# Mechanical Properties and Wear Strengths of Piston Alloy-Alumina Composites

**Sheikh Jaber Nurani, Chandan Kumar Saha, M.N Haque**

***Abstract— Aluminium metal matrix composites reinforced with alumina particles have better mechanical and tribological properties than aluminium alloys. For this reasons these composites are widely used in aerospace and automobile industries. In this work Scrap piston alloy was used as master alloy because it contains silicon and magnesium. Silicon increases the casting ability and magnesium increases the wettability of alumina particles in master alloy. The desired composites were produced by the stir casting method by adding 5%, 10% and 15% alumina particles in master alloy respectively. For each of the composite alumina particles were preheated to a temperature of 800°C for 2 hours. Then particles were added gradually into the molten master alloy for achieving improved wettability and uniform distribution. The stirring was continued for 5 minutes. Finally composites ware poured into permanent metallic moulds at a temperature of 650°C. The hardness and tensile strength of the composites were examined. All composites have higher strength than master alloy. Addition of alumina particles in master alloy increases the hardness of the composites. The wear tests were conducted using pin on disc wear testing machine with counter surface as steel disc of hardness HRC 32 and surface roughness of 0.62 µm. The composite pin was used as specimens and all the wear tests were carried out in air and dry sliding conditions. It was found that composites have superior wear resistance property over master alloy. It was also examined the effect of load, sliding speed and sliding distance on wear behaviour. All these three factors increase the wear loss. Microstructural characterization of the composites has performed.***

***Keywords: — Alumina Particles, Composite, Hardness, Piston Alloy, Stir Casting, Tensile Strength, Wear Properties.***

## I. INTRODUCTION

Metal matrix composites (MMCs) have higher mechanical and physical properties such as high strength and modulus, superior strength to weight ratio, excellent wear resistance [1]. Aluminium and magnesium alloys are used extensively for MMCs due to their light weight [2]. These alloys also provide good mechanical properties, easy availability and corrosion resistance. Aluminium metal matrix composites are widely used in aerospace, automobile and electricity industries due to its improved mechanical properties [3]. $Al_2O_3$, SiC, TiC, and $TiB_2$ particles are extensively used as reinforcement in aluminium alloy to improve mechanical properties and wear resistance [4]. Prabu et al [5] studied high silicon content aluminium metal matrix composites material reinforced with ceramic particles. In present work piston alloy used as master alloy because it contains higher amount of silicon which increase casting ability by increasing fluidity**.** There are different routes by which a metal-matrix composite can be manufactured e.g. solid phase fabrication, liquid phase fabrication and vapour phase fabrication methods. Solid-phase fabrication methods are diffusion-bonding method and powder metallurgy technique. Liquid-phase fabrication methods are infiltration, squeeze casting infiltration, gas pressure infiltration, pressure die infiltration, deposition and stir casting process. Vapour state method is physical vapour deposition (PVD). In this project stir casting process has adopted because it has some important advantages than other processes e.g. the wide choice of materials, easier control of mixer structure, better matrix particles bonding, simple and inexpensive processing, flexibility and applicability of enormous quantity production and excellent productivity for near net shaped components. AA 2024 aluminium alloy metal matrix composites (MMCs) reinforced with $Al_2O_3$ particles of three different sizes and various weight percentage up to 30 wt. % have investigated by vortex method [6]. It is shown that the tensile strength and hardness of the composite increases with increasing the weight fraction and decreasing the size of alumina particles. It has shown that wear properties of Aluminium alloy increases with the addition of hard ceramic particles in aluminium alloy [7]. Straffelini et al. [8] shows that dry sliding wear behaviour of 6061Al - $Al_2O_3$ depends on matrix hardness. The addition of ceramic particles increases the hardness hence decreases wear [9]. $Al_2O_3$ particles increase the dislocation density and decreasing the grain size of the metal matrix. In this work Piston alloy-$Al_2O_3$ composites containing 0 to 15% percentage of $Al_2O_3$ in step of 5 have produced by stir casting process and study the effect of $Al_2O_3$ particles on mechanical properties and wear strength.

## II. EXPERIMENTAL

### *A. Preparation of Master Alloy*

Eight kilogram of scrap pistons was melted in the crucible in a pit furnace at temperature 800°C.

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**Sheikh Jaber Nurani**, B.Sc. in Materials and Metallurgical Engineering, Department of Materials and Metallurgical Engineering, Bangladesh University of Engineering and Technology (BUET), Dhaka, Bangladesh, e-mail: sheikh.jaber.nurani@gmail.com.

**Chandan Kumar Saha**, B.Sc. in Materials and Metallurgical Engineering, Department of Materials and Metallurgical Engineering, Bangladesh University of Engineering and Technology (BUET), Dhaka, Bangladesh, e-mail: Chandan_buet08@gmail.com.

**Prof. Dr. M.N Haque**, Former Head of the Department of Materials and Metallurgical Engineering and former Dean of Engineering Faculty, Bangladesh University of Engineering and Technology (BUET), Dhaka, Bangladesh, e-mail: nhaque@mme.buet.ac.bd.

Degasser was used before pouring to remove dissolved gasses. Finally melt was poured in sand mould at temperature 750°C. Rectangular shaped 3.7 cm × 7.3 cm × 126 cm bar was produced. This bar was used as the master alloy. The composition of the master alloy is shown in table 1-

**Table 1: Chemical Composition of Master Alloy**

| Si | Cu | Mg | Mn | Fe | Ni | Zn | Al |
|---|---|---|---|---|---|---|---|
| 9.8 | 2.84 | 0.58 | 0.56 | 0.36 | 0.21 | 0.12 | BAL. |

### B. Preparation of Composites

The desired composites were produced by the stir casting method shown in figure 1. At first the master alloy was cut into several pieces and 1 kg of master alloy placed in graphite crucible in a pit furnace. The master alloy was melted at a temperature of 800°C. After complete melting, crucible was removed from furnace and degasser is used to remove dissolved gasses. After that master alloy melt was transferred to holding furnace of the stir casting machine to hold the temperature which is shown in figure 1. Then the alumina particles size of 74-115 µm were gradually added into the molten alloy which was continuously stirred at 500 rpm. The particles were preheated at 800°C for 2 hours before adding in order to improve its wettability

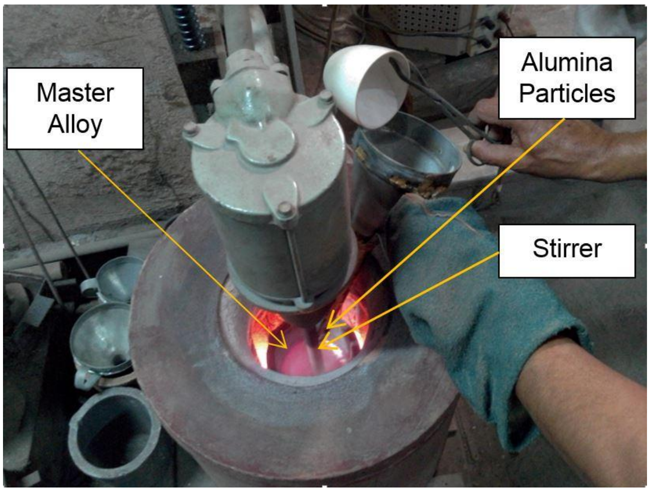


**Figure 1: Preparation of alumina particles reinforced aluminium alloy matrix composites by the stir casting method.**

The particles were added in the vortex which was produced due to stirring and after adding all the particles, the stirring was continued for 5 minutes in order to get a homogeneous distribution of the reinforced particles. Three different composites were produced by adding 5%, 10% and 15% alumina particles in master alloy respectively. Finally the composite was poured into permanent cast iron mould at a temperature of 650° C. After cooling to room temperature the composite was removed from metal mould.

### C. Wear Test

ASTM G 99-05 standard was followed in preparing all the wear test specimens. 8 mm diameter and 6.5 mm long cylindrical samples were produced for wear test. Wear test of the composites were conducted under dry sliding condition using pin on disc method at room temperature without lubrication. The tests were subjected on specimen against a rotating mild steel disc of hardness HRC 32 and surface roughness of 0.62 µm. Acetone was used to clean the frictional surfaces of the counterpart. An arm was used to hold and load the pin specimen vertically on the disk. The arm can move freely in both vertical and horizontal direction. The disc rotates with the help of a DC motor. Three different parameters load, sliding speed and sliding distance were selected and their effects on wear loss were observed in three different composites and the master alloy. The weight loss of the wear specimens was calculated for three different loads 7 N, 12 N and 17 N at rotational speed of 300 rpm and for three different sliding speeds 300 rpm, 450 rpm and 600 rpm at 12 N loads.

### D. Hardness Test

Hardness of the master alloy and composites was tested by Rockwell hardness testing machine (model: FR-1E) using F scale. Indentation ball was $^1/_{16}$ inch (1.588 mm) diameter steel sphere and load of 60 kgf.

### E. Tensile Test

Three tensile samples were prepared for each of the samples namely master alloy, composite contains 5% Alumina particles, composite contains 10% Alumina particles and composite contains 15% Alumina particles.

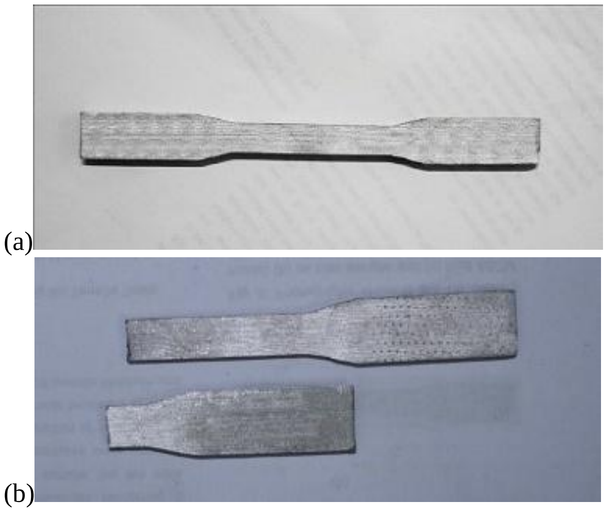


**Figure 2: Tensile test sample a) before tensile test b) after tensile test**

ASTM E8 standard was followed for preparation of tensile test sample. Gauge length of the sample was 40 mm. After preparing tensile test samples these samples were tested using Instron Tensile Test Machine.

## III. RESULT AND DISCUSSION

### A. Tensile Strength

Tensile strength of the master alloy and composites is shown in figure 3 as a function of wt. percentage of alumina particles. From figure 3 it is seen that all composites have higher tensile strength than master alloy.


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This significant increase in tensile strength because of hard ceramic particle inhibits the motion of dislocation. Tensile strength decreases with increasing the amount of ceramic particles beyond 5% alumina particles. The reason of such decrease is that with increasing ceramic particles mixing is not uniform. Non uniform mixing increases porosity.

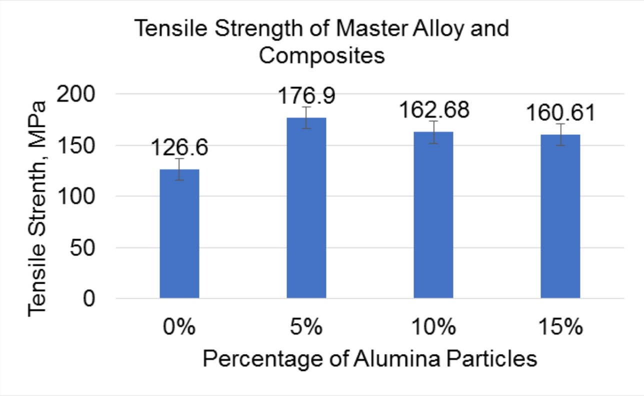


**Figure 3: Tensile Strength of master alloy and composites containing 5% alumina particles, 10% alumina particles and 15% alumina particles**

Porosity increases with increasing wt. percentage of alumina particles which is shown in figure 9. Porosity influences on the poor adhesion at the interface of matrix and ceramic particles. From figure 3 it is seen that composite containing 5% alumina showed the maximum tensile stress was 176.9 MPa which is 39.7% larger than the matrix.

### B. Hardness

Hardness tests were conducted to observe the effects of addition of alumina particles on master alloy. Variations of hardness with addition of particles are shown in figure 4.

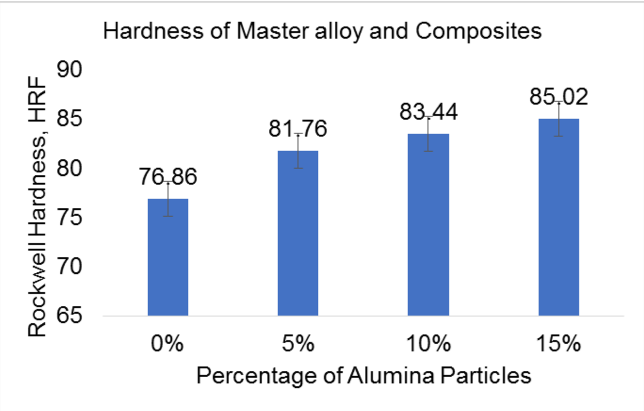


**Figure 4: Variations of hardness of unreinforced master alloy and composites.**

From figure 4 it is seen that hardness increases with the addition of alumina particles. Alumina particles are ceramic materials that are very hard. Matrix material is soft. Hard particles influence the hardness positively. Hard ceramic particulates also inhibit the motion of dislocation and increase the hardness

### C. Wear

Wear test were carried out to see the effect of percentage of reinforcement particles, load, sliding speed and sliding distance on wear loss. Wear test results at various loads at master alloy and different composites are described below.

### D. Effect of Reinforcement on Wear

It is clearly seen from figure 5 that wear loss is decreased with increasing the percentage of reinforcement alumina particles. That means wear resistance is increased with increasing in the percentage of alumina particles.

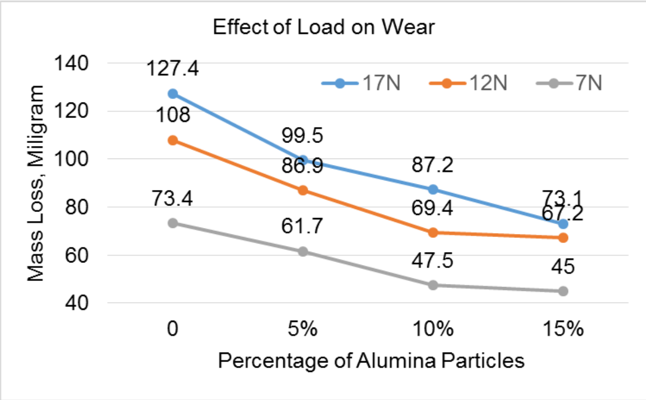


**Figure 5: Mass loss of the master alloy and composite at different load at constant 0.77 $ms^{-1}$ sliding speed**

Hard alumina particles give resistance to penetration, grinding and ploughing by steel counterpart. Hard alumina particles also act as a main load bearing system for the multicomponent system which also improves wear resistance. In figure 5 it is seen that slope of the curve of 5% alumina particles to 15% alumina particles reinforcement composite is lower than the slope of master alloy to 5% alumina particles reinforcement composite. That means rate of wear loss decreasing with increasing percentage of reinforcement particles. Initially up to 5% alumina particles wear resistance is higher because alumina particles from sample will plough the surface of counterpart. Alumina particles will crush to very minute particles form a layer which is known as mechanically mixed layer (MML). The MML forms a layer between the sample and the counterpart surface and reduce the sliding wear [10]. With further increase in reinforcement from 5% alumina particles to 15% alumina particles in step of five, the wear resistance is less. Because it increased thickness of the MML layer only.

### E. Effect of Load on Wear

From figure 5 it is seen that wear loss increases with increasing the amount of load. Wear loss curve of 17 N loads over 12 N loads and wear loss of 12 N is greater than 7 N loads for master alloy and all composites. The mass loss of 12 newton loads is 86.9 mg which is greater than the mass loss of 61.7 mg at 7 newton load at same composite.

The penetration ability of the fractured particles increases with increasing the load will increase the removal of the material on the specimen surface. The fractured small alumina particles between the specimen surface and the counterpart surface form a three-body abrasion system and remove the material from the specimen surface

### *F. Effect of Sliding Distance on Wear*

Figure 6 shows mass loss increases with increasing the sliding distance. It is also seen from figure 6 that initially rate of mass loss is higher and after some sliding distance it gets decreased. Because initially asperity contacts take place consequential in higher wear rates. Later asperity get flattened which Increases the contact area. So wear rate decreases which represent the decrease slope of the curve.

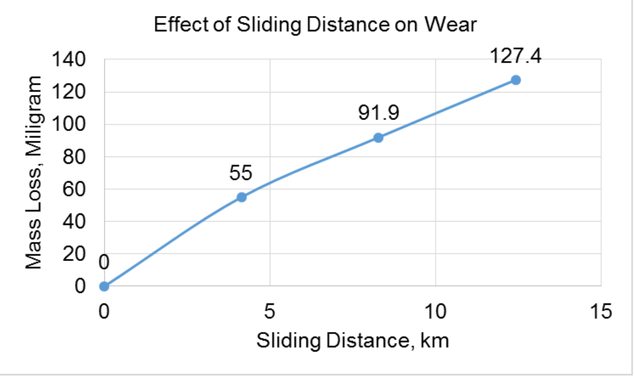


**Figure 6:** Mass loss of the matrix at 17 N loads at various sliding speed

### *G. Effect of Sliding Speed on Wear*

Mass loss of the master alloy and composites at different sliding speed at constant 12 N load is shown in figure 7.

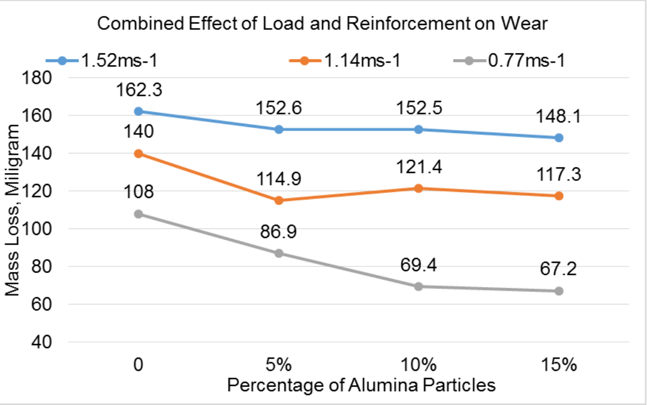


**Figure 7: Mass loss of the master alloy and composite at different sliding speed at constant 12 N loads.**

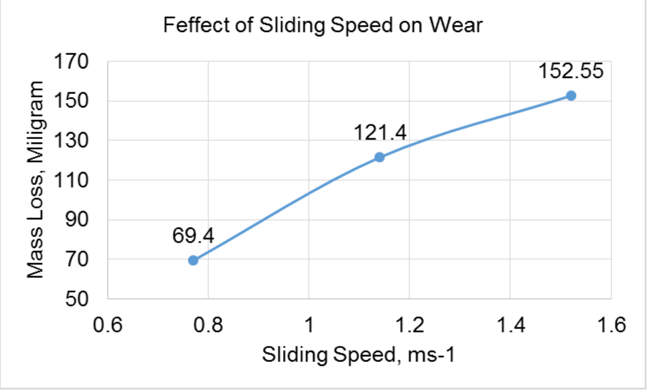


**Figure 8: Mass loss of the composites containing 10% alumina at 12 N load at different sliding speed**

It is clearly seen that wear loss increases with increasing the sliding speed. Wear loss of sliding speed of 1.52 $ms^{-1}$ over sliding speed of 1.14 $ms^{-1}$. From figure 7 it is seen that composite contains 5% alumina particles shows minimum wear loss than composites contains 10% at constant sliding speed 1.14 $ms^{-1}$. Reason is that composite contain 10% alumina particles has higher amount of porosity than composite contains 5% alumina particles which is shown in figure 9. Mass loss of the composite containing 10% alumina particles at 12 Newton load at different sliding speed is shown in figure 8. It is seen that wear rate decreases at the higher speed as slope of the curve decreases. Higher speed increases the interface temperature hence increases the extent of oxidation of master alloy containing aluminium, copper etc. The thicker oxide film protects the sliding interfaces hence lowers the wear rate

### H. Microstructure

Microstructure consists of white aluminium matrix, primary silicon, eutectic silicon particles and intermetallic and alumina particles. The primary silicon had a blocky appearance, while both eutectics and intermetallic had a flaky appearance. Both of these structures are shown in figure 9.

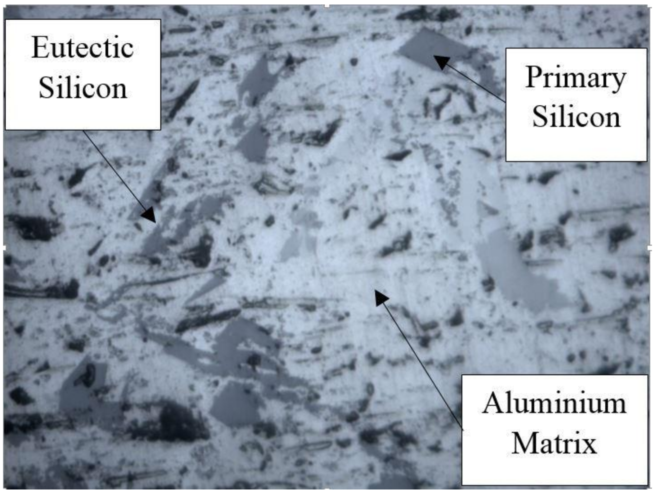


**Figure 9: 500X optical micrograph showing the microstructure of the master alloy**


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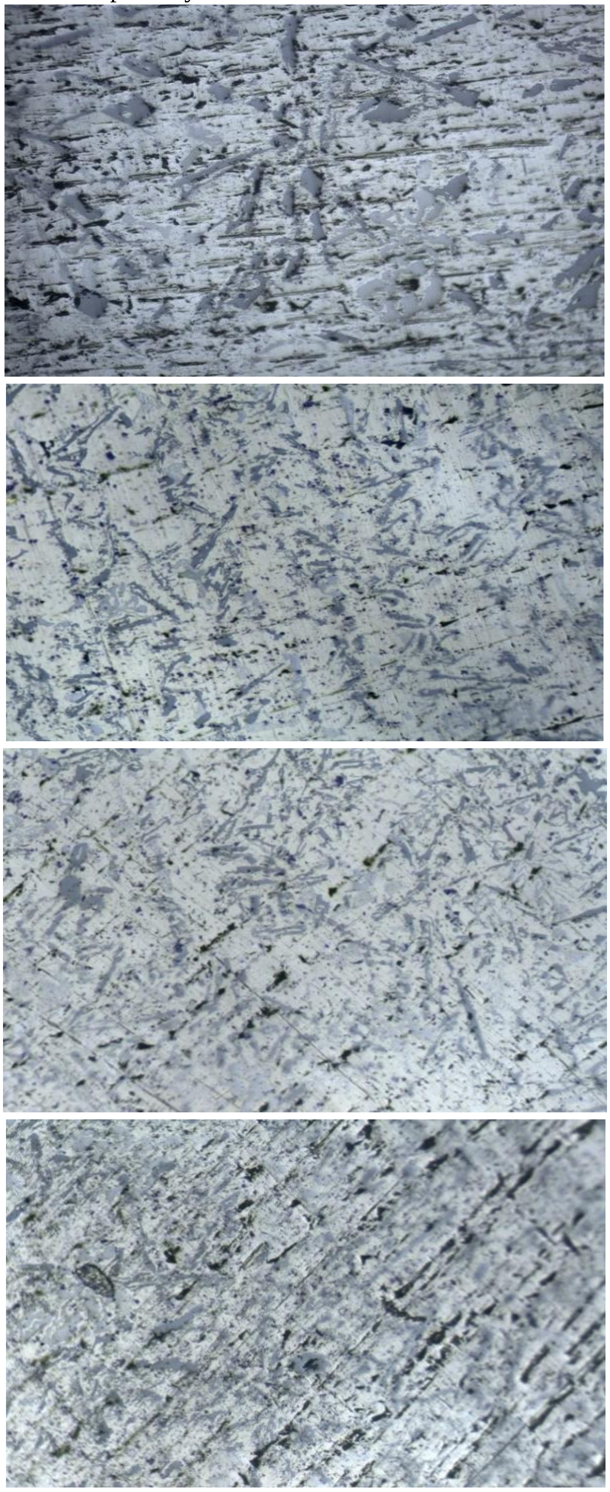
Figure 10 shows the microstructure of the a) master alloy, b) Composite containing 5% alumina particles, c) Composite containing 10% alumina particles and d) Composite containing 15% alumina particles. The micrographs further show that porosity has increased with increasing the addition of alumina particles. Increased amount of particles cause poor adhesion between master alloy and alumina particles hence increases the porosity



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

**Figure 10: 200X optical micrograph showing the microstructure of the a) master alloy, b) Composite containing 5% alumina particles, c) Composite containing 10% alumina particles and d) Composite containing 15% alumina particles**

## IV. CONCLUSION

Alumina particles reinforced piston alloy composites have produced by stir casting method. Tensile Strength, hardness and wear property have been investigated of the master alloy and prepared composites. All composites have higher tensile strength than master alloy. The hardness is increased with addition of alumina particles while tensile strength is decreased with addition of alumina particles beyond 5% of alumina because presence of crack and also porosity. Porosity causes crack during tensile test which easily propagate under tensile load hence decreases tensile strength. Crack has minor effect on hardness than tensile strength. Composites have superior wear resistance property over master alloy. It was also examined the effect of load, sliding speed and sliding distance on wear behaviour. All these three factors increase the wear loss.

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