Automotive industry application of aluminium-based hybrid metal matrix composite

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Abstract: Monolithic materials cannot fulfil the demands for the advanced industrial requirements. Therefore, composite materials which possess the combined properties of different constituents are developed. In this experimental work, Al 6061 was used as matrix and Al_2O_3, SiC and E glass short fibres were used as the reinforcement material. The composite specimen is fabricated through stir casting by varying the weight percentage of reinforcements and matrix materials. The investigation concluded that the load and sliding speed are expanded to improve the wear rate, and developing the sliding distance the wear rate is decreased. The different compositions of the materials are tested by using Pin on Disc apparatus to find the wear rate. From the experimental results the least wear rate is obtained in the composition (C_4) of 70% wt of Al 6061, 15% wt of Al_2O_3, 9% wt of SiC and 6% wt of E glass short fibre.

Keywords: wear rate; Al 6061; Al_2O_3; SiC; E glass fibre; stir casting.

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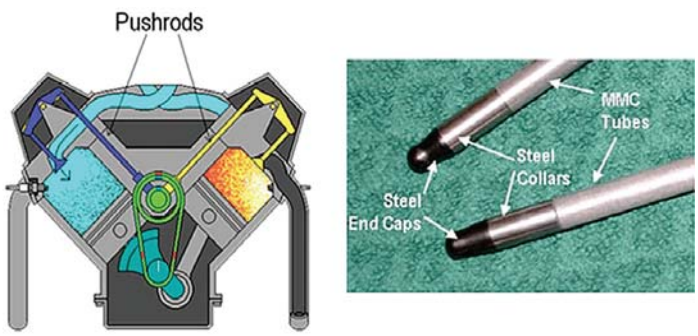
1 Introduction

Metal matrix composites (MMCs) offer high quality to weight ratio, high solidness, improved hardness and lower wear rate. Consequently, they are utilised as a part of the aerospace, biomedical and automotive industries. The matrix materials commonly utilised are aluminium, titanium, and magnesium and the reinforcements used are silicon carbide, aluminium oxide, boron carbide. The properties of any composite depend on the size, shape and volume division of the reinforcements along with the matrix material.

Aluminium metal matrix composites have required properties, for example, low weight, particularly high quality and higher wear resistance. They are utilised as a part of replacement for ferrous composites since they have lower density, higher quality to weight ratio, higher thermal conductivity, and higher electrical conductivity. They are also cheaper when compared with other matrix materials such as magnesium and titanium. The composite materials, despite the fact that being basically evolved for the desires of airplane and area enterprise, find an accelerated utility in automobile industry, where they may be utilised for production of pistons, cylinders, engine blocks and brakes. Aluminium engine blocks, suspension additives, frame panels, and frame participants are increasingly common, further to the usage of magnesium in additives including instrument panels, valve covers, transmission housings, and steering column additives. Metal matrix composites with ceramic reinforcements used for producing of pistons have appreciably higher resistance in terms of materials used for matrices. Concurrently, pistons have small values of thermal growth coefficients that offer use of slender tolerances, so that it results increased maximal allowed pressures and progressed thermal conductivity residences. Aluminium MMCs bolstered by way of fibres are used for manufacturing of pushrods of valves in engines (Figure 1).

Figure 1 Pushrods manufactured from aluminium MMCs at engines (see online version for colours)

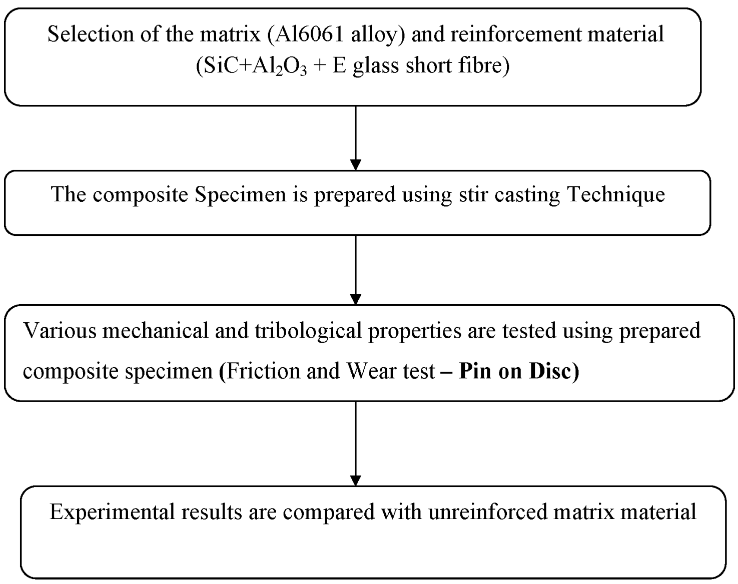


2 Literature survey

Prashant et al. (2012) has prepared and evaluated of mechanical and wear properties of aluminium 6061 alloy strengthened with graphite particulate. The experimental result shows that inflexibility of combined decreases with varying the weight gain of graphite particulate. The wear rate decreased up by to six weight percent of graphite particulate further addition of graphite particulate the wear rate is increased. Suresh and Prasanna Kumar (2013) investigated the tribological behaviour of Aluminium 6061 reinforced with Al_2O_3. The wear rate is for the most part influenced by expanding the heap and sliding rates. The Co productive of rubbing varies inversely weight level of support, sliding speed and load. Mishra et al. (2012) has characterised the wear behaviour of Al 6061 reinforced with silicon carbide by using Taguchi's techniques. The connected load and sliding velocity have the most noteworthy impact on wear rate and coefficient of grinding while at the same time increasing the weight level of silicon carbide the wear rate is somewhat diminished. Umanath et al. (2011) has integrated the friction and wear behaviour of Al 6061 alloy fortified with silicon carbide and aluminium oxide particulate. The wear rate decreases with increasing content of reinforcements. The composite materials got the wear rate and Co effective of friction is less compared with the unreinforced aluminium 6061 alloy. Veeresh Kumar et al. (2010) has studied the mechanical and tribological behaviour of the aluminium 7075 reinforced with Al_2O_3 and aluminium 6061 reinforced with silicon carbide. The experimental results show that hardness and wear rate of the composite is expanded with changing the weight level of SiC and Al_2O_3.

3 Research methodology

The following steps are involved to fabricate the aluminium reinforced MMC and also to find the mechanical and tribological properties.



4 Material and experimental methods

4.1 Matrix material

Al 6061 alloy is taken as matrix material for this experimental study because it is a precipitation cemented aluminium alloy, containing magnesium and silicon as its major alloying segments. It has extraordinary mechanical properties and shows great weldability. It is a standout amongst the most common alloys of aluminium for universally usefulness with the goal that it is primarily utilised as a part of the building, automobile, and marine industries. Figure 2 shows the raw material of Al 6061 rods and Table 1 indicates the compound synthesis of the Al 6061 alloy as made by the Aalco metals Ltd.

Figure 2 Aluminium 6061alloy rods (see online version for colours)

Table 1 Chemical composition of Al 6061 alloy by weight percentage

Mg	*Si*	*Cu*	*Ti*	*Cr*	*Zn*	*Mn*	*Be*	*V*	*Fe*	*Al*
0.8–1.20	0.4–0.8	0.15–0.40	0.0–0.15	0.04–0.35	0.0–0.25	0.0–0.15	0.0–0.15	0.0–0.05	0.0–0.7	Balance

4.2 Reinforcement material

In this study, three reinforcements are selected for enhancing the properties of the composite material. Al_2O_3 has good hardness, and also it has excellent tensile strength. SiC is taken for improving the hardness of the composite material. SiC is mainly used as abrasive because it has high hardness. E glass fibre is also used in this study for improving the corrosion resistance, strength and to reduce the weight of the composite. Table 2 shows the compositions of Al-based mixture composite.

Table 2 Composition of Al-based hybrid composite by wt.%

S. No.	*Matrix Al 6061 wt.%*	*Reinforcement materials* (wt.%)		
		Al_2O_3	*SiC*	*E glass short fibre*
C_1	100	–	–	–
C_2	90	5	3	2
C_3	80	10	6	4
C_4	70	15	9	6
C_5	60	20	12	8

4.3 Experimental procedure

Stir casting is a liquid state method of composite materials fabrication, in which a dispersed phase (ceramic particles, short fibres) is mixed with a molten matrix metal by means of mechanical stirring. In general, the natural process synthesis of metal matrix composites involves softening of the chosen matrix material followed by the introduction of a reinforcement material, getting an appropriate dispersion. The next step is the solidification of the melt containing suspended dispersions under selected conditions to obtain the desired distribution of the dispersed phase in the cast matrix. In preparing metal matrix composites by the stir casting technique, there are many factors that require wide attention, including the difficulty in achieving a uniform distribution of the reinforcement material and:

- Wettability between the two main substances.
- Porosity in the cast metal matrix composites.
- Chemical reactions between the reinforcement material and therefore the matrix alloy.

To achieve the optimum properties of the metal matrix composite, the distribution of the reinforcement material in the matrix alloy must be uniform, and the wettability or bonding between these substances should be optimised. The porosity levels need to be minimised.

The dry crucible and furnace are used for composite fabrication. Initially, the electric furnace is set at150°C for removing moisture inside the furnace. Al 6061 alloy was used in the form of rods, at the beginning of melting a few aluminium scraps were heated to a molten stage by utilising the stir casting apparatus, and then the weighed Al 6061 rods are added based on the compositions, and the temperature is raised to 840°C for complete melting to form a molten liquid state. Figures 3 and 4 show the stir casting setup and melting of Al 6061 alloy.

Figure 3 Stir casting setup (see online version for colours)

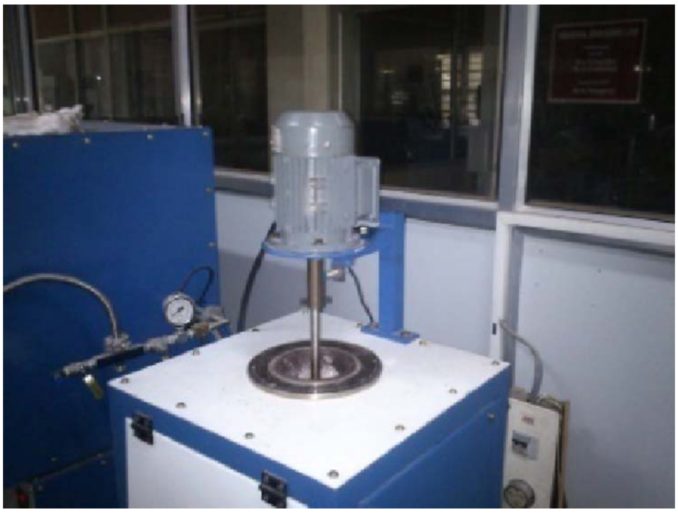
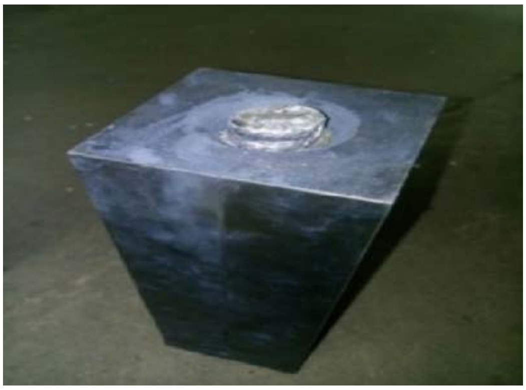


Figure 4 Casting of composite (see online version for colours)

The preheated Al_2O_3 powder is added to Al 6061 alloy molten metal then mechanical stirrer is rotated 150 rpm for complete mixing of the reinforcement material into the matrix material. After that, the weighed SiC powder is added and stirred then the weighed E glass short fibre is inserted, and the stirrer is rotated 200 rpm to prevent settling of E glass short fibre in the furnace. A small amount of magnesium is added for improving the wettability. After complete melting, the molten metal is continuously poured into the prepared steel mould die to avoid gas bubbles formation and then molten metal is allowed to solidify. The machining is done in the lathe to get required size and shape as per the ASTM standards for conducting wear test under the dry sliding condition with the assistance of Pin on Disc mechanical assembly. The wear test examples are machined into cylindrical pins of size 10 mm diameter and 30 mm length from the respective cast composites. The experimental set up is shown in Figure 5 and mould die is shown in Figure 6.

Figure 5 Stir casting apparatus (see online version for colours)

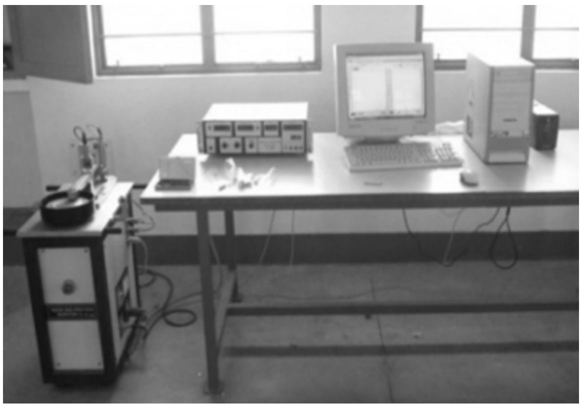
Figure 6 Moulding die (see online version for colours)



4.4 Testing for wear

The Pin on Disc is a mechanical assembly used to determine tribological properties of the strengthened and base matrix material. These properties included frictional coefficient and wear rate. The covered example is set on a rotating disc spring at a variable angular speed. A ball held by the vertically responding pin is squeezed against the instance for a settled measure of full rotations of the disc. The tangential force and frictional coefficient are estimated, and extra procedures can estimate the volume of removed materials. The Pin on Disc machine is a flexible unit intended to assess the wear and grinding attributes of an assortment of materials presented to sliding associates in dry or greased up situations. The descending rubbing analysis happens among a fixed stick and a rotating disc. Typical load, rotational speed, and wear track separate crosswise over can contrast. Electronic sensors screen wear and the distracting energy of disintegration as a segment of load, speed, oil, or natural condition. The sample which is to be tested is rigidly held and utilised as the stick example. The test machine causes either the plate example or the stick example to spin around the circle focus. In either case, the sliding way is a hover on the plate surface. The stick example is squeezed against the plate at a predetermined load as a rule utilising an arm or lever and connected weights. Figure 7 shows the complete experimental setup of Pin on Disc.

Figure 7 Pin on Disc experimental setup



The test is directed under the encompassing states of temperature and humidity. The dry sliding test is completed according to ASTM G 99 test models on pin-on-disc tribometer. En 31 steel circles with the hardness of 60HRC which are grounded to the surface complete of 1.6 Ra is mounted and secured tight opposite to the hub of the pivot. The completion of cases are cleaned with grinding paper of grade 1/0 and took after by review 4/0.The pins are cleaned with acetone and weighed when testing to an accuracy of ± 0.0001 g to choose the measure of wear. The sliding ends of the stick and the plate are cleaned with acetone before testing. The stick example is embedded into its holder and balanced with the goal that the example is opposite to the circle surface when in contact. The wear rates were resolved to utilise the weight reduction strategy. Wear test was completed for followings situations

- five different applied loads of 10 N, 20 N, 30 N, 40 N and 50 N for a total sliding distance of 400 m at a constant sliding speed of 300 rpm
- five different sliding distances of 200 m, 400 m, 600 m, 800 m and 1000 m against the run of the mill load of 30 N for a consistent sliding rate of 300 rpm
- five distinctive sliding speeds of 100 rpm, 200 rpm, 300rpm, 400 rpm and 500 rpm against the normal load of 30 N at the constant sliding distance 400 m
- the below mentioned formula is used to find the wear rate

$$\text{wear rate} = \frac{\text{mass loss}}{9.81 \times \text{density} \times \text{sliding distance}}.$$

- $$\text{volume loss} = \frac{\text{mass loss}}{\text{density}}.$$

  where, mass loss is in kg, density is in kg/mm^3 and sliding distance in m.

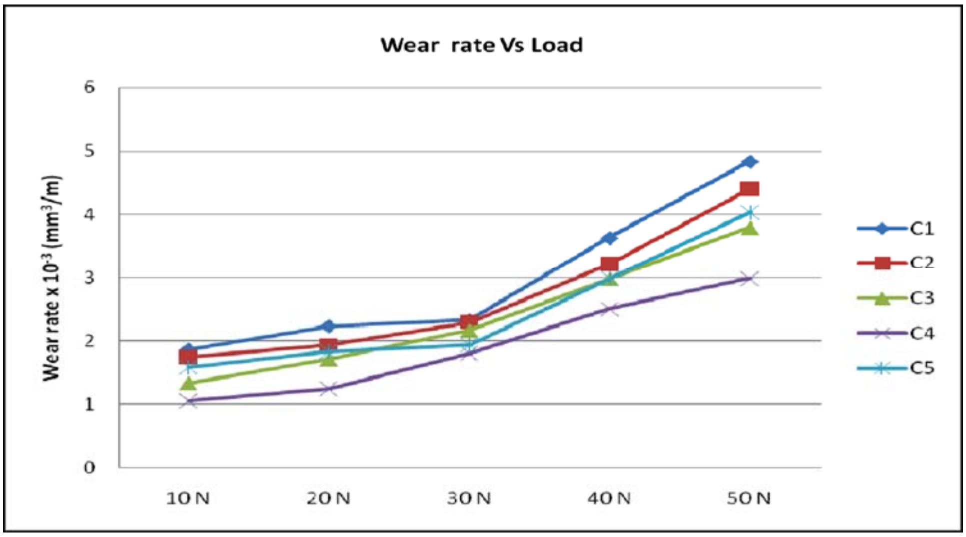
5 Results and discussion

- Effect of applied load on wear rate

The trial demonstrates that the connected load influences the wear and tear rate of alloy and composites basically and is that the most dominating issue dominant the wear and tear conduct at the consistent speed, the wear and tear rate of the Al 6061 composites and therefore the matrix increments with increment in load. The outcomes likewise demonstrate that the volume of particulates SiC, Al_2O_3 and E glass fibre support markedly affect the wear rate. The wear rate of the composite examples diminishes with expanding weight level of fortifications. It is clear from analysing that at low applied load the worn pin surface overwhelmingly uncovers fine and shallow notches in sliding way. The wear rate increases with increase in load on the pin, this behaviour is due to wear of the ceramic particles at higher load or due to the fracture of the particles. The surface was protected with the transferred fabric layer which increases the damage. The detachment of the particles from the matrix was noticed at higher load and results in the increase in contact zone of the framework and the plate which additionally expands the wear.

Figure 8 demonstrates the wear rate at various connected loads of 10 N, 20 N, 30 N, 40 N and 50 N for an aggregate sliding distance of 400 m at a consistent sliding speed of 300 rpm. According to the above condition the wear test is conducted to find the wear rate.

Figure 8 Wear rate at different loads and constant sliding distance 400 m, sliding speed at 300 rpm (see online version for colours)



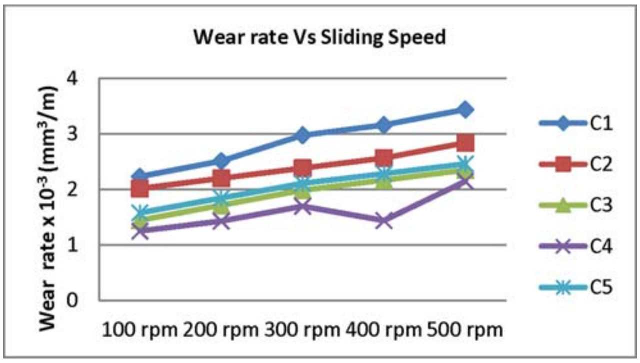
- Effect of sliding speed on wear rate

The sliding rate expands the wear rate of the composite and furthermore increases with the speed, which gives an immediate connection amongst velocity and wear rate. It was discovered that the increase of reinforcement's particle concentration increases the wear resistance of the composites compared with to the matrix alloy. The wear protection increment improves with the composite containing SiC and Al_2O_3 particles with E glass fibre. The wear rate of the tried materials expanded with the increment of the sliding speed yet for both composites that expansion was not as marked as for matrix alloy, but then the composite containing SiC, Al_2O_3 and E glass fibre demonstrated the most minimal increment. Heavy noise and vibration had been found at some stage in the system, and switch of the pin material to the disc become also observed. Figure 9 demonstrates the wear rate at a various sliding rate and the consistent load of 30 N and sliding distance of 400 m.

- Effect of sliding distance on wear rate

The wear rate was observed to be a maximum for unreinforced Al 6061 alloy when compared with reinforced composite. The addition of Al_2O_3, SiC and E glass fibre to reinforced Al 6061 alloy material decreased the wear loss because the stress was distributed over the entire area, and Al_2O_3, SiC and E glass fibre act as the solid lubricator. The wear rate of the unreinforced and composite examples diminishes with extending the sliding distance. It is seen from the graphs that the wear rate of the unreinforced alloy specimens extends all the more quickly with connected load contrasted and the composite alloy specimens. The most significant wear rate was obtained at 200 m of sliding distance. Figure 10 shows the wear rate at the various sliding distances and the constant load of 30 N and sliding speed at 300 rpm.

Figure 9 Wear rate at various sliding speed and consistent load of 30 N and sliding distance of 400 m (see online version for colours)



5.1 *Automotive applications of hybrid metal matrix composites*

In present situations, MMCs are typically important for army and aerospace programs. Experimental MMC components were evolved for use in planes, satellites, jet engines, missiles and countrywide aeronautics and area management (NASA) space shuttle. The maximum essential application of MMC is diesel engine piston made by Toyota. MMCs with high specific stiffness are used in robots, high velocity machinery and high pace rotating shafts for ships and land vehicles. In car engineering, the fabrication of diesel crown pistons is a crucial application of MMCs. Carbon fibre and alumina particles in an aluminium matrix for cylinder liners are used in vehicle engineering. More automobile parts are fabricated in composite substances. The ratios of their charges and features are important causes for applications of these materials. Composite materials with MMCs are generally used for responsible components at modern-day cars. Engine pistons function in very tough dynamical, thermal and mechanical situations. The pistons are loaded to cyclic mechanical load with frequency of around a hundred Hz, so fatigue damages are often unavoidable. Pistons have to offer intimate contacts with cylinders at maximal pressures throughout expansion intervals. Dynamic patience, excessive resistance to put on and thermal enlargement coefficient are important behaviours of materials for cylinders. It is also important that pistons can function at temperatures of about 3000°C. Because of temperature gradients and thermal cycles, excessive thermal conductivity has to be supplied so that it will lessen temperatures and thermal impacts. The substances for the pistons have been composite materials with aluminium alloy matrices strengthened by using ceramic debris and fibres with a purpose to reduce wear and to enhance resistance to fabric fatigue at excessive temperatures. Due to useful characteristics, high resistance to put on and high thermal conductivity, aluminium MMCs are used for production of damage discs and drums in cars. On the idea of the load reductions, inertial forces are also reduced, in order summary weight of cars and gas consumptions. The composites had been made with the aid of stir casting method. Figure 11 shows the piston, cylinder barrel and brake system.

Figure 10 Wear rate at the various sliding distance and the constant load of 30 N and sliding speed at 300 rpm (see online version for colours)

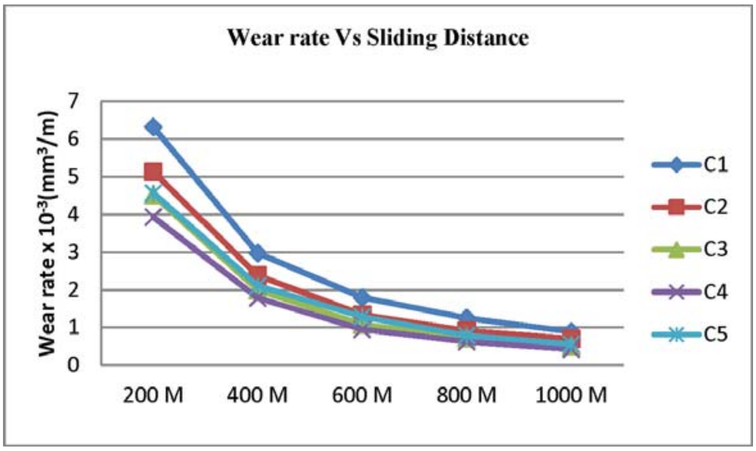
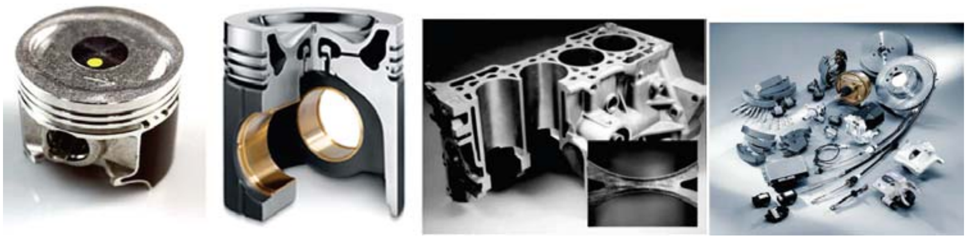


Figure 11 Pistons, engine of Honda Prelude with cylinder barrel and brake systems made of aluminium MMCs (see online version for colours)



5.2 Microstructural studies

The optical micrographs of unreinforced alloy and of the composites made by changing the weight level of reinforcement are shown in Figure 12. The microstructure investigation of these examples demonstrates that the reinforcement particles are uniformly distributed in the matrix. This perception might be credited to wetting conduct of Al alloy. It is additionally seen from the optical micrographs that the porosity of the cases increases with growing volume of the particulate reinforcements. Figure 12 demonstrates that the reinforced particles are uniformly distributed into the grid material. Figure 12(a) shows the microstructure of base metal Al 6061, Figure 12(b)–(d) shows the uniform distribution of reinforcements into the matrix material.

Figure 12 (a) Unreinforced Al 6061 alloy; (b) reinforced composite; (c) reinforced composite and (d) reinforced composite (see online version for colours)

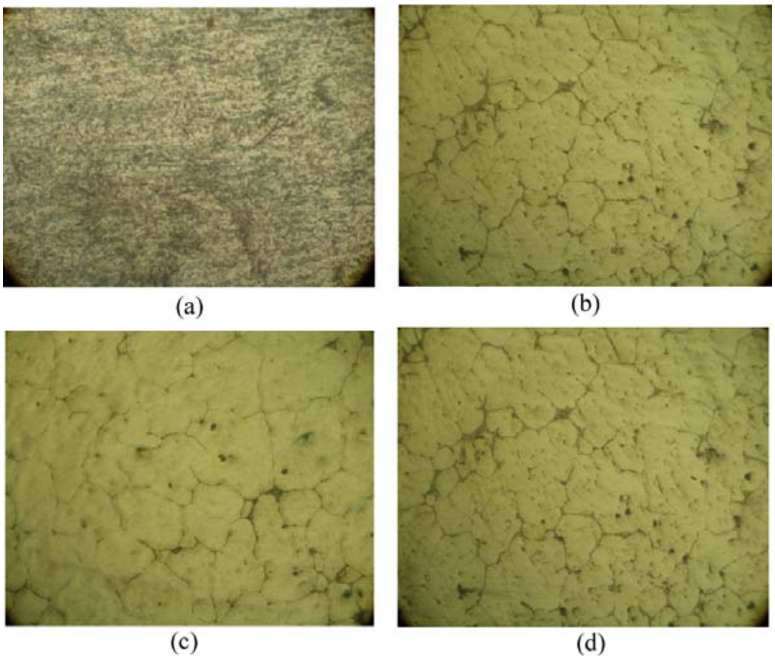
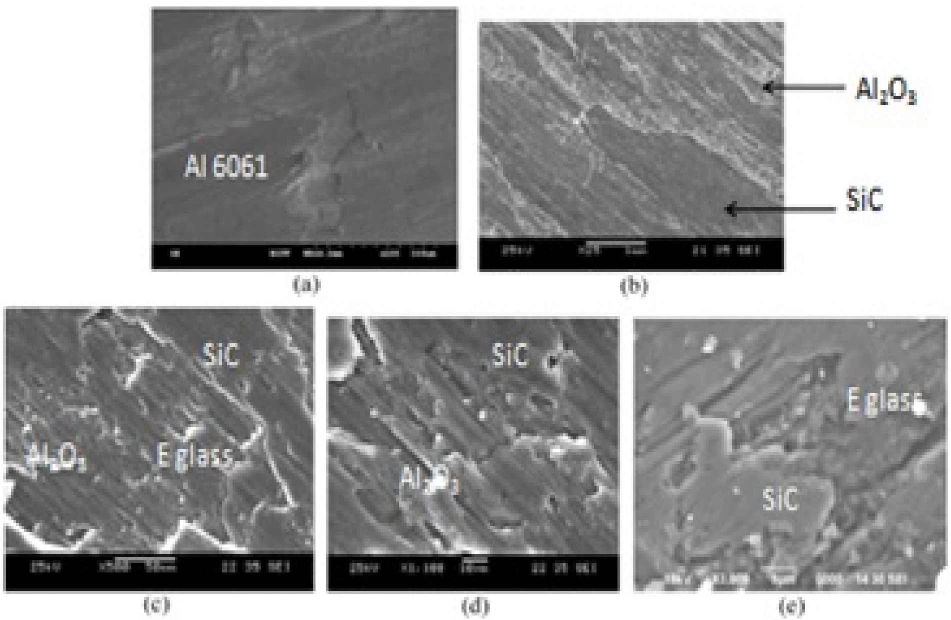


Figure 13 (a) C_1 – Al 6061 alloy after wear; (b) C_2 – reinforced composite after wear and (c) C_3, C_4 and C_5 – reinforced composites after wear



5.3 Scanning electron microscope

A scanning electron microscope (SEM) is a kind of electron magnifying instrument that produces photos of a case by filtering it with an engaged light emission. The electron bar is all things considered sifted in a raster filter design, and the bar's position is joined with the distinguished flag to make a photo. SEM can achieve assurance unrivalled to 1 nanometre. The micrograph demonstrates the association of support particles with the surface of a hard disc, to such an extent that the underlying arrangement of the lubricant layer can be watched and the reinforcement particles are anticipating outside. The SEM micrographs of the worn surfaces of the 6061 aluminium alloy and its composites with varying wt.% of reinforcement particles content are shown in Figure 13(a)–(c). An examination of the micrographs shows the formation of microgrooves here is analogous to a role being played by a two-body mechanism. The severe patches and grooves resulting from plastic deformation of the aluminium 6061 alloy matrix material and relatively small grooves and mild patches on the increasing reinforcement particles of a composite. The SEM pictures likewise demonstrate that the particles are consistently disseminated into the lattice material.

6 Conclusion

The use of composite substances in car manufacture continues to be growing. Up to date, they have been used for manufacturing pistons, cylinders, engine blocks, brakes and electricity switch device elements. Performance benefits of using the Al MMCs in automobile industry are decreased weight and improved resistance, together with higher thermal conductivity comparing to the conventional substances (metal and gray forged iron). In future, packages of Al MMCs will probably keep growing because of the continuing need to reduce automobile weight and stages of car emissions and to improve fuel economy.

Aluminium 6061 alloy reinforced with Al_2O_3, SiC and E glass fibre of composites is produced through stir casting method. The incorporation of Al_2O_3, SiC and E glass fibre particles as reinforcements improved the tribological behaviour and caused an improvement in the wear rate of Al 6061composites amid the dry sliding procedure. The wear rate of the Al 6061 alloy and the expanded weight level of reinforced particles of the composites are varied by expanding the load. The sliding speed increases the wear rate of the composite; likewise, increments of the speed which gives an immediate connection between the speed and wear rate. It was additionally discovered that the option of reinforcement's particle increases the wear resistance of the composites when compared with matrix alloy.

The experimental results show that wear rate was maximum for unreinforced Al 6061 alloy for all dry sliding wear conditions when compared with reinforced composite. The addition of Al_2O_3, SiC and E glass fibre to Al 6061 alloy decreases the wear loss because the stress is distributed over the entire area and Al_2O_3, SiC and E glass fibre material acts as the solid lubricator. The wear rate of the unreinforced and composite examples decreases with expanding sliding distance. The maximum wear rate was obtained at 200 m of sliding distance. The SEM image shows the fair, uniform distribution of Al_2O_3, SiC and E glass fibre particles in the matrix metal of Al 6061 alloy. These reinforcements enhance the tribological conduct and induce a reduction of the put on fee of aluminium 6061 composites amid the dry sliding system. The SEM pictures of the well-used surfaces of the composite demonstrate the worn surface of the composite is by and large substantially rougher than that of the unreinforced alloy. This demonstrates a grating wear system which is basically a consequence of hard reinforcement particles uncovered on the ragged surface. Coefficient grating differs inversely with the weight level of support, sliding velocity and load. A coefficient of friction decreases with increment in weight rate of reinforcement particles and sliding distance. Finally the experimental results show that the minimum wear rate is obtained in the composition (C_4) of 70% weight portion of Al 6061, 15% weight fraction of Al_2O_3, 9% weight fraction of SiC and 6% weight fraction of E glass fibre.

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