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Mechanical and wear behaviour of flyash reinforced epoxy composites

In this research, a flyash/epoxy composite was fabricated using conventional hand layup method. The mechanical and tribological behaviour of composite was investigated by changing the volume of flyash to 5, 10 and 15% vol. The mechanical properties such as compression strength, hardness, impact strength and tensile strengths were determined as per ASTM standards. Results reveal that the mechanical properties, such as density, tensile strength and the compression strength increased as the amount of flyash increased up to a critical point, decreased with further increment in percentage of flyash. Tribological results reveal that, when the percentage of flyash is increased there is a significant decrease in wear volume loss. The minimum wear loss is observed at the optimum values for loads 15N, speed 300rpm and distance is 300m.

Keywords: Boron carbide, flyash, hybrid composites, hand layup

1.0 Introduction

The mechanical properties of the composite are governed by many factors such as type of reinforcement, size, shape, and matrix material. Composites show higher strength, stiffness and have resulted in many applications including aircraft, automobiles, and sports equipment. [Liu et al. 2014 and Yu et al. 2011].

The mechanical and tribological behaviour of epoxy based composites can be altered by type of nano reinforcements, size of particles and volume fraction. Depending on the type of filler materials, the density of the composite can be reduced which results in high strength and enhanced electrical and mechanical properties [Lau et al. 2006 and Patankar et al. 2010]. Epoxy based polymer composites provide extremely good mechanical properties. In the past three decades, nano particles have been used to enhance the properties such as resistance to fire, chemical attack, dimensional stability, and good corrosion resistance [Viswanathan et al. 1993].

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Many researchers have reported that, the properties of the composite can be improved by reinforcing with nano-fillers and fibers [Thostenson et al. 2001 and Singla et al. 2010]. In this perspective, nano particles and nano-filler are more effective and attractive than their micro particles due to high surface area, high aspect ratio and lower requirement of quantity as compared to micro particles. These characterises of the nano particles results in developing strong interface between matrix and fibers and effective transfer of load from the matrix to fibers. This bonding enhances the structural properties of the fiber reinforced composites [Thostenson et al. 2001].

Flyash is the best suited reinforcement for polymeric matrix composites among other micro particles/filers. Because of exceptional mechanical qualities like strong electrical conductivity, low density, high aspect ratio, and high elasticity modulus. Flyash is an industrial by-product produced by the combustion of coal in power plants and was one of the reinforcements employed in this investigation. The cost of composite is a key issue to consider. Innovative methods for lowering the cost of composite materials can aid in the development of a wide range of applications. There are various advantages to use flyash as a reinforcing material. Because of the low density of the flyash, the total structural weight of the composite can be reduced without sacrificing mechanical qualities (Venkatesh B K et al., 2020) compared the results of experimental investigation of mechanical properties of composites with simulation values. The compressive strength of the flyash reinforced epoxy composite was shown to increase when the percentage of flyash reinforcement was increased. The hollowness of the flyash particles and the strong interfacial bonding that occurred between epoxy and flyash are responsible for this increase. At the same time, due to the lack of epoxy resin, the impact strength of the composite was reduced [Singla et al. 2010].

Experimental research was carried out by [Subham and Tiwari, 2013] to assess fly concentration and surface change on FRP composites. Experiments were carried out with different percentages of flyash reinforcement and surface modification. The damping factor and thermal stability of the FRP composite rose dramatically as the concentration of surface modified flyash increased, according to the findings reported. Furthermore, the ultimate tensile strength and elongation at break decreased as flyash concentration increased; nevertheless, silanization of flyash improved strength when compared to unmodified flyash at the same concentration. The inclusion of flyash lowered the toughness of the FRP composite in the impact test, while silanization resulted in improved toughness. Surface modification of flyash with coupling agent improved their bonding with polymer resin, resulting in lower damping capability and better strength and toughness.

2.0 Materials and specimen preparation

Fibers are held tightly in place by matrix materials. It protects the fibres against chemical and environmental degradation. Matrix materials with a lower modulus and higher elongation should hold the fibres rigidly. Matrix materials are chosen depending on a variety of factors, including curing time, matrix performance at various temperatures, corrosion, chemical resistance, manufacturing cost, and matrix cost, among others [19].

Lapox L-12 epoxy resin and ambient temperature curing K6 hardener, both from Yuje Enterprises in Bengaluru, were employed as the matrix material. This epoxy matrix was chosen because it has good adhesive qualities, is a medium viscosity excellent thermoset plastic, and is ideal for mechanical and tribological testing. Flyash, an industrial waste product that has been identified as an environmental pollutant, is the reinforcement employed in this project. Many experts have conducted extensive study to recycle flyash by manufacturing usable items as a result of this environmental problem [Hanumantharaya et al. 2019, Rangaswamy et al. 2019 and Rangaswamy, et al. 2020].

The main integrals of flyash are 29.7% of silicon oxide (SiO_2), 10.65 % of aluminium oxide (Al_2O_3), 32.92% of calcium oxide (CaO) and 6.18% of iron oxide (Fe2O3). The minor integrals are sodium carbonate, magnesium oxide (MgO), 0.61% of potassium oxide (K_2O), 9.98% of sulphur trioxide (SO_3)

2.1 Preparation of composite material

Hand lay-up is used to manufacture the epoxy composite with flyash reinforcement. The tensile, compression, and wear test specimens are moulded in Teflon, and the tensile and wear test specimens are shown in Fig.1.

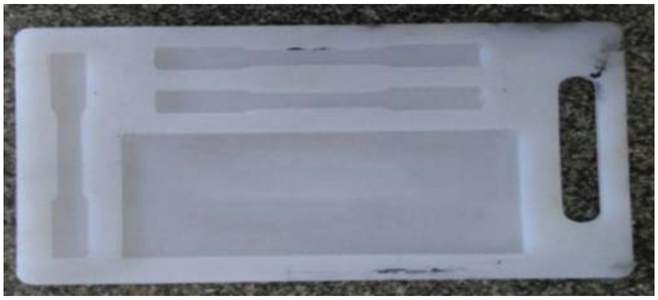

Fig.1: The mould for tensile test and wear test

In a mixing container, add the Lapox L-12 epoxy resin and K-6 hardener in a 100:10 ratio and mix for 1 minute. The weighted reinforcing filler material (flyash) is added to the container and thoroughly mixed for ten minutes. The samples were then poured into the mould after being mixed. The samples were pre-cured for 24 hours at room temperature before being removed from the mould [Hanumantharaya et al. 2020 and Rangaswamy, et al. 2020]. The wear test samples are 100mm × 200mm × 4mm, the tensile test samples are 170mm × 20mm × 4mm, and the compression specimens are diameter 13mm × height 40mm. Figs.2 and 3 show specimen samples from the tensile and compression tests.

The composition of filler materials and epoxy are tabulated in Table 1.

Table 1: Epoxy and filler material composition (vol. %)

Specimen code	Epoxy %	Flyash %
A	95	5
B	90	10
C	85	15

3.0 Results and discussions

3.1 Density

A physical balance was used to determine the mass of the hybrid composites. Three specimens were made in compliance

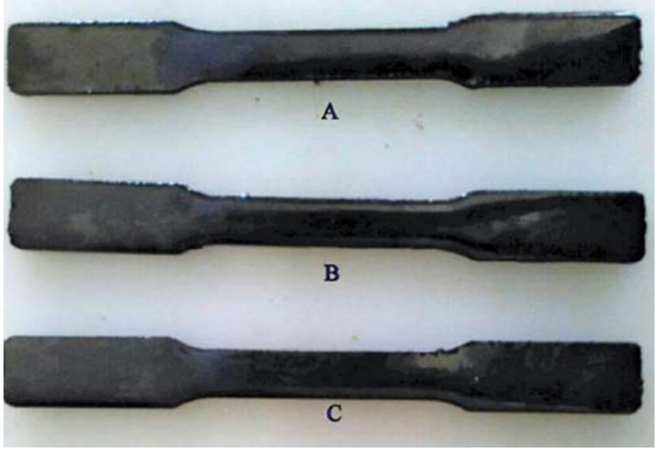

Fig.2: Tensile test specimen

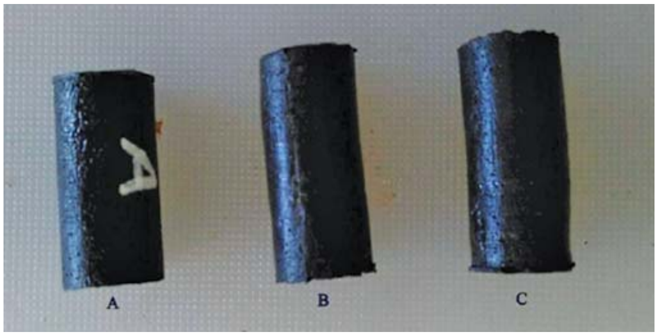

Fig.3: Compression test specimen

Fig.4: Wear test specimens

with ASTM standards. The specimens were balanced on a physical balance, and the results were shown on a computer screen. The density was determined by plugging the numbers into the formula. Density = Mass/volume.

As a result of the specimen compositions, it has been discovered that increasing the amount of filler material composition increases overall density. Table 2 shows the density variations for several composite compositions.

3.2 Hardness test

A Vickers micro hardness testing instrument is used to determine the hardness of the composite specimen. Table 3 shows the hardness test results for various composite specimen samples.

According to the experimental micro hardness data, hardness rises for different specimen samples. When the density of the filler material increases, the hardness of the filler material rises. When the amount of flyash is increased from 5% to 15%, the hardness of the material increases. [Mohammed et al. 2017].

Tensile test

The tensile strength of composite specimens is determined using a universal testing machine. Table 4 shows the results that were achieved.

The tensile test findings of specimens A, B, and C are displayed in Table 4. Tensile strength and failure load increased from 18.16 MPa to 21.48 MPa and failure load increased from 18.16 kN to 21.48 kN when the proportion of flyash was raised from 5% to 10%.

It was also shown that as the proportion of flyash is increased, the tensile stress lowers, and for example, adding 15% flyash reduces the tensile strength from 21.48 Mpa to 17.38 Mpa and the load from 1183.61 N to 1032.25 N. This could be owing to the lack of reinforcement fibre components in the epoxy matrix, since only filler materials are used, resulting in a lower tensile strength [Mohammed et al. 2017].

3.3 Compression Test

The universal testing machine is used to test the composite specimen's compression strength. The acquired data were provided in Table 5.

Table 2: Density of composite specimen samples

Specimen code	Density(g/cm^3)
A	1.58
B	1.66
C	1.75

Table 3: Hardness of composite specimen samples

Specimen code	Hardness
A	16.85
B	21.74
C	34.75

Table 4: Tensile test results for different specimen samples

Specimencode	Max.Tensile Stress (Mpa)	Failure load (N)	Modulus of Elasticity (Mpa)
A	18.16	717.21	2641.54
B	21.48	1183.61	2640.17
C	17.38	1032.25	2926.10

Table 5: Compression test results for different specimen samples

Specimencode	Max. compression stress (Mpa)	Failure load (kN)	Modulus of elasticity (Mpa)
A	50.230	-7.78	785.32
B	61.53	-8.93	1862.73
C	77.38	-12.01	2126.10

Figs.6 and 7 show the results of compression tests for various specimen compositions. Both compression stress and load at peak rise when the proportion of flyash is increased from 5% to 15%. It's possible that the addition of flyash particles is the reason for this, the substance becomes tougher when flyash is added to it [Tang et al 2016], the composite becomes brittle as a result of this; the load is increased to the maximum.

3.4 Tribological test results

A pin-on-disc the tribological test for manufactured composites was performed using DUCOM: TR–20LE–CHM–400 in accordance with the ASTM G 99 standard. [Mahesha et al. 2016]. The counter face was polished with SiC abrasive paper of grade No.1200 before the test, while the specimens were polished with grade No.800 abrasive paper, ensuring proper contact between the specimens and the counter face. Dry sliding wear test was conducted at different applied loads (FN), sliding speeds (VS) and sliding distances (DS).

The dry sliding wear test was conducted using pin-on-disk wear testing machine at different loads (5, 10 and 15N), sliding speeds (100,200, 300rpm) and sliding velocity (0.5, 1 and 1.5m/s)

Material loss (mg)

In the present investigation, the material loss of the produced composites was addressed as a function of applied load, sliding speed and sliding velocity. The material loss of

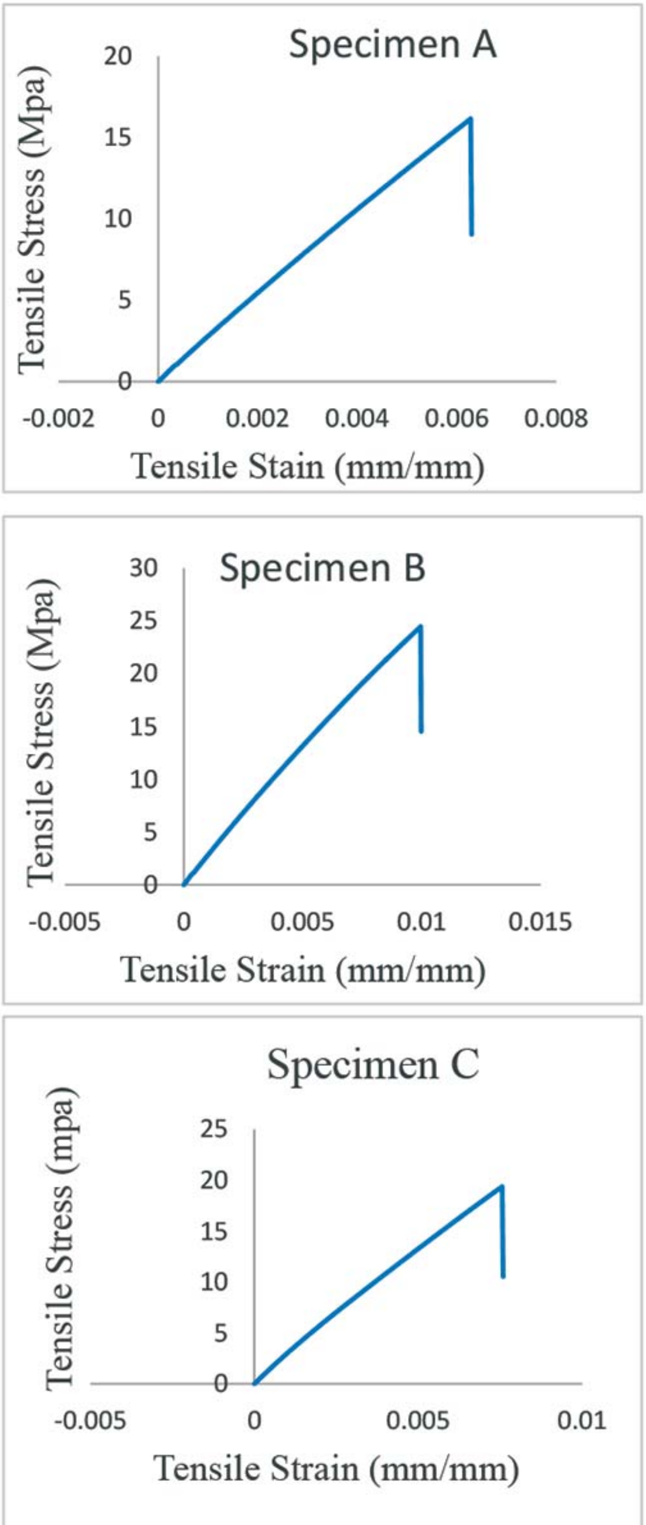

Fig.5: Tensile stress v/s tensile strain of specimen A, B and C

flyash reinforced composites with changing failure load is demonstrated in Fig.7. It was discovered that when the failure load increased, the composites' wear rate began to rise. This can be explained by the fact that higher loading conditions cause the matrix to pulverise [Hanumantharaya, et al. 2018] causing the composite samples to get thoroughly worn-out, resulting in significant material loss.

Effect of normal load on material loss

The graph of material loss vs. load is drawn using a constant distance of 100m and a constant speed of 100 rpm. Fig.7 depicts a material loss vs. load graph for composite specimen samples A, B, and C.

The material loss increases when the load is increased from 5N to 25N, as shown in the graph above. i.e., material loss for specimen A is 0.77 mg at load 5N and 1.33 mg at load 25N. When the load is increased, there is a steady material removal until the load reaches 20N, after which the material removal suddenly rises when the load reaches 25N. For specimen C it is found that material removal decreases from 0.63mg to 0.6mg at load 10N, then it slightly increases to 0.85mg.

When compared to specimens A and B, specimen C shows the least amount of wear. Material removal of Specimen A at

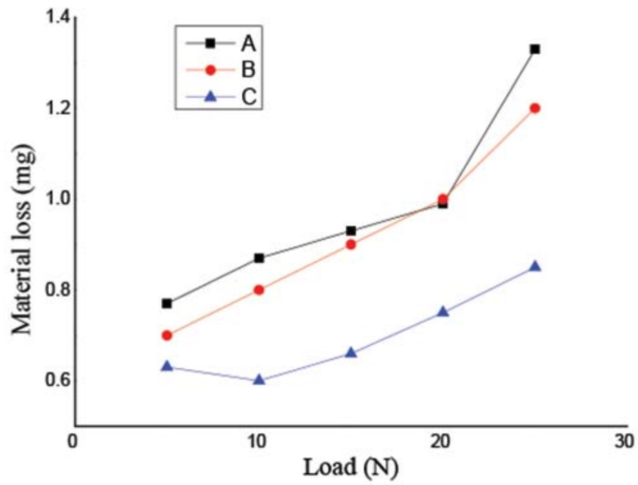

Fig.6: Compression stress v/s compression strain of specimen A, B and C

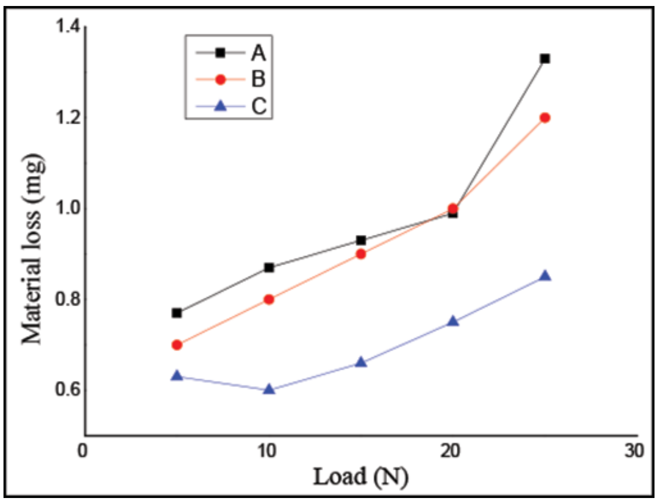

Fig.7: Material loss v/s load

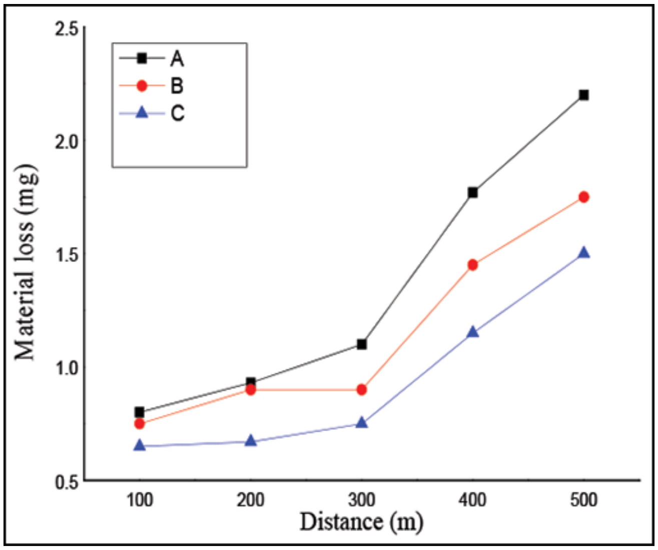

Fig.8: Material loss v/s sliding distance

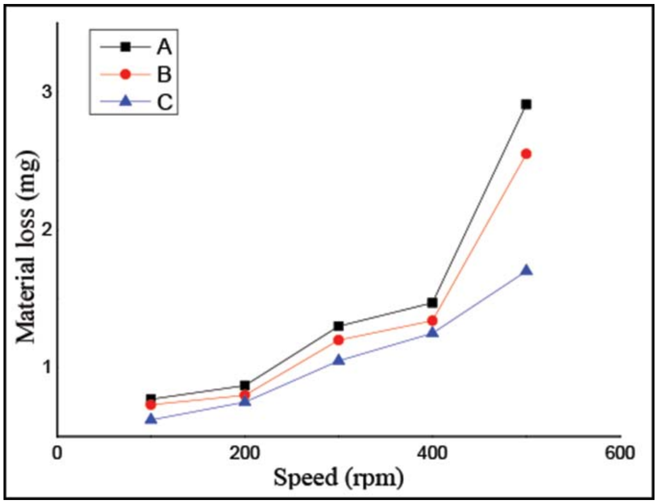

Fig.9: Material loss v/s speed

25N is 1.33mg, Specimen B is 1.2mg, and it is further reduced at specimen C to 0.85mg. The material loss is shown to be reduced when the flyash percentage is increased to 10%. There is a progressive decrease in wear as the percentage of flyash is increased [Gull et al].

Effect of sliding distance on material loss

Material loss v/s distance graph are plotted by considering constant load of 5N and constant speed of 100 rpm. The material loss v/s distance graph for composite specimen samples A, B and C are shown in Fig.5.3 (a). From the above graph it is seen that when abrading distance is increased, material loss found to be increased. i.e. for specimen A, material loss at distance 100m is 0.8mg increased to 2.2mg at distance 500m. It is also found that till 300m distance the material loss slightly increases then there is a sudden rise in material loss. This type of behaviour can be observed for specimen B and specimen C. when percentage of flyash is increased, the material loss is found to be decreased as 2.2mg, 1.75mg and to 1.5mg for specimen A, B and C at distance 500m respectively. The wear of specimen C is found to be low when compared to specimen A and B.

Material loss v/s sliding distance graph are plotted by considering constant load of 5N and speed of 100 rpm. The material loss v/s sliding distance graph for composite specimen samples A, B and C are shown in fig 8. From the above graph it is clear that when abrading distance is increased, material loss found to be increased. [Chairman et al. 2011, Venkatesh B K et al. 2021 and Mohan et al. 2010] i.e. for specimen A, material loss at distance 100m is 0.8mg increased to 2.2mg at distance 500m. It is also found that till 300m distance the material loss slightly increases then there is a sudden rise in material loss. This type of behaviour can be observed for specimen B and specimen C. when percentage of flyash is increased, the material loss is found to be decreased as 2.2mg, 1.75mg and to 1.5mg for specimen A, B and C at distance 500m. The wear of specimen C is found to be low when compared to specimen A and B.

Effect of sliding velocity on material loss

Material loss vs. speed is plotted using a constant load of 10N and a distance of 100m. Fig.9 depicts a material loss vs. speed graph for composite specimen samples A, B, and C. When the speed is increased from 100 rpm to 500 rpm, material loss increases from 0.77mg to 2.91mg for specimen A, 0.73mg to 2.55mg for specimen B, and 0.62mg to 1.7mg for specimen C. It is also discovered that material loss rises gradually until 400rpm, then suddenly increases at 500rpm. This type of behaviour may also be seen in specimens B and C. When the flyash % is increased, the material loss is reduced to 2.91mg, 2.55mg, and 1.7mg for specimens A, B, and C at 500rpm, respectively. The wear of specimen C is found to be low when compared to specimen A and B.

4.0 Conclusions

Based on the mechanical tests and tribological tests following conclusions can be drawn:

- Mechanical tests reveals that when the percentage flyash increased from 5 to 10%, the density, hardness, and compressive strength was found to be increased. And reveals that further increment in flyash percentage leads to decrease in mechanical properties.
- Abrasive wears are found to minimum in lower loads, distances and speeds. There is a much increase in abrasive wear at high loads, distances and speeds.
- Results shows that when the percentage flyash is increased, there is a decrease in wear volume loss
- From the conventional test results the optimum values obtained for loads is 15N, speed is 300rpm and distance is 300m

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