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Experimental Investigation on Mechanical and Tribological Properties of Al / Sic / Carbon Fibre Metal Matrix Composite

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Abstract: ***The preparation and characterization of aluminum 6061 alloy with low-cost reinforcements such as Silicon Carbide and Carbon fibre in different combinations is presented in this study for Automobile brake pad application. The reinforcements Silicon Carbide and Carbon fibre were varied as 2%, 4%, 6%, and 8% by volume and fabricated using Stir casting process. Five samples were fabricated and their mechanical properties, micro structural properties were analyzed and results are obtained. The composite with Al 6061 and reinforcements Silicon Carbide-8%, Carbonfibre-2%, by volume fraction has shown improved mechanical properties like tensile strength, wear resistance and hardness compared to the parent material. The microstructural properties analyzed using Scanning electron Microscope and XRay Diffraction shows good bonding between there inforcements and matrix materials in the composite.***

Keywords: Metal matrix composite; Reinforcements; Mechanical properties; Tribological properties

1. Introduction

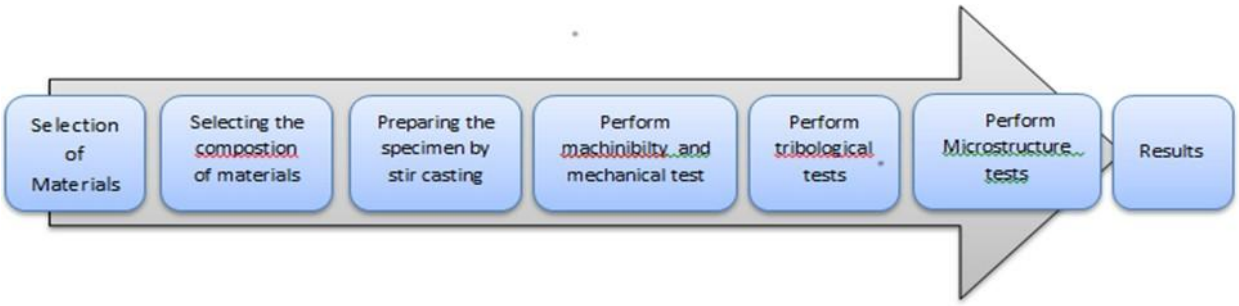
The aluminum alloy AA6061 is one of the vastly used alloys in engineering and commercial applications due to its appreciable mechanical properties and weldability. In addition to that, the use of metal matrix composites with Al6061 as parent material and inclusion of reinforcements like Silicon Carbide, Carbon fibre have resulted in materials with improved mechanical strength and usability. The application of such composites is found in almost all the fields of engineering especially in Automobile and Aerospace applications. These light weight, but strong materials have almost replaced heavy metals used in the past like cast iron and Bronze. As more and more materials are needed with improved strength and less weight, there is a huge scope of development of such materials.

2. Background Literature

During the recent past, due to the increased usage of metal matrix composites with improved properties, there are many researches performed towards achieving the same. A few of the relevant findings from the reported literature is presented below:

1) Rathod Abhik (2016) attempted to create a hybrid material of Al/SiC/Cf by the powder metrology process and then perform l test like hardness test, porosity test and wear analysis to evaluate the properties. It is observed that strength improved by increasing fiber content. The wear rate also found to be improved. The wear reduce due to better bonding between matrix and other reinforced materials. By improving the interface and reducing the porosity we can achieve high performance.
2) Sijo M T (2015) proposed multiple advantages of stir casting over the other fabrication processes. Stir casting mechanical properties are depend on the various factors like fabrication techniques, shape, reinforcement particulate size and properties of constituents and distribution. By the addition of reinforcement mechanical properties increase but fracture toughness is decreased. To enhance fracture toughness reinforcements homogenous distribution is required. The motive of this work was to help the researchers to identify strategies for experimentation.
3) Rachitwarwaha et al. (2013) Experimental analysis has been done to find the parameter of wear on Al/SiC/Gr hybrid (fabricated through Stir casting with the composition of 5% Gr and 10% SiC) by the help of taguchi method. Sliding wear test is performed on the Pin-on-disk wear test machine. ANOVA technique is use to find out the frictional coefficient and from this it was observed that by sliding speed and load has influence on the track diameter.
4) B. Stojanovic (2013) presents tribological characteristics of hybrid composites with aluminium matrix, reinforced with silicon carbide (SiC) and graphite (Gr). Newly formed Al/SiC/Gr hybrid composites are the combination of the two different hybrid materials. Namely, hard particles of silicon carbide increase the hardness and resistance to wear, while soft particles of graphite improve lubrication and reduce friction coefficient and wear. It is possible to obtain Al/SiC/Gr hybrid composites by different methods of casting. Tribological tests show that load, sliding speed, sliding distance, content and size of reinforcement particles influence the size and the type of wear and friction coefficient of Al/SiC/Gr hybrid composites with aluminium matrix.
5) Mohammad. Asif (2012) proposed to fabricate brake pad by Al-MMC against the cast iron. It was observed that the Al based brake pads possess less wear rate at same order of coefficient as in resin bounded brake pad. Temperature rise and vibration of Al based brake pad slightly higher as compare to the brake pad of resin based material. Al based brake pad has lower wear loss than the brake pad of resin. Coefficient of friction lower

in Al based brake pad as compare to the brake pad of resin based material. Temperature risen in developed Al based composite three time lower then resin based material.



3. Experimental Procedure

1) Selection of Raw materials.
2) Set the composition of the materials for preparation of specimen.
3) Prepare the specimen of the material by the use of stir cast fabrication.
4) Perform Machinability and Mechanical tests over the specimen
5) Perform tribological test over the specimen.
6) Perform SEM, EDS, XRD analysis for Microstructure analysis of Specimen.
7) Results.

1) Selection of Raw materials

Aluminium 6061 was used as a main raw material reinforced with SiC and carbon fibre. The material was procured from M/s. Vision castings and Alloys, Hyderbad. Al 6061 is a precipitation-hardened aluminium alloy, containing magnesium and silicon as its major alloying elements. . Alloys in the 6xxx series contain silicon and magnesium approximately in the proportions required for formation of magnesium silicide (Mg2Si), thus making them heat treatable.6xxx series alloys have good formability, weldability, machinability, and corrosion resistance, with medium strength. Commercial grade Al6061 Alloy was obtained in the form of ingots and cut into the small pieces by an electric power saw in order to feed the crucible properly.

Table 1: Chemical composition of Al 6061

	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Others-Each	Others Total	AI
6061	0.40-0.8	0.7	0.15-0.40	0.15	0.8-1.2	0.04-0.35	0.25	0.15	0.05	0.15	Remainder

Silicon Carbide

It was procured from M/s Vision castings and Alloys, Hyderabad. It is used as reinforcement. Silicon carbide was originally produced by high temperature electrochemical reaction of sand and carbon. It is a compound of silicon and carbon with a chemical formula SiC. The material has been developed into a high quality technical grade ceramic with very good mechanical properties. It is used in abrasives, refractory, Ceramics and numerous high performance applications. Silicon Carbide is the only chemical compound of carbon and silicon. Silicon carbide is also known as "Carborundum. Particle size received silicon carbide was in the range of50micronsis used for the experiment.

Figure 1: Silicon carbide powder

Carbon Fibre

It is procured from M/s Vision Castings and Alloys, Hyderbad. It is used as reinforcement. In this long chain is formed by the bounded carbon atoms. The fibers are light, strong and stiff. Different order of carbon fiber waves result in different properties for composite parts. Carbon fibre is the strongest and light weight material. It is five time stronger then the steel and one third of the weight of the steel. Carbon fibre in flakes was used in this experiment.

Figure 2: Carbon Fibre flakes

2) Composition for preparation of Al6061with different reinforcements

Table 2: Composition of Al 6061 with SiC and Carbon Fibre

Sample	Composition
S	Al-6061Pure
S1	Al-6061+2%SiC+8%Carbon fibre
S2	Al-6061+4%SiC+6%Carbon fibre
S3	Al-6061+6%SiC+4%Carbon fibre
S4	Al-6061+8%SiC+2%Carbon fibre

3) Stir Casting Procedure

Stir casting was carried at M/s Vision castings and Alloys, Hyderbad. Five specimens were prepared by using stir casting. A stir casting setup consists of an induction furnace and a stirrer assembly was used to synthesize the composite. The stirrer assembly consists of a graphite stirrer, which was connected to a variable speed vertical drilling machine with range of 80 to 890rpm by means of a steel shaft. The stirrer was made by cutting and shaping a graphite block to desired shape and size manually. The stirrer consisted of three blades at an angle of 120° apart. Graphite crucible of 2Kg capacity was placed inside the furnace. Approximately 2Kg of Aluminium6061 in solid form was melted at 800°C in the induction furnace, and then preparing the alloy 6061 in weight percentage. Preheating of reinforcement Silicon Carbide (SiC), Carbon fibre was done for one hour to remove moisture and gases from the surface of the particulates. The stirrer was then lowered vertically up to 3 cm from the bottom of the crucible (total height of the melt was 9 cm).The speed of the stirrer was gradually raised to 800 rpm and the preheated reinforced particles were added with a spoon at the rate of 10- 20g/min into the melt. The speed controller maintained a constant speed of the stirrer, as the stirrer speed got reduced by 50-60 rpm due to the increase in viscosity of the melt when particulates were added into the melt. After the addition of reinforcement, stirring was continued for 5-8 minutes for proper mixing of prepared particles in the matrix. The melt was kept in the crucible for approximate half minute in static condition and then it was poured in the mould. The melt with reinforcement particles was poured into a cylindrical permanent metallic mould with a diameter of 20 mm and 170 mm length. The cast rods were rapidly cooled to room temperature by knocking them out after casting for five minutes.

Figure 3 (a): Stir Casting machine

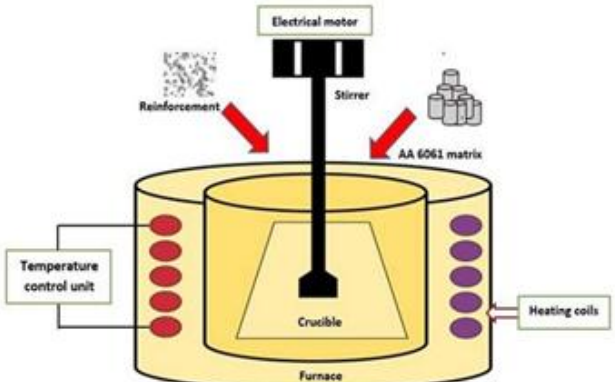


Figure 3(b): Schematic diagram of stir-casting method

4) Mechanical Tests Tensile test

It was carried at M/s Hyderbad Mettalurgical Labs, Hyderabad. Tensile strength is a measurement of the force required to pull something to the point before it breaks. Tensile test was done using Universal Testing Machine (UTM). The Specimen used is of ASTM E8 standard. Fig 4 (a) and (b) shows the specimens before and after tensile testing.

Figure 4(a): Before Tensile Test specimen

Figure 4(b): After Tensile Test specimen

Table 3: Results of Tensile strength of different specimen

Tensile Strength (N/mm2)	Al6061	Al6061+2%Sic+ 8% Carbon Fibre	Al6061+4%Sic+ 6% Carbon Fibre	Al6061+6%Sic+ 4% Carbon Fibre	Al6061+8%Sic+ 2% Carbon Fibre
	211.08	220.89	213.89	220.36	223.97

The variation of tensile strength of the specimen as compared to the parent material (Al6061) is shown in above Table. The Tensile Strength of specimen Al 6061 + 8%SiC + 2% Carbon Fibre increase by the addition of SiC by 8%.

Impact test

It was carried at M/s Hyderbad Metallurgical Labs, Hyderabad. In an impact test a notched bar of material, arranged either as a cantilever or as a simply supported beam, is broken by a single blow in such a way that the total energy required to fracture it may be determined. The energy required to fracture a material is of importance in cases of - shock loading when a component or structure may be required to absorb the kinetic energy of a moving object. Energy absorbed is the energy which is absorbed by the material. The energy is calculated in joules. The energy absorbed is calculated the energy available at the end. The energy absorbed can be found with the help of Charpy impact test. The standard specimen size for Charpy impact testing is10mm×10mm×55mm. Fig.6 (a) and (b) shows the specimens before and after testing

Figure 5(a): Before Impact Test specimen

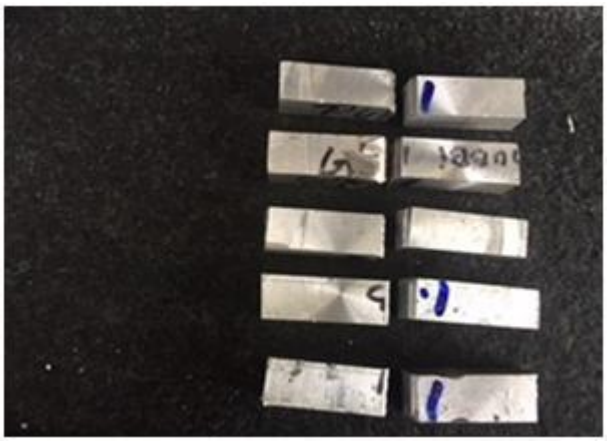


Figure 5(b): After Impact test specimen

Table 4: Results of Impact test of different specimen

Impact Test (Joules)	Al6061	Al6061+2%Sic+ 8% Carbon Fibre	Al6061+4%Sic+ 6% Carbon Fibre	Al6061+6%Sic+ 4% Carbon Fibre	Al6061+8%Sic+ 2% Carbon Fibre
	20.5	21	21.5	22	23.5

Among all tested samples, Specimen with composition Al6061+ 8% SiC +2%Carbon fibre gives high Impact strength i.e 23.5 joules.

Hardness test

It was carried at Hyderbad Metallurgical Labs, Hyderabad. Hardness test is conducted for each specimen using a load of 250 N and a steel ball indenter of diameter 5 mm.

Figure 6(a): Before Hardness test Specimen

Figure 6(b): After Hardness Test Specimen

Table 5: Results of hardness test for different specimen

Hardness test (HBN)	Al6061	Al6061+2%Sic+ 8% Carbon Fibre	Al6061+4%Sic+ 6% Carbon Fibre	Al6061+6%Sic+ 4% Carbon Fibre	Al6061+8%Sic+ 2% Carbon Fibre
	74.26	80.1	82.32	81.9	82.72

Among all tested samples, Specimen with composition Al6061+ 8% SiC +2%Carbon fibre gives highHardnessi.e.82.72HBN.

5) Wear Test

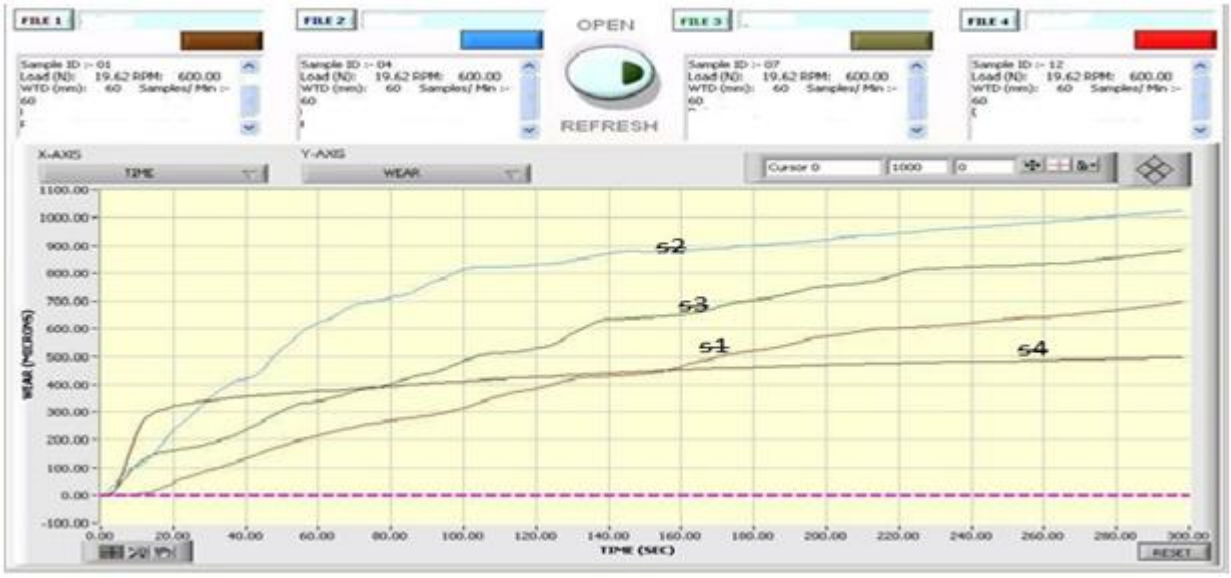
It is carried at Mechnaical Lab at PDA College of Eng,Kalaburagi. The prepared specimens were subjected to wear against a rotating EN-32 pin on disc under dry sliding wear testing machine. The tests were carried out at room temperature without lubrication for 300sec. In this test, track Dia = 60mm and time = 300sec are kept constant. The characteristics are deteremined by the comparison of all specimens.. The results shows at600rpm at 2kg weight, specimen Al- 6061+8%Sic+2%Carbon fibre shows less wear 500µm and specimen Al-6061+4%Sic+6%Carbon fibre shows highest wear 1010µm.Table shows the results of wear test.

Figure 7(b): Pin on Disk Device

Figure 7(a): Specimen for Wear testing

Table 6: Results of Wear test of specimen

	Specimen	Load (N)	Sliding Speed (RPM)	Sliding Time (sec)	Wear Rate (µm)
Al6061 Pure	Pure	20	600	300	785
Al6061+2%SiC+8%Carbon Fibre	S1	20	600	300	725
Al6061+4% SiC+6%carbon Fibre	S2	20	600	300	1010
Al6061+6%SiC+4%Carbon Fibre	S3	20	600	300	885
Al6061+8%SiC+2%Carbon Fibre	S4	20	600	300	500



Graph 1: Wear test of Specimen

6) Microstructure Analysis

They are carried by SEM (Scanning Electrom Microscope) at Nishaka Labs, Hyderabad. The SEM images of the Sample 05 of Al6061, Sic8% and Carbon Fibre 2% are obtained and the wetability and bonding of the constituents is analysed. From the below figure, it is seen that there is better wetting of reinforcements into the matrix shown by the dark patches of SiC and also alumina particles. It can be concluded that the better wettability results in deagglomeration of reinforcements thereby improving the tribological characteristics of the composite. Also, the addition of Carbon fibre enables the elimination of voids in the composite, thereby increasing the bonding and strength of the matrix and reinforcement materials.

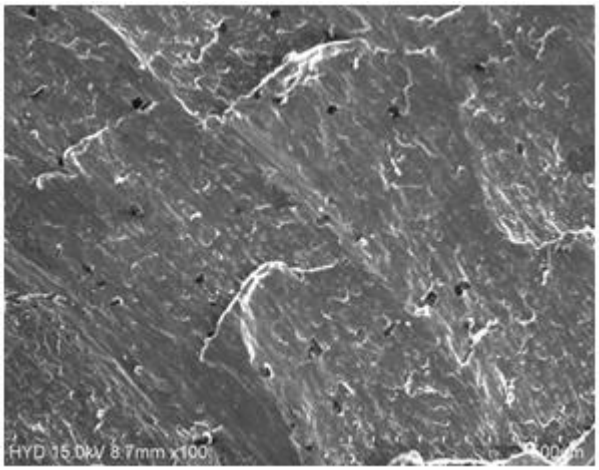


Figure 8(a): SEM of Specimen 5 with Magn 100x

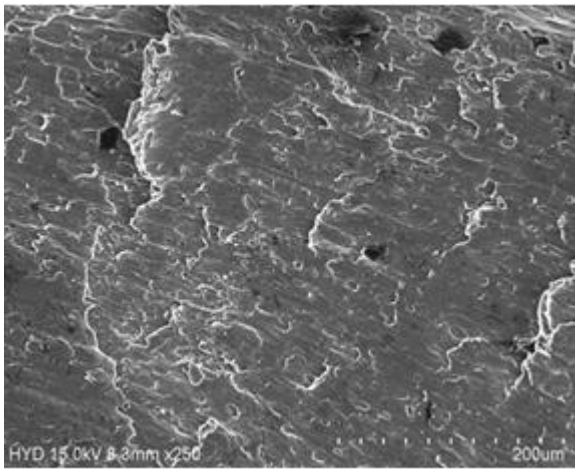


Figure 8(b): SEM of Specimen 5 with Magn 250x

The EDX (Energy-dispersive X-ray spectroscopy) and XRD (X-ray diffraction analysis)was done to identify the elemental composition of the Metal Matrix composite. The EDX image shown in below figure shows the peaks generated by the presence of various constituents of the composite.

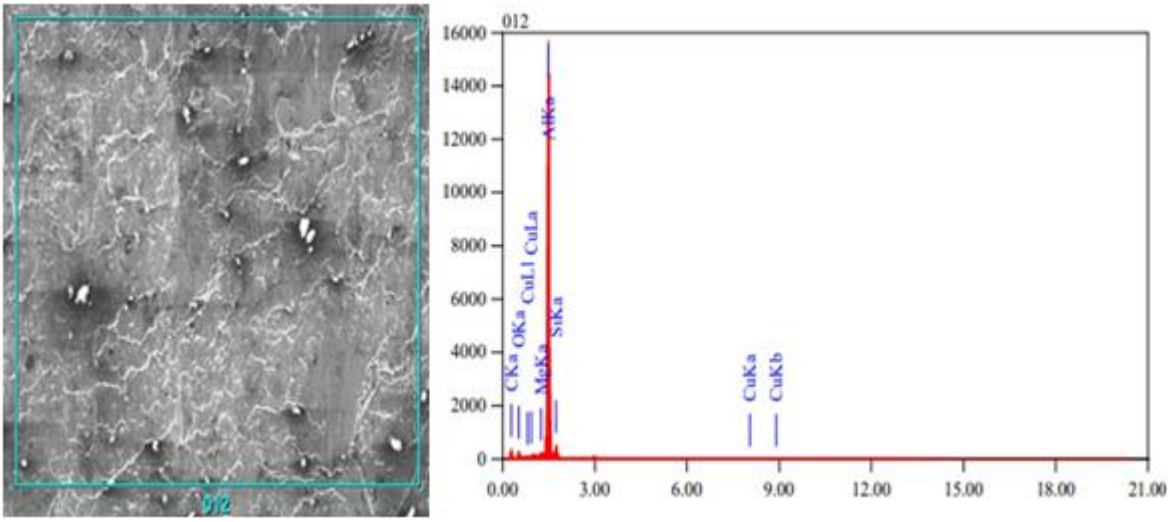


Figure 9: EDX/XRD Results of Specimen 5

4. Conclusion

A Metal matrix composite with AL6061 as matrix and reinforcements SiC along with small quantities of Carbon fibre as a wetting agent is stir casted and analysed. The mechanical and tribological properties of the samples is performed and the following results are obtained.

1) Tensile strength of Sample 48%SiC and 2% Carbon fibre is increased by addition of8%SiC and 2% Carbon fibre in Al 6061. Among the four composition, Al6061+ 8% SiC+ 2% Carbon fibre is better for tensile strength while comparing with Al-6061 Alloy.
2) Impact energy absorbed is increased in Sample 5 when 8%SiC and 2% Carbon fibreis added to Al 6061. The energy absorption was found to be better for Al6061+ 8% SiC+ 2%Carbon fibre while comparing Al-6061 Alloy
3) Hardness of Sample 4 is increased when8%SiC and 2% Carbon fibre is added in Al 6061.Hence Hardness ofAL6061+ 8% SiC+ 2%Carbon fibre is superior to other composites.
4) Wear rate is less for Sample 05 when Al6061+8% SiC + 2%Carbon fibrethan that of all four composites. Enhance of wear resistance was found to be superior for Al6061+8%SiC+2%CarbonFibreofothercomposites.
5) The micro structural analysis using SEM, EDS AND XRD shows good bonding of the reinforcement with the matrix material.

It is evident that from the above study that SiC and carbon Fibre are low-cost materials that can be used as reinforcements in Metal Matrix of Aluminium 6061 with improved mechanical properties for Automobile brakepad application.

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