Evaluation of Wear Behavior of LM26/SiC MMC's using Pin on Disc Experiment

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Abstract

The metal matrix composites are the most adoptable and innovative materials in the field of Automobile, Aerospace, Defense, infrastructure etc., because of its advantages like high strength to weight ratio, high stiffness, corrosion resistance and low maintenance compared to its parent metals. Apart from these properties the material also possess high wear resistance. LM26 is a novel Aluminium alloy which have superior Casting and Mechanical properties. Hence in the present investigation LM26 Aluminium alloy reinforced with Silicon carbide particle is subjected to dry sliding wear test to study its wear behavior. For this purpose ASTM standard G99 Pin on disc test machine set up is employed. The test has several variables like Speed(RPM), Load(N), Time(Min) Wear(Micron) and Wear rate(mm^3/N-m). Among these parameters Speed of the experiment is kept constant at 300(RPM) and other parameters are varied to study the material behavior. The Design of Experiment method is used with Minitab to identify the factor influencing most to the wear. The results are tabulated and graphs are plotted. These results are supported by SEM images were also discussed.

Keywords: MMC'S, LM26, SiC, Pin on Disc, DOE, SEM, ASTMG99, Wear Rate, L9 Orthogonal Array.

1. Introduction

Metal matrix composites reinforced with ceramic particles greatly enhances mechanical and wear properties limiting the material deformation under mechanical rubbing working condition[1,2,3,6]. These properties greatly benefits the engineers designing the parts for automobile and aerospace industries.[4] Hence in this research work a novel Aluminium alloy LM26 is used as a matrix and silicon carbide particles are used as a reinforcement.[5,6] Liquid metallurgical process along with stirring method is used to prepare composites. Once casted the parts are machined to produce ASTM standard test specimens at increasing percentage of reinforcement.[13-17]

1.1 LM26 Aluminium alloy is a designation for a specific type of aluminum alloy commonly used in casting applications where LM stands for Linear monolithic.[3] It is part of the Al-Si (Aluminum-Silicon) family of alloys, which are particularly known for their good castability, low shrinkage, and excellent wear resistance. LM26 is often used for parts that are exposed to moderate to high stress, especially where good strength-to-weight ratio, wear resistance, and corrosion resistance are important.[3,4,5,6,10,12]

ASM standard composition for LM26 Aluminium alloy;[1]

Table 1.1 Standard composition of LM26

Sl No	Element	Percentage
1	Silicon (Si)	08.5 – 10.5
2	Cupper (Cu)	2.0 – 4.0
3	Magnesium (Mg)	1.5 – 0.5
4	Iron (Fe)	1.2
5	Zinc (Zn)	1.0
6	Nickel (Ni)	1.0
7	Manganese (Mn)	0.5
8	Lead (Pb)	0.2
9	Tin (Sn)	0.2
10	Titanium (Ti)	0.1
11	Aluminium (Al)	Remaining

Fig 1.1 Casted billets of LM26

Table 1.2 Important properties of LM26:

Sl No	Property	Value
1	Density (g/cm^3)	2.6-2.7
2	Melting Point (°C)	600-650
3	Thermal Conductivity (W/m-K)	120-150
4	Co-Efficient of Thermal Expansion	$22x10^{-6}$°C
5	Hardness (Brinnel Hardness)	75-90
6	Modulus of Elasticity (GPa)	70-80
7	Ultimate Tensile Strength (MPa)	180-250
8	Yield Strengtth (MPa)	140-190
9	Tensile Elongation (Ductility)	2 – 5 %

1.2 Silicon Carbide Particles

Silicon carbide or carborundum is a material with exceptional thermal, mechanical, and electrical properties.[1,3,4] These properties make it highly valued in a variety of applications, including power electronics, abrasive materials, heat exchangers, wear-resistant components etc. Silicon carbide is the third hardest material available[4]. SiC's hardness is due to its unique crystal structure, which consists of silicon and carbon atoms tightly bonded together. This arrangement gives SiC its great strength and hardness, and makes it highly resistant to wear and abrasion. Below are the key physical properties of silicon carbide:

Fig 1.2 Silicon carbide powder, 325 Grit size

Table 1.3 Important properties of Silicon Carbide:

Sl No	Property	Value
1	Density (g/cm^3)	3.21
2	Melting Point (°C)	2700
3	Thermal Conductivity (W/m-K)	120-180
4	Co-Efficient of Thermal Expansion	4 – 5 x10^{-6}/°C
5	Hardness	9.0 (Mohs scale)
6	Modulus of Elasticity (GPa)	400-500
7	Ultimate Tensile Strength (MPa)	400-600
8	Yield Strengtth (MPa)	810-1150
9	Tensile Elongation (Ductility)	0.1% or less

2. Composite Preparation

The metal matrix composites can be prepared by various methods like Liquid infiltration, Powder metallurgy, In-situ process and few others. Among these process liquid metallurgical process or Casting process has advantages like easy process, economical, no need of skilled technicians, suitable for mass production and less material wastage. But the drawback is when Aluminium allow is melted to molten state heavy alloying elements settles at the bottom and even reinforcing silicon carbide particles also settles at the bottom. Hence uniform distribution become difficult to achieve.

Hence to overcome these limitations a novel stir casting method is employed, which involves stirring of the mixture at a specified speed for a specified time frame and then pouring it into steel dies. In liquid stir casting process the base metal alloy is melted to a molten state and reinforcing particles are add in a required quantity. The reinforcing particles are pre heat treated to remove any moisture absorption and to avoid agglomeration of reinforcement particles. The mixture is stirred at 200RPM for about 10 min and poured into steel dies for producing rods and plates. The moulds are allowed to cool down allowed MMC's to solidify 45 to 60 min and the solid parts are ejected and marked for reinforced percentage. The casted parts are later machined as per ASTM standards.

Fig 2.1 Electrical power operated, Temperature control Stirring mechanism casting machine setup

Table 2.1 Specifications stir casting machine

Sl No	Description	Capacity
1	Capacity	5 kg
2	Power Rating	6 kw
3	Crucible Size	150 mm dia, 200 mm height
4	Power Supply	400 V 50Hz 3 Phase
5	Max Temp	900^o C
6	Stirrer	1 hp DC motor 600rpm

Fig 2.2 Casted MMC's for varying SiC% plates.

3. Pin on Disc Experiment

Wear is nothing but the gradual loss by relative movement between two surfaces or substances which are in contact. Material wear is a very serious problems faced by design engineers when designing parts which involves rubbing, sliding, friction and interlocking. Hence need for material which resists wear is a wide spread area for research. To understand the wear behavior of materials, the test specimen is tested under varying loads, varying time, varying sliding distance and varying sliding velocity.

For this purpose dry sliding wear, Pin on Disc setup is used as shown in the figure.

Fig 3.1 Pin on disc wear test setup

Fig 3.2 Pin on disc test specimen as per ASTM standard with varying percentage of SiC

0% SiC **2% SiC**

4% SiC **6% SiC**

8% SiC **10% SiC**

4. Results and Discussions

For pin on disc test ASTM G99 test specimen dimension are round rods of diameter 8mm and height 30mm. The test was conducted at a constant speed of 300 RPM, for load varying at 30N, 50N, 70N and 90N, the wear in terms of micron was noted down at a regular time interval of 5 min, 10min, 15 min, 20 min, 25 min and 30mins. Also coefficient of friction are noted down by taking the images at regular intervals. The results are tabulated for different loads, different time frame and for different percentage of SiC particles. The sample test results tabulation is as shown in table 4.1.

Table 4.1: Pin on Disc Test results

Speed=300 RPM 0% SiC

Load in N	Time in mins	Wear in µm	Friction Force in N	Wear rate mm^3/N-m	Co-effecent of Friction	sliding velocity (Vs) in m/sec	sliding distance (L) in m
30	5	130	11.8	0.069	0.39	0.63	3.15
	10	167	12.5	0.044	0.42	0.63	6.30
	15	210	12.6	0.037	0.42	0.63	9.45
	20	254	13.2	0.034	0.44	0.63	12.60
	25	297	11.6	0.032	0.39	0.63	15.75
	30	340	13.0	0.030	0.43	0.63	18.90

4.1 Pin on disc test result plots

After collecting all the date the various graphs are plotted by considering various variables. The figure 4.1 shows the graph plotted between wear loss in micron V/S percentage of reinforcement of SiC. The plots for all 30N load along with 50N, 70N and 90N loads are combined for comparison.

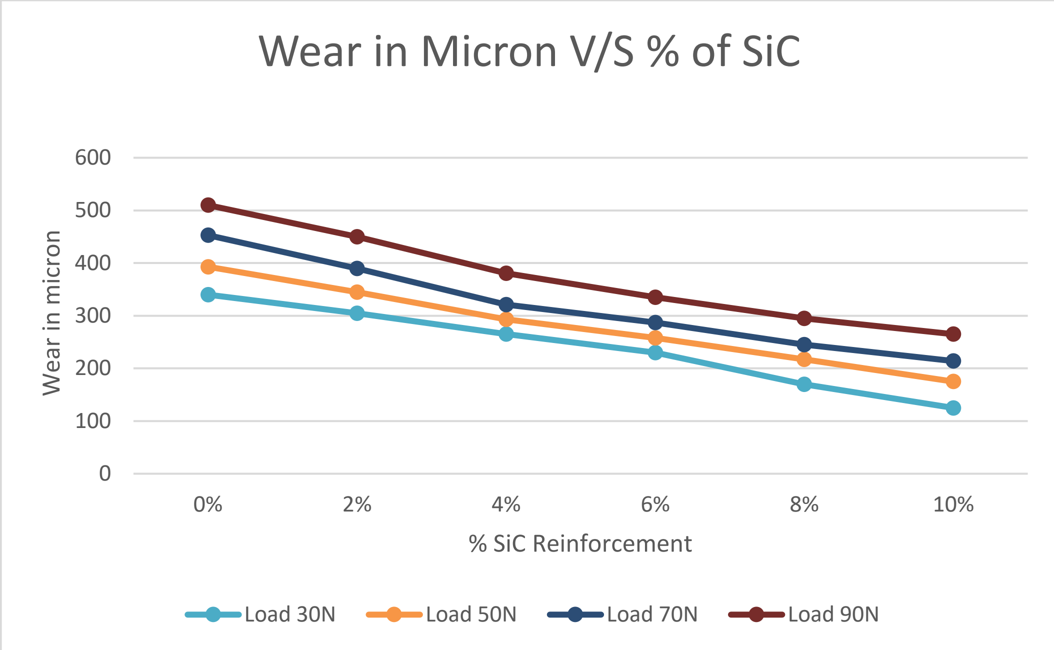


Fig 4.1: Wear in micron V/S Percentage of SiC, for different loads in Newton

The pin on disc test results shows that, as the percentage of SiC reinforcement increases the wear in micron decreasing and trend continues till 10% SiC reinforcement. This is due to increasing reinforcement SiC particle which is a hard ceramic particle reduces the wear of material. The higher loads also shows similar behaviour with little higher wear at regular intervals.

Further another plot is made for wear rate in terms of mm^3/N-m V/S Percentage of SiC as shown in Fig 4.2. The graph contain 30N load and 50N, 70N and 90N, which are combined for comparison purpose.

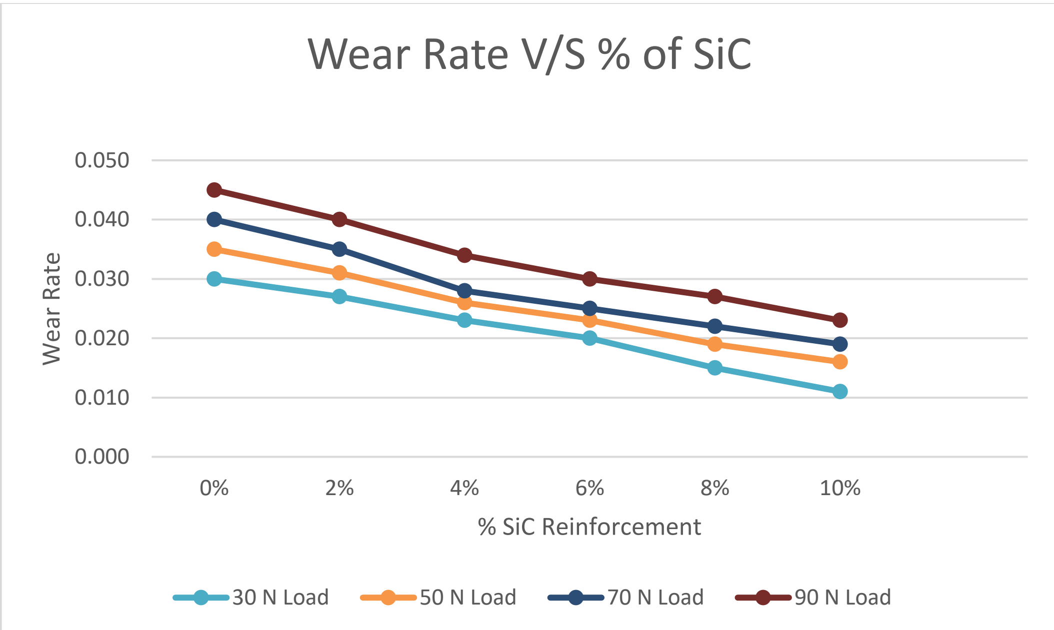


Fig 4.2: Wear rate in mm^3/N-m V/S Percentage of SiC, for different loads in Newton

The wear rate of materials is also calculated in terms of mm^3/N-m, and the values are plotted. The graph shows that, with increasing % of SiC the wear rate is also decreasing which is similar to wear(micron) V/S % SiC. The increased loads also shows similar behaviour with little higher wear rate values.

Fig 4.3 shows the plots of Wear in micron V/S load(N) for all percentage SiC are combined for comparison purpose.

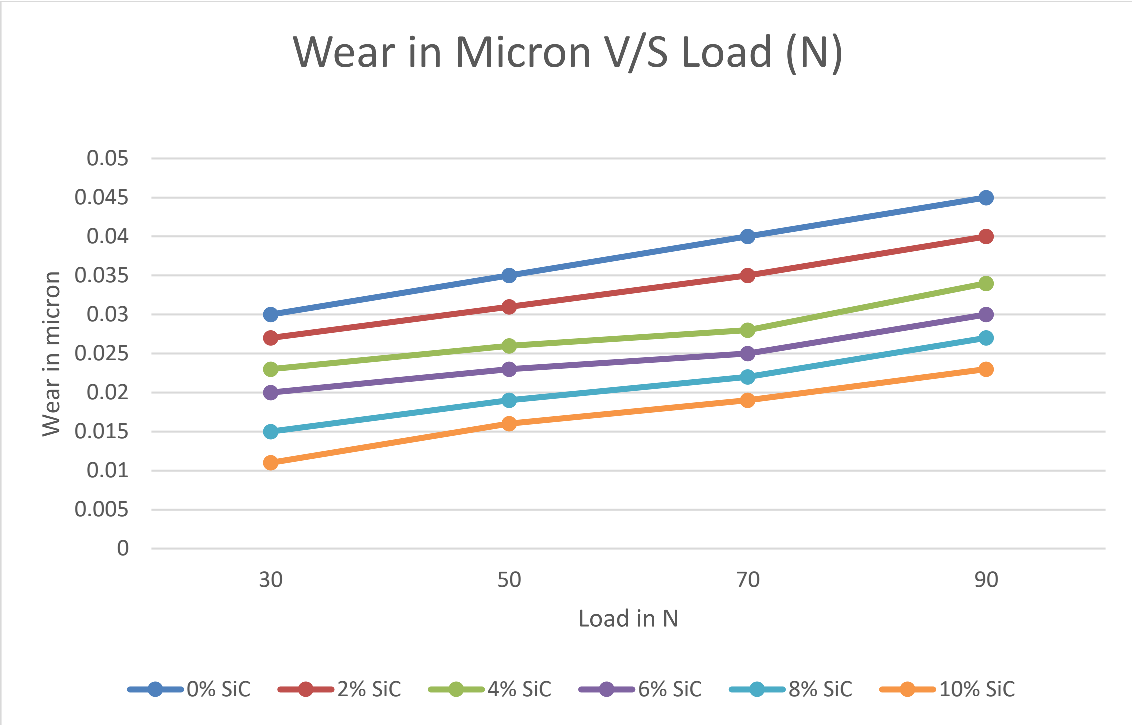


Fig 4.3: Wear in micron V/S different loads in Newton for different SiC Percentage

Another graph was plotted to understand the behaviour, the plot Load in Newton V/S wear in micron is as shown in figure. The plots shows as the load on specimen increases the wear increases. These trends are followed by all other specimens from 2% to 10%. From the plots it can also observed that as the percentage of SiC reinforcement increases the wear is decreasing.

5. Design of Experiment

Design of Experiments is a structured, organized method for determining the effect of various input variables (factors) on an output response. It is widely used in scientific and engineering disciplines to reduce number of trials or experiments needed to identify the factor that is greatly affecting the output, and reduce time, raw material, efforts and many more. In this experiment, the three variables are selected are, Load (N), Percentage of Silicon Carbide (%SiC), Time (Mins) all the three variable are taken at three levels Low, Med and High.

Table 5.1 Standard L9 orthogonal array

Experiment	Parameter1	Parameter2	Parameter3	Result
1	1	1	1	
2	1	2	2	
3	1	3	3	

4	2	1	2	
5	2	2	3	
6	2	3	1	
7	3	1	3	
8	3	2	1	
9	3	3	2	

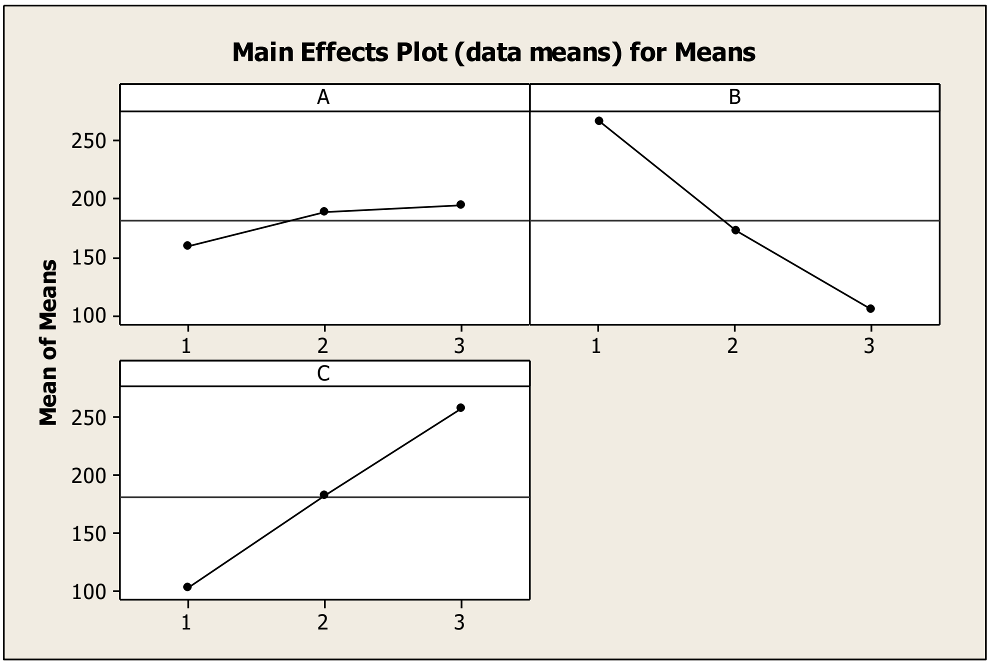
In the pin on disc experiments the three variables are taken at three levels,

1. Load:- 30N, 50N and 70N
2. Percentage of SiC:- 2%, 6% and 10%
3. Time:- 10 min, 20min and 30min

Table 5.2: L9 Orthogonal array with parameter levels and test results

Experiment	Parameter1 Load(N)	Parameter2 % SiC	Parameter3 Time(Min)	Result Wear (Micron)
1	30	2	10	167
2	30	6	20	186
3	30	10	30	125
4	50	2	20	241
5	50	6	30	258
6	50	10	10	68
7	70	2	30	390
8	70	6	10	73
9	70	10	20	120

Fig 5.1: The response from Minitab application.



Plot A indicates as the load on specimen increases the wear increases, the plot B indicates as the percentage of reinforcement increases the wear decreases. The plot C indicated as the time interval increases the wear increases.

As from the plots it can be observed that wear majorly affected by percentage of reinforcement and time interval but load on specimen have lesser effect compared to Percentage of SiC and Time interval.

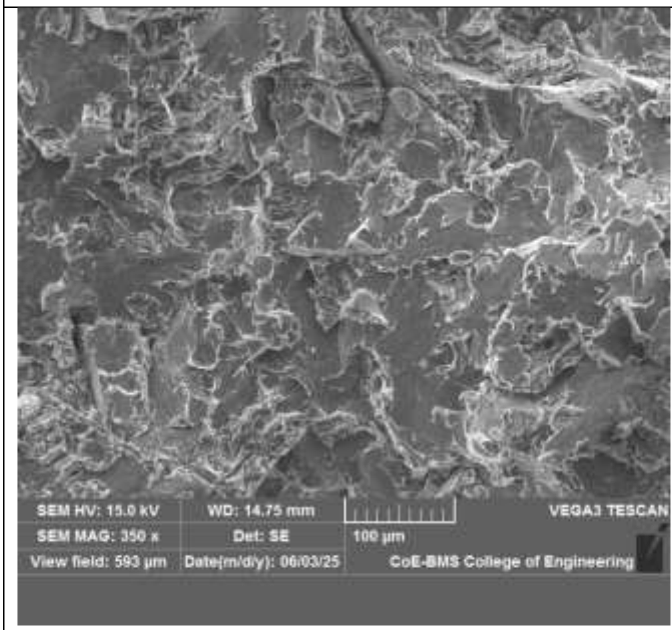
6. Microstructure characterization

Microstructure characterization is the process of analyzing and describing the arrangement of phases, grains, orientation, distribution and defects within a material at a microscopic level, typically ranging from nanometers to micrometers. It is a crucial step in understanding how a material's internal structure influences its macroscopic or mechanical properties. This analysis often involves using various microscopy techniques and other methods to reveal the size, shape, and distribution of microstructural features.

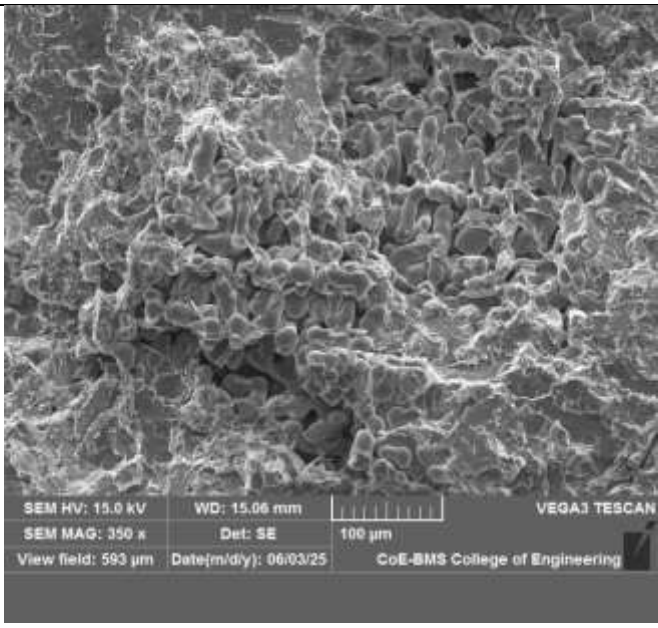
In the present investigation SEM at 350X has taken for different composition of SiC particle percentage and compared. For this purpose a standard test specimen of area less than $1cm^2$ and thickness in the range 10mm to 8mm was prepared for each percentage. The following images are obtained.

Fig 6.1. SEM images of 0% and 2 % SiC Reinforced LM26 MMC's

0% SiC Reinforced



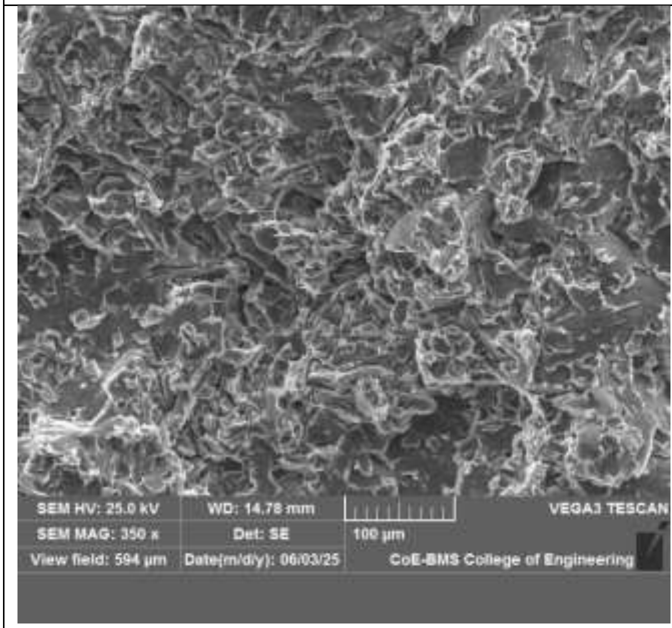
2% SiC Reinforced



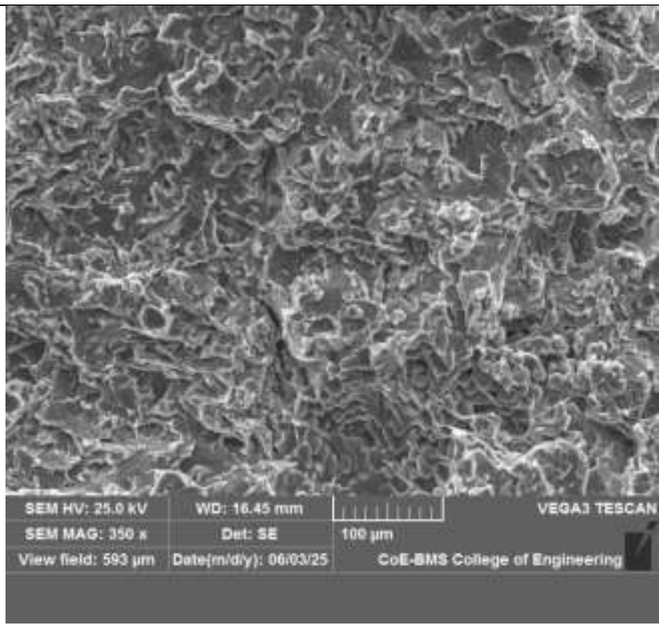
The figure 6.1 shows at 350X SEM images, from 0% SiC reinforcement images we can see rough and fractured morphology indicating brittle fracture. Presence of Dendritic structure and semi Dendritic structure indicates Al-Si alloy, in LM26 Aluminium alloy Silicon is one of the major alloying element and SEM images confirm it. The 2% SiC reinforced SEM images, indicates clustered SiC particles with cylindrical or rod like structures. The reinforcement are rare and oddly distributed as 2% SiC is small weight percentage.

Fig 6.2. SEM images of 8% and 10 % SiC Reinforced LM26 MMC's

8% SiC Reinforced



10% SiC Reinforced



The figure 6.2 shows SEM images of 8% SiC reinforcement LM26 Al MMC's. In the image it can clearly observed that uniformly distributed SiC particle and reduced dendritic structure indicate enhanced properties. The image also shows SiC particle surrounded by matrix materials. The 10% SiC reinforced LM26 Al alloy, the SEM images shows high distribution of SiC particles, increased reinforced particles induced the brittleness in material. Also reinforcement and matrix bonding reduced due to reduced wetting of reinforcement as matrix become inadequate to completely wet the particles. Hence there is been an overall down trend in mechanical properties but were in wear resistance properties shows continued trends.

7. Conclusions

In the present work, LM26 Al alloy reinforced with SiC particle (325 Grit size) was successfully done. For casting a specimen, a stir casted machine was used which stir the molten composition at 200rpm for 10 min before pouring it into steel mold. The Pin on Disc test specimens were machined as per ASTM standard and was tested in a Dry sliding Pin on Disc test rig. Also to understand the microstructure the specimens were studied under SEM for 350X. The results were obtained and tabulated. After this following conclusion were drawn.

1. LM26 Aluminium alloy composition as per ASTM standard was noted and both chemical test and EDAX test results shows that the alloying elements percentage are in the range and acceptable.
2. Pin on Disc test results were tabulated and graphs are plotted. The graphs shows that as SiC reinforcement increases the material wear decreases. This decreasing trend mirrors for all loads and all time intervals.
3. Pin on disc test results graphs also shows that material wear increases as load on specimen and time interval increases. In these graphs also shows that no reinforcement or low reinforcement of %SiC material shows higher wear and high %SiC reinforcement shows lesser wear.

4. The design of experiment (DOE) method was used to identify the variable which is influencing highly to the experiment. For this L9 orthogonal array was used with reinforcement percentage, load and time as three variable and taking three levels. With the help of minitab plots it was observed that Load and Time are highly influencing the material wear than SiC reinforcement.

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