FABRICATION AND CHARACTERIZATION OF MECHANICAL AND TRIBOLOGICAL PROPERTIES OF SIC/AL_2O_3/AZ91 MAGNESIUM BASED COMPOSITE MATERIAL

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Abstract— Magnesium is the lightest of all light metal alloys and therefore is an excellent choice for engineering applications when weight is a critical design element. It is strong, has good damping and is readily available. The use of pure magnesium is rare due to its instability at high temperatures and it is extremely corrosive in wet environments. Therefore the use of magnesium alloys when designing aerospace and automotive parts is critical. In this work the composite material study carried out by selecting magnesium alloy AZ91 and is strengthened by silicon carbide (SiC) micro powder particles which have the potential to have excellent mechanical and tribological properties with light weight. In this project metal matrix composite reinforced silicon carbide from 15-25 volume fraction-% where fabricated by stir casting. Aluminium oxide (Al_2O_3) is added at 20% volume fraction of SiC_p to promote the elongation behavior of the composite material. Hence, it can be called as a hybrid composite material. The process involves the SiC blended inside the molten magnesium alloy by stirrer with speed of 500rpm and magnesium flux is added to overcome from the lack of wettability of reinforcement. The molten composite was then cast into the permanent die cast mould. Tensile test was performed on the specimen to analyze its tensile property as well as hardness of sample material. The wear test is carried out for 1, 2 and 3kg load at 300, 400, 500rpm sliding speed respectively which gives wear, frictional force and coefficient of friction of samples. The results were characterized and analyzed by comparing with pure AZ91 magnesium alloy.

Keywords - SiC/Al_2O_3/AZ91Mg alloy, Casting, Mechanical properties, Tribological properties.

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1. Introduction

The definition of composite in engineering field is a material which is composed of two or more materials microscopically with chemically different phases. Therefore, at microscopic scale a composite is heterogeneous but at macroscopic scale it is homogeneous. The materials which frame the composite are referred as constituents or as phases. One of the constituent materials acts as base or matrix material and another as reinforcement material in which, both of them have significantly different properties.

Magnesium alloy is a fusion of magnesium with other metals like, aluminium, copper, manganese, silicon, zinc and zirconium. The properties which attracts for application in various fields are their low density, high strength to weight ratio in cast form or wrought form. Due to their lightweight property the magnesium alloys have been used more and more in the automotive industry in recent years as metal matrix material. As far as thermal stability of the reinforcement are concerned ceramic particles are the most desirable due to their high level of hardness, strength and high wear resistance. Hence SiC is one of ceramic reinforcement used in Mg alloy MMC, where as in this work aluminium oxide is used as filler material in AZ91/SiC composite. The present work aims to reveal the mechanical properties by applying loads in tensile manner and tribological properties like wear, coefficient of friction of SiC/Al_2O_3/AZ91 composite fabricated by stir casting.

2. Literature review

Hai Zhi Ye, Xing Yang Liu: Have done a study on recent evolution in magnesium matrix composite which include some conventional and new fabrication process for magnesium based composites, reinforcement distribution and mechanical properties.

Xia Zhou, Liming Liu: made a research on mechanical property of magnesium AZ91 alloy with Silicon carbide (size in nanometre) and carbon nanotubes with very little amount of volume fraction i.e. 0.3% and 0.7% respectively and stirring assisted ultrasonic cavitation method has used for fabrication, from which they got the result as the SEM images of composites showed good distribution of SiC nanoparticles and Carbon nanotubes in the base material as well as concluded that the properties like tensile, elongation of hybrid composites were more than the pure AZ91 magnesium alloy.

Abhilash Viswanath, K.K. Ajith Kumar, H.Dieringa: Have made experiment on mechanical properties and creep behaviour of stir cast AZ91-SiC composites with different volume fraction where the creep test carried out at temperature 175^0C under constant stress of 80, 100, and 120 MPa. The results conclude that for higher volume fraction of SiC, the plot of creep rate v/s creep deformation shows creep rate increases with increase in applied load.

S. Aravindan, P.V. Rao, K.Ponappa: Carried a experiment using different particle size of SiC (32 and 105 μm) by two step stir casting to analyse mechanical and physical properties of AZ91 with different volume fraction. The results reveal that, as the volume fraction of SiC increases the mechanical properties of the composite increases but decreases when SiC particles size increases.

3. Methodology

In order to achieve the research the following actions are performed in sequence

- Selection of base material and reinforcement material with the type of Material matrix composite
- Selection of type of casting process which suits the selected material.

- Preparation of specimens using stir casting process.
- Performing the tensile test, hardness test and wear test on specimens.
- Analysing the results.

3.1 Material selection

Matrix material:

Magnesium alloy AZ91 which is a magnesium cast alloy comes under metal matrix composite type. Chemical composition of AZ91 is

Grade	% Al	% Zn	% Si	% Mn	% Mg
AZ91	9.1	1.02	0.02	0.34	Remaining

Table 1: Chemical composition of AZ91

Reinforcement material:

(1) Silicon Carbide in micro powder form which is a ceramic fibre reinforcement. Chemical composition of SiC is

silicon	Carbon
70.06%	29.94%

Table 2: Composition of SiC

(2) Aluminium Oxide (Al_2O_3), Chemical composition is

Oxygen	Aluminium
47.1%	52.9%

Table 3: Composition of Al_2O_3

3.2 Preparation of composite by stir casting

The process includes mixing of preheated SiC with molten AZ91, stirring and die casting. About 3500 g of the matrix alloy AZ91 was taken and melted at 725°C under an inert atmosphere in a steel crucible. The stirrer was inserted just below the surface of the melt by using a speed of 500 rpm. This rotational speed creates a vortex of adequate depth. Then 15% (525 g) of the silicon carbide which has the particle size about 30µm (pre-heated) was gradually added to the vortex. Magnesium flux was added randomly in-between the process to dissolve exciting oxides on the metal surface and promote wetting of reinforcement. To ensure complete inclusion of the particles, the melt was continuously stirred for 2 min and the molten metal was poured at 700°C into the permanent mold of standard size rod shaped 120 mm length and 20 mm diameter. Similar process is continued for 20%, 25% volume fraction of SiC and 5% volume fraction of Al_2O_3 with 20% of SiC, where each volume fraction has three specimens.

(a) (b) (c)

Figure 1: (a) Stir casting setup (b) composite material after casting (c) prepared specimens for tensile test

3.3 Tensile test

In this present work the specimens shown in figure 1.c have total 13 specimens with four different volume fractions, and each volume fraction has three specimens with one pure AZ91 magnesium specimen. These specimens tested for tensile test on UTM having ASTM Standard name- FIE/ UTN-40, serial no-10/90-1346 conducted at room temperature.

Figure 2: Universal Tensile Testing Machine

3.4 Hardness Test

Hardness test was performed on Vickers Hardness Test Machine of standard 536HY30 with model no BV50 at normal temperature. The hardness of sample was calculated by applying 10 kg load and 20 kg load. The load is applied for 30 to 40 seconds. After unloading the impression delivered by the two diagonal indentations on the surface of the specimen are measured using a microscope and then their average is calculated. The average of diagonals of indentation has been determined once; the Vickers hardness can be calculated by using following formula

$$\text{Vickers Harness Number (VHN)} = \frac{1.8544 * P}{d^2} \quad (1)$$

Where, Arithmetic mean of two diagonals $d = \frac{d_1 + d_2}{2}$ (2)

d_1, d_2 = Two indent diagonals in mm
P = Load in kg
θ = Angle between opposite faces given by 136^0

Figure 3: Vickers Hardness test machine

3.5 Wear test

Material Samples (Pin material)	AZ91, AZ91+15% SiC, AZ91+20% SiC, AZ91+25% SiC, AZ91+20% SiC+5% Al_2O_3
Pin dimension	32 mm length and 10 mm diameter
Wear track diameter	60 mm
Sliding speed	300 rpm, 400 rpm, 500 rpm
Normal load (applied load)	1 kg, 2 kg, 3 kg
Time duration	5 min

Table 4: Specification of machine and specimens for wear test

Pin-on-disc machine was used to carry out dry sliding wear tests for different number of specimens, and the machine Model is: Wear & Friction Monitor TR-20LE, supplied by DUCOM as shown in Figure. The setup for this method requires a pin with spherical surface as the tip and rotating circular disc, placed at right angles with respect to the spherical pin surface. The diameter of the pin is 10 mm and the length is 32 mm. The disk is made of material En-31steel hardened to 60HR on which jaw in the apparatus holds the pin and revolution is given to the disk which causes wear of the pin on a fixed path. The pin is then pushed against the surface of the disk by applying load with the arm attachment given to the apparatus. Machine is connected with a data acquisition system and WINDUCOM 2010 software which gives result values and graphs i.e. wear, frictional force, and coefficient of friction.

(a) (b)

Figure 4: (a) Pin-on-disc wear test machine setup (b) prepared specimens for wear test of length 32 mm and dia 10 mm

Wear test results in form of graphs

The comparison of wear between 1 kg load at 300 rpm, 2 kg load at 400 rpm and 3 kg load at 500 rpm for different materials are given below in form of graphs and each graph contains three types of plot i.e. wear (micrometers) v/s time (seconds)

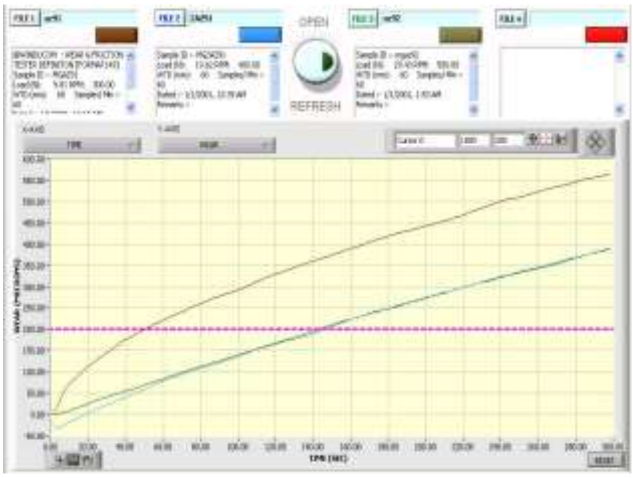

Figure 5(a): AZ91

Figure 5(b): AZ91+15% SiC

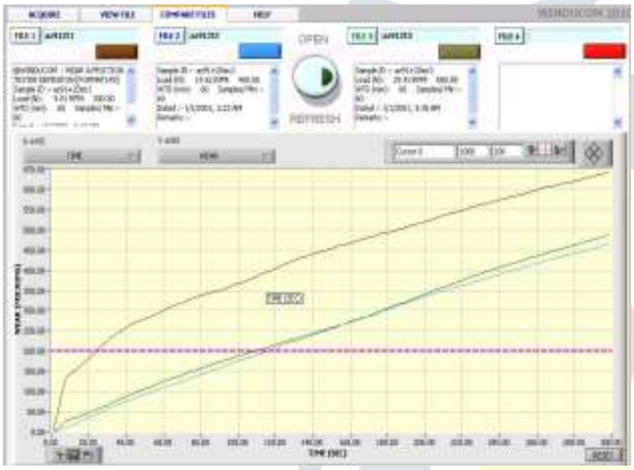

Figure 5(c): AZ91+20% SiC

Figure 5(d): AZ91+25% SiC

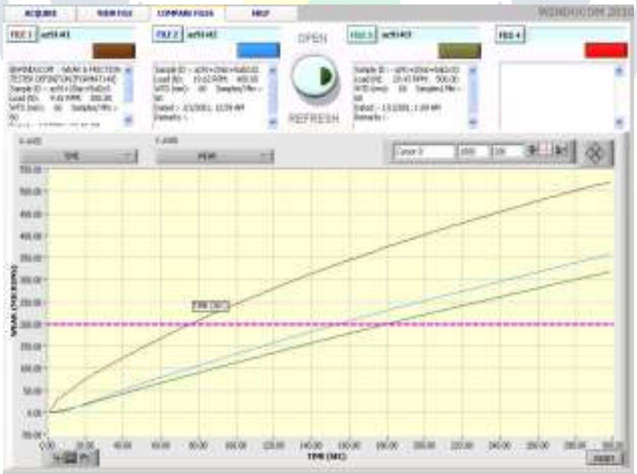

Figure 5(e): AZ91+20% SiC+5% Al_2O_3

Figure 5: (a) to (e) shows wear for different composite material

4 Results and Discussion

4.1 Tensile test

Material	Tensile strength (MPa)	Yield strength (MPa)	Elongation (%)
AZ91	77.384	74.506	2.340
AZ91+15% SiC	64.382	52.349	2.58
AZ91+20% SiC	119.395	110.782	1.826
AZ91+25% SiC	103.256	90.107	2.373
AZ91+20% SiC+5% Al_2O_3	108.82	104.33	1.94

Table 5: Mechanical propertis of AZ91/Sic/Al_2o3 composites

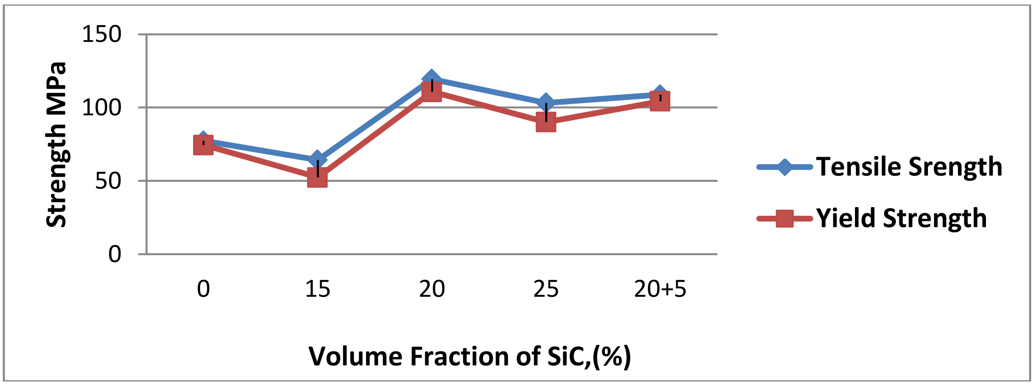

Figure 6: Change in yielding and tensile strength of AZ91 alloy as a function of volume fraction of SiC

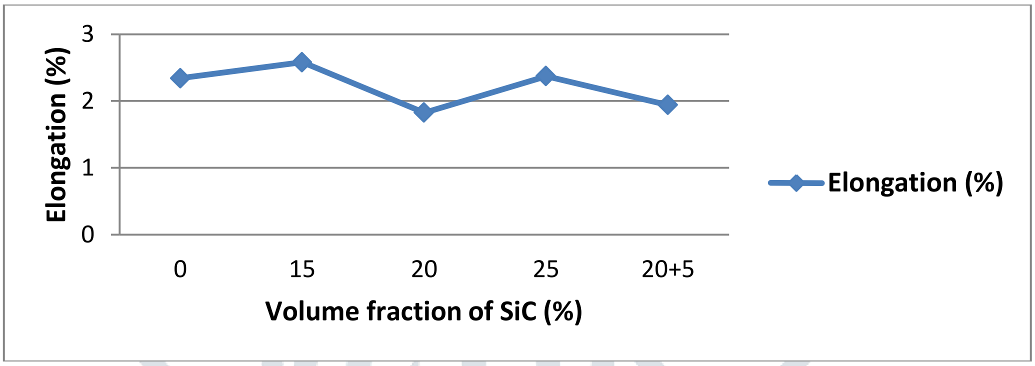

Figure 7: Variation of tensile elongation of AZ91 alloy with volume fraction of SiC

The tensile properties of AZ91 with SiC and Al_2O_3 composites are shown in figure 6 and 7. The table no 5 reveal that the accumulation of SiC particulates to the matrix material increases the ultimate tensile strength and yielding strength up to 20% volume fraction but reduces the elongation or strain to failure. At 25% volume fraction, the elongation has increased but both the strengths have decreased. To overcome this, little modification has been done, i.e. 5% aluminium oxide has been added as additional filler material, having better elongation property compared to AZ91+20% SiC combination. As expected there is improvement in elongation but tensile strength has reduced. This implies that the matrix probably does not have adequate internal ductility to redistribute the very high localized internal stress. Another explanation behind decreased ductility is the conflict to the dislocation motion of the hard particles.

6.2 Hardness test:

Material samples	HV10	HV20
AZ91	126.08	115.06
AZ91+15% SiC	90.57	80.20
AZ91+20% SiC	121.14	85.142
AZ91+25% SiC	135.45	76.67
AZ91+20% SiC+ 5%Al_2O_3	90.967	89.98

Table 6: Vickers hardness number (HV) measured for composites

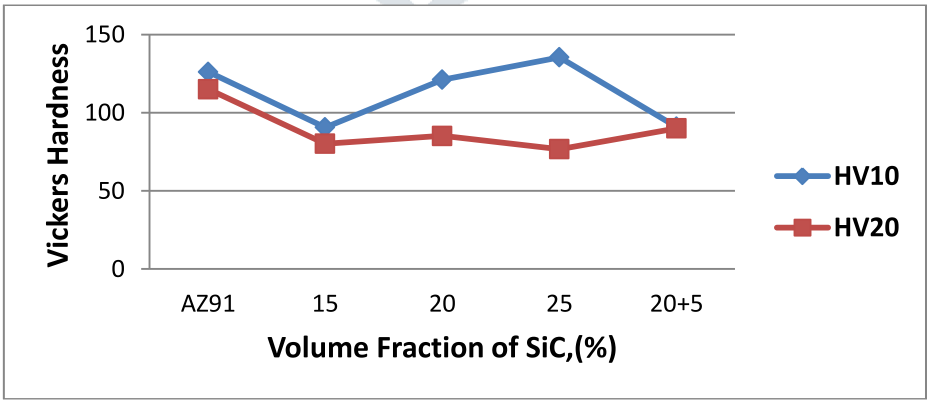

Figure 8: Variation of the hardness values of AZ91 with different volume fraction of SiC-particles

Figure 8 shows the comparison of Vickers hardness of sample material with each other at load 10 kg and 20 kg. There is improvement in hardness at 25% volume fraction of SiC compared to other volume fraction of SiC as well as AZ91. And there is no additional effect of Al_2O_3 in the composite. However the hardness value is more for all composite material at 10 kg load compared to 20 kg.

4.3 Wear Test

Material sample	Wear (µm)	Frictional force (N)	Coefficient of friction
AZ91	573	1.53	0.164
AZ91+15% SiC	255	0.14	0.0132
AZ91+20% SiC	649	0.74	0.075
AZ91+25% SiC	517	2.5	0.259
AZ91+20% SiC+ 5%Al_2O_3	524	0.23	0.0257

Table 7: Tribological properties for 1 kg load at 300 rpm

Material sample	Wear (µm)	Frictional force (N)	Coefficient of friction
AZ91	381	4.6	0.234
AZ91+15% SiC	311	4.99	0.248
AZ91+20% SiC	472	0.82	0.044
AZ91+25% SiC	374	4.6	0.236
AZ91+20% SiC+ 5%Al_2O_3	357	4.75	0.243

Table 8: Tribological properties for 2kg load at 400rpm

Material sample	Wear (µm)	Frictional force (N)	Coefficient of friction
AZ91	390	5.8	0.200
AZ91+15% SiC	334	5.9	0.199
AZ91+20% SiC	498	4.6	0.158
AZ91+25% SiC	308	7.2	0.241
AZ91+20%SiC+ 5%Al_2O_3	319	3.9	0.133

Table 9: Tribological properties for 3 kg load at 500 rpm

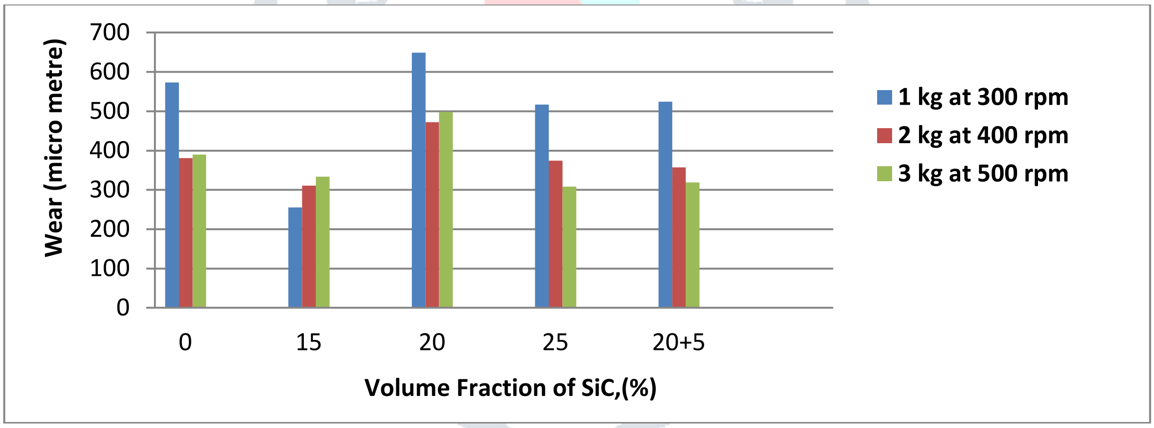

Figure 9: Shows change in wear of AZ91 as a function of volume fraction of SiC and Al_2O_3

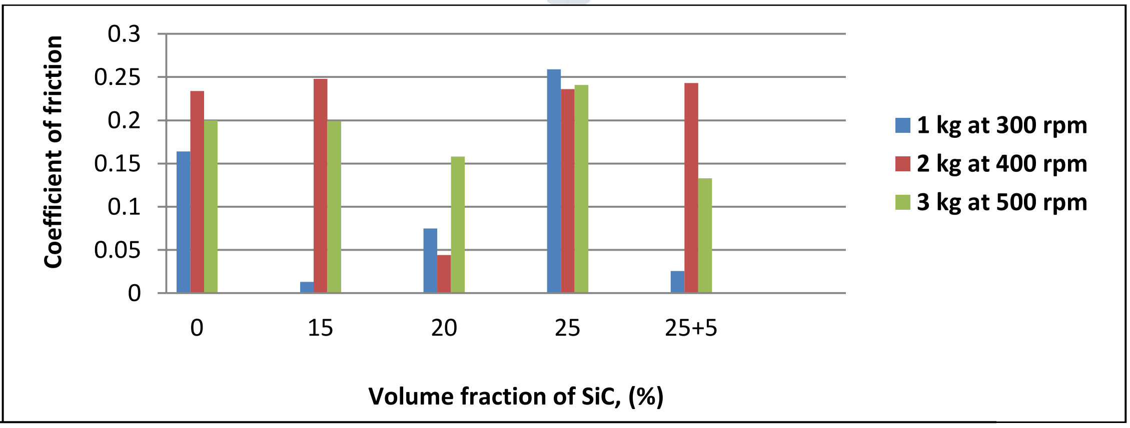

Figure 10: Shows change in coefficient of friction of AZ91 with different volume fraction of SiC and Al_2O3

Wear

Figure 9 shows value of wear of the sample specimen under applied load and sliding speed. The wear is more at 20% volume fraction of SiC compared to all other specimen, and decreases as volume fraction of SiC increases. The hybrid composite shows no significant difference in wear property and as the load increases from 1 to 3 kg with increase in speed from 300 to 500 rpm the wear value is less i.e. 1 kg-300 rpm > 2 kg-400rpm > 3 kg-500 rpm.

Coefficient of friction

Figure 10 shows plot of coefficient of friction v/s sample specimen with different volume fraction of SiC in AZ91 MMC loading from 1 to 3 kg at 300 to 500 rpm respectively. It revealed that, at 25% volume fraction of SiC the coefficient of friction is very high compared to pure AZ91 in every load- speed condition. The graph also describes that coefficient of friction is more under 2 kg load at 400 rpm compared to other load condition.

5 Conclusion

- Stir casting is an effective and reasonable method for fabrication of AZ91/SiC and AZ91/SiC/Al_2O_3 composites. According to the results, yield strength and ultimate strength of the composite material has enhanced at 20% volume fraction compared to other volume fraction of SiC. The additional reinforcement aluminium oxide has no effect on the mechanical properties of the composite. This may be due to lack of wetting condition of reinforcement materials, and non-uniform distribution of reinforcement into the base material.
- There is an improvement in hardness of composite at 25% volume fraction of SiC than the base material at 10 kg load than 20 kg load. Which indicates that as load increases hardness may reduce. But the results are random, may be this is due to not properly preparing the specimen for Vickers hardness test which requires a flat surface.
- Pin on disk dry sliding wear test was carried out with different loads and sliding speed on steel counterface. The obtained data and graphs show random results which may be due to less accurate or less précised surface of the pin with non-uniformity. Wear track diameter might have also lead to random results.
- The SEM (Scanning electron microscope) analysis is important to know the distribution of reinforcement material in required amount to get better results which is not covered in this work and may be one of the causes for the random results.

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