogeneity of the processed zone, densification, and homogenization of precipitates of aluminum alloys and composites materials [7]. FSP has been established for improvement of the surface properties of the metal alloys, improvement in ductility, formability, hardness and strength as well as increase the fatigue life without altering the bulk metal properties[8]. In order to improve the surface quality by FSP, some challenges are encountered during the process of reinforcing the composite materials such as tool wear, sticking of the substrate to the backing plate especially when the job is in thickness between 1mm to 2mm, challenge on how to improve fatigue property and joining strength, many optimizations may be required to obtain optimum parameters and this may lead to the usage of manymaterials[9].

The fabrication and development of surface and bulk composites of aluminium substrate have been made possible by a novel technique via FSP. FSP as a solid-state processing method has significant advantages over conventional metalworking processing technique. It has proven to have a short-route, homogeneity and refined microstructures as well as densification. It is worth mentioned that mechanical and metallurgical properties of the processed zone can be controlled via the optimization of tool geometry such as shoulder diameter, probe length, probe profile, groove dimensions (width and depth) , and processing parameters such as rotational speed, travel speed, plunge rate, heat input, and cooling/heating methods[10]–[15]. The Schematic of a typical FSP shown in Figure 1 demonstrated how the microchannel (groove) is being packed with reinforcement phase in Figure 1a and the use of pinless tool in Figure 1c to compact the powder inside the groove thereafter a tool with pin as shown in Fig 1d is used to process the surface by the application of optimum process parameters. The schematic diagram of FSP showing advancing and retreating side is as depicted in Figure 2 and the compacting (pinless) and the stirring tool pin profiles are shown in Figure 3. The flowchart of the process parameters used in FSP is shown in Figure 4. Tables 1 and 2 show the use of reinforcements using powder metallurgy (PM) and agro-waste powder (AP) during FSP. The calculations of the proportion of the groove to the second phase materials are as shown in equation 1 to 3 [16].

$$Volume\ of\ Fraction = \frac{Area\ of\ groove}{Projected\ Area\ of\ tool\ pin}\ x\ 100 \qquad 1$$

$$Area\ of\ the\ groove\ = Groove\ width\ x\ Goove\ depth \qquad 2$$

$$Projected\ Area\ ofthe\ tool\ pin = Pin\ diameter\ x\ Pin\ length \qquad 3$$



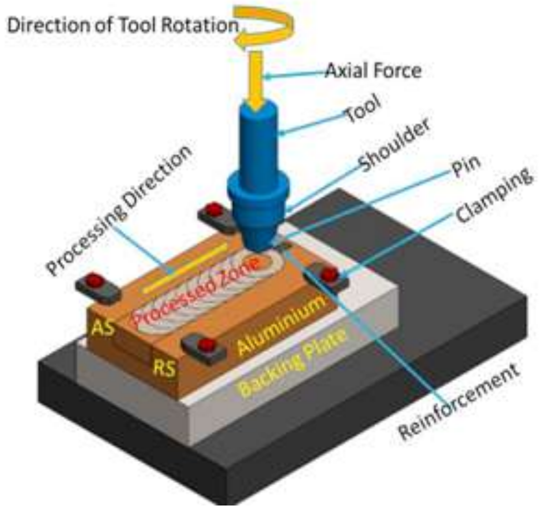
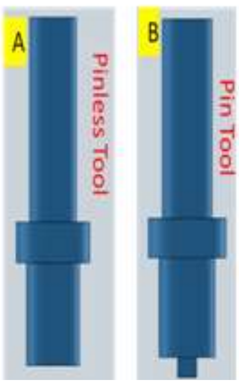


Figure 1: Schematic of atypicalFSP **Figure 2:** Schematic of FSP showing Advancing and RetreatingSide



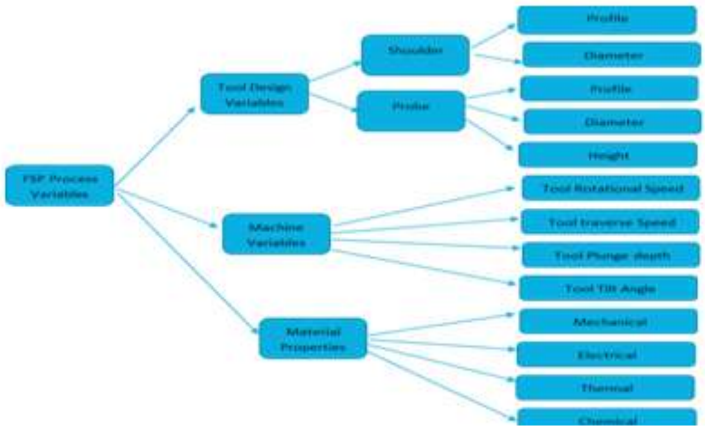


Figure 3: FSP Tool (a) For Compartment (b)ForStirring **Figure 4:** Flowchart of Process Variables used in FSP

Table1: Powder Metallurgy reinforcements based FSP

Types of Al and Dimensions	Tool Geometry	Reinforcement Particles	Groove Dimension	Process Parameters	Findings	Ref.
AA6082/Ceramic AMC & AA6082/SS AMC (100mmx50mmx1 0mm)	Cutting tool of threaded pin profile made of High carbon high chromium steel ,having 18mm Shoulder diameter and Pin diameter(5mm & 6mm) Pin length(5.5mm & 5.8mm)	Ceramic particles, of different grades like SiC, Al2O3, TiC, B4C and WC (18% vol) & Stainless Steel (316L) with (0, 6, 12 and 18 vol%) SS	Depth= 5mm and width=1.2 mm	RS = 1600 rpm; TS=60mm/min Axial force=10 kN.	Superior hardness and wear resistance ; Fine grain and enhanced tensile strength	[6], [20]
AA1050/TiC (200mm×160mm ×3mm)	H13 tool steel and hardened to 52 HRC	Titanium Carbide (TiC)	V-groove of about 5 mmwidth	RS =1200 min–1 ; 1600 min–1 TS= (100, 200 and 300) mm/min	Improved and Enhanced Hardness and Increased wear resistance	[7]
AA5083 (50 x 80 x 6mm^3)	Taper threaded pin and Pinless was used with 18 mm Shoulder diameter and 6mm of Pin diameter and also 4mm Pin length	B4C/SiC/TiC	Depth= 2.5 mm and width=1 mm	Pinless (RS=800rp m, TS=40mm/min) Pin(RS=600rpm, TS=20mm/min)	Improved hardness, tensile and wear properties	[18]
AA5083-H111, Thickness= 8mm	H13 steel treated with oxidizing andnitriding	Alumina particulate	NS	TS =180 mm/min and RS= 1120 rev/min.	Particles were evenly distributed having a good bonding affinity to the substrate and withconstant high hardness profile.	[21]
AA6061/SiC 220 mm×50 mm×8mm	H-13 steel (threaded and square). Shoulder diameter(20mm), Pin diameter(6mm) , Pin length(7.8 mm)	Silicon Car bide (SiC) - 50nm	Depth= 5.9mm and width=1m m	RS= 800-1600 r/min TS=40-160 mm/min And also RS=1400 rpm, TS=40 mm/min	Higher Tensil e strength was obtained for threadedtool	[22], [23]
Al-1050-H24), 5mm Thickness And A 1050-H24 aluminum of 5mmthick	Square probe shape of 5mm length and 3.3 mm height. 15 mm Shoulder diameter; 6mm and 4.3 mm Pin diameter and Pin length respectively	iron (Fe) of 4 µm and magnetite (Fe_3O_4) of 180 µm particles and SiC and Al_2O_3 particles 1.25mm	Depth= 1.5 mm and width=3 mm	RS = 1000–2000 rpm, TS = 1.66 mm/s	Homogenous and even distribution of Fe particles in the nugget zone at 1000 rpm after triple passes and Fe_3O_4 in the sound nuggetat 1500rpm	[24], [25]
AA5083	Plain cylindrical tool made of hardened steel. 15mm of Shoulder diameter; 5mm and 3.5 mm dimensions for Pin diameter and Pin length respectively	Ni particles of 20 µm. And Cu particles	Depth= 2 mm and width=1 mm; Length=50mm	RS= 1000 – 1800 rpm while TS=0.1 – 0.5 mm /s. Optimum were traverse speed of 0.4 mm/s as well as Rotation speed of1200 rpm	The strength increased significantly. Refined grains wereachieved.	[17], [26]

AA2024 of thickness 3.5 mm	Cylindrical shape of tool steel made of Hardened K- 110, With 25 mm and 8 mm for Shoulder diameter and Pin diameter respectively as well as 2.5 mm Pin length	Al_2O_3 of 30 nm nanoparticles	Depth= 2 mm and width=3 mm	RS= 900, 1120, 1400, to 1800 rpm and TS = 10, 15, and 20 mm/min, dwell time of 2 s as well as 0.5 mm/s of plunge speed	There was improvement in UTS and average hardness with respective percentage of 25% and46%.	[27]
Al 6061 plate of 6 mm thickness	H-13 Steel with a square probe tool of pin dimensions 5 mm X 5 mm and shoulder of diameter 25mm	SiC and Graphite powder of ~100 and ~44 µm, respectively	Grooves of 2mm X 3 mm	RS=1800, 2200, and 2500 rpm, TS= 25 mm/ min and Shoulder plunge depth is varied as 0.2,0.3, and 0.4 mm	Best and uniform mechanical properties are achieved	[28]
AA1100 (250mmx200mmx 5mm)	High speed steel (HSS) tool	Ti-6Al-4V of 35 nm	Grooves of width 3.5 mm and depth 3 mm	RS= 600 and 1200 rpm	Higher tensile strength; smoother and better anduniform distribution and reduction in agglomeration of particles	[29]
AA6063 ($100x50x10mm^3$)	Cylindrical threaded cutting tool made of HCHCr steel , having a pin profile which is straight , and Shoulder diameter(18mm), and Pin length(5.7mm) With Pin diameter(6mm)	TiO2 (~0.56 µm) of 0,6, 12, and18 vol%.	Width= (0,0.4,0.8,1.2mm) depth=5.5 mm	RS = 1600 rpm, TS = 60 mm/min	Reduction in the grain size. Excellent interfacial bonding. At a much particle content of about 18 vol%, there was a reductionin Tensile strength	[16]
NS – Not Listed; RS – Rotational Speed; TS – Traverse Speed						

Table 2: Agro-Waste (organic powders) reinforcements in FSP

Types of Al and Dimensions	**Tool Geometry**	**Reinforcement Particles**	**Groove Dimensions**	**Process Parameters &Conclusions**	**Findings**	**Ref**
AA6061 (100mmx50mmx10mm)	Threaded pin tool profile made of HCHCr steel with Shoulder diameter of values 18mm, 6mm and 5.8 mm for Pin diameter and Pin length resp.	Fly Ash (FA), varying from 0 to 18 vol. i.e. (0, 6, 12, and 18 vol.%).	Depth=(5.5m m), Width=(0.4, 0.8, and 1.2 mm)	Axial force of 10 kN, with 1600 rpm rotational speed as well as60mm/min of traverse speed	Enhanced the microhardness and wear resistance of theAMC.	[30]
Al6061	H13 tool steel	rice husk ash (RHA) of 5 weight %	NS	RS= 800, 1000, 1200 rpm and travel speed = 100mm/min	Higher value of micro hardness with rotation speed 1200 rpm	[8]
Al 1100 plate of 6-mm thick.	High-speed tool steel Shoulder diameter(20mm), Pin diameter(5mm) Pin length(5 mm)	Rice Husk Ash Silica	1 mm width and 0.5 mm depth	RS= 600 rpm, 865 rpm, 1140 rpm and 1500 rpm , TS=45 mm/min	Wear reduction, fine grain and higher hardness were	[31]

					achieved	
AA606, AZ3 and Cu	H13 & HCHCr steel of Shoulder diameter(18 & 24mm), Pin diameter(6mm) Pin length(4.5, 5 & 5.8 mm)	FA of 5 µm.	NS	RS= 1000 rpm, 1200 rpm, 1600 rpm and TS=40 , 60 mm/min	FA particles increased the microhardness in all composites.	[32]
Al5083 (100×100×5 mm^3)	NS	fly ash powder	Grooves dimensions of width 1 mm and depth of 2 mm	RS= 1100 rpm, 1400 rpm, 1800 rpm and TS=20 , 25 mm/min Optimum at RS=1400rpm and TS=25mm/min	Fly Ash as inhibitor for Corrosion mitigation in Al5083 does not favoured composites compared with the grain refined one	[33]
NS – Not Listed; RS – Rotational Speed; TS – Traverse Speed						

In the past, attentions of the researchers have been on the use of metallic powders but of recent research findings have shown that agro-waste powders could also be used as promising alternative reinforcement in FSP [8, 30 – 33] because it is readily available, not hazardous or harmful to user, environmentally friendly, and very cheap. Table 2 shown that few works have been done in the use of agro-waste powders since is a new area of findings. It was also shown that the use of agro-wastes such as fly ash and rice husk, enhanced microhardness and reduction in wear rate which are also the achievements of metallic powders.

II. Summary and Conclusions:

This survey presented different combinations of reinforcement phases used in the fabrication of AMMHCs and how it improves performance. The overview centered on the diversified reinforcement particles used at different aluminium alloy metal, types of tool profile and its dimensions, the microchannel (grooves) dimensions and its calculations, processing parameters used as well as their findings to the composites applications applied. It can be inferred from the literature that the powder metallurgy (PM) reinforcement in FSP has been widely used by the researchers as compared to agro-waste powder (AP) reinforcement in FSP. AMMHCs have proven to be materials with high potentials and have found diverse applications in a number of industries. In this survey, many authors highlighted the main reasons for fabricating AMMHCs and it was established to be its remarkable mechanical and metallurgical characteristics in terms of surface modification, improved hardness, wear and corrosion resistance, mechanical strength, damping, and creep behavior and many more. Most of the researchers reported having achieved uniform and homogenous distributions of the particulate leading to improved performance. In order to improve the surface of matrix composite during FSP, some challenges are encountered during the process of reinforcing the composite materials such as tool wear, sticking of the substrate to the backing plate when the processed substrate is of smaller thickness between 1mm to 2mm, challenge on how to improve fatigue property and joining strength, many optimizations may be required to obtain optimum parameters and this may lead to usage of many materials.

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