Effect of Fly Ash on Aluminum Matrix Composites Produced by Stir Casting Route: A Review

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ABSTRACT

Aluminum matrix composites (AMCs) are replacing monolithic materials for various applications due to their improved stiffness, strength, creep, wear and fatigue properties over monolithic materials. This improvement in the properties of the composite materials can be attributed to the addition of reinforcements. The aluminum matrix composites are finding wide applications in the field of automobile, aerospace, machine building etc. This paper presents a review on various properties of fly ash reinforced Aluminum matrix composites produced by stir casting method. The focus is made on the effect of various fractions of fly ash as reinforcement on the mechanical and tribological behavior of the aluminum matrix composites. The review includes the mechanical and tribological behavior of fly ash reinforced aluminum matrix composites. The studies shows that there is an improvement in mechanical and tribological behavior of the aluminum matrix composites with an increase in the fly ash percentage up to certain limit, and beyond which it results in decrease in the properties.

KEYWORDS:* *AMCs, Monolithic materials, Mechanical, Stir casting, Fly ash, Reinforcement.

INTRODUCTION

Now-a-days, many of the applications demand for the low cost materials possessing superior properties like high strength to weight ratio, wear resistance, impact strength, and corrosion resistance over the monolithic materials. The composite materials represent a class of materials possessing above superior properties. The composite materials consists of two phases one being the matrix phase and other being the reinforcement phase. Different types of reinforcements like alumina, silicon carbide, fly ash, E-glass fiber, boron carbide etc. can be dispersed in the matrix phase to alter the properties of the composite material. The present study is concerned with the study of properties of fly ash reinforced AMCs.

Composite material

A composite material is a material system consists of two physically separable phases, one phase forms the discrete phase and the other continuous phase (F. Smith et al. 2008). Metal matrix composites are the promising materials for the various applications due to their superior properties. The metals which possess low density are preferred for fabrication of metal matrix composites (K S Lakshmi Narayana et al. 2018). The demand for the advanced materials in the automobile and aerospace industries has led to the rapid development of metal matrix composites (C K Narula et al. 1996). The aluminum matrix composites represent a class of metal matrix composites which are finding wide applications in structural, automobile and aerospace industries (A. Macke et al. 2012, T.V. Christy et al. 2010). The materials which possess low densities are favorable for fabrication of composite materials. Aluminum and its alloys drawing more attention as base matrix phase in metal matrix composites due to their low density, low cost, high thermal conductivity and electrical conductivity (D L McDanels et al. 1985).

The distribution of reinforcement phase in the matrix phase influences the properties of the aluminum matrix composites. When a composite material is subjected for external load, the matrix phase deforms and transforms the load applied to the reinforcement phase to cause uniform distribution of load applied (K K Chawla et al. 2000).

The composites can be categorized into polymer matrix composites, ceramic matrix composites and metal matrix composites based on the nature of matrix phase used in fabrication of a composite material (Shakelford J F et al. 2001). Both the properties and the applications of the composites fabricated depend on the type of reinforcement incorporated. The reinforcement incorporated in the matrix phase exist in the form of fiber or particle. Particulate-reinforced AMCs are attracting researchers due to their isotropic properties and relatively low cost.

Fly ash

Fly ash is an industrial waste obtained from the coal power plants. The property of the fly ash depends on the nature of the coal used. Fly ash is available abundant in nature due to its low cost and low density. Fly ash is used as a reinforcement in fabrication of composites to achieve desired mechanical and physical properties for various industrial applications (Prabu S B et al. 2006). Figure 1 shows the SEM image of fly ash particles of various sizes (Bharathi V et al. 2017).

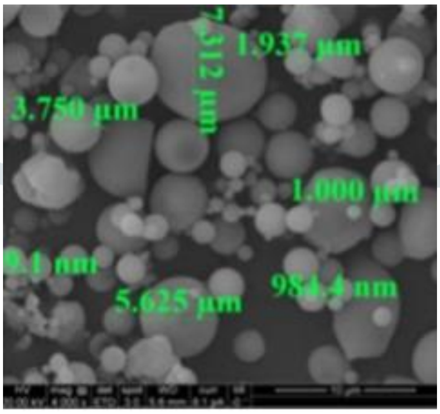

Figure 1: SEM image of fly ash particles (Bharathi V et al. 2017)

When fly ash is reinforced with Aluminum castings, it results in increased stiffness, wear resistance and hardness with reduced cost and density (B. Vijaya Ramnath et al. 2014). The size of the fly ash particles range from few µm to several nm. The fly ash particles may exist either in the form of hollow particles (density less than 1 gm/cc) or spherical particles (density in the range of 2 – 2.5 gm/cc). The spherical particles are used in fabrication of composites to improve the wear resistance, stiffness and density of the composite materials whereas hollow fly ash particles are used in the fabrication of light composite materials when compared to metal matrix density (Matsunaga T et al. 2012). Typical composition of the fly ash is as given in the table 1 (Sumit kumar Tiwari et al. 2017).

Table 1: Chemical composition of fly ash by wt. % (Sumit kumar Tiwari et al. 2017)

Al_2O_3	$zSiO_2$	Fe_2O_3	TiO_2	Carbon/LOI
29.9%	56.92%	8.44%	2.75%	1.99%

Aluminum Matrix Composites (AMCs)

The aluminum matrix composite materials are most interesting for manufacturing of parts for the applications in automotive, aerospace industries due to their low density and high specific mechanical properties (Himanshu Kala et al. 2014). The aluminum matrix composites consist of two phases one being the matrix phase and the other being the reinforcement phase, which is embedded in the aluminum or aluminum alloy matrix phase. The discrete constituent is called the reinforcement and the continuous phase is called the matrix. According to the chemical nature of the matrix phase, composite are classified as metal matrix (MMC), polymer matrix (PMC) and ceramic matrix composites (CMC).

The properties of the AMCs cab be tailored through the application of reinforcements to the base matrix phase. For most of the applications the AMCs are more economical compared to the castings of iron and steel. The properties of AMCs depend on microstructural parameters of the reinforcement viz. shape, size, dispersion, orientation and volume fraction in the matrix phase. The AMCs are capable of withstanding high tensile and compressive stresses by transferring the applied load from the base matrix phase to the reinforcement phase. Different techniques like stir casting, squeeze casting and powder metallurgy are used for fabrication of metal matrix composites. The application of a particular method in fabrication of composites depend on the type of reinforcement and property requirements.

The researchers have fabricated the composites by using different reinforcements like SiC, B_4C, Al_2O_3, Si_3N_4, TiB_2, MgO, mica and E-glass fiber. The commonly used metallic matrix phases include Al, Ti, Mg, Cu and their alloys. The reinforcements are used in the form of fibers, whiskers and particulates (T. Miyajima et al. 2003). Particulate-reinforced AMCs because of their isotropic properties and relatively low cost are attracting researchers. The strength of the composites produced is proportional to the volume percentage and fineness of the reinforced particles used in fabrication (M.D. Bermudez et al. 2001).

In this study, focus is made on the effect of varying percentages of fly ash particles on the various properties of AMCs developed by stir casting route. The studies show that there is an improvement in the mechanical properties of the developed composite materials with an increase in the percentage of fly ash up to certain limit, and beyond which it results in decrease in the properties.

Stir casting

The cost effective method for fabrication of composites is very important for expanding their applications in various sectors. With the evolution of new fabrication techniques, stir casting route is proved to be a relatively economical and easy to use liquid state fabrication method. The stir casting route set-up is as shown in Figure 2.

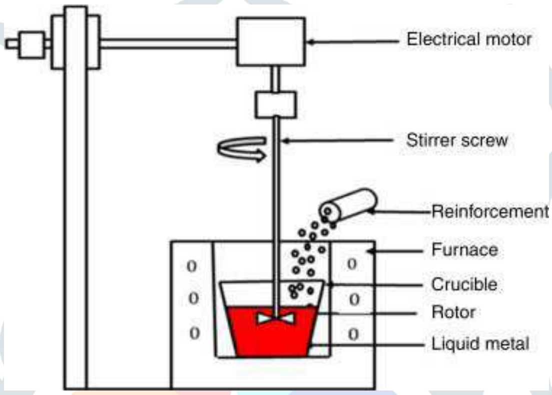

Figure 2: Stir casting set-up

In stir casting method, usually the particulate reinforcement is distributed evenly into the aluminum melt by mechanical stirring. The mechanical stirrer is generally made up of a material that can withstand high temperatures than melting point of base metal matrix phase. The mechanical stirrer used consists of mainly two components, one being the cylindrical rod and the other impeller. One end of the stirrer rod is connected to the impeller and the other end of the rod is connected to the shaft of the motor. The stirrer is held in vertical position in the crucible and rotated at various speed by means of a motor. The resultant molten metal from the crucible is then poured in to the die for casting.

Composites with up to 30% volume fraction of reinforcement can be suitably manufactured using stir casting route (R. A Saravanan et al. 2000). The factors affecting this method include speed of stirring, time duration of stirring and temperature of the melt (F. A. Girot et al. 1987). The distribution of reinforcement particles in the melt is also affected by the geometry of the mechanical stirrer, location of the stirrer in the crucible and the properties of the reinforcement particles added to the matrix phase (N. Harnby et al. 1985). The main advantage of stir casting route is its applicability to mass production. The cost of metal matrix composites produced by stir casting route is less than other fabrication methods, when produced in mass production (M.K. Surappa et al. 1981).

LITERATURE REVIEW

Tensile Strength

H.C. Anilkumar et al. (2011) developed fly ash reinforced Al 6061 composite and observed an increase in the tensile strength with an increase in the wt.% of fly ash particles upto 15% (Figure 3). The improvement in the tensile strength of the developed composite is attributed to the fact that the higher strength of the fly ash particles which acts as a filler in the base matrix. It is also due to fly ash particles which act as barriers to the dislocations, when the material is subjected for external load (Seah K et al. 1995, Basavarajappa S et al. 2004). The matrix is strengthened as the fly ash particles act as hindrance for the advancing dislocations (Suresh K.R et al. 2003). Decrease in the tensile strength of the samples was noticed with an increase in the fly ash weight fraction beyond 15 wt.% due to poor wettability of the reinforcement with the base matrix phase.

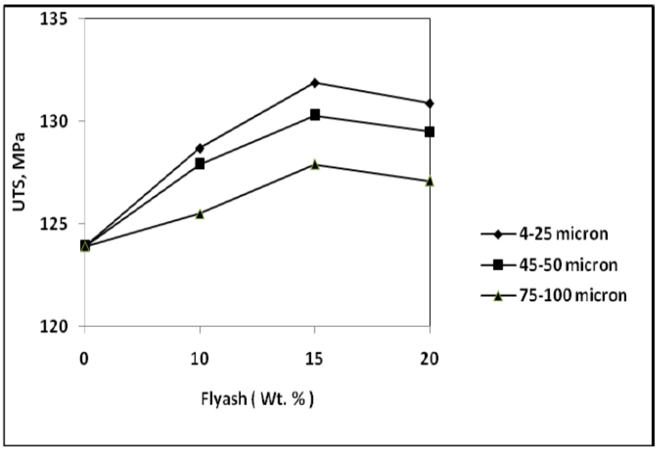

Figure 3: Effect of fly ash on Tensile Strength (H.C. Anilkumar et al. 2011)

Arunkumar et al. (2011) fabricated Al 6061 alloy composite reinforced with fly ash/E-glass fiber and observed an increase in the tensile strength of the composite material with an increase in the wt.% of fly ash. An increased tensile strength of about 153.22 MPa was noticed for 8 wt.% of fly ash and 4 wt.% of E-glass fiber (Figure 4).

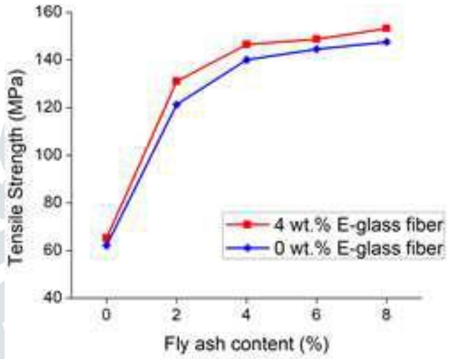

Figure 4: Effect of Fly Ash and E-Glass Fiber on the Tensile Strength (Arunkumar et al. 2011)

Mahendra Boopathi et al. (2013) developed Al 2024/fly ash metal matrix composite. The authors noticed an increase in tensile strength of the composite compared to unreinforced alloy. The tensile strength of the unreinforced Al 2024 was found to be 236 N/mm^2 and this value increased to 263 N/mm^2 for Al 2024/fly ash 10 wt.% composite, which is about 11% improvement over that of the unreinforced Al 2024 matrix phase.

M Sreenivasa Reddy et al. (2014) fabricated composite of Al 7075 with E-glass/Fly ash as reinforcements and subjected the developed composite specimens for heat treatment. It was noticed from the observation that the tensile strength of the heat treated specimens found to be improved over Al 7075 alone (Figure 5). The increase in the tensile strength of the composite can be attributed to the increase in the weight percentage of the reinforcements. The increase in the wt. % of reinforcements leads to an increase the resistance to dislocations and effective bonding between the reinforcements and the aluminum matrix phase.

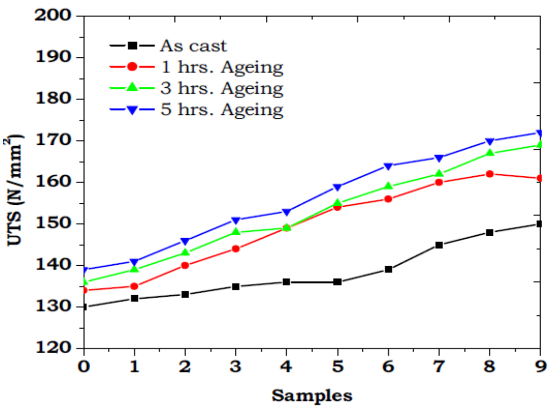

Figure 5: Effect of variation of fly ash and E-glass on

Tensile strength (M. Sreenivasa Reddy et al. 2014)

E-glass/Fly ash reinforced Al 2219 alloy hybrid composite exhibited increased tensile strength compared to matrix phase alone. The tensile strength was found to be 351.3 MPa for the composite of 5 wt.% E-glass and fly ash of 8 wt.%. The increase in the tensile strength is due to the increased wt.% of reinforcements. The uniform dispersion of E-glass fiber and the fly ash in the base matrix phase and the proper bonding of the reinforcements lead to the increased strength of the composite material. The yield strength increased with the addition of E-Glass fiber as in the table 2. This is due to the E-Glass fiber addition which acts as barrier for dislocations in the microstructure (Ramakrishnaiah et al. 2014).

Table 2: Effect of fly ash wt.% on Yield strength (Ramakrishnaiah et al. 2014).

EG 1%	EG 3%	EG 5%	% Fly ash
100.1	140.9	190.7	2
155.6	166.7	235.2	4
190.6	229.6	281.3	6
247.5	274.3	336.8	8

SiC and fly ash reinforced Al 6082 hybrid metal matrix composite exhibited an increase in the tensile strength with an increase in the wt. % of fly ash (B. Ramgopal Reddy et al. 2018).

Compressive strength

H.C. Anilkumar et al. (2011) observed an increase in compressive strength of the developed composite with an increase in the wt.% of fly ash particles (Figure 6). It was also observed a decrease in compressive strength with an increase in the size of fly ash particles.

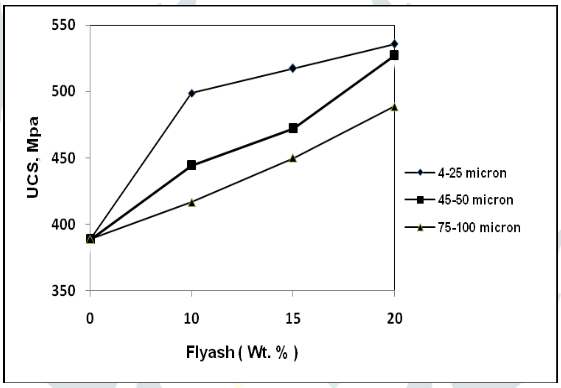

Figure 6: Effect of wt.% and size of fly ash on compressive strength

Prabhakar Kammer et al. (2012), noticed an increase in the compressive strength of the E-Glass/fly ash reinforced Al 7075 composite with an increase in the wt.% of E-Glass fiber (Figure 7). The specimens were capable of taking more loads compared to the Al 7075 alloy alone

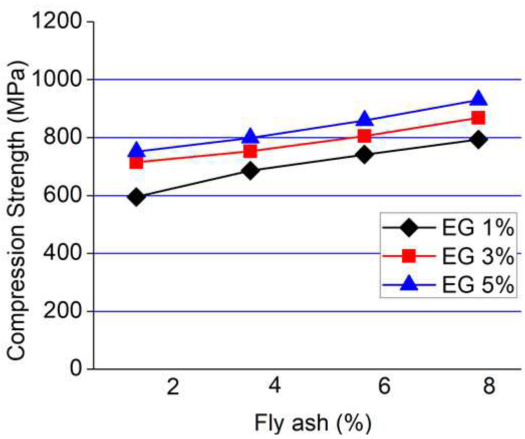

Figure 7: Comparative Line Chart of Compression Strength (Prabhakar Kammer et al. 2012)

Yoganand et al. (2013) studied the compressive strength of the composite developed and noticed an increase in the compressive strength of the composite with an increase in the wt.% of fly ash. They concluded that the monotonic increase in the compressive strength of the Al 8011 based hybrid composite is due to the decrease in the inter-particle spacing between the particulates. The reinforcement fly ash powder and E-glass fiber are harder than the base matrix material. E-glass fiber and fly ash content in the composite resist deforming stresses and thus increase the compressive strength of the composite material.

Ramakrishnaiah et al. (2014) observed an increase in the compressive strength of the developed composite with an increase in the wt.% of fly ash (Table 3). They concluded this increase in the compressive strength is due to the decrease in the inter-particle spacing between the particulates since fly ash powder particles and E-glass fiber are much harder than Al 2219 alloy. R Prajit et al. (2014) noticed an increase in the compressive strength of the composite developed up to 6 wt.% of E-glass fiber and 10 wt.% of fly ash, beyond which it decreased.

Table 3: Effect of fly ash wt.% on compressive strength in MPa (Ramakrishnaiah et al. 2014).

1% E-glass	3% E-glass	5% E-glass	% Fly ash
715.8	729.9	775.7	2
793.5	853.5	905.7	4
843.3	895.7	989.8	6
941.7	980.6	1051.6	8

Hardness

N. Natarajan et al. (2012) observed an increase in the hardness with an increase in the wt.% of fly ash in the hybrid composite developed by reinforcing fly ash and graphite with Al 6061. Mahendra Boopathi et al. (2013) have reported an increasing trend in the hardness of composite with increase in weight fraction of reinforcements. They observed maximum hardness for Al/10 wt.% SiC/10 wt.% fly ash hybrid composites. This shows that incorporation of fly ash particles significantly improves hardness of the Al-matrix. In another study, Vivekanandan et al. (2013) fabricated aluminum/fly ash composite. They observed an increase in the hardness of the composite with an addition of fly ash as it acts as a barrier for the movement of dislocations.

M. Sreenivasa Reddy et al. (2014) noticed an improvement in the hardness of the hybrid composite developed with incorporation of reinforcements fly ash/E-glass and heat treatment of the developed hybrid composite over the Al 7075 alone The increase in the hardness was attributed to the dispersion of the hard reinforcements in the soft and ductile metal matrix phase and good bonding between the matrix phase and the reinforcements. The load transfer to the reinforcement phase from the matrix phase will be more, which in turn increases the hardness of the composite. B. Ramgopal Reddy et al. (2018) fabricated SiC and fly ash reinforced Al 6082 hybrid metal matrix composite and observed an increase in the hardness of the fabricated composite with an increase in the wt.% of fly ash (Figure 8)

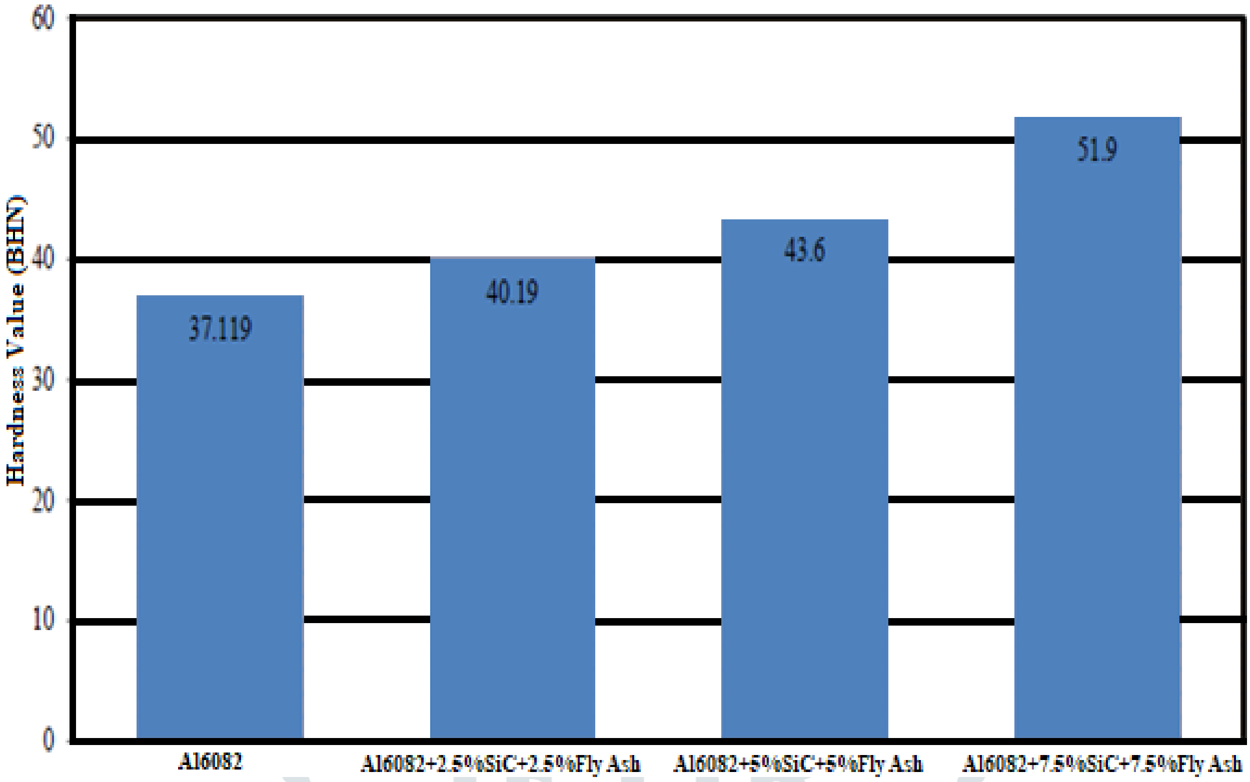

Figure 8: Effect of wt.% of fly ash on hardness (B. Ramgopal Reddy et al. 2018)

R Prajit et al. (2014) noticed an increase in the hardness of the composite with an increase in the wt.% of fly ash up to certain limit, beyond which a decrease in the hardness (Table 4). A hardness of 68.48 BHN was obtained for the composite with 6 wt.% E-glass and 10 wt.% fly ash. This increase in hardness is due to dispersion strengthening.

Table 4: Hardness for Various Sample Designations (R Prajit et al. 2014)

Sl. No	Sample Designations	Hardness (BHN)
1	Aluminum 6061	47.53
2	Al + E-glass 2% + Fly ash 5%	51.78
3	Al + E-glass 4% + Fly ash 5%	54.25
4	Al + E-glass 6% + Fly ash 5%	54.25
5	Al + E-glass 2% + Fly ash 10%	59.54
6	Al + E-glass 4% + Fly ash 10%	64.99
7	Al + E-glass 6% + Fly ash 10%	68.48
8	Al + E-glass 2% + Fly ash 15%	68.48
9	Al + E-glass 4% + Fly ash 15%	64.99
10	Al + E-glass 6% + Fly ash 15%	61.84

Ramakrishnaiah et al. (2014) observed an increase in the hardness of the developed composite with the wt.% of fly ash reinforcement over the matrix phase alone (Figure 9). A hardness of 103 BHN was noticed for a composite containing 8 wt.% fly ash and 5 wt.% E-glass fiber over a composite containing 8 wt.% fly ash and 1 wt.% E-glass fiber with a hardness of 88 BHN.

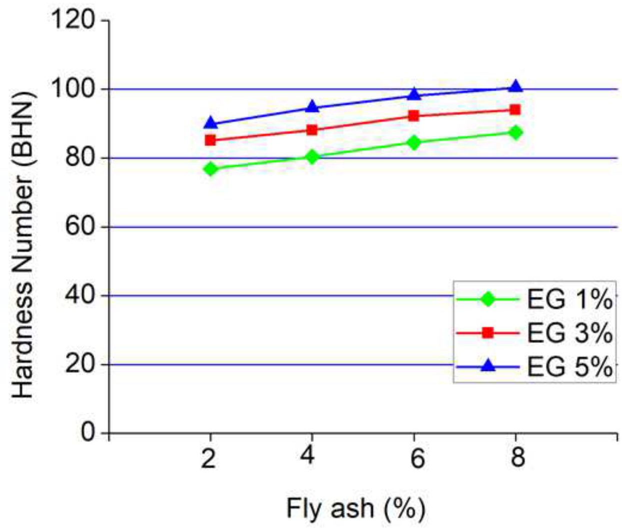

Figure 9: Comparative Line Chart of BHN (Ramakrishnaiah et al. 2014)

Wear

Ramachandra et al. (2007) investigated the wear and friction characteristics of Al/SiC matrix composite reinforced with fly ash particles. The authors observed an increase in the wear resistance of the composite with an increase in wt. % of fly ash. Venkat Prasad et al. (2011) studied the dry sliding wear behavior of Al/fly ash/graphite hybrid composite and revealed that the hybrid composite showing reduced wear losses.

H.K Shivanand et al. (2012), studied the effect of reinforcements on the wear properties of E-Glass/Fly ash reinforced Al 8011 hybrid metal matrix composites. It was noticed an increase in the wear resistance of the composite developed with an increase in the wt.% of fly ash.

Vivekanandan et al. (2013) noticed an increase in the wear resistance of Al/fly ash composite. The increase in the wear resistance is attributed to solid solution strengthening, dispersion strengthening and addition of fly ash particles which acts as reinforcement phase in the base matrix phase. B. Ramgopal Reddy et al. (2018) fabricated SiC and fly ash reinforced Al 6082 hybrid metal matrix composite and observed fairly increase in the wear resistance of the fabricated composite over the matrix phase with an increase in the wt. % of fly ash.

M. Sreenivasa Reddy et al. (2014) fabricated composite of Al 7075 with E-glass fiber and Fly ash as reinforcements and subjected the developed composite specimens for heat treatment. It was noticed from the observation that the reinforcements and heat treatment have a significant influence on wear resistance of the specimens (Figure 10). The increased wear resistance of the composites is due to the increased hardness and strength of the composite. The large number of fine grains due to grain refinement leads to increased hardness and strength of the composite, which in turn requires more stress to cause plastic deformation. The load transfer to the reinforcement phase from the matrix phase will be more, which in turn increases the wear resistance of the composite.

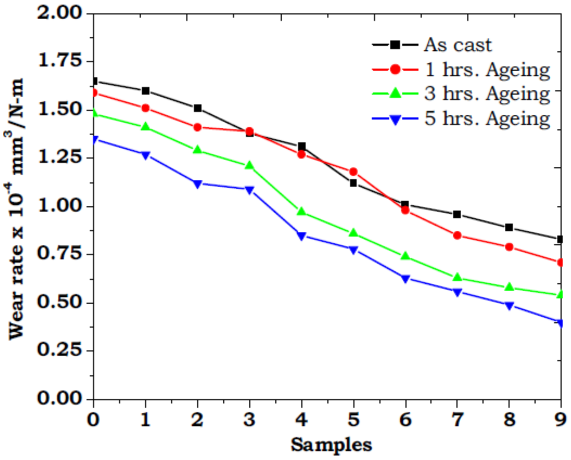

Figure 10: Effect of heat treatment on wear resistance (M. Sreenivasa Reddy et al. 2014)

Figure 11 and 12 shows the SEM images of Al 7075 matrix phase and 5 hours aged Al 7075+3% SiC+3% Fly Ash composite subjected for wear test. It was observed that the wear rate considerably being high in as cast composites compared to heat treated composites.

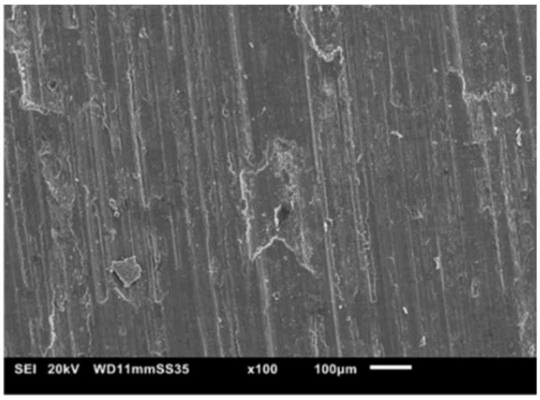

Figure 11: Al 7075 matrix

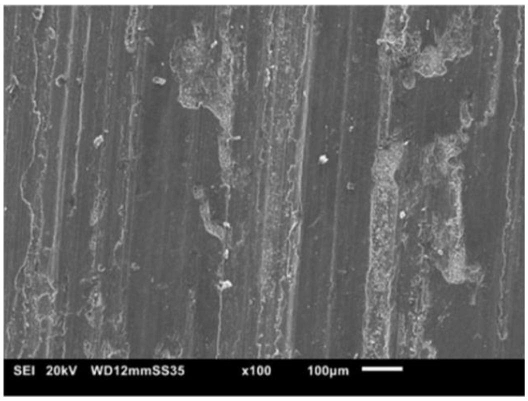

Figure 12: Al 7075+3% SiC+3% Fly ash

CONCLUSIONS

In this review article, the mechanical and tribological characteristics of the fly ash reinforced Al matrix based composites have been discussed. Review of the available literature shows that the stir casting process is extensively adopted for the fabrication of metal matrix composites to obtain the properties of interest, because of its simplicity, flexibility and low cost for the fabrication of large sized composites. The stir casting process allows for uniform dispersion of the reinforcement phase in the base matrix phase. The mechanical properties like tensile strength, hardness, compressive strength reported to improve with the addition of E-glass fiber as reinforcement up to certain limit, and beyond which there is a decrease in the properties. It was noticed that there is an increase in the wear resistance of the composite with the increase in the percentage of fly ash as reinforcement. From the economic and technical point of view, fly ash is the promising reinforcement material for the Aluminum matrix composites. The fly ash from the thermal power plants can be utilized effectively in fabrication of composites without disposing to atmosphere to prevent environmental pollution.

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