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Experimental Investigations on Mechanical and Tribological Properties of Extruded Aluminium A356 - AL_2O_3 Stir Cast MMC

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Abstract

Ceramics in particulate form are normally used as reinforcement materials in MMCs. The basic purpose of adding reinforcement into the metal matrix is to increase the yield strength, tensile strength and hardness at ambient temperatures which leads to improvement in thermal, structural and tribological properties. Aluminium alloys are most commonly used MMCs because of their light weight, anticorrosive properties and large scale availability. However, the main weaknesses of aluminium alloys are their poor high-temperature performance and wear resistance. To overcome these problems, aluminium alloys are reinforced by harder particles. Among many types of MMCs, the most popular types are aluminium alloys reinforced with SiC or Al_2O_3 particles since they provide favourable properties with only a minimum increase in density over the base alloy. The mechanical and tribological properties of the composite material are strongly dependant on the microstructural parameters of the system in particular, the shape, size, volume fraction and the orientation of the reinforcing particles. Among the various methods to fabricate metal matrix composites, liquid metallurgy vortex method (Stir casting) has drawn keen attraction among the researchers due to its industrial feasibility. Alumina (Al_2O_3) particles mixed with Aluminium matrix in appropriate proportions are reported to exhibit improved mechanical properties because of the higher modulus of elasticity and strength of the reinforcement particles. The MMC materials processed by primary processes like Stir casting and powder metallurgy technique contain defects like porosity, blow holes and irregular grain structure. Secondary processing like extrusion can reduce these defects and enhance the structural features. The present work is an investigation towards the properties of Al-Al_2O_3 material.

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Keywords: **A356, Al_2O_3, Particles, MMC's, Extrusion;**

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1. Introduction

A composite is generally defined as a multiphase system that consists of two different groups of materials which are chemically and physically distinct and separated by interfaces. It consists of one or more discontinuous phases embedded in a continuous phase. The discontinuous and continuous phases are termed as reinforcement and matrix respectively. In a composite material, the reinforcement phase normally enhances the properties which are deficient in the matrix material. MMC's recently are drawing interest of the researchers because of the ability to alter their physical properties like density, thermal expansion, thermal diffusivity and mechanical properties like tensile and compressive behavior, creep, tribological behavior etc. by varying the filler phase. Aluminium alloys are the most commonly used due to good corrosion resistance, high damping capacity, low density and good electrical and thermal conductivities. The particulate reinforced composites can be prepared by injecting the reinforcing particles into the liquid matrix through liquid metallurgy route by casting. The problem associated with the stir casting process is the non-uniform distribution of particulates due to poor wettability and gravity related segregation.

The MMC materials processed by primary processes like Stir casting and powder metallurgy technique contain defects like porosity, blow holes and irregular grain structure. Secondary processing like extrusion can reduce these defects and enhance the structural features. Extrusion is defined as the process of shaping material, by forcing it to flow through a shaped opening in a die. The main factors that influence the properties of extruded component are Extrusion temperature, Extrusion pressure, Extrusion ratio and Extrusion speed.

Extrusion force depends on the flow stress of the billet material, the extrusion ratio, the friction condition at the billet container interface, initial billet temperature and the speed of extrusion. Increasing the ram speed produces an increase in the extrusion pressure where as slower ram speed facilitates more time for heat transfer. The extrusion ratio affects the amount of mechanical working that will occur as the shape is extruded. The effect of extrusion ratio has a greater influence on the microstructure and mechanical properties of extruded material. The parameters influencing the characteristics of extruded metal matrix structure include percentage composition of the reinforcement, particulate size of the reinforcement, extrusion ratio, extrusion temperature etc.

2. Experimental Details

2.1 Work Material Details: The details of the material selected for present investigation are as discussed below. Aluminum (A356) based metal matrix composite with varying particle sizes particulate aluminum oxide with volume fraction of 10% are used. α- aluminum oxide average particles sizes of 23μm, 45μm, 75μm, and 120μm has been selected for the present investigation.

Elements	Percentage
Al	91.1-93.3
Cu	<=0.2
Iron	<=0.2
Mg	0.25-0.45
Mn	<=0.1
Other each	<0.05
Silicon	6.5-7.5
Titanium	<=0.2
Zinc	<=0.1

Table 2.1 Percentage Composition of Aluminium (A356)

2.2 Stir Cast Processing Details: The casting unit consists of a graphite crucible of about 5 kg capacities, which is heated by electrical resistance type heating coils. The temperature level of the heating unit is controlled by thermocouple activated controlling unit. Duration of heating is determined based on the quantity of material to be melted. The furnace used in the present work is of bottom pouring type, which is regulated using a valve operated from the bottom. A motor operated stirrer is provided at the top, for mixing the particulate reinforcement with the molten metal. The mechanical stirrer used for stirring the molten alloy during fabrication of composites is made of steel blades coated with Alumina powder and sodium silicate mixture to withstand high temperature and to avoid iron pickup by the melt. Arrangement is made at the bottom of the crucible for exact positioning of the split mould below the valve as shown in Figure2.1.

2.3 Extrusion Process: Cast specimens are subjected to secondary process of Extrusion where in the aluminum composite are hot extruded from 35mm to 10mm with an extrusion ratio of 12.25. Band heaters are used to maintain the required temperature of extrusion die. Figure 2.2 shows the extrusion assembly along with the band heater. Figure 2.3 shows the extruded specimen.

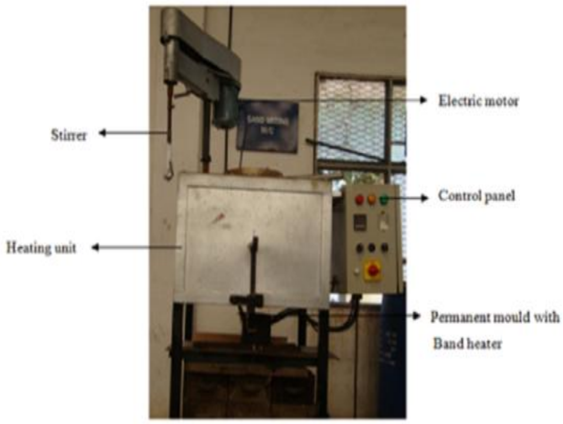


Figure 2.1: Electrical Heating Furnace

Figure 2.2: Extrusion Assembly

Figure 2.3: Extruded Specimen

2.4 Mechanical Properties

2.4.1 Hardness Test: In Brinell hardness test, a steel ball of diameter (D) is forced under a load (F) on to a surface of test specimen. Mean diameter (D_i) of indentation is measured after the removal of the load (F).

BHN is calculated by the formula

$$\text{BHN} = \frac{2F}{\pi D\,(D - \sqrt{D^2 - Di^2})}$$

Where,

BHN= Brinell hardness number
F = Imposed load in kg
D = Diameter of the spherical indenter in mm
D_i = Diameter of the resulting indenter impression in mm

2.4.2 Tensile test: The tensile test specimens are prepared as per the ASTM B557 standard as shown in the Figure 2.4.

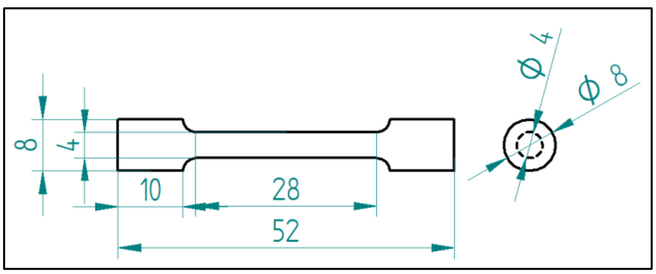


Figure 2.4: Tensile Specimen

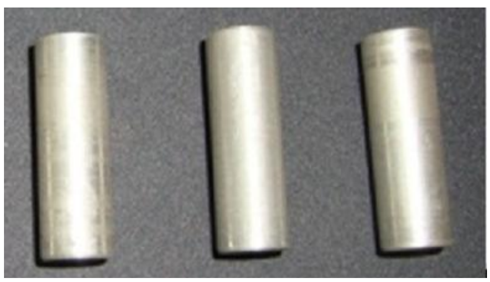


Figure 2.5: Wear Testing Pins

2.5 Tribological Properties: Dry Sliding Wear Test: Dry sliding wear tests of the specimens were conducted using pin- on- disc test apparatus conforming to ASTM G99 standards with electronic data acquisition system. EN32 hardened steel disc with a hardness of 65HRC and R_a value of 2.5–3.5 μm was used as the counter surface. The counterface disc has a diameter of 120 mm and thickness of 8 mm. The specifications of the equipment are given in the Table.2.2.

Rotational Speed	Up to 2000 rpm
Track Diameter	40mm – 118 mm
Load Range	Up to 200 N
Disc Size	Dia 120 mm ×Thickness 8 mm
Pin Size	6 to 12 mm
Wear or Displacement	±2000 microns
Frictional Force	Up to 200 N

Table 2.2: Technical Specifications of Wear and Friction Test Rig

Wear test specimen: The wear test specimens of 28mm length and 10mm diameter are prepared as per the ASTM G99 standard as shown in the Figure 2.5. The wear test was conducted at different loads, with increments of 10N and constant velocity of 2 m/s. After every 5000m run the specimen was removed, cleaned, dried and weighed to calculate the mass loss. The friction coefficients and wear were recorded continuously.

3. Results and Discussion

3.1. Microstructural Study: Scanning Electron Microscopy

Figure 3.1-3.2 shows the various SEM images of alumina reinforcement particles with varying particle sizes (average). Figure 3.3 shows the SEM image of composite material (A356+10% 23**μ** Al_2O_3) for extruded conditions. From the figures it can be seen that the reinforcement particles are uniformly distributed in the matrix material. The presence of reinforcement particles in the matrix material yields in higher strength of the composite materials.

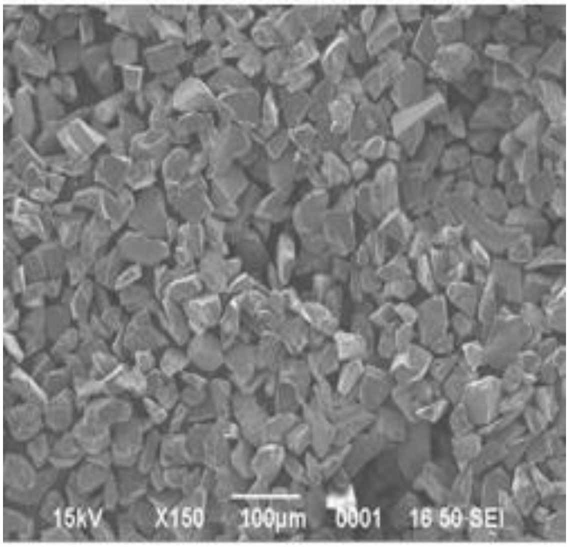


Figure 3.1: 23μ AL_2O_3 Particles

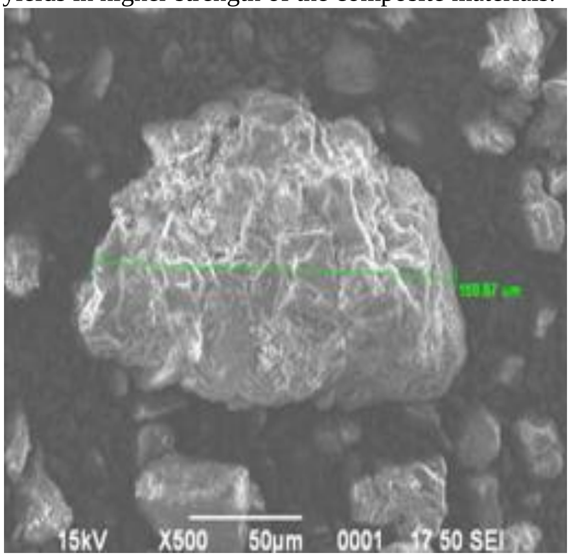


Figure 3.2: 125μ AL_2O_3 Particles

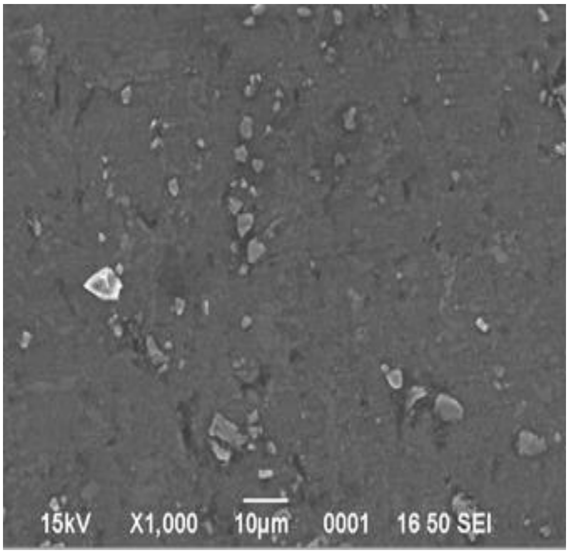
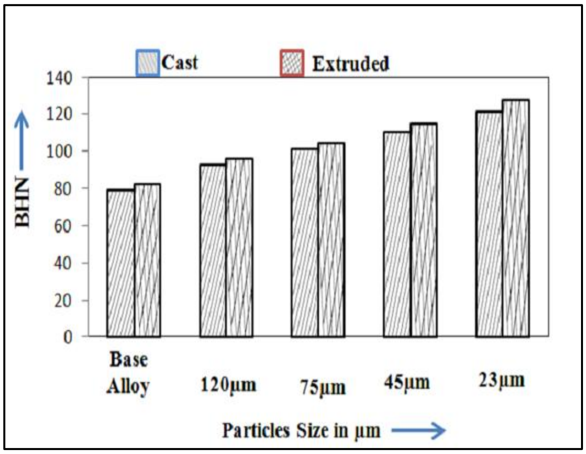


Figure 3.3: A356 (Extruded) [10% 23µ AL_2O_3]

3.2 Hardness Test

Figure 3.4 illustrates the variation in Brinell Hardness Number (BHN) of composite test specimens with reinforcements. It can be observed that the addition of Al_2O_3 particulates has increased the hardness of the composite materials compared to that of the base alloy. Test results also indicate the progressive increase in hardness of the composite structure with decrease in the size of the particulate reinforcement. Increase in hardness is due to the increased number of hard alumina particles. Extrusion process helps in dislocation densification, grain refinement and lowering of porosity. Extrusion also helps in breaking down of agglomerates of the reinforcement particulates and their uniform distribution in the matrix phase. Results indicate that extrusion process has caused marginal increase in the hardness of composite material compared to the as cast specimens.

3.3 Tensile Strength Test



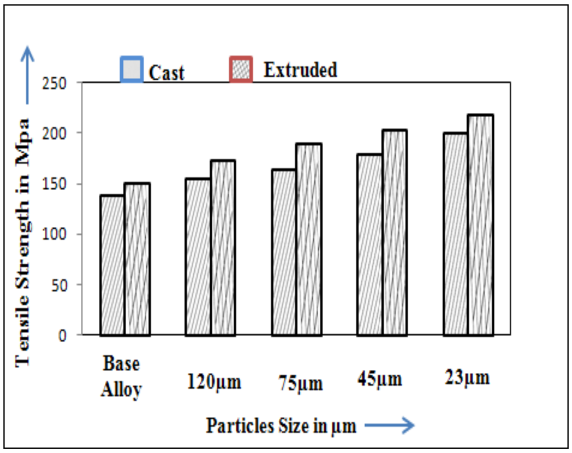


Figure 3.4: BHN of Cast and Extruded Composites **Figure 3.5: Tensile strength of Cast and Extruded Composites**

Figure 3.5 illustrates the variation in tensile strength of composite test specimen. It can be observed from the results that tensile strength of composites is higher than that of base alloy (A356) and also observed that there is in increasing trend in the tensile strength values of the composites with decreasing particle size of reinforcement in both as cast and Extruded specimens. This trend can be attributed to the fact that for same weight percentage of reinforcement, the number of particulates increases with decrease in their size, resulting in increased area of interficial bonding between the matrix and the reinforcement. The increased interficial bonding offers higher contribution of the mechanical characteristics of the reinforcement to the composite structure.

3.4 Dry Sliding Wear Test Results

3.4.1 Influence of Sliding distance and Normal load on Material wear:

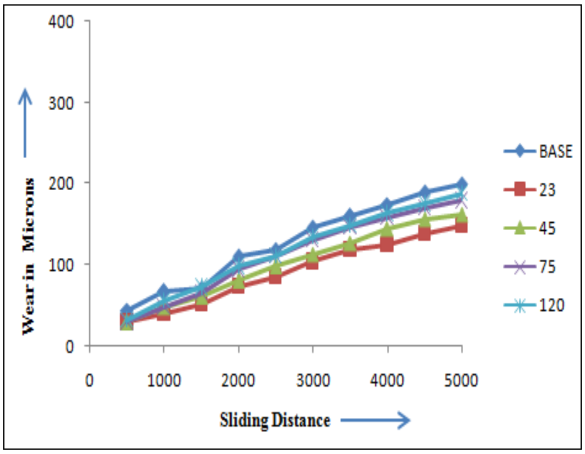


Figure 3.6: Wear v/s Sliding Distance [Cast 30N]

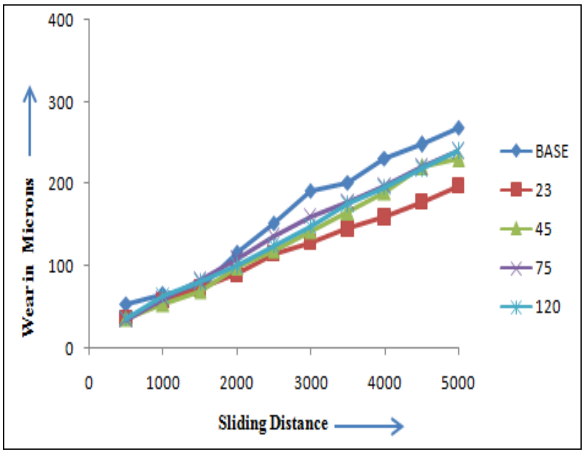


Figure 3.7: Wear v/s Sliding Distance [Extruded 30N]

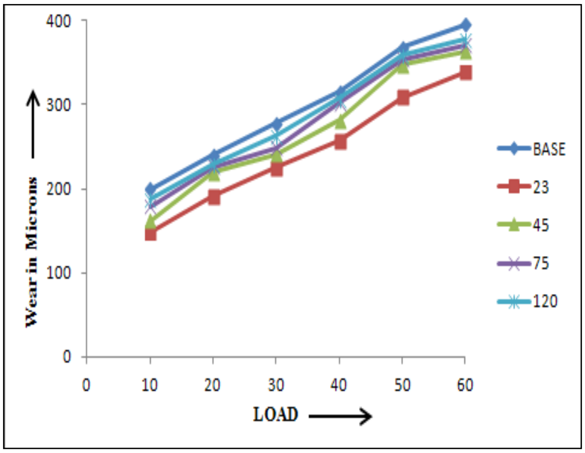


Figure 3.8: Wear v/s Load [5000m Sliding Distance] (As Cast Condition)

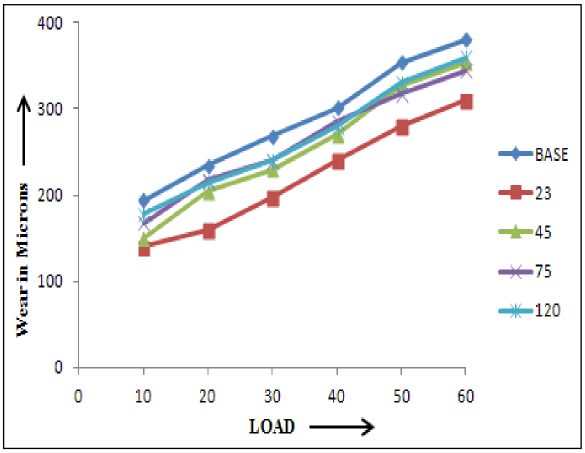


Figure 3.9: Wear v/s Load [5000m Sliding Distance] (As Extruded Condition)

Wear with respect to the sliding distance for varying load conditions [10N to 60N] are carried out. Figure 3.6-3.7 indicates the wear with respect to sliding distance of different test specimens at normal load of 30N for both as cast and extruded conditions. It can be observed that the slope of the curves is higher initially, indicating running-in wear, Later as the asperities get flattened, contact area increases decreasing contact pressure with reduction in wear rate. With the increase in sliding distance, the number of fatigue load cycles also increases resulting in localized failures of the asperities. This results in increased wear rate of the material with increase in sliding distance. Wear rate of extruded composite material at all loading conditions experiences lower wear rate than that of the as cast composites. Figure 3.8-3.9 indicates the wear with respect to the increasing load (10N to 60N) at 5000m for both as cast and extruded specimens. It can be seen from the figure that the wear rate of extruded specimen are lower than the as cast specimens at all the loading conditions.

3.4.2. Wear V/s Particle Size: Figure 3.10-3.12 indicates the wear with respect to the varying particle size with a varying load from 10N, 30N and 60N for both cast and extruded composites. From the chart it can be observed that wear value is lower for the composite with lesser particle size at all the loading condition. This can be attributed to the observed higher mechanical strength of composites where reinforcement particle size of smaller size.

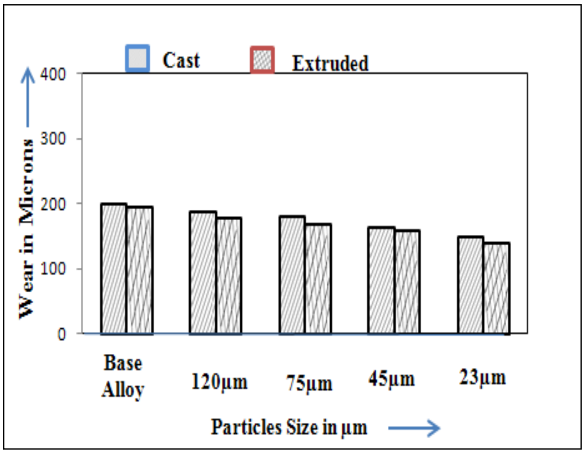


Figure 3.10: Wear v/s Particle size
(Sliding distance: 5000m, Load 10N)

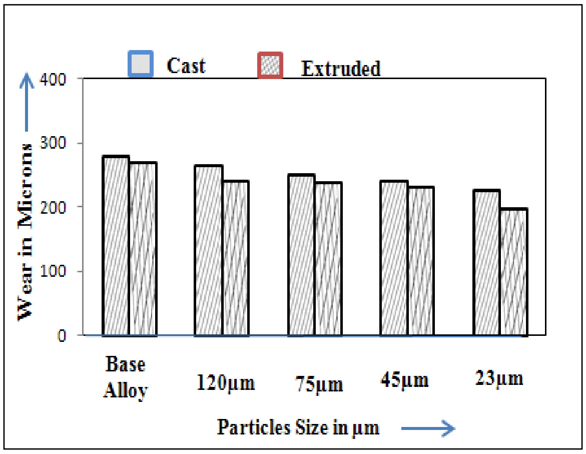


Figure 3.11: Wear v/s Particle size
(Sliding distance: 5000m, Load 30N)

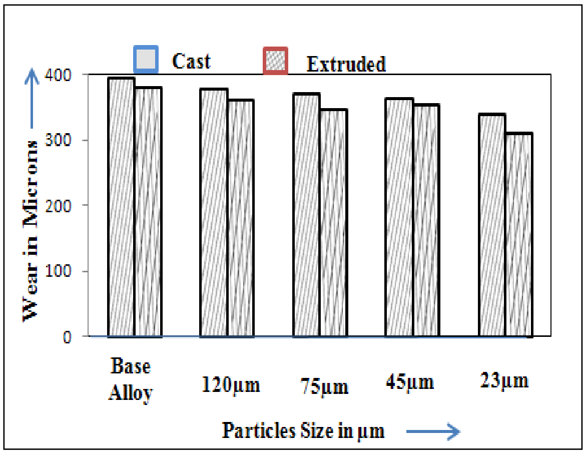


Figure 3.12: Wear v/s Particle size
(Sliding distance: 5000m, Load 60N)

3.4.3. Specific Wear Rate v/s Normal Load: Figure 3.13-3.14 illustrates variation of specific wear rate with load for both as cast and extruded composites. Specific wear rate is the wear loss of the material per unit load per unit sliding distance. It actually represents the slope of the wear curves plotted with respect to normal load. It can be observed from figures, that specific wear rate decreases initially with load indicating the decreasing slope of the wear curves. After the critical load for severe wear is reached, specific wear rate becomes constant, indicating a constant slope of the wear curve, where material wear increases at a constant rate with load.

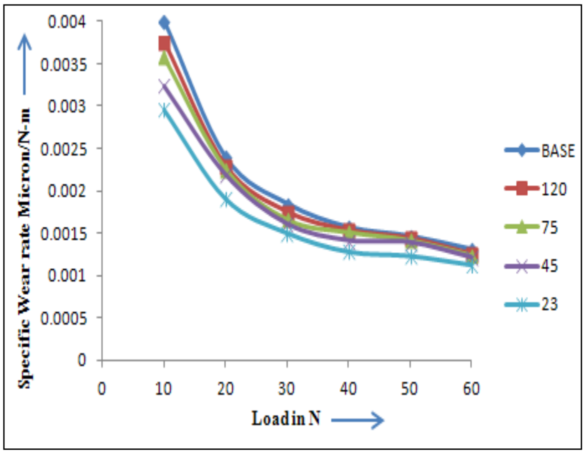


Figure 3.13: Specific Wear Rate v/s Normal Load [Cast]

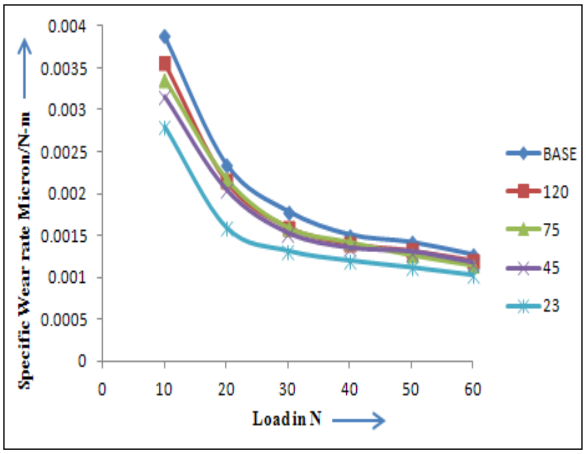


Figure 3.14: Specific Wear Rate v/s Normal Load [Extruded]

4. Conclusions

Experimental investigations conducted in processing of Al-Al_2O_3 metal matrix composites provided the following conclusions.

- The micrographs reveal the precipitation of silicon phase in acicular form at grain boundaries of the alloy structure.
- Tensile strength of composite samples increased but the elongation of them decreased with decreasing size of Al_2O_3 particulates.
- Graphs indicate that the hardness of the composite samples increased with decreasing the particle size of Al_2O_3 particulates.
- The wear properties of the A356 alloy were considerably improved by the addition of Al_2O_3 and the wear resistance of the composites was much higher than that of the unreinforced A356 aluminium alloy.
- Mass loss due to sliding is found to increase initially with load, but rate of wear is found to decrease at higher loads due to the work hardening effect on the sliding surface. The wear resistance of composites increased with decreasing particle size of Al_2O_3.

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