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# Wear Characterization of Al 7075 –$Al_2O_3$ Metal Matrix Composite Fabricated by Stir Casting Process

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***Abstract-*** **The present work aims at development of particulate metal matrix composite using Aluminum alloy(AL 7075) as the matrix material and alumina($Al_2O_3$) as Reinforcement.Al2o3 is reinforced in the weight fraction of 5%,10%,15% and 20% with the particle size varying between 50 microns to 150 microns .The aluminum alloy was melted at 700°C in an electrical heating furnace for 20 minutes and the reinforcement is heated separately at 950° C was added in the form of powder.The mixture was stirred for 5 minutes at the temperature of 730°C,then poured in to the sand mold. Optical micro graph of the developed composite was obtained to demonstrate the distribution of the reinforcement in the matrix.The hardness testswas carried out to determine the effect of reinforcement on the hardness of the composites. It is observed that the hardness of the composite increases with the increase in weight fraction of the reinforcement.The density of the composite determined theoretically and experimentally shows the presence of porosity up to maximum of 25%,which indicates degassing process to be carried out to reduce it. The wear test carried out at various speed,load and sliding distance which indicates improvement in the mechanical properties of the composites. The wear resistance of the composite was found to reduce with the increase in the weight fraction of the reinforcement. The wear resistance was found to decrease with increase in speed, but it increases with the increase in load and sliding distance for all specimens.The coefficient of friction was found to decrease with the increase in weight fraction of the reinforcement.The investigation carried out will lead to development of the composite system with high strength, improved wear resistant,light weight for automobile parts like disc brake,piston, cylinder liner, drive shaft etc.**

***Key words - Wear, Al7075/$Al_2O_3$, Stir casting, Weight fraction.***

## I INTRODUCTION

The innovation in the materials domain opened unlimited possibility for the modern automobile and aircraft industries to develop light weight & high strength parts.

The main objective of developing composite with new material system is to obtain high strength,l ight weight, high wear resistance& fuel efficient, pollution free, recyclable properties. The Metal Matrix composite is an unique material system which try to address all the requirement of the modern material behavior. The light weight metals like Aluminum, Titanium and Magnesium are researched more intensively along with their alloy in different percentage of additives. The work on composite began in 1920s from then various combinations of alloy and reinforcements are investigated. The commercialization and industrialization of the new materials depends on the cost of production, availability, recyclability and establishment of standards for design and development. The process of developing and commercializing needs the research data obtained on all possible combinations, the idea which has to be developed, & validated followed by pilot development and prototype development, finally application or development for commercial use[1].

The reinforcing material selected as ceramic material as they are light weight and have the capacity to withstand high temperature and wear. The combined density of reinforcement and matrix in a composite material is very less as compared to conventional materials like steel and cast iron .The reinforcement are of oxides, carbides, borides. The oxides are more stable at high temperature with the aluminum alloy hence more widely used ceramics are oxides. The reinforcement shape chosen will have effect on the properties and cost of production. The powdered form of the reinforcement i.e. Particulates of various sizes from micro to nano range were investigated for the production of the MMC.The cost and availability of the reinforcement will popularize the usage of composites for mass production. Most of the investigations were carried on silicon carbide and aluminum oxide from the beginning. The silicon carbide(SiC)is costlier compared to alumina($Al_2O_3$), also presence of carbon in SiC will give rise to interface reactions in aluminum matrix. Careful control of the melting temperature and mixing time is essential for composite development with SiC. In Al/$Al_2O_3$ reinforced composite the reinforcement is more stable at high temperature and improved properties are obtained. 40% of the final product cost depends on the material cost and 30% of the cost depends on the manufacturing process. As the alumina is readily available in particulate form,which are more easily fabricated by low cost stir casting process. The stir casting also provides uniform distribution of the reinforcement to get isotropic properties for the composite.

The stir casting process is one of the liquid state process which is also called as compo casting. The process is carried out by melting the matrix in an furnace, a vortex is created by continuously stirring the melt and addition of the reinforcement in the particulate form by direct pouring or through pressured gas. Care must be taken to avoid entrapment of the gas to avoid porosity. The temperature of the melt is kept at optimum level to maintain the required density so that the reinforcement will not either sink to the bottom of the crucible or float at the top of the melt due to mismatch of the density of the reinforcement and molten matrix. Dispersion strengthened composite will have restrictions on the moment of the dislocations due to distribution of the reinforcement. The degree of strengthening depends on amount of particulate volume fraction distribution, shape & size of particles etc. Alumina has received attention as reinforcing material due to its low cost, availability, high strength and hardness. Researchers studied mica, alumina, silicon carbide, clay, graphite as reinforcement in the production of composites. The volume fraction of the particulates are less than 30% for structural application and as high as 70% for the packaging industries. It is generally accepted that strength of the composite is controlled by matrix material there-fore the researchers use 2xxx,6xxx and 7xxx series aluminum alloy for high strength.
The effect of reinforcement quantity on the composite is significant. The volume fraction or weight fraction of reinforcement alters the mechanical properties of the composite materials. The strength and wear resistance of the composite can be improved significantly by addition of the various percentages of reinforcements as compared to unreinforced alloy. Most of the research has been carried out to study the strength of the composite with respect to weight fraction but the inherent property of the $Al_2O_3$ makes it necessary to investigate the wear and friction behavior .The parts like disc brake, piston, cylinder liner which experiences higher wear can be fabricated by composite based on the wear behavior at high speed, load and temperature conditions. The effect of $Al_2O_3$ particles weight fraction and size on the properties of the composite was studied [6].addition of $Al_2O_3$ particulate toA365-aluminum alloy increases dry wear [13] Addition of Mg and Zr up to 1% in aluminum will increase the strength and toughness by wetting the reinforcement.

EXPERIMENT

The objective of the present study is to incorporate the ceramic particles in to the matrix by melting and stirring. The reinforcement is added to the matrix which is in the liquid state. The fig 1 shows the stir casting process in which the stirrer is used to disperse the reinforcement particle to get homogeneity by inducing vortex.

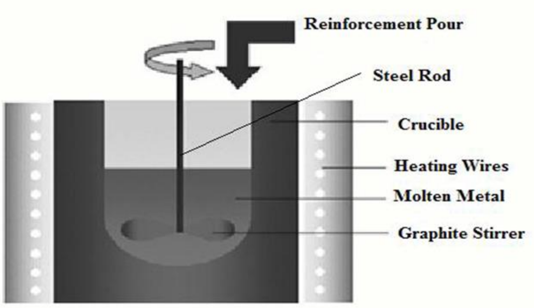



Table1. Composition and Properties of AL-7075

| Element | Weight |
|---|---|
| Si | 0.4 |
| Fe | 0.5 |
| Mn | 0.3 |
| Mg | 2.9 |
| Cu | 2 |
| Zn | 6.1 |
| Ti | 0.2 |
| Cr | 0.28 |
| Al | 87.32 |

| **Mechanical properties** | |
|---|---|
| Hardness –Brinell | 150 |
| Ultimate tensile strength | 572MPa |
| Tensile yield strength | 503MPa |
| Elongation at beak | 11% |
| Modulus of Elasticity | 71.7GPa |
| Poission’s ratio | 0.33 |
| Fatigue strength | 159MPa |
| Machinability | 70% |
| Shear modulus | 26.9GPa |
| Shear strength | 331Mpa |

The reinforcement material selected is Alumina ($Al_2O_3$) supplied by Rolex Ltd,in the form of powder of particle size 50 to 200 microns.The properties of alumina is shown in table 2. The weight fractions of the particulates are 5%,10%,15% and 20% .For one kg melt the reinforcement material for 5% weight fraction was 50gms and matrix material was 950gms.Simillarly for the weight fraction of 10%,15% ,20% the reinforcement of 100gms,150 gms ,200gms were used.

**Fig 1. Stir casting process set up.**

The aluminum alloy used for the present study was Al7075 supplied by Hindalco Ltd , which contains Zn as major alloying element(6.1%).The matrix material has good response to heat treatment and age hardening. It is light weight and withstands high temperature compared to other series of alloy. The composition and properties of the Al7075 is shown in table 1.

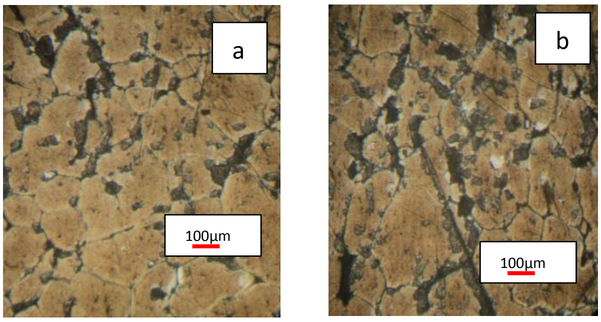
Table 2. Properties of Alumina

| Property | values |
|---|---|
| Melting Point °C | 2072 |
| Hardness(kg/mm2) | 1175 |
| Density(g/cm3) | 3.69 |
| Coefficient of thermal expansion(micron/m 'C) | 8.1 |
| Fracture Toughness | 3.5 |
| Poission's ratio | 0.21 |
| Colour | White |

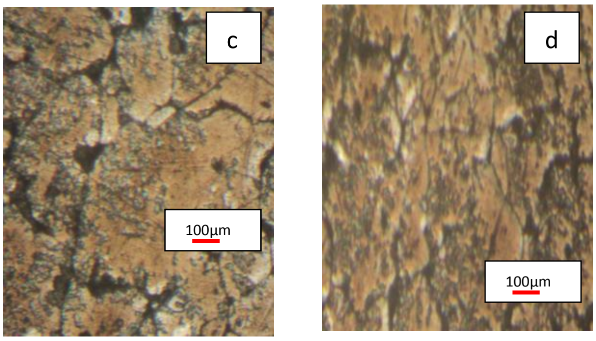
The matrix material was in the form of bar of 20mmX20mm c/s and 100 mm length which are cleaned, placed inside the graphite crucible and melted in electric furnace.The melting temperature was kept at 700° C so as to get the desired viscosity of the melt.The reinforcement particles were heated to 950° C separately and added to the melt ,the stirring of the mixture was carried by alumina rod to get uniform distribution of particles. The melt was degasified and the slag was removed manually before pouring. The stirring was continued for 10 minutes and the melt was poured in to the sand mold. The castings was obtained in the form of rod diameter 20mm and length 200mm.The pouring temperature was recorded as 650° C.
The casted specimens were turned to reduce the diameter to 16mm their by removing the oxide layer and rough surface from the castings. The specimen with diameter 16mm and length 30 mm were used for hardness test and microstructure analysis. The wear test specimens were prepared with diameter 12mm and length 25mm.

## RESULTS AND DISCUSSION

The microstructure characterization was carried out as per ASTM E407 standards in which the specimen id grinded initially followed by polishing with 300,600, 800, 1000, 1200 grit size sand paper.The samples are grounded on golden touch 1,2,3,4 grit size emery sheet. Polishing the specimens were carried out with diamond paste and followed by etching by kellers solution. The optical micrograph was obtained at 50x in etched and un etched condition for all the casted specimens, the microstructure is as shown in the fig 2.




a) b)




(c) (d)

Fig 2. Optical micrograph of composite with Various weight fraction.a) Al 7075 with 5% $Al_2O_3$,b) Al 7075 with10% $Al_2O_3$,c) Al 7075 with 15% $Al_2O_3$,d) Al 7075 with 20% $Al_2O_3$

The theoretical density and experimental density were calculated and compared to get the amount of porosity in the composite.The hardness test conducted with the Brinell and Vickers harness tester.The hardness measured was bulk hardness which is an average estimation of hardness. The load of 250 kg with 5mm ball indenter was used for Brinell test and 20kg load and 10 seconds dwell was used for Vickers hardness test. The BHN, VHN and density for various weight fraction of reinforcement are shown in fig 3& 4.
The wear test was carried out by pin on disc wear test machine (wear and friction monitor –TR20 ) supplied by DUCOM, Bangalore. The wear test conducted as per ASTM G99 standards under dry condition. The specimen in the form of pin diameter 12 mm and length 25mm were inserted in the collet and made to contact against the rotating disc of EN 40 steel of 60 HRC. The surface finish of the disc was 1.6Ra.The load on the pin material is applied through the dead weight. wear in micron was measured by LVDT and friction force by load cell. The wear rate was calculated based on the volume loss and sliding distance.

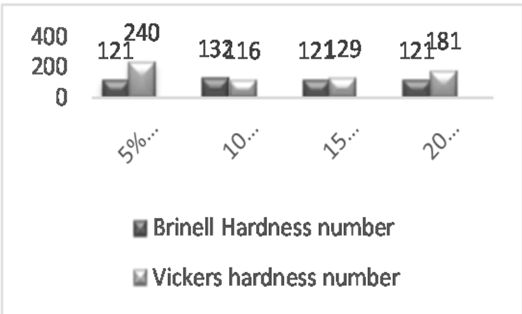



**Fig 3. Brinell and Vickers hardness Values for various weight fractions**

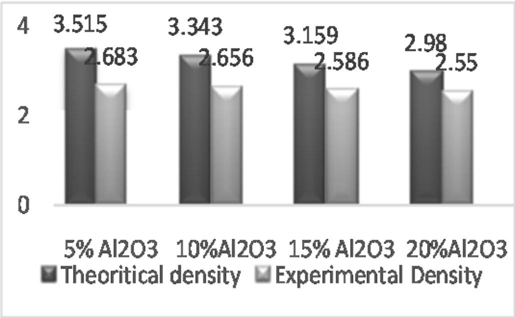



Fig 4. Theoretical and Experimental Density for various weight fractions

The tests were carried out in phases at varying load on pin ,varying speed of the disc and varying sliding distance of pin. The liner wear indicated by the wear monitor was recorded and wear rate was calculated for all the three phases of the test.The plot of the wear rate vs load,wear rate vs speed and wear rate vs sliding distance are shown in fig 5 ,6 & 7.

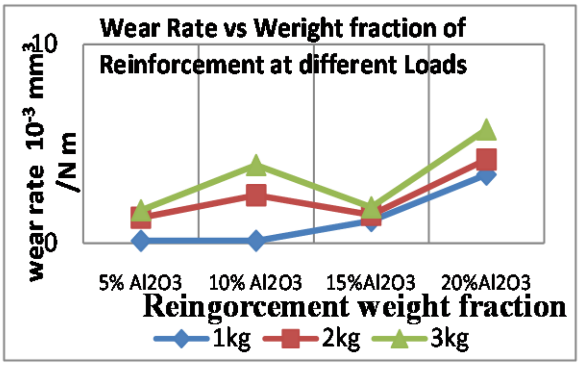



Fig 5 variation of wear rate with applied load of 1kg,2kg and 3kg for speed of 300 rpm and sliding distance of 2000m

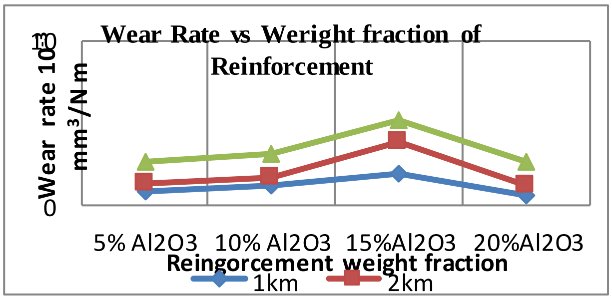



Fig 6 variation of wear rate with applied sliding distance of 2km,2km & 3k m for speed of 300 rpm and load 2

**kg.**

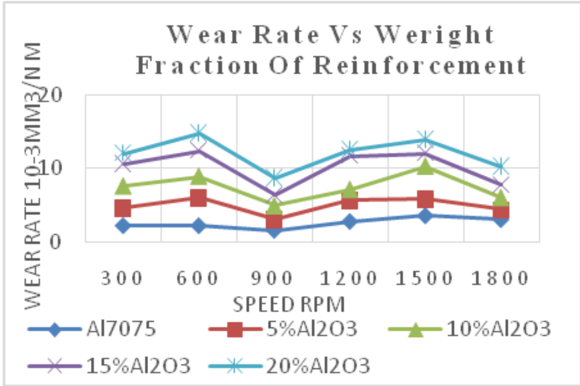



Fig 7 variation of wear rate with applied speed 300, 600, 900, 1200& 1500 rpm for load of 2kg and sliding distance of 2000m

The variation of wear vs speed, load, weight fraction is as shown in fig 8,9,10.As determined by the winducom software with the data acquisition system.

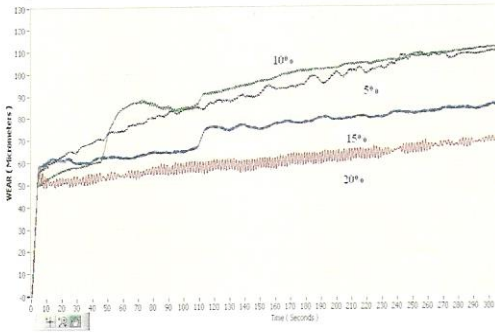



Fig 8 variation of wear with time as indicated by the winducom software for varying weight fraction of the reinforcement

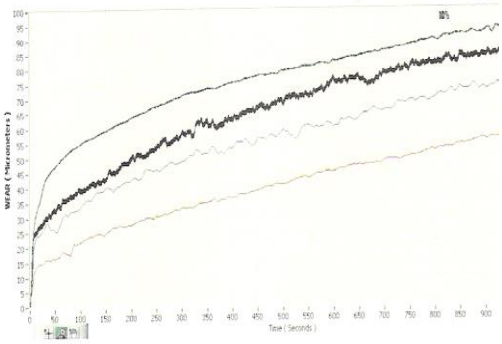


Fig 9 variation of wear with time as indicated by the winducom software for varying load on the specimen pin.

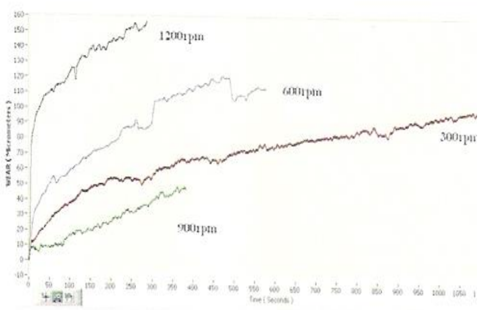



Fig 10 variation of wear with time as indicated by the winducom software for varying speed of the disc.

The coefficient of friction has to be associated with the wear phenomenon has been recorded for all conditions of the test parameter. It is calculate by recorded frictional force and applied load. The variation of the coefficient of friction was shown in fig 11.The consolidated table 4 shows variation of all the parameter found experimentally with the weight fraction of reinforcement.

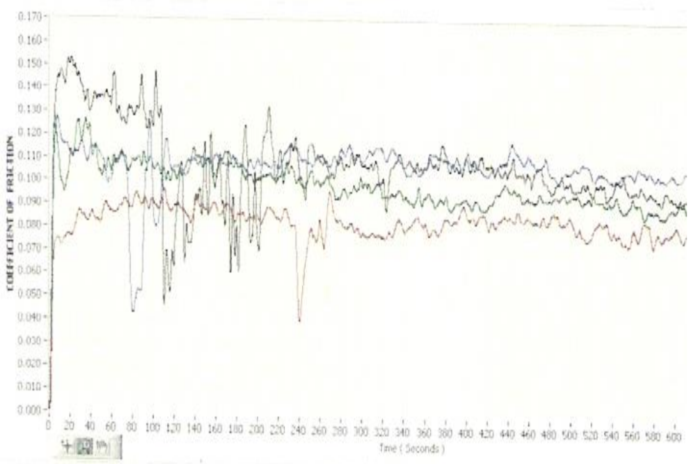


Fig 11 variation of coefficient of friction with time as indicated by the winducom software for varying load on the specimen

The mechanical test carried out on the specimen at different condition and their values are tabulate in table 3 and the comparison of the consolidated properties of the composite are shown in fig 12.

Table 3. Consolidate Test results for varying weight Fraction

| Specimen code and weight fraction. | Density $Kg/m^3$ | Vickers Hardness HV 30kg/15 sec | Wear Rate $10^{-4}$ $mm^3/$ N m | Coefficients of friction |
|---|---|---|---|---|
| Al7075 +5% $Al_2O_3$ | 2683 | 116 | 2.795 | 0.152 |
| Al7075 + 10% $Al_2O_3$ | 2656 | 132 | 2.882 | 0.132 |
| Al7075 +15% $Al_2O_3$ | 2586 | 121 | 1.498 | 0.122 |
| Al7075 + 20% $Al_2O_3$ | 2550 | 121 | 1.269 | 0.132 |

The Al7075/$Al_2O_3$ particulate composite was successfully developed by stir casting process using sand mold. The particulate composite are suitable for mass production by low cost stir casting process. The uniform distribution can be achieved by stirring the matrix and reinforcement at the optimum melting temperature of 700°C.The availability and low cost of the $Al_2O_3$ reinforcement proves itself as good candidate for low cost, light weight and wear resistant automotive parts. Isotropic property is obtained with optimum stirring speed.

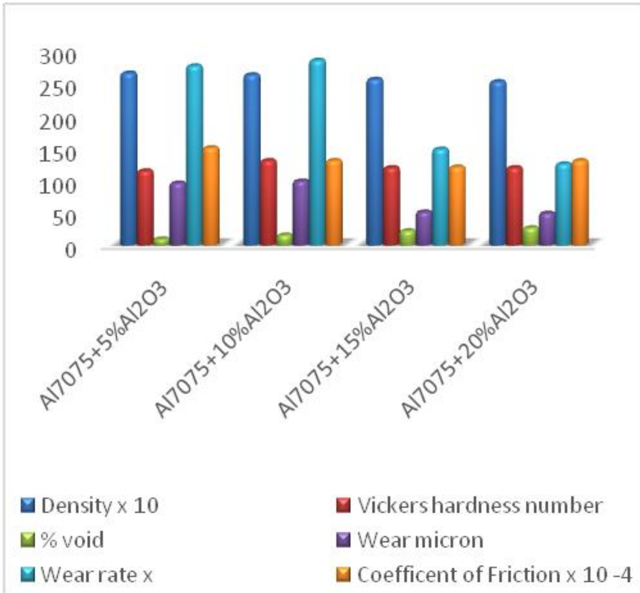



Fig12 variation of the mechanical test results foe varying weight fractions of the $Al_2O_3$ reinforcement.

The density of composite was shown in fig 4 indicated the variation with weight fraction. It increases with increase in weight fraction. The porosity was is maximum for highest weight fraction of reinforcement which is due to segregation and entrapment of gases. The density of the composite is still less than the conventional alloy like steel and cast iron which can be used for light weight and fuel efficient purpose. The variation of density values from theoretical and experimental method is due to porosity it was about 20%, which can be reduced by secondary process like rolling, extrusion and forging.

The optical microstructure shown in fig 2 indicates the presence of $Al_2O_3$ particles in the matrix of Aluminum. The distribution of these particle depends on the temperature of the melt and stirring speed. More agglomeration can be noticed in case of higher weight fraction of reinforcement.

The hardness table shows the increase in weight fraction increases the hardness of the composite. The uniform variation of the hardness can be obtained with micro hardness test than the bulk hardness .The reinforcement particle influences the hardness but reduces the ductility of the alloy.

The particle reinforce composite is primarily developed for tribological application .The hard particle SiC, $Al_2O_3$,$B_4C$,$TiB_2$etc. are added for wear and strength , where as soft particles like graphite,$MSO_2$are added for friction control .The behavior of these hard and soft particle exhibit different wear and friction variation in the same matrix under varying speed ,load and time. The wear rate reduces with the increase in speed and lowest at the speed of 300 rpm and 900 rpm. As the sliding distance is increased the wear rate reduces .wear rate increases with the increase in load. The reduction in the wear rate is due to hard particles are in contact with the disc material that are not worn out with the increase in load or sliding distance.

The coefficient of friction reduces with the increase in sliding distance, this variation is only little as the but the noise and vibrations are observed at higher speed and loads due to hard particle rubbing against the hard disc material which produces the noise due to excessive vibration and distortion of the pin. As the reinforcement is hard ceramic it will influence the reduction of the noise which can be possible with the soft ceramic like graphite or $MSO_2$ also.

Conclusion

1. Stir casting route for the development of particulate composite is suitable and cost effective method. Uniform distribution of the reinforcement is obtained by stirring the melt at 750°C.
2. Enhanced strength, wear resistance and low cost composite can be developed with Alumina ($Al_2O_3$) ceramics material. These materials are fuel efficient and light weight suitable for automobile and aircraft applications.
3. Hardness of the composite increases with the increase in weight fraction up to 30% and further it intensity reduces .ceramic particles increases the hardness at the same time the material becomes brittle.Porosity increases with weight fraction which can be controlled by extrusion and rolling.
4. The density of the composite is in between the density of matrix and reinforcement material which is 50% less than the density of steel and cast iron.
5. Wear resistance of Al7075/ $Al_2O_3$ particulate composite increases with the weight fraction. Coefficient of friction depends on the weight fraction which reduces with increase in weight fraction.
6. The wear rate reduces with speed, but increases with load and sliding distance.

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