# Study on the Fabrication and Properties of Aluminium Hybrid Composites

**Igor Petrov[1], Dr. Vladimir Ivanov[2], Elena Morozova[3]**

[1]Master's Student, Aerospace Engineering, Moscow Institute of Physics and Technology, Russia
[2]Associate Professor, Aerospace Engineering, St. Petersburg State University, Russia
[3]Assistant Professor, Aerospace Engineering, Tomsk State University, Russia

## ABSTRACT

Metal matrix composites (MMCs) constitute an important class of design and weight-efficient structural materials that are encouraging every sphere of engineering applications. There has been an increasing interest in composites containing low density and low cost reinforcements. Among various discontinuously dispersed solids used, fly ash is one of the most inexpensive and low density reinforcement available in large quantities as solid waste by-product during combustion of coal in thermal power plants. Hence, composites with fly ash as reinforcement are likely to overcome the cost barrier for wide spread applications in automotive and small engine applications. To produce Al matrix cast particle composites, wettaility of the ceramic particles by liquid Al is essential. To improve wettabilty, elements such as Mg and Si are added into Al melt to incorporate the ceramic particles. The present investigation has been focused on the utilization of abundant available industrial waste fly ash in useful manner by dispersing it into aluminium matrix by liquid metallurgy route. Wide size range (0.1-100μm) fly ash particles are used. To increase lubrication 5% of graphite is added as extra reinforcement. These composites were analyzed and tested the mechanical properties. The result reveals that the addition of flyash and graphit particles in aluminium matrix improves the mechanical properties.

**KEYWORDS**: Composites, Mechanical Testing, Stir Casting, Wear behaviour

## I. INTRODUCTION

Composite is the tailor made material, which means that two or more materials are combined together to get the required physical and mechanical properties. The characteristics of the developed material are totally different from its individual constituent materials. The individual constituent materials are remains distinct within the finished structure. The development of composites has reflected the requirement to accomplish property combinations beyond those achievable in monolithic metals alone. Thus, customized composites resulting from the addition of reinforcements to a matrix may give improved specific stiffness together with improved wear resistance, fatigue and toughness [2]. The composite materials are less expensive than the conventional materials.

The matrix is the continuous phase binding and keeping the reinforcements in position and orientation, transferring the load to and between the reinforcements and protecting reinforcement from the environment and handling. Further, the matrix determines the overall service temperature limitations of composites as well as their resistance to environment. The major metal matrices used for the fabrication of composites include aluminium, magnesium, titanium and copper based alloys [3]. The other matrices studied are based on zinc, tin, steel, super alloys and inter-metallics. Among the various matrix materials available, aluminium and its alloys are widely used for the fabrication of MMC due to the fact that they are light in weight, economically viable, amenable for production of composites by various processing techniques and possess high specific strength and good corrosion resistance. In the case of aluminium, both cast and wrought alloys are commonly used.

The important characteristics of the reinforcement in a composite material are to increase the mechanical properties. Reinforcements are the second phase materials added to the matrix alloy, which normally enhance the strength, stiffness, wear and creep resistance of the composites. The choice of reinforcements always depends on the final property requirements of the composite system or the component to be fabricated. Certain dispersoids normally impart some special properties to composites such as enhanced wear resistance and reduced density at the expense of strength [5]. Generally, the dispersoids are refractory materials, such as, oxides, carbides and nitrides of different elements. Basically, they are stable and non-reactive in most of the matrix alloys. In addition, they do not undergo any change in phase or shape during composite synthesis or in use except those produced by in-situ methods. At present, there are a wide range of reinforcement materials, which can provide varying combinations of properties.

The interface is the region that lies between the matrix and the reinforcement. It plays a crucial role in determining the composite properties. It may contain a simple row of atomic bonds or reaction products between the matrix and the reinforcement coatings . The types of interface bonding are mechanical keying or interlocking effects between two surfaces which could lead to a considerable degree of bonding. Any contraction of the matrix on the fibre would result in the gripping of the fibre by the matrix. The physical bondings are those involving weak, secondary or Van der Waals forces, Dipolar interactions and hydrogen bonding. Chemical bonding involves the atomic or molecular transport by diffusional process. Solid solution and compound formation may occur at the interface, resulting in a reinforcement/matrix interfacial reaction region with a certain thickness. This encompasses all types of covalent, ionic and metallic bonding.

Metal matrix composites are widely used in automotive and aerospace applications due to their excellent properties such as vibration damping, high resistance to wear, corrosion and fatigue. Selflubricating metal matrix composites with desirable trobological properties are widely used in load bearing applications such as journal bearing, sleeves and machine slides. Aluminium and solid lubricant based bearings are employed as connecting rod, main bearings in internal combustion engines and industrial compressors. Other aluminium bearing applications are in heavy tooling, such as boring mills, presses, lathes, milling machines, grinding mills and hydraulic pump bushings.

## II. LITERATURE REVIEW

Kumar et al [1] inferred that the composite materials pose for strong candidature for replacing conventional structural materials. But what makes them stand apart is the ability to customize their properties to suit the service requirement. Such advantages have made this group of materials a nice pick for use in weight-sensitive and stiffness-critical components in transportation systems. MMCs can be described as a group of materials in which a continuous metallic phase (matrix) is combined with one or more reinforcement phases. The interaction between matrix and reinforcement is inherent for MMCs. The resulting strength is a direct function of effectiveness of the interface between the matrix and the reinforcement.

Sarkar S et al [7]The most conventional method of production of composites by casting route is vortex method, where the liquid aluminum containing 2-5% Mg is stirred with an impeller and ceramic particles are incorporated into vortex formed by stirring of the liquid metals. Addition of Mg into the liquid metal reduces the surface tension.

Matthews et al [8] The MMCs is light in weight and resist wear and thermal distortion, so it mainly used in automobile industry. Metal matrix composites are much more expensive those PMCs and, therefore, their use is somewhat restricted.

Tu et al[6] aluminium alloys are considered the most commonly used matrices especially for the applications which require low density with reasonably high thermal conductivity.

Rohatgi et al[9] Composite materials are attractive since they offer the possibility of attaining property combinations which are not obtained in monolithic materials and which can result in a number of significant service benefits. These could include increased strength, decreased weight, higher service temperature, improved wear resistance, higher elastic modulus, controlled coefficients of thermal expansion and improved fatigue properties. The quest for improved performance has resulted in a number of developments in the area of MMC fabrication technology .These includes both the preparation of the reinforcing phases and the development of fabrication technique

M. Ramachandra K. Radhakrishna [10] has worked on the Effect of reinforcement of fly ash on sliding wear, slurry erosive wear and corrosive behavior of aluminium matrix composite. Al (12 wt% Si) as matrix material and up to 15 wt% of fly ash particulate composite was fabricated using the stir casting route.

## EXPERIMENTAL WORK

**Matrix Material**

Al 6061 is the material selected because it it the most significant and widely used material in the industries now a days. Al6061 is an easily available metal which is prepared by the precipitation of hardened aluminium alloy, containing magnesium and silicon as its major alloying elements. Originally called Alloy 61S , it was developed in 1935.It has good mechanical properties, exhibits good weldability, and is very commonly extruded (second in popularity only to 6063). It is one of the most common alloys of aluminium for general purpose use.

Al6061 is commonly used for the following:

- Construction of aircraft structures,

- Yacht construction, including small utility boats.
- Automotive parts, such as the chassis of Audi A8.
- Some tactical flashlights
- Aluminium cans for the packaging of food and beverages.

***Table 1.material composition of al 6061***

| **Components** | Al | Mg | Si | Fe | Cu | Zn | Cr | Ti | Other elements |
|---|---|---|---|---|---|---|---|---|---|
| **Wt.%** | 98.5-98.56 | 0.8-1.2 | 0.4-0.8 | 0.7 | 0.15-0.4 | 0.25 | 0.04-0.35 | 0.15 | 0.05-.15 |

**Reinforcement Material**

Fly ash is one of the residues generated in the combustion of coal and it comprises the fine particles that rise with the flue gas. Ash which does not go up is termed as bottom ash. In an industrial context, fly ash usually refers to ash produced during the combustion of coal fuel. Fly ash is generally collected by electrostatic precipitators or other particle filtration techniques before the flue gas reaches the chimney of coal fired power plants. Together with the bottom side the ash particles are removed from the furnace. Both bottom ash and the ash collected by the precipitator is jointly known as coal ash.Fly ash particles are mostly spherical in shape and range from less than 1µm to 100µm with a specific surface area, typically between 250 and 600m2/kg. It includes substantial amounts of silica and lime. The specific gravity of fly ash varies in the range of 0.6 to 2.8gm/cm3. The largest application of fly ash is in the cement and concrete industry, though, creative new uses for fly ash are being actively sought like use of fly ash for the fabrication of MMCs.

Graphite provides improved friction and high wear resistance to sliding surfaces. Because of good lubricity, abundance and low cost, graphite has been prioritised for many industrial applications. Graphite can provide lubrication up to 500°C in open air, although friction tends to increase as the temperature rises. At higher ambient temperatures, it begins to oxidize and lose its lubricity. Graphite is inexpensive and readily available in various forms tending to widen its applications. Graphite possesses the properties such as high tensile strength, low density, lowfriction and wear resistance, and high thermal conductivity. Presence of graphite in aluminium also improves the machinability due its self-lubricating property.

**Experimental Work**

Figure1 shows the schematic view of the stir cast setup. The stir cast furnace has been rigidly fixed on the ground and the temperature of the furnace has precisely been measured and controlled in order to achieve high quality of the composite. Two thermocouples and one PID controller have been used for this purpose. The stirrer was made by mild steel materials having high temperature stability. This stirrer has been connected with one horse power DC motor through power transmission drive, which is used to stir the molten metal in semi-solid state. The screw operator controls the position of the stirrer in contact with the mixing materials. The melt has been maintained at a temperature between 750 to 800ºC for one hour. Vortex has been created by using a mechanical stirrer. Before adding the particulates into matrix, it has been preheated in the range of 400 to 550ºC using electric furnace and it was added into the melt with constant mechanical stirring of about 10min at 500 to 650rpm condition. After the complete addition of the reinforcement particulates into the molten matrix alloy, the molten metal has been poured into the preheated (300ºC) permanent steel die and allowed to cool in atmospheric conditions (Room Temperature). The poured molten metal has been solidified in die in the form of a cylindrical bar and plate.

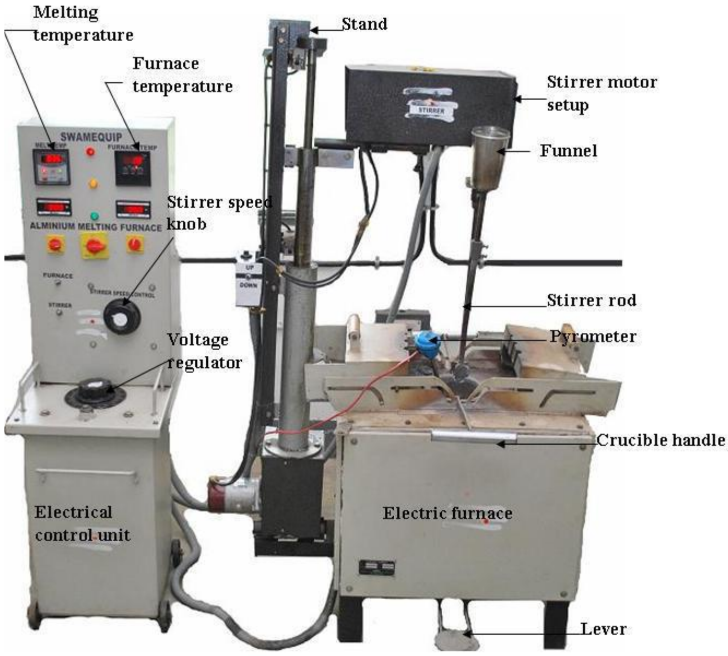


***Fig1. StirCasting Machine***

The composition percentage is chosen from the literatre and the most common percentage is used in the most of the literature was selected is given below. According to the volume fraction the percentage of reinforcement of flyash is varied in steps of 5% to 11% .

***Table 2. Specimen compositions for varying volume fraction***

| Specimen Code | AL- 6061 | Flyash | Graphite |
|---|---|---|---|
| 1 | 100% | 0% | 0% |
| 2 | 90% | 5% | 5% |
| 3 | 88% | 7% | 5% |
| 4 | 86% | 9% | 5% |
| 5 | 84% | 11% | 5% |

**Mechanical Testing**

**Hardness**

Bulk hardness measurements were carried out on the base metal and composite samples by using standard Brinnel hardness test. Brinnel hardness measurements were carried out in order to investigate the influence of particulate weight fraction on the matrix hardness. Load applied was 750kgs and indenter was a steel ball of 5 mm diameter.

**Tensile Test**

The tensile testing of the composite was done, on Instron testing machine. The sample rate was 9.103pts/sec and cross-head speed 5.0 mm/min. Standard specimens with 30mm gauge length were used to evaluate ultimate tensile strength. The comparison of the properties of the composite material was made with the commercially pure Al.

**Impact Test**

The purpose of impact testing is to measure an object's ability to resist high-rate loading. It is usually thought of in terms of two objects striking each other at high relative speeds. A part, or material's ability to resist impact often is one of the determining factors in the service life of a part, or in the suitability of a designated material for a particular application. Impact resistance can be one of the most difficult properties to quantify. The ability to quantify this property is a great advantage in product liability and safety. The impact test is a method for evaluating the toughness and notch sensitivity of engineering materials. It is usually used to test the toughness of metals, but similar tests are used for polymers, ceramics and composites. Impact testing most commonly consists of Charpy and IZOD Specimen configurations. The Charpy Impact Tests are conducted on instrumented machines capable of measuring less than 1 foot-pound. to 300 foot-pounds. at temperatures ranging from -320°F to over 2000°F. Impact test specimen types include notch configurations such as V-Notch, U-Notch, and Key-Hole Notch.

**Compression Test**
The compression test was performed using a computerized universal testing machine (UTM-Auto instrument) at room temperature and ultimate compression strength of these samples was measured as per ASTM: E9 standards.

**Sliding Wear Behaviour**
Wear has been defined as the displacement of material caused by hard particles or hard protuberances where these hard particles are forced against and moving along a solid surface. Two body sliding wear tests were carried out on prepared composite specimens. A Ducom, Bangalore makes computerized pinion- disc wear test machine was used for these tests. The wear testing was carried out at a constant sliding velocity of 1m/sec with normal loads of 10N, 15N, 20N. A cylindrical pin of size 1.1cm diameter and 2.1cm length prepared from composite casting was loaded through a vertical specimen holder against horizontal rotating disc. Before testing, the flat surface of the specimens was abraded by using 2000 grit paper. The rotating disc was made of carbon steel of diameter 50 mm and hardness of 64 HRC. Wear tests were carried out at room temperature without lubrication for 30 min. The principal objective of investigation was to study the coefficient of friction and wear.

***Fig2. StirCasting Machine***

## III. RESULT AND DISCUSSIONS
The casting of circular cross section of 25mm diameter and 100mm length have been casted. The specimen were machined to reduce the diameter to 24mm and length to 1 inch for microstructure characterization and hardness test. All the tests are carried out as per ASTM standards.

**Hardness**

***Table3: Mean hardness No***

| Composition | Mean Hardness No |
|---|---|
| 0% | 48 |
| 5% | 58.5 |
| 7% | 60.3 |
| 9% | 62.2 |
| 11% | 64 |

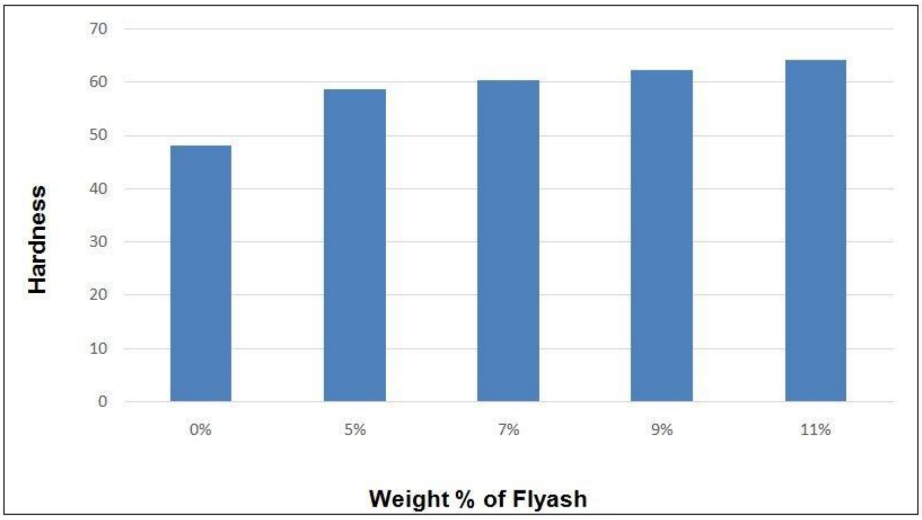


*Fig3. Hardness no for weight % of flyash*

The above table shows that incorporation of fly ash particles in Aluminum matrix causes reasonable increase in hardness. The strengthening of the composite can be due to dispersion strengthening as well as due to particle reinforcement. Thus, fly ash as filler in Al casting reduces cost, decreases density and increase hardness which are needed in various industries like automotive etc.

**Tensile Test**

*Table4: Ultimate Tensile strength*

| Composition | UltimateTensile Strength(Mpa) |
|---|---|
| 0% | 152 |
| 5% | 171 |
| 7% | 210 |
| 9% | 238 |
| 11% | 121 |

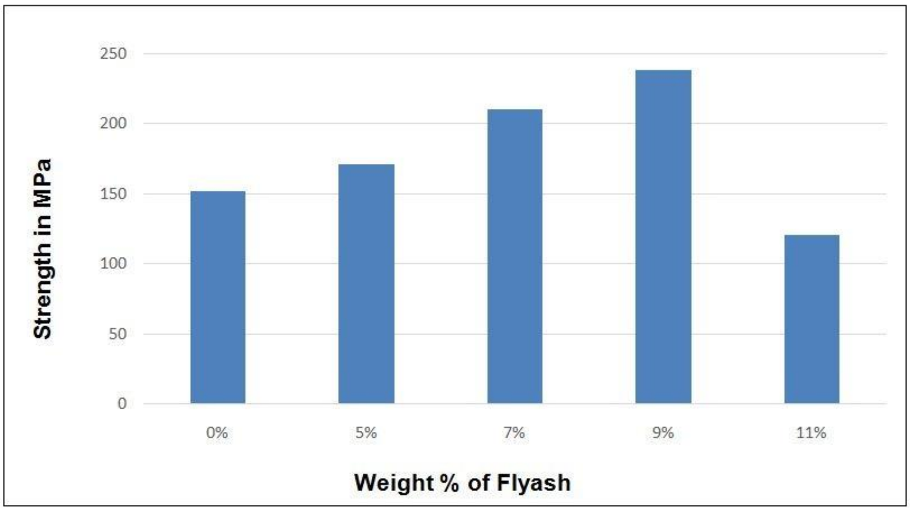


*Fig4. Strength for weight % of flyash*

This indicates that the fly ash addition leads to improvement in the ultimate tensile strength. Form the table it is clear that addition of Mg improve the tensile properties of the composite. The size range of the particles is very wide. The size ranges of the fly ash particles indicate that the composite prepared can be considered as dispersion strengthened as well as particle reinforced composite. As is seen from the particle size distribution there are very fine particles as well as coarse ones (1-100 μm). Thus the strengthening of composite can be due to dispersion strengthening as well as due to particle reinforcement. Dispersion strengthening is due to the incorporation of very fine particles, which help to restrict the movement of dislocations, whereas in particle strengthening, load sharing is the mechanism.

**Impact Test**

*Table5: Impact enegy*

| Composition | Impact Energy(J) |
|---|---|
| 0% | 2 |
| 5% | 2 |
| 7% | 4 |
| 9% | 5 |
| 11% | 6 |

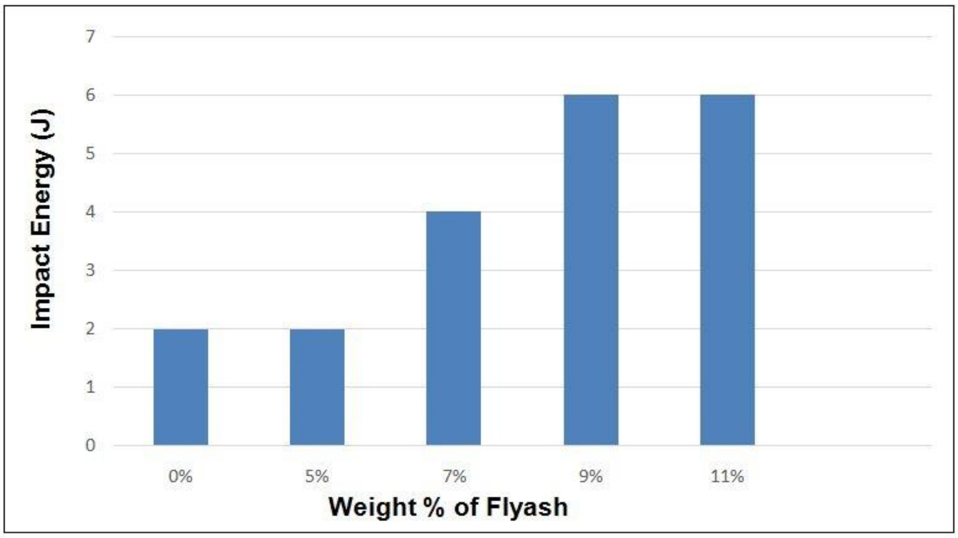


***Fig5. Impact energy for weight % of flyash***

The Graph and Impact table shows that pure aluminium having low impact value and then impact value increases as the percentage of reinforcement increases upto 11% reinforcement. Hence from the above data we can say that the strength of AMC increases with the addition of flyash.

**Compression Test**

*Table6: Compression strength*

| Composition | Compression Strength($N/mm^2$) |
|---|---|
| 0% | 640 |
| 5% | 680 |
| 7% | 738 |
| 9% | 740 |
| 11% | 745 |

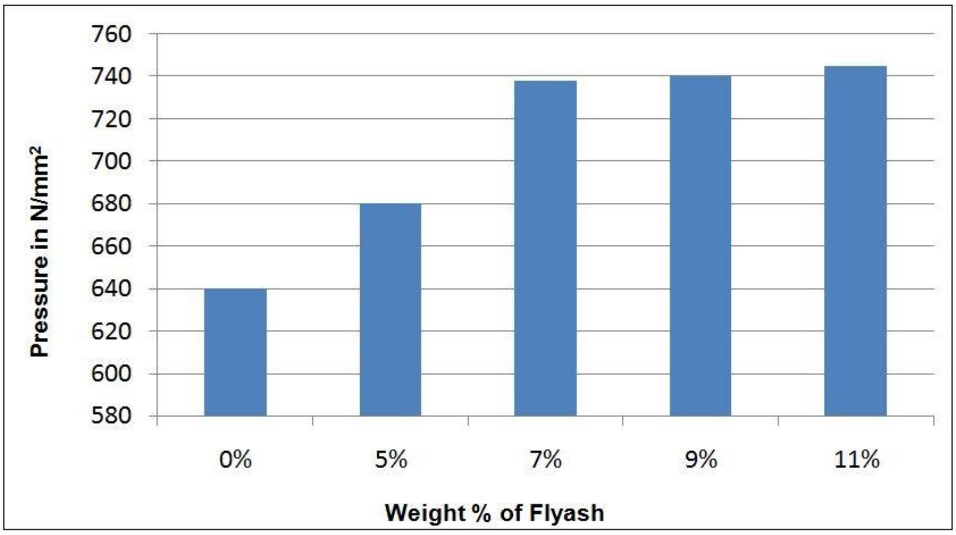


*Fig6. Pressure for weight % of flyash*

The Graph and Compression table shows that pure aluminium having low compressive strength and then compressive value increases as the percentage of reinforcement increases upto 11% reinforcement.

**Sliding Wear Behaviour**

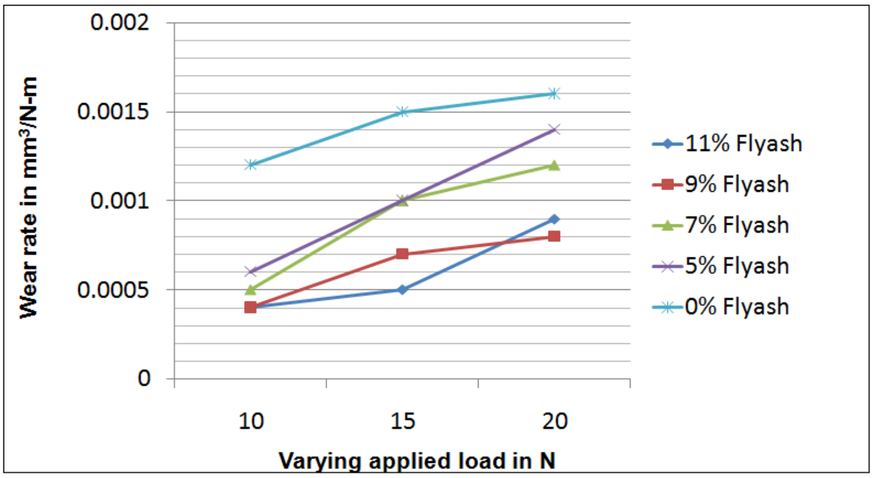


*Fig7. Wear rate for applied load*

Fig 5.1 shows thw graph plotted for wear rate having sliding velocity 1m/s having loads 10N, 15N, 20N. It shows that gradual decrease in the wear rate by the addition of flyash reinforcement.

## IV. CONCLUSIONS AND FUTURE SCOPE

The flowing conclusion may be drawn form the present work:

- From the study it is concluded that we can use fly ash for the production of composites and can turn industrial waste into industrial wealth. This can also solve the problem of storage and disposal of fly ash.
- Fly ash up-to 20% by weight can be successfully added to commercially pure aluminum by stir casting route to produce composites.
- Addition of magnesium and silicon improves the wettability of fly ash with aluminium melt and thus increases the retention of the fly ash in the composite.
- Hardness of commercially pure aluminium is increased from 58BHN to 86BHN with addition of fly ash and magnesium.

- The Ultimate tensile strength has improved with increase in fly ash content. Where as ductility has decreased with increase in fly ash content.
- The effect of increased reinforcement on the wear behavior of the MMCs is to increase the wear resistance and reduce the coefficient of friction. The MMCs exhibited better wear resistance due to its superior load bearing capacity.
- The wear resistance of composites is much greater than the commercially pure aluminium.
- Different wear mechanisms were found to operate under the test conditions of variation of normal loads, composition, and sliding velocity .They are oxidation abrasion and delamination.
- Increased normal load and sliding velocity increases magnitude of wear and frictional force.

As a future work:

- In the present study, the reinforcement particulate of size ranging from 01to 100µm (Fly ash) has been used. Hence, there is a scope for furtherstudy in which the effect of particulate sizes on tribological properties ofthe composites can be investigated.
- The present study has mainly focused on the dry sliding wear behaviourof the composites. Further, the work may include the wear behaviour ofthe composite with wet conditions (Liquid Lubrication).
- In this study, the composites have been cast by stirring cast method only. However, the effect of other manufacturing techniques can be attempted and analyzed so that a final conclusion in terms of suitable casting technique can also be drawn.
- Heat treatment of composites can be attempted with different quenching media and the effect of heat treatment on mechanical and tribological properties of composites may be investigated.
- Based on the author‟s investigation, it has been found that the research on structural behaviour of composite structure by Finite Element Analysis (FEA) may attract more interests in the future research.

## V. REFERENCES


[i] Anilkumar, HC, Hebbar, HS & Ravishankar, KS 2011, „Mechanical properties of fly ash reinforced aluminium alloy (Al6061) composites‟, International Journal of Mechanical and Materials Engineering (IJMME), vol. 6, no.1, pp. 41-45.

[ii] Ibrahim, IA, Mohamed, FA & Lavernia, EJ 1991, „Particulate reinforced metal matrix composites - a review‟, J. Mater. Sci., vol. 26, no. 5, pp. 1137-1156.

[iii] Hutching, IM 1994, „Tribological properties of metal matrix composites‟, J. Mater. Sci. Technol., vol. 10, no. 6, pp. 513 -517.

[iv] Arsenault, RJ & Taya, M 1987, „Thermal residual stress in metal matrix composite‟, Acta. Metall. Mater., vol. 35, no. 3, pp. 651-659.

[v] Banerji, A, Surappa, MK & Rohargi, PK 1983, „Cast aluminum alloys containing dispersions of Zircon particle‟, Metall. Trans., vol. 14, no. 2, pp. 273-283.

[vi] Chaudhury, SK, Singh, AK, Sivaramakrishnan, CS & Panigrahi, SC 2005, „Wear and friction behavior of spray formed and stir cast Al- 2Mg-11TiO2 composites‟, Wear, vol. 258, no. 5-6, pp. 59-767.

[vii] Sarkar S., Sen S. and Mishra S. C, Aluminum – fly ash composite produced by impeller mixing, Journal of reinforced plastics and composites,(2008):pp 1-6

[viii] Matthews F.L., Ralwlings R.D, Composite materials engineering ans science, Glasgow, UK, Champaman and hall, 1994

[ix] Rohatgi P.K, Metal-matrix Composites, Defence Science Journal, Vol 43, No 4, (1993): pp 323-349

[x] Radhakrishna M. Ramachandra K., Effect of reinforcement of flyash on sliding wear, slurry erosive wear and corrosive behavior of aluminium matrix composite, Wear 262 (2007): pp1450–1462.

[xi] Chen, MY & Breslin, MC 2001, „Friction behavior of co-continuous alumina/aluminum composites with and without SiC reinforcement‟, Wear, vol. 249, no. 10-11, pp. 868-876.

[xii] Chen, J, Hao, C & Zhang, J 2006, „Fabrication of 3D-SiC network reinforced aluminum- matrix composites by pressure less infiltration‟, Mater. Lett., vol. 60, no. 20, pp. 2489-2492.