Effect of Different Weight Percentage on Mechanical Properties of Aluminum Metal Matrix Composites through Hybrid Reinforcement – A Review

Nagender Kumar Chandla[1] Yashpal[2] C. S Jawalkar[3] N. M Suri[4]
[1,2,3,4]Department of Production & Industrial Engineering
[1,2,3,4]PEC University of Technology, Chandigarh 160012 India

Abstract— In last few years due to industrialization and advancement of latest technology, the demand for lightweight, high performance, eco-friendly and energy efficient material in the field of construction, aerospace and automotive has increased because conventional materials were fail to achieve desired combination of mechanical and physical properties due to their heavy weight, high processing cost and insufficient mechanical properties. To overcome this and to fulfill the latest demand for today's materials, aluminum metal matrix composites (AMMC,s) is one of the best alternatives for researcher in various engineering fields like transportation, structural, mechanical, nuclear and aeronautics due to its excellent properties like low density, adequate strength, large coefficient of linear expansion, superior castability, good corrosion resistance and easily alloyed with other elements. Among various fabrication methods, stir route of casting is adopted for the manufacturing of AMMC,s as it is simple, flexible & cost-effective. The aim of present work is to study aluminum hybrid metal matrix composite(AHMMC,s) through different combination of hybrid reinforcements such as two different ceramics, two different wastes and one ceramic and one waste and see the effect of different weight percentage on the mechanical properties like hardness, toughness, compressive & tensile strength.

Key words: Aluminum Hybrid Metal Matrix Composite (AHMMC), Hybrid Reinforcement, Mechanical Properties, Stir Casting, Weight Percentage

I. INTRODUCTION

Composites material are the advanced class of engineering material, which formed by the combination of two or more constituents in which one is a matrix material and another one is reinforcing material which combines the properties of two different materials and molds them into a single improved material than existing one[1].Due to their advanced and excellent properties like high stiffness to weight ratio, high strength to weight ratio and improved thermal and physical properties makes them one of the best choices for today's engineering materials. In term of matrix constituents, composites are classified into polymer matrix composites, ceramic matrix composites and metal matrix composites and in term of reinforcements, composites are in the form of particulates-reinforced composites, fibrous-reinforced composites and in structural (sandwich and laminated) form [2-3].Among these composites, metal matrix composites are widely used and provide improved properties for the processing of aluminum-based metal matrix composites [4].

Metal matrix composite (MMC,s) is a combination of at least two phases, in which one is metallic matrix phase and another is reinforcing phase generally ceramics or some other materials[5-6]. When at least three phases are used know as a hybrid composite in which one is metal necessarily and others two may be both metals or the combination of metals and ceramics (oxide and carbide) [7].Most commonly used alloys for metal matrix composites (MMC,s) are aluminum, titanium and magnesium and these alloys are reinforced with ceramics such as silicon carbide (SiC), boron carbide (B_4C) and aluminum oxides (Al_2O_3) in particulates form [8-10].

Amongst the various MMC,s aluminum and its alloy considered as a family of newly adopted material and attracted most attention as base alloy because of its superior and excellent properties like low density, high specific modulus, good wear and corrosion resistance, sufficient strength to weight ratio, low coefficient of thermal expansion and good electrical and thermal conductivity.[11] the aluminum alloy generally divided into wrought and cast alloy. The most common wrought alloys in AMMC,s are copper(Cu), manganese(Mn), silicon(Si), magnesium(Mg), silicon(Si) and magnesium(Mg) and zinc(Zn) and are designed by four digits number such as 20xx, 30xx, 40xx, 50xx, 60xx, 70xx respectively. The cast alloy is designated by three digits and single decimal after three digits like 2xx.0 and 3xx.1. [12-14]

AMMC,s are the growing trend in today's word due to the factors like cost, processing route and isotropic properties. AMMC,s possesses unique and improved combinations of properties in such a manner that today no existing conventional material can rival such as strength and weight, stiffness and hardness, ductility and toughness, corrosion and wear and thermal and electrical. AMMC,s with single and hybrid reinforcement finds application in various sectors like military, ground water, air transportation, automotive components and metal processing industries [15-16].

One of the major challenges for the researcher in material science is the selection of a right combination of reinforcement, the weight percentage of reinforcement, processing of reinforcement and availability of reinforcement as they play an important role in deciding the overall behavior of composites. In this paper our main focus to analyze the effect of different weight percentage on the properties of AMMCs. ykuntarao et.al reported that the porosity and hardness of composite material increased with increasing the weight percentage of Al_2O_3 particles and decreasing the particle size and compressive strength increased with increasing Al_2O_3 percentage [17]. Raghavendra et.al reported that hardness was found to be increased by increasing the weight percentage into a matrix of aluminum 7075, with the reduction in coefficient of friction and wear [18]. Kadadevaramath et.al reported surface roughness of Al-1100 increase as the weight percentage of SiC increases [19].

A. Fabrication route for the processing of hybrid aluminum metal matrix composites through stir casting

Fabrication technique used for processing hybrid aluminum metal matrix composites are classified as (a) solid state process, (b) semi-solid state process, (c) liquid state process. Powder metallurgy, vapor diffusion, diffusion bonding comes under solid state process. Compo and rheo casting come under semi-solid process. stir casting, squeeze casting comes under liquid state process [20-21]. For particulates reinforced aluminum metal matrix composites there are different manufacturing techniques depends upon the selection of matrix and reinforcement material but amongst them, impeller mixing (stir casting) is widely used because of its simplicity, ease, flexible nature, most economical and can process wide ranges of shapes and size (upto500kg) [22]. Srivastava et.al reported the fabrication of al-6063 alloy reinforced with fly ash through mixing and stirring of a ceramic particle into the molten matrix which exhibits easy manufacturing procedure and low setup cost [23].

Stir casting also known as impeller mixing technique which is suitable for the production of AMMC,s. It mainly consists of crucible for holding matrix material, a stirrer for mixing and distribution of particles into molten matrix and furnace for heating purpose as shown in figure 1. In stir casting generally, reinforcing material introduced into the molten matrix by the means of mechanical stirring i.e key element of this process. The cast molten alloy, with reinforcing particles, can then be used for sand casting, die casting and for permanent mold casting.30% volume fraction of reinforcement can be easily merged with molten matrix [24-25].

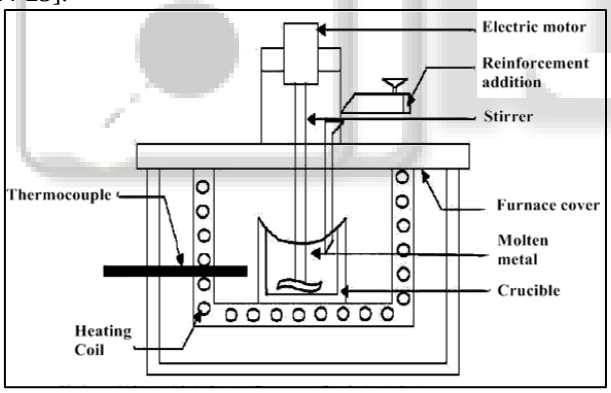

Fig. 1: Stir casting setup [37]

Kala et. al reported in his work that the particulates distribution into molten matrix mainly depends upon the wettability of the particles with the matrix, solidification rate, geometry & position of the stirrer , melt & mould temperature [22,26]. The major problem associated with stir casting technique is non-uniform distributions of particles and sufficient wetting of the particles by the molten metal. J.hasim et.al reported the wetting condition between the reinforcement and metal alloy in AMMC,s and concluded that by using magnesium and SiC particles there is an enhancement in wettability between the molten matrix and reinforcement particles[27].

B. Reported literature on different weight percentage and their effect on mechanical behavior of aluminum hybrid metal matrix composites (AHMMC,s)

Recent interests for the researcher to develop low-cost high-performance hybrid aluminum metal matrix composite through stir casting process is increasing day by day because the combined effect of two different reinforcement improves the physical and mechanical properties of composites. This paper presents an overall review on the different combinations of reinforcing particulates used in the development of AHMMC,s and how it influences the overall performance of the composites. Three different combination of reinforcement material and their literature review discuss below in detail

- Two different ceramics reinforced with AHMMC,s
- Two different agro-industrial waste reinforced with AHMMC,s
- Ceramic and industrial waste reinforced with AHMMC,s

1) Two different ceramics reinforced with AHMMC,s

The most commonly used ceramic material reinforced with AMMC,s are SiC (silicon carbide), Al_2O_3(alumina), B_4C (boron carbide), graphite and WC(tungsten carbide) but amongst them, alumina and SiC are mostly used reinforcement compares to other reinforcing material [28].Their unique combination & proper utilization with each other can significantly improve the properties. Singh et.al have successfully prepared aluminum based hybrid MMC,s from stir casting process with a uniform distribution of aluminum oxide (Al_2O_3) and silicon carbide(SiC). By varying the weight % of both reinforcement(Al_2O_3+ SiC) in the same amount like 2.5%, 5%, 7.5% and 10% respectively the properties like % elongation, hardness, impact and tensile were examined. From test results, it was observed that by increasing the weight% of hybrid reinforcement, % elongation tends to decrease which mean incorporation of hybrid reinforcement increase the brittleness of composite. The hardness, impact and tensile values increased marginally by the addition of hybrid reinforcement into molten matrix [29]. James et. al have observed the mechanical behavior of aluminum based hybrid metal matrix composite reinforced with titanium di boride(TiB_2) and silicon carbide(SiC).The properties like hardness and tensile strength were measured by varying the weight percentage of TiB2(0%,2.5%,5%) and keeping the weight percentage of SiC(10%) constant. Tensile and hardness sample were processed in the following manner like Al/0%TiB_2/10%Sic, Al/2.5%TiB_2/10%SiC and Al/5% TiB_2/10%SiC.It has been noticed from results that incorporation of SiC into base metal increased the tensile value up to 20% but an addition of TiB_2 into base metal along with SiC reduced the tensile value from 50 to 60%. Increased in hardness has been observed as the overall wt% of reinforcement increased up to 12.5% but more than that(up to 15%) the hardness value start decreasing. It has been concluded that decay in both hardness and tensile strength mainly affected by overall wt% of hybrid reinforcement this is due to the clustering of particles starts which leads to the formation of porosity and porosity further leads to a deduction in properties[30]. Ramnath et. al have prepared aluminum/boron carbide(B_4C)/alumina(Al_2O_3) metal matrix composites and evaluate the mechanical properties. After fabrication of composites, three samples (S1,S2 and S3) were prepared and tested for impact, hardness and tensile. Final results of testing compared with each-others for different weight percentage. The overall weight fraction of composites was kept constant i.e 95% for al-alloy (AA) and 5% for Al_2O_3 and B_4C. The composition used for S1,S2 and S3 of 95%AA-2%B_4C-3%Al_2O_3, 95%AA-3%B_4C-2%Al_2O_3 and aluminum

alloy respectively. Result analyses showed that the impact and hardness value for S2 is comparatively more than S1 and S3, but tensile value for aluminum alloy(S3) is marginally more than other to samples i.e S1 and S2[31]. Niranjan et. al have studied the effect of hybrid reinforcement on the mechanical behavior of Al6061 through stir route of casting. Fabrication of base alloy (Al60610) was done with graphite (Gr) and silicon carbide(SiC) reinforcements by varying the weight percentage(wt%) of Gr in order of 3%,6% and 9% and keeping the wt% of SiC constant i.e 6%. Preparing the hybrid composite by using these reinforcements properties like compressive strength, hardness and tensile were measured. It was concluded after analyses that by increasing the wt% of the hybrid composite, compressive strength increased in large amount from 743 mpa to 987 mpa. An addition of Gr particles into AHMMC reduced the hardness value due to poor wetting condition between Gr and SiC but the tensile strength of hybrid composite noticed more than the base alloy(AL6061) [32].

2) Two different agro-industrial waste reinforced with AHMMC,s

Due to industrialization and advancement in material science new generation of the hybrid composite using agro-industrial waste as a reinforcement are in recent demand for the development of AMMC,s. By control burning of these agro-industrial waste such as rice husk ash(RHA), fly ash(FA), sugarcane bagasse ash(SCBA) and maize stalk ash(MSA) in the suitable environment the ashes produces used as reinforcing material for the development of low-cost good performance AMMC,s [33-35]. These agro-waste ashes offer attractive properties such as low cost and availability, lesser density, high refractoriness, and another refractory oxide such as Al_2O_3 and the high percentage of silica (SiO_2) with a hematite (Fe_2O_3), which makes a good choice in reinforcement. [36,37]. Khan et. al studied the effect of adding bagasse ash(BA) and fly ash(FA) as hybrid/ un-hybrid reinforcement on mechanical properties of aluminum based MMC,s. The wt % of hybrid reinforcement varied in the same amount(10, 20 and 30%) of the combination. Ten samples including base alloy, un-hybrid, and hybrid reinforcements were prepared and compared the properties like tensile strength and brinell hardness with each other. It was seen from test results that increasing the above wt% of hybrid reinforcement the brinell hardness and tensile value gets reduced but it gives maximum value when compared with base alloy and un-hybrid reinforcement. The wt% which gives the satisfactory high value of hybrid reinforcement were base alloy/10%B.A/10%F.A. With this wt % above hybrid AMMC could used in automotive industry for the components like piston and engine block [38].

3) Ceramic and industrial waste reinforced with AHMMC,s

Combination of ceramics(SiC,B_4C,Al_2O_3) and agro-industrial wastes (RHA,FA,CSA,SCBA) used for the fabrication of AHMMC,s. Harnessing the potential of agro-waste and their utilization with oxides and carbides as the combination of reinforcement promotes yet another combination of low-cost, lightweight, environment-friendly, high strength material for the composites. Garg et. al developed Al6061 hybrid mmc and reinforced this alloy with fly ash and silicon carbide(SiC).The aim was to prepare low cost conventional Al based MMC,s and to obtain a uniform dispersion of the ceramic material. Composite fabricated through the liquid route of casting i.e stir casting and then investigated the various mechanical properties like hardness, toughness, % elongation and tensile strength. Four samples were prepared by keeping weight percentage of fly ash constant with base alloy(Al6061) i.e 5% and varying the weight percentage of SiC in order of 2.5%, 5%, 7.5% and 10%. Results revealed that the fly ash and SiC particles successfully incorporated into the pool of Al matrix and there is an increase in the value of toughness(Izod), tensile and hardness(Rockwell on scale C).best results of the above mention properties shown for the Al6061-5%B.A-10%Sic composition. It was observed that %elongation start decreasing as the weight percentage start increasing due to this composite start moving from ductile to brittle nature[39]. Alanemea et. al investigated the mechanical properties of rice husk ash & AL_2O_3 reinforced with Al-Mg-Si alloy using 2 step stir casting approach. The aim of these study was to develop complementing low-cost high-performance hybrid AMMC,s with constant wt fraction of rice husk(10%) and varying wt fraction of AL_2O_3(0%,2%,3% & 4%).It was examined that the value of fracture toughness, %elongation and specific strength higher than that of un-hybrid reinforcement(AL alloy + AL_2O_3). Reduction in mechanical properties like hardness and tensile has been noticed with increase in rice husk content but overall improved properties noticed than base alloy and un-hybrid alloy[40]. Kumar et. al studied the results of an experimentation of the mechanical behavior of aluminum alloy(LM6) reinforced with fly ash and silicon carbide(SiC). Fly ash, silicon carbide and AA(LM6) have been chosen for reinforcement and matrix material respectively. AHMMC,s fabricated through stir route of casting by keeping weight% of SiC constant(5%) and varying weight % of fly ash(5% & 15%). It was found that increasing the weight% of fly ash up to certain level the properties like impact and tensile strength gets improved but the reduction in % elongation has been noticed as weight% of fly ash increased. Improvement in wear resistance also been examined by increasing the weight% of fly ash. It was concluded after results that hybrid composite possesses marginally higher properties than un-hybrid composite and base alloy[41]. Mali et. al observed the mechanical properties of aluminum based MMC,s using hybrid reinforcement and seen the effect of hybrid reinforcement on AHMMC by stir casting technique. The author used Al356 as the matrix material and alumina (AL_2O_3) and fly ash (F.A) as the reinforcement material. The weight percentage of hybrid reinforcement [F.A & AL_2O_3] varied in equal amount like 2%, 4%, 6%, 8%, 10%, 12% respectively. After final casting and sample preparation mechanical properties like toughness, compression & tensile strength and hardness were examined by impact tester, Universal testing machine (UTM) and brinell hardness tester respectively. It was seen that addition of AL_2O_3 & F.A as hybrid reinforcement fairly distributed into aluminum MMC,s and enhanced value of above mention properties(toughness, compression and tensile & hardness) has been noticed up to certain level(12%) of hybrid reinforcement[42]. Quader et. al studied the effect of red mud and aluminum oxide(AL_2O_3) reinforced with aluminum alloy(AA) 6061 and prepared AHMMC,s by vortex method of fabrication. Four samples (AA6061 and red mud + AL_2O_3) were processed with varying wt% from 2.5% to 10% for the interval of 2.5 in each sample. The optimum parameters were

obtained through series of an experiment as stirring speed was 450r.p.m and stirring time of 5 min(after pouring of reinforcement) along with pouring temperature of 710 oC. On the basis of these parameters mechanical properties (tensile & Rockwell hardness) were measured. It was observed that there was an enhancement in mechanical properties like tensile strength and Rockwell hardness was noticed as the wt% of hybrid reinforcement (red mud & AL_2O_3) increase [43].

4) Reported works on different weight percentage and their effect on mechanical properties of aluminum hybrid metal matrix composites (AHMMC,s)

Authors	Matrix Material	Reinforcement With Wt.%	Hardness (Max)/Impact	Tensile/Compressive(Max) Strength	Remarks
Garg et.al 2012[39]	AA 6061	10%SiC & 5% fly ash	HRC-93	UTS-115Mpa	Hardness & tesile both increased
Singh et. al 2012[29]	AA LM6	10%SiC & 10% Al_2O_3	HRB-120	UTS-370Mpa	
Bopathi et. al 2013[44]	AA 2024	10%SiC & 10%fly ash	BHN-95	UTS-298Mpa	
Alanemea et. al 2013[40]	Al/Mg/Si	4%Al_2O_3 & 10%RHA	VHN-70	UTS-110Mpa	Decrease in both hardness and tensile
Kumar et.al 2013[41]	AA LM6	5%Sic & 15% fly ash	8.5 kg-m	UTS-238Mpa	
Mahalingegowda et. al 2014[45]	AA 6061	9% Al_2O_3 & 2% Gr	BHN-77	UTS-152.35Mpa	
Fatile et. al 2014[46]	Al-Mg-Si alloy	4% SiC & 10% corn cob ash	HVN-81	UCS-752.42Mpa	Decrease in both hardness and tensile
Pradeep et. al 2014[47]	AA 7075	6% SiC & 2% red mud	BHN-121	UTS-160Mpa	
Ramnath et. al 2014[31]	Al alloy	3% B_4C & 2% Al_2O_3	BHN-52.80	UTS-118.15Mpa	
James et. al 2014[30]	AA 6061	2.5% TiB_2& 10%SiC	BHN-75	UTS-68.24Mpa	
Mali et. al 2015[42]	AA-356	12% Al_2O_3 & 12% flyash	BHN-94	UTS-54.8Mpa	hardness increases but tensile strength decreases
Khan et. al 2015[38]	AA-LM6	10% Bagaase ash & 10% fly ash	BHN-80	UTS-192.74Mpa & UCS-758 MPa	
Jose et. al 2016[48]	AA 7075	3% Zircon & 6% fly ash	BHN-121 & 2 joule	UTS-180Mpa	UTS increase for 2% of MoS_2 BHN increases for 4% of MoS_2
Pitchayyapillai et.al 2016[49]	AA 6061	12% Al_2O_3 & 2-4% molybdenum (MoS2)	BHN-107.56	UTS-173.1Mpa	hardness increses but UTS decrease
Murthy et. al 2016[50]	AA 6063	4% Al_2O_3 & 6%bamboo leaf	VHN-82	UTS-259.5Mpa UTS-100Mpa	Impact is same for all samples
Niranjan et. al 2017[32]	AA 6061	6% SiC & 3% to 9% graphite	BHN-106	UTS-156 Mpa & UCS-987Mpa	hardness increases at 3% % UTC & UCS increases at 9%

Table 1: Authors reported work

II. Conclusion

The conclusion drawn from the literature review is that weight percentage of hybrid reinforcement marginally affects the various mechanical properties like hardness, toughness and strength (tensile & compressive) in aluminum hybrid metal matrix composites (AHMMC,s). In hybrid reinforcement weight percentage for both reinforcements play an important role in deciding the overall behavior of composite. The literature showed the increase or decrease in mechanical properties by increasing the weight percentage of hybrid reinforcement and it mainly depends on the processing of reinforcement (preheat & pouring), uniform distribution of reinforcement, the combination of reinforcement and also upon the matrix alloy upon which they reinforced. It is concluded that decay in properties mainly because of clustering of particles due to increasing level of reinforcement and porosity formation. This review paper can help in future to decide the optimum weight percentages of hybrid reinforcement along with the type of reinforcement and combination of reinforcement for the development of AHMMC,s.

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