ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

INFLUENCE OF FLYASH/SICP/AL_2O_3 ON MECHANICAL CHARACTERISTICS OF AL-MG BASED HYBRID METAL MATRIX COMPOSITES SYNTHESISED BY STIR CASTING PROCESS

Anand Babu. K and Venkataramaiah. P
Department of Mechanical Engineering, Sri Venkateswara University, Andhra Pradesh, Tirupati, India
E-Mail: anand.k301@yahoo.com

ABSTRACT

This paper mainly focused on the study of hybrid reinforcement ie, SiCp with Fly Ash (FA) and Al2O3 with Fly Ash (FA) influences on Mechanical characteristics of Aluminium based Hybrid Metal Matrix Composites (AHMMCs) Synthesised by Stir Casting Process. The AHMMCs is synthesised by amalgamated the fly ash particles with a particle size of 53-106 µm and synthetic ceramic particles with a size of 53 µm into the vortex of matrix material with a proportion of 3 wt.%, 6 wt.% and 9 wt.%. The mechanical and physical properties of AHMMCs are investigated and the results reveal that the increase of hybrid reinforcement content shows the increasing trend of Hardness, Tensile Strength and Porosity while the density decreases. Furthermore, the hybrid reinforcement particle distribution was examined using SEM analysis and the results revealed that the particles are fairly distributed.

Keywords: Al-Mg alloy, hybrid metal matrix composites, industrial waste, synthetic reinforcements, stir casting process, ultimate tensile strength, hardness, density, porosity.

1. INTRODUCTION

From the past few decades, engineers have paying attention on development of new composite material to substitute the solitary reinforced metal matrix composites with Thermal and chemically stable property to meet the widespread demands in many engineering applications. These demands have led to develop the Hybrid Metal Matrix Composites which offer such tailor made property combinations required in many engineering industries.

The Hybrid MMCs are basically metallic alloys reinforced with two or more chemically non-reactive materials to enhance the material properties, in which aluminium, magnesium and titanium etc were utilized as metallic matrix material and some other non-metallic materials, commonly synthetic ceramics particulates such as silicon carbide, aluminium oxide, boron carbide, zirconia, tungsten carbide, graphite and silica were used as primary reinforcement and industrial waste may be used as secondary reinforcing materials such as fly ash [Bodunrin, M., O. *et al* (2015)].

[Das, D., K. *et al* (2014), Alaneme, K., K. *et al* (2013)] presented the reasons for drawing an immense attraction of Aluminium alloys as a matrix metal for the development of metal matrix composites. Similarly, [Surappa, M. K. (2003), Kok, M. (2005), Yigezu, B., S. *et al* (2013)] reported the advantages of discontinuous ceramic particulates (DCPs) over continuous ceramic fibres (CCFs) and also stated that the synthetic ceramic particulates such as silicon carbide and alumina were widely used as reinforcing particulates for a development of an aluminium metal matrix composites (AMMCs).

[Sourabh Gargatte *et al* (2013)] reported the properties and application of 5XXX series aluminum alloy. [Jaswinder Singh *et al* (2016)] Stated that the Aluminum based Hybrid Metal Matrix Composites have capabilities to substitute the single reinforced composites with enhanced properties for satisfying the modern demands. [Kulkarni, S., G. *et al* (2014)] studied the effects of flyash and alumina reinforcement materials on mechanical and density characteristics of Hybrid Metal Matrix Composite. An average particle size of less than 100 µm of flyash and alumina materials were reinforcing into Al 356 aluminium alloy using stir casting method. They stated that flyash was an environmental pollutant and the usage of flyash along with alumina as reinforcements were improved the mechanical properties and reduce the density of composites. [Rohatgi, P., K. *et al* (2006)] reported that the yield stress, Young's modulus and plateau stress of cenosphere flyash reinforced A356 composites were increased with the increase of density. [Srikanth, B., G. *et al* (2015)] reported that the tensile strength and hardness of aluminium metal matrix composites synthesised by stir casting method were increased with an increase of vol. fraction of tungsten carbide particulate and flyash reinforcement contents. [Senapati, A., K. *et al* (2016)] reported that the Mechanical properties such as tensile strength, compression strength and hardness of the hybrid metal matrix composite were increased with an increase of silicon carbide and fly ash particulate reinforcement percent.

[Elangovan, R. *et al* (2015)] Studied the mechanical and machining characteristics of prepared composites of Al 6061 alloy reinforced with flyash and silicon carbide particles using stir casting process. They revealed that the mechanical properties such as tensile, hardness and toughness were increased with an increase of reinforcement. [Mohan kumar, T., S. *et al* (2015)] Studied the mechanical properties of fabricated Al-4.5wt.%Cu Alloy based metal matrix composites reinforced with Fly ash and Silicon Carbide by using stir cast technique. They reported that composite hardness and ultimate tensile strength were significantly improved with the addition of Fly ash and SiC reinforcement materials and also confirmed the uniformity of particle distributions in matrix alloy using optical microscopy.

[Deuis, R., L. *et al* (1996)] reported that the hardness of the composites increase with an increase of hard ceramic particles content and that will not depends on the reinforcement size only but on the structure, interface bonding between matrix and reinforcement material of the composite also. Several researchers have reported that the strength, wear resistance and hardness of composites could have been enhanced by the addition of hard ceramic particulates or short fibres into the matrix metals [Pai, B., C. *et al* (1976), Sato, A. *et al* (1976)].

[Umanath, K. *et al* (2013)] stated that stir casting method is the least expensive method to synthesis the hybrid metal matrix composites. [Balasivanandha Prabu, S. *et al* (2006)] Explored the several technical challenges that need significant attention while synthesising the composite using stir casting method, as follows:

a) Difficulty to achieve a uniform distribution of reinforcement particles

b) Wettability between the reinforcement and the matrix materials

c) Porosity in the cast metal matrix composites and

d) Chemical reactions between the reinforcement and the -matrix materials.

To resolve the above technical challenges, [Naher, S. *et al* (2003)] used the fixed four blade flat 45^{o} angled stainless steel stirrer to achieve the uniform particle distribution with the depth of the immersed impeller of turbine stirrer, approximately 2/3 of the height of the molten metal from the bottom of the crucible [Hashim, J. *et al* (2002)].

So far considerable research work had been done on the mechanical characterisation of Aluminium based Hybrid Metal Matrix Composites reinforced by synthetic ceramic particulate materials along with industrial waste. On the other hand, there is no recognised work particularly emphasised on SiCp, Flyash and Al_2O_3 particulates reinforced Al-4.62 wt.% Mg-based hybrid metal matrix composites in the contemporary literature. Therefore, the intention of present work is:

a) To study the effects of Flyash/SiCp/Al_2O_3 on mechanical characteristics of Al-4.62 wt.% Mg-based Hybrid Metal Matrix Composites synthesised using Stir Casting Process by overcoming the above technical challenges.

b) To explore the wide range potentialities of Flyash (secondary reinforcement) for the development of HAMMCs.

c) To increase the utilisation of Fly Ash material as secondary reinforcements in the synthesis of MMCs.

2. EXPERIMENTAL PROCEDURE

2.1 Materials

In the present study, Al-4.62wt%Mg wrought aluminium alloy was used as the matrix material and was procured from M/s PMC Corporation, Bangalore, India for a synthesis of an aluminium hybrid metal matrix composites. The matrix alloy Al-Mg is a wrought aluminium alloy, which belongs to 5XXX series and the principal alloying element is magnesium, so it is termed as Al-Mg alloy and the chemical compositions (in weight percent) of Al-Mg was found using Spectro analysis and is tabulated in Table-1.

Table-1. Chemical composition of AA 5083 material in wt%.

Mg	Si	Fe	Cu	Mn	Cr	Zn	Ti	Al
4.62	0.141	0.169	0.021	0.583	0.091	0.029	0.048	Bal.

The reinforcement material selected was Discontinues Silicon Carbide Particles (SiCp) supplied by M/s Snam Abrasives Pvt. Ltd., Hosur, Tamil Nadu and Discontinues Aluminium Oxide particles (Al_2O_3) supplied by M/s Carborundum Universal Limited, Chennai, India with a size of 53 μm and these reinforcement particles were identified as an effect on the mechanical properties [Essam R. I. Mahmoud, *et al* (2010), Gurcan, A., B. *et al* (1995), Hayrettin Ahlatci, *et al* (2006), Basavarajappa, S. *et al* (2007)]. The properties of selected matrix and reinforcing materials were presented in Table-2.

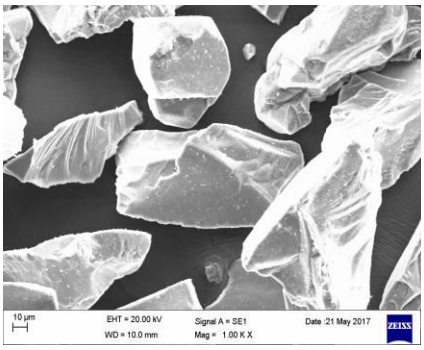
Table-2. Properties of Al-4.62Mg/SiCp/Al_2O_3/Flyash.

Properties	Al-4.62Mg	SiCp	Al_2O_3
Density (gm/cc)	2.66	3.1	3.69
Hardness (BHN)	93	2800	1175
Tensile Strength/Compressive Strength (MPa)	345 (T)	3900 (C)	2100 (C)
Melting Point (^{0}C)	638	1650	1700
Poisson's Ratio	0.33	0.14	0.21

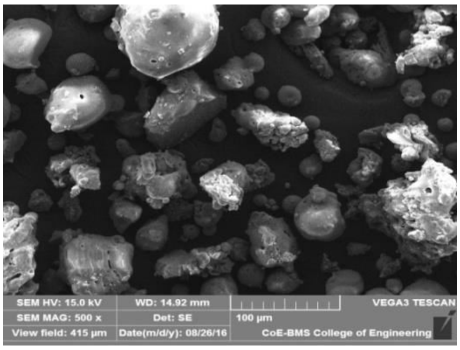
The flyash (FA) was also selected as reinforcement to fabricate the Hybrid Metal Matrix Composites with the size range of 53-106µm. The Flyash was collected from Dr Narla Tata Rao Thermal Power Station, Vijayawada, Andhra Pradesh, India. According to ASTM C 618, FA is classified into two types ie, class C, obtained by combustion of lignite coal and class F, obtained by combustion of bituminous and sub-bituminous coal [Lal C. Ram *et al* (2010)]. The fly ash mainly consists of SiO_2, Al_2O_3 and Fe_2O_3 and that Oxide content contains more than 70% of the total composition with less CaO content than Fe_2O_3 content is called as Class F flyash [ASTM C 618 (1997)]. The chemical composition of fly ash was found by using EDX and is tabulated in Table-3 and the SEM micrograph of fly ash, SiCp and Al_2O_3 is illustrated in Figure-1. In this work, the Class F hollow sphere flyash particles with a density of 1.36 gm/cc separated from solid spheres by using flotation method [Rohatgi, P., K. *et al* (2006)] was selected for synthesis of Hybrid Aluminium Metal Matrix Composites and this Hollow spheres flyash particles are hard, hollow, free flowing [Ramachandra, M. *et al* (2005)] and microspheres were found in flyash. Due to the lower content of Calcium Oxide (CaO) over a class C fly ash, the class F flyash is suitable for AMMCs [Gikunoo, E. *et al* (2005)].

Table-3. Chemical composition of Flyash used as reinforcement in wt%.

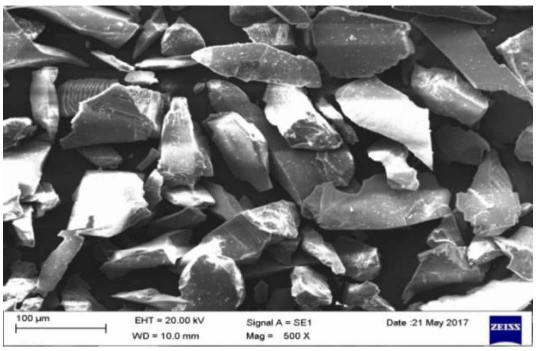
SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	LOI
59.41	25.01	6.23	3.76	1.90	0.41	0.25	0.96	1.33



(a) SiCp



(b) Flyash



(c) Al_2O_3

Figure-1. SEM micrograph of SiCp/Flyash/Al_2O_3 particles.

2.2 Preparation of an Aluminium hybrid metal matrix composite samples

In this study, liquid metallurgy route via stir casting method was used to synthesise the Hybrid metal matrix composites which comprises the reinforcement materials in the proportion of 3% (1.5 wt. percentage of SiCp and 1.5 wt. percentage of flyash) and (1.5 wt. percentage of Al_2O_3 and 1.5 wt. percentage of flyash), 6% (3 wt. percentage of SiCp and 3 wt. percentage of flyash) and (3 wt. percentage of Al_2O_3 and 3 wt. percentage of flyash) and 9% (4.5 wt. percentage of SiCp and 4.5 wt. percentage of flyash) and (4.5 wt. percentage of Al_2O_3 and 4.5 wt. percentage of flyash) in the matrix material.

Initially, the calculated amount of Al-Mg alloy in the form of ingots was charged into the graphite crucible placed in a stir casting furnace. Then the Al-Mg alloys were first heated above the liquidus temperature (700^0C) for complete melting and then it is cooled down just below the liquidus temperature to maintain the slurry in the form semi-liquid state. The temperature of the melt was measured using a K-type thermocouple with digital display as shown in stir casting setup of Figure 2. The melt was agitated with an aid of mechanical stirrer to create a fine vortex for getting a uniform dispersion of particles and homogeneous mixture of the molten metal slurry. The stirrer was made up of stainless steel coated with zirconium material to stir the molten metal at a stirring speed of 600 rpm for 10 minutes [Balasivanandha Prabu, S. *et al*. (2006)].

During stirring process, the preheated SiCp, Al_2O_3 and flyash particles at 1000^0C (to make their surface oxidized for improving the wettability between the reinforcement and the matrix materials and to reduce the surface tension of molten matrix) along with 2% magnesium as a wetting agent were added gradually into the vortex of the molten metal after an effective degasified with hexachloroethane tablet [Veeresh Kumar, G., B. *et al* (2012)]. After thorough stirring, the temperature of the composite molten slurry was increased to equivalent melting temperature of an aluminium alloy and was poured into preheated steel mould 500 mm x 60 mm x 20 mm size (Figure 2) and then allowed to cool to obtain cast composites.

The obtained cast samples are coded as A_1 for Al-4.62Mg/1.5%SiCp/1.5%FA, A_2 for Al-4.62Mg/3%SiCp/3%FA and A_3 for Al-4.62Mg/4.5%SiCp/4.5%FA. Similarly, B_1 is coded on Al-4.62Mg/1.5%Al_2O_3/1.5%FA, B_2 on Al-4.62Mg/3%Al_2O_3/3%FA and B_3 on Al-4.62Mg/4.5%Al_2O_3/4.5%FA hybrid metal matrix composites. The casted samples were tested for mechanical properties such as Tensile Strength, Hardness and Density and data are summarised in Table-4. The Uniformity of Particle distribution in synthesised composites was also analysed using SEM analysis.

(a) (b) (c) (d)

Figure-2. Stir Casting setup: (a) Furnace (b) Temperature indicator and frequency adjuster (c) four blade 45^0 angled stirrer with motor (d) Mould with molten slurry.

3. RESULTS AND DISCUSSIONS

Table-4 presents the mechanical and physical properties i.e., Tensile Strength, Hardness, Density and Porosity levels of the hybrid metal matrix composites. Each value represented is an average of three measurements, except for those of Tensile Strength and Density readings.

3.1 Tensile strength

The Measure of material resistance to breaking or plastic deformation under tension is termed as Tensile Strength and it may be described as the prediction of material behaviour under tension loading.

The Tensile Strength test has been conducted on each fabricated specimen according to ASTM E8 standard under room temperature using the computerised universal tensile testing machine. The rectangular tension test

VOL. 13, NO. 6, MARCH 2018 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

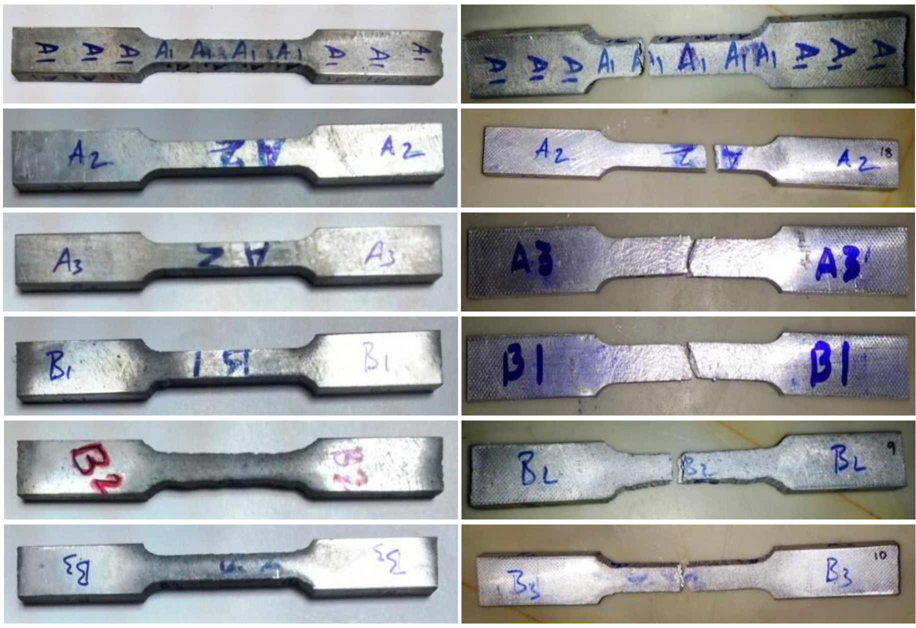
www.arpnjournals.com

specimens of an overall length of 100 mm and a gauge length of 32 mm were machined from the cast hybrid metal matrix composites.

The specimens are loaded hydraulically and recorded the measurements (Table-4) at which the specimen has reached the yield point and broken under the tension load. The tensile specimens of hybrid metal matrix composites ie, before and after the test are illustrated in Figure-3.

Table-4. Mechanical properties and porosity level of AHMMCs.

Hybrid AMMCs	**Theoretical density** (gm/cc)	**Hardness** (BHN)	**Tensile strength** (N/mm^2)	**Measured density** (gm/cc)	**Porosity** (%)
A_1	2.6471	134.19	353.86	2.63	0.37%
A_2	2.6342	176.56	362.84	2.62	0.38%
A_3	2.6213	220.10	371.92	2.611	0.3815%
B_1	2.65595	109.45	345.25	2.64	0.564%
B_2	2.6519	126.35	345.36	2.63	0.792%
B_3	2.64785	143.69	345.39	2.625	0.831%



A_1

A_2

A_3

B_1

B_2

B_3

(a) Before the test (b) After the test

Figure-3. Tensile tested specimens.

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

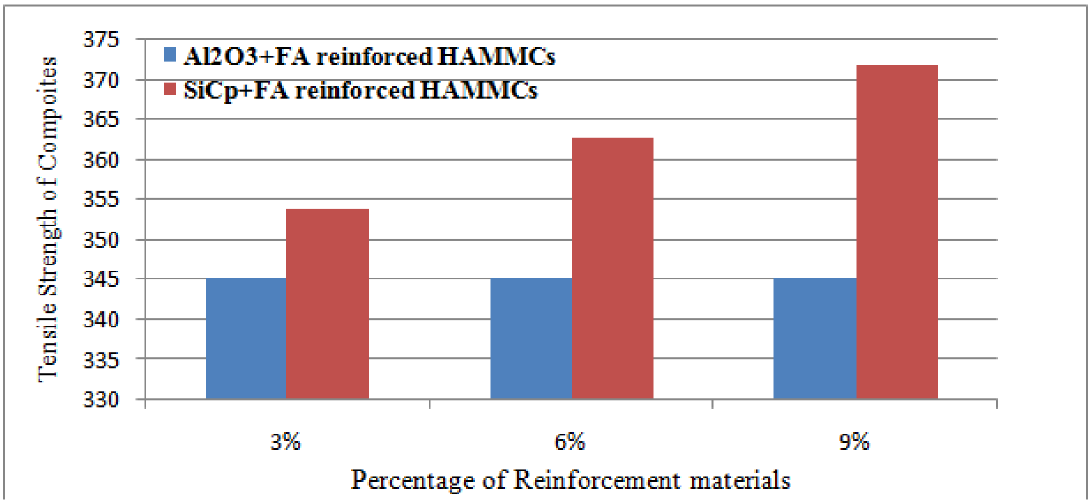


Figure-4. Effect of hybrid reinforcements on the tensile strength of AHMMCs.

Figure-4 is a graph showing the effect of the hybrid reinforcement particulate contents on the Ultimate Tensile Strength (UTS) of the hybrid metal matrix composites. It can be seen that the UTS of the composite increases with increases of hybrid reinforced particulate content.

From the above Figure, it is observed that the SiCp, Flyash reinforced hybrid composites exhibits higher UTS than that of Al_2O_3, Fly ash reinforced hybrid composites. This phenomenon is happening with the presence of hard ceramic particulates along with fly ash that imparts strength to the matrix alloy, thereby providing enhanced tensile strength to the hybrid composites. Furthermore, the UTS of hybrid composites were observed as a linearly increasing trend with an increase of volume percentage of hybrid reinforcement materials in the matrix alloy.

3.2 Hardness

The Brinell hardness test has been performed on each fabricated specimen according to ASTM E10 standard by using 10 mm diameter of steel ball as indenter at an applied load of 500 kg for a period of 30 seconds. The diameter of indentation made by indenter has been measured using the microscope. The average of three measured indentation diameter was considered to calculate corresponding values of hardness (BHN) using standard formula as follows:

$$\text{Hardness} = \frac{2F}{\pi D(D-\sqrt{D^2-d^2})}$$

where, F = the applied load, D = the diameter of the spherical indenter, d = diameter of the resulting indenter impression

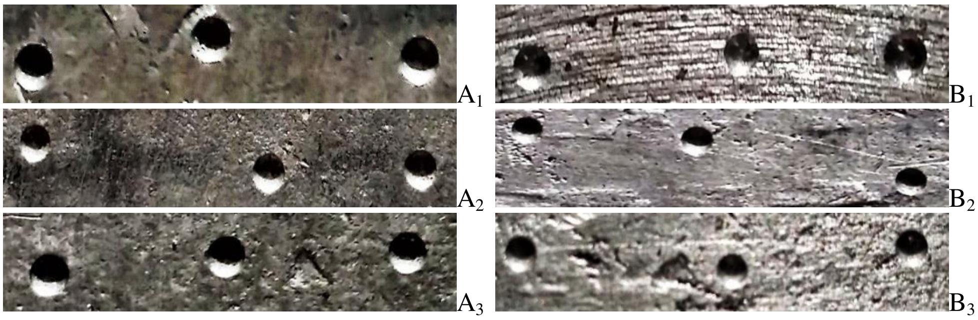


Figure-5. Hardness tested specimens.

Figure-5 illustrates the hardness tested specimens and Figure-6 shows the graph of effects of hybrid reinforcements on the hardness of hybrid metal matrix composites.

ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

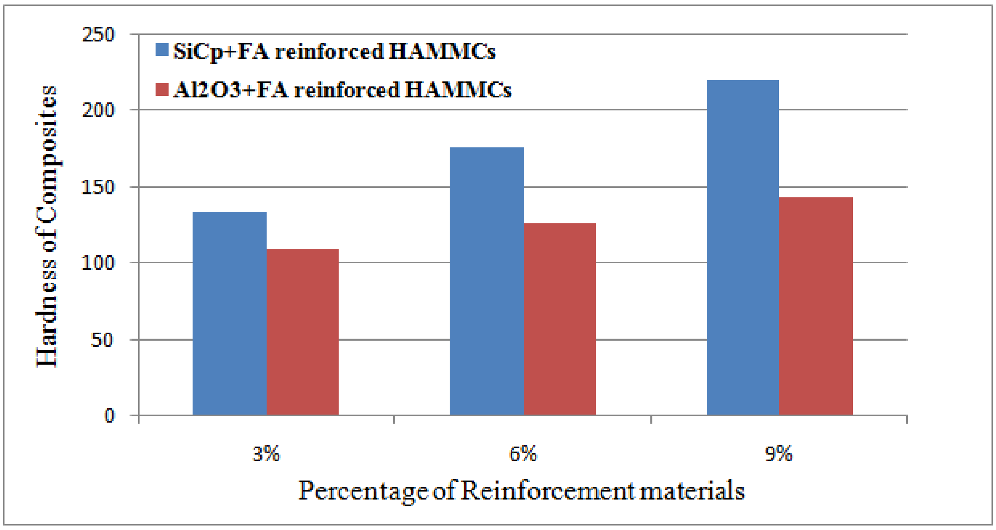


Figure-6. Effects of hybrid reinforcements on the hardness of AHMMCs.

From the Figure-6, it is observed that the Al-4.62Mg/SiCp/FA Hybrid Composites exhibits higher hardness than that of Al-4.62Mg/Al_2O_3/FA Hybrid Composites due the presence of hard dispersoids particles in the matrix material. Furthermore, the hardness of hybrid composites was observed as the linear increasing trend with an increase of volume percentage of hybrid reinforcement materials in the matrix metals.

3.3 Density

The Density of hybrid metal matrix composites was calculated both in experimentally and theoretically using Archimedes principle and rule of mixtures given by:

Density of composite = $\rho_r v_r + \rho_m v_m$

Where v is the volume fraction and ρ is the density (m stands for matrix and r stands for reinforcement materials)

The obtained theoretical and experimental density values of hybrid metal matrix composites are listed in Table-3. These density measurements were used to estimate the porosity levels of hybrid MMCs. This was obtained by measuring the differences in theoretical and measured densities of each volume percent hybrid reinforcement material of composites.

[Kok, M. (2005), Hizombor, M. *et al* (2010)] reported the maximum permissible range of porosity percent in cast metal matrix composites is within the 4%. The results of as cast hybrid metal matrix composites porosity levels are presented in Table-3. From the Table-3, it is observed that the porosity level in cast hybrid metal matrix composite is in increasing trend with the increase of hybrid reinforcement percent contents. Due to the presence of air bubbles in the slurry, shrinkage during solidification and hydrogen evolution causes the increase of porosity level in a material. However, the porosity levels in cast hybrid metal matrix composites are between 0.37–0.817 percent which is within the acceptable range of 4%.

Figure-7 shows the graph of the experimental densities of the composites according to their mixtures of hybrid reinforcements in the matrix material ie. SiCp/fly ash and Al_2O_3/fly ash.

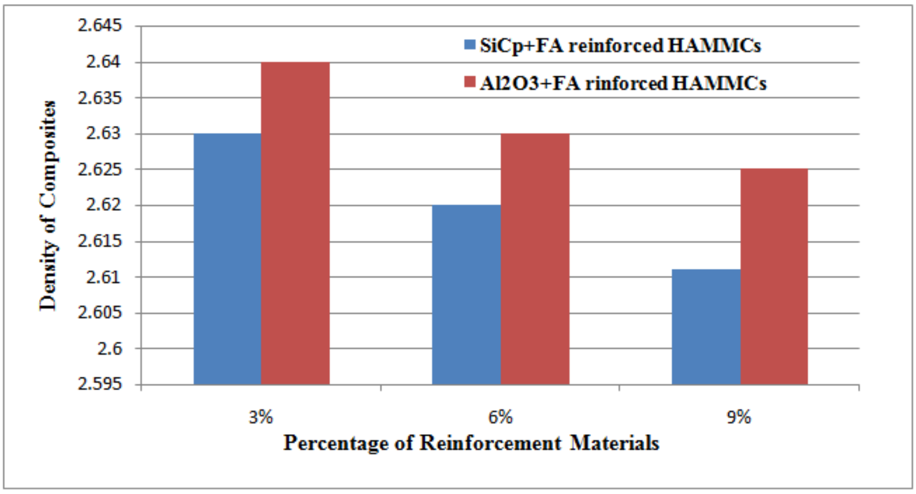


Figure-7. Effect of hybrid reinforcements on the densities of AHMMCs.

From the above figure, it can be observed that the Al_2O_3, fly ash reinforced hybrid metal matrix composites exhibits higher densities than the SiCp, fly ash reinforced hybrid metal matrix composites. The amalgamation of Fly ash as a secondary reinforcement in the matrix material leads to decreases the density of hybrid composites. It is, therefore, the densities of hybrid metal matrix composites were decreased and at higher concentration of hybrid reinforcements, the density of SiCp, flyash reinforced composites was decreased by 1.84% and $Al2O_3$, fly ash reinforced composites was decreased by 1.31% when compared matrix aluminium.

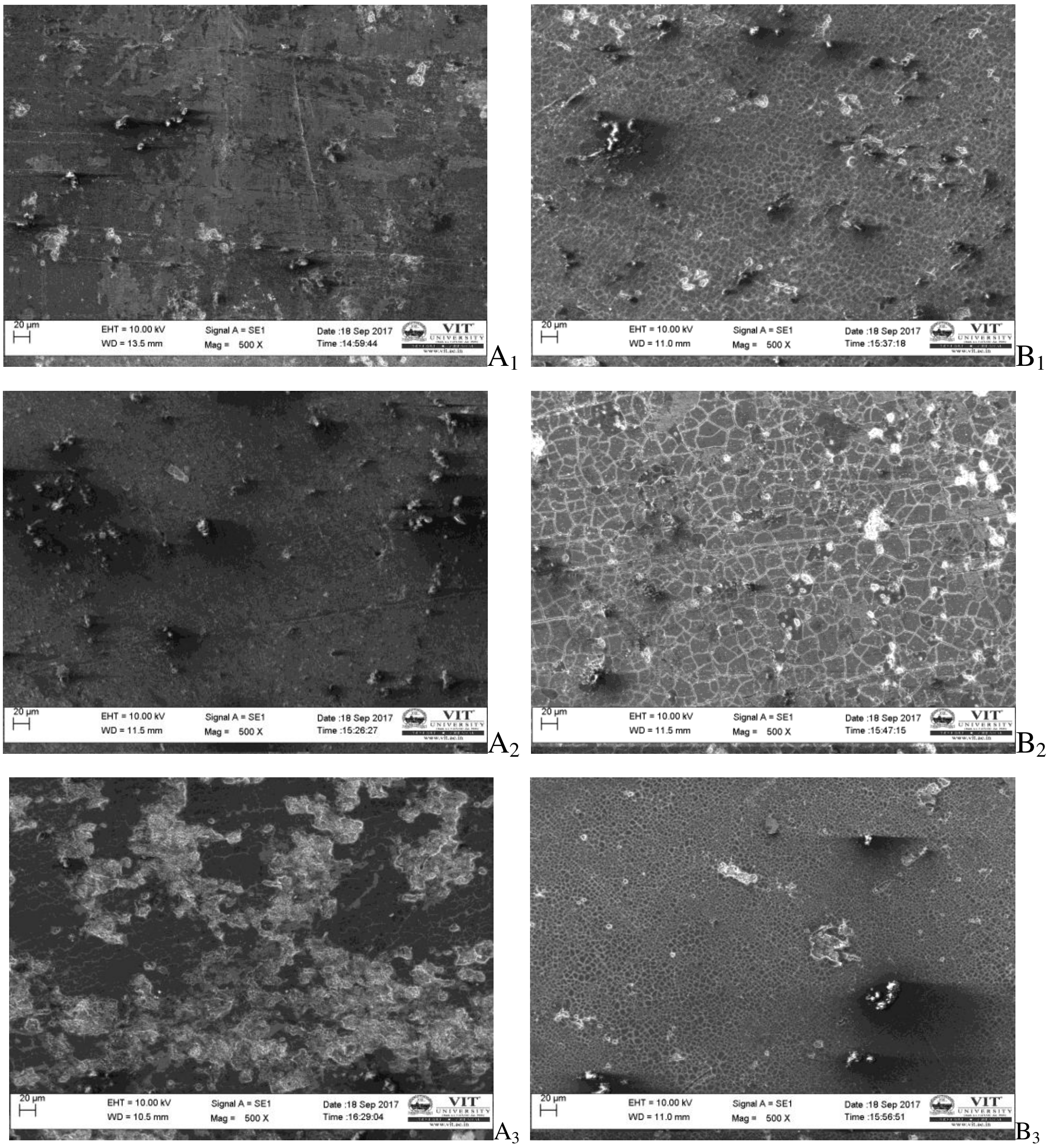


Figure-8. SEM micrographs of the worn surface of SiCp with Fly ash and Al_2O_3 with Fly ash reinforced AHMMCs.

Figure-8 shows the representative SEM micrographs for the 3 to 9 volume percent hybrid reinforced Al-4.62Mg composites. It is observed that the SiCp, Fly ash and Al_2O_3, Fly ash particulates on the composite surface are visible and a uniform dispersion of the particulates into matrix material is evident and this indicates an efficiency of the fabrication technique for the synthesis of Hybrid metal matrix composites.

4. CONCLUSIONS

This investigation reveals that the AHMMCs can be treated as the best replacement for conventional materials in various modern engineering applications. The present discussion confirms that the fly ash as a secondary reinforcement in aluminium hybrid metal matrix composite (AHMMC) for various engineering application seems to be feasible. The mechanical properties of the synthesised AHMMCs using stir casting technique are significantly altered by varying the amount of hybrid reinforcement particulates therein.

a) From the results, it is noteworthy that the increasing of hybrid reinforcement content in the matrix material results in significant increases in the UTS, hardness and porosity levels but there is a decrement in the density and also a slight improvement in Tensile Strength of Al_2O_3 and fly ash reinforced hybrid metal matrix composites.

b) From the Tensile Strength test results, it is found that the addition of Synthetic reinforcements along with flyash has a significant effect on the tensile properties. The addition of flyash particles as a secondary reinforcement material leads to increase the tensile strength mainly by load transferring from matrix to the reinforcement due to the differences in the elastic constants.

c) From the Brinell hardness test results, it is concluded that the hardness of AHMMCs increases with the increase of hybrid reinforcement content in the matrix material. The augmentation of hardness is occurred due to agglomeration of the hard synthetic reinforcement particles on the matrix material, and it acts as a barrier to the movement of dislocations within the matrix.

d) From the density and porosity results, the density of AHMMCs has decreased, whereas porosity levels were increased with the increase of hybrid reinforcement content. However, the porosity levels obtained in these composites have been found to be within acceptable limits. It is also noted that the theoretical values are nearer to the experimental values and it confirms the suitability of the stir casting technique for the synthesis of hybrid metal matrix composites.

e) From the SEM results, the microstructures of the AHMMCs synthesised by stir casting process have been found that the hybrid reinforcement particles are fairly distributed and also it revealed the good interfacial bond between the matrix and hybrid reinforcement particles. Finally, it can be concluded that SiCp and fly ash reinforced HAMMCs exhibits superior properties in Tensile Strength, Hardness and lower property in Densities than that of Al_2O_3 and fly ash reinforced hybrid metal matrix composites.

ACKNOWLEDGEMENTS

The authors wish to register their sincere thanks for the financial support rendered by the Ministry of Human Resource Development, Govt. of India under the University Grants Commission scheme of National Fellowship for Higher Education of ST students with UGC Sanction No. F1-17.1/2016-17/NFST-2015-17-ST-AND-102/ (SAIII/Website), dt: 01.04.2016 to carry out this research work. Authors also wish to thank Dr G. RajyaLakshmi, Associate Professor, VIT University, Vellore, India for providing SEM analysis. Authors are also thankful to Mr C. Murali Krishna Reddy, Technical Staff, Department of Mechanical Engineering, Sri Venkateswara University, Tirupati, Andhra Pradesh, India for his assistance offered to execute the above work.

REFERENCES

Alaneme, K. K., Bodunrin, M. O. 2013. Mechanical behaviour of alumina reinforced AA 6063 metal matrix composites developed by two step - stir casting process. Acta Tech Corvininesis - Bull Eng. 6(3): 105-110.

ASTM C 618. 1997. Standard Specification for Coal fly ash and Raw or Calcined Pozzolan for use as a mineral admixture in concrete. ASTM International, West Conshohocken, Pa., 4.

Balasivanandha Prabu, S., Karunamoorthy, L., Kathiresan, S., Mohan B. 2006. Influence of stirring speed and stirring time on distribution of particles in cast metal matrix composite. Journal of Materials Processing Technology. 171, 268-273.

Basavarajappa S., Chandra mohan G., Arjun Mahadevan, Mukundan Thangavelu, Subramanian R., Gopalakrishnan P. 2007. Influence of sliding speed on the dry sliding wear behavior and the subsurface deformation on hybrid metal matrix composite. Wear. 262(7-8): 1007-1012.

Bodunrin M., O., Alaneme K., K., Chown L., H. 2015. Aluminium matrix hybrid composites: a review of reinforcement philosophies; mechanical, corrosion and tribological characteristics. j mater res technol. 4(4): 434-445.

Das D., K., Mishra P., C., Singh S., Pattanaik S. 2014. Fabrication and heat treatment of ceramic-reinforced aluminium matrix composites - a review. Int. J Mech Mater Eng. 9(1): 1-15.

Deuis R. L., Subramaniun C., Yellup J. M. 1996. Abrasive wear of aluminium composites - A review. Wear. 201 pp. 132-144.
Elangovan R., Ravikumar M., M. 2015. Performance of Al-fly ash metal matrix composites. ARPN Journal of Engineering and Applied Sciences. 10(4): 1691-1696.

Essam R. I. Mahmoud, Makoto Takahashi, Tishiya shibayanagi, Kenji ikeuchi. 2010. Wear characteristics of surface-hybrid-MMCs layer fabricated on aluminum plate by friction stir processing. Wear. 268(9-10): 1111-1121.

Gikunoo E, Omotoso O, Oguocha INA. 2005. Effect of fly ashparticles on the mechanical properties of aluminium casting alloy A535. Mater Sci Technol. 21(2): 143-52.

Gurcan A., B., Baker T., N. 1995. Wear behaviour of AA6061 aluminium alloy and its composites. Wear. 188(1-2): 185-191.

Hashim J., Looney. L., Hashmi M., S. J. 2002. Particle distribution in cast metal matrix composites. Part 1, J. Mater. Process. Technol. 123(2): 251-257.

Hayrettin Ahlatci, Tolga Koçer, Ercan Candan, Huseyin Çimenoğlu. 2006. Wear behaviour of Al/(Al_2O_3p/SiCp) hybrid composites. Tribology International. 39(3): 213-220.

Hizombor M., Mirbagher S. M. H., Abdideh. 2010. Casting of A356/TiB_2p Composite Based on the TiB_2p/CMC/PPS MORTAR. Vol. 18, Roznov pod Radhostem, Czech Republic, EU.

Jaswinder Singh, Amit Chauhan. 2016. Characterization of hybrid aluminum matrix composites for advanced applications - A review. j mater res technol. 5(2): 159-169.

Kok M. 2005. Production and mechanical properties of Al_2O_3 particle reinforced 2024 aluminium alloy composites. Journal of Materials Processing Technology. 161, pp. 381-387.

Kulkarni S. G., Meghnani J. V., Achchhe Lal. 2014. Effect of Fly Ash Hybrid Reinforcement on Mechanical Property and Density of Aluminium 356 Alloy. Procedia Materials Science. 5, pp. 746-754.

Lal C. Ram, Reginald E. Masto. 2010. An appraisal of the potential use of fly ash for reclaiming coal mine spoil. Journal of Environmental Management. 91, pp. 603-617.

Mohan kumar T. S., Srinivas S., Ramachandra M., Mahendra K. V., Nagaral M. 2015. Effect of Fly ash and SiC Particulates Addition on Mechanical Properties of Al-4.5wt. %Cu Alloy Composites. IOSR Journal of Mechanical and Civil Engineering, Vol. 12, Issue 4, pp. 1-5.

Naher S., Brabazon D., Looney L. 2003. Simulation of the stir casting process. Journal of Materials Processing Technology. 143-144, pp. 567-571.

Pai B. C., Ray S., Prabhakar K. V., Rohatgi P. K. 1976. Fabrication of aluminium-alumina (magnesia) particulate composites in foundries using magnesium additions to the melts. Mater. Sci. Engng. 24(1): 31-44.

Ramachandra M., Radhakrishna K. 2005. Synthesis-Microstructure-Mechanical Properties-Wear and Corrosion behavior of an Al-Si (12%) - Flyash Metal Matrix Composite. Journal of Materials Science. 40, pp. 5989-5997.

Rohatgi P. K., Kim J. K., Gupta N., Simon Alaraj Daoud, A. 2006. Compressive characteristics of A356/fly ash cenosphere composites synthesized by pressure infiltration technique. Composites: Part A 37, pp. 430-437.

Sato A., Mehrabian R. 1976. Aluminium matrix composites: fabrication and properties. Metall. Trans. B 7(3): 443-451.

Senapati A. K., Mohanta G. K. 2016. Experimental study on mechanical properties of aluminium alloy reinforced with silicon carbide and fly ash, hybrid metal matrix composites. International Journal of Advance Research in Science and Engineering. 5(1): 457-463.

Sourabh Gargatte, Rahul R. Upadhye, Venkatesh S. Dandagi, Srikanth R. Desai, Bhimappa S. Waghamode. 2013. Preparation & Characterization of Al-5083 Alloy Composites. Journal of Minerals and Materials Characterization and Engineering. 1, pp. 8-14.

Srikanth B. G., Amarnath G. 2015. Characterization of Aluminium reinforced with Tungsten Carbide Particulate and Flyash Metal Matrix Composites. International Journal of Engineering Research & Technology. 4(05): 623-627.

Surappa M., K. 2003. Aluminium Matrix Composites: Challenges and Opportunities. Sadhana. 28(part 1 & 2): 319-334.

Umanath K., Palanikumar K., Selvamani S., T. 2013. Analysis of dry sliding wear behaviour of Al6061/SiC/Al2O3 hybrid metal matrix composites. Composites: Part B, 53, pp. 159-168.

Veeresh Kumar G., B., Rao C., S., P., Selvaraj N. 2012. Studies on mechanical and dry sliding wear of Al 6061 - SiC composites. Composites: Part *B*, 43, pp. 1185-1191.

Yigezu B., S., Mahapatra, M., M., Jha P., K. 2013. Influence of reinforcement type on microstructure, hardness and tensile properties of an aluminum alloy metal matrix composite. J Miner Mater Charact. Eng. 1(4): 124-30.