Erosion behaviour of graphitic carbon nitride (g-C3N4) reinforced epoxy composites

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Abstract. This paper deals with the manufacture and examination of tribological properties of epoxy composites reinforced with graphitic carbon nitride (g-C3N4) nanopowder. The composites had prepared with five different proportions of g-C3N4 nanopowder using a hand layup process. Comparison of tribological properties has made between the composites laid at different percentages of g-C3N4 in epoxy. The results showed the maximum erosion resistance of g-C3N4 particulate polymer matrix for 3% filler content. Also, by Scanning Electron Microscope (SEM), the erosion morphology analysis is done on the internal structures of the specimen.

1. Introduction
The graphitic carbon nitride (g-C3N4) has emerged as a polymeric photocatalyst recently [1], is an inorganic material. Graphitic carbon nitride has a great potential to resist indentation due to its ultra-hard property [2]. Unlike other conventional organic materials, g-C3N4 shows chemical resistance and scratch resistance. The aim of this current research is to determine the erosion rate of composites of different weight percentages of filler material (g-C3N4) in epoxy. Before the potential of g-C3N4 can be fully realized, a comprehensive analysis of fillers and their role in adapting the tribological properties of polymer composites is important.

Epoxy resins have extensive industrial applications such as in aircraft, automotive parts, electronic devices, electrical machines, protective coatings etc. [3] Epoxy resin belongs to thermoset polymer. Epoxy resins have a number of advantages over metals including high strength, durability, chemical resistance, thermal stability, and ease of production [3-5].

Though the composites of pure epoxy have poor tribological properties, the addition of proper fillers can enhance their performance [6]. The erosion resistance behaviour of polymer composites has a great prominence, mostly while selecting the substitute materials. A progressive permanent failure of the surface of any material upon the impact of solid particle is defined as erosion wear. The losses of material due to erosion wear will increase the cost of maintenance and repair. Therefore, a major attention is required in case of solid particle erosion as this is responsible for progressive and permanent damage of components in many dynamic applications.

A wide range of filler materials is available today to increase the resistance to erosion in polymer composites such as Al2O3 [7, 8], SiO2 [9], CaCO3 [10, 11] etc. Still, a better understanding is
required to incorporate the nanofillers into composites instead of conventional fillers in the area of polymer composites [12].

The objective of the present work is to develop the composite materials based on inorganic nanofillers, in this case, g-C3N4 nanofiller at different weight percentages in epoxy. The purpose is hence to highlight the impact of the erosion resistance of epoxy composites incorporated with g-C3N4. The results showed that composites with 3wt% of g-C3N4 particulate nanofiller have better erosion resistance relatively with the other composites. SEM analysis is also made on the eroded surface of the specimen and the results were presented.

2. Experimental details and Materials

2.1 Raw Materials
Raw materials for composite
1. g-C3N4(Graphitic carbon nitride)
2. Hardener, HY 951
3. Epoxy resin, LY 556

2.2 Preparation of composite
The actual density of g-C3N4 nanopowder is 2.76 g/cm³. Five different samples (1%, 2%, 3%, 4%, and 5%) of g-C3N4 composites were prepared using epoxy by hand layup method. The average size of g-C3N4 particles is in the range of 190 nm to 21nm. The epoxy to hardener ratio is 10:1. The mixture (filler and epoxy) is stirred with a mechanical stirrer in a container to attain a uniform solution. The mixture is transferred to a mould of dimensions 200x180x4 mm. A mould release sheet was used to easily remove the composite from the mould. A mould releasing liquid is sprayed on the mould wall which facilitates easy removal of the composite. Dead weight was placed on each composite while curing for 30 h before they have collected from the mould. The composites were removed from the mould to cut for required dimensions to conduct experimental test according to ASTM G76 standards.

2.2.1 Density and voids of the specimen. Using the Archimedes principle, the actual density of the composites is determined and void percentage in the composite is calculated according to ASTM D-2734-70 standards. The density and void percentages of the specimen for different composition of g-C3N4 in epoxy is given in table 1.

| Filler % | Density actual (gm/cm³) | Density theoretical (gm/cm³) | Voids in the composite (%) |
|----------|-------------------------|------------------------------|-----------------------------|
| 1        | 1.154                   | 1.166                        | 1.02                        |
| 2        | 1.165                   | 1.18                         | 1.27                        |
| 3        | 1.180                   | 1.2                          | 1.66                        |
| 4        | 1.201                   | 1.215                        | 1.15                        |
| 5        | 1.213                   | 1.23                         | 1.38                        |

2.1. experimental conditions
Table 2 shows the experimental factors for air jet erosion test and figure 1 show the experimental set up of air jet erosion test. The erosion test conducted according to ASTM G76 standards.
Table 2: Test parameters for the erosion

| Parameter                              | Value                  |
|----------------------------------------|------------------------|
| Erodent material                       | Silica Sand            |
| Size of the erodent (µm)               | 200±50                 |
| Shape of erodent                       | Angular                |
| Silica particles hardness (HV)          | 1420±50                |
| Sand Impact angle (α°)                 | 30, 45, 60 and 90      |
| Impact velocity (m/s)                  | 119.2                  |
| The sample to nozzle distance (mm)     | 10                     |
| Feed rate of sand (gm/min)             | 2±0.02                 |
| Testing temperature                    | Room temperature       |

3. RESULTS AND DISCUSSION

3.1 Density and Void Content of the specimen
The density of g-C3N4 reinforced composites increases with filler content when related to a polymer which is given in Table 1. The reason is that the density of filler material, i.e., 2.76 g/cm³ is relatively higher than epoxy. It is observed in present composites that an increase in filler percentage up to 5 wt% increases the void percentage.

3.2 Wear Behaviour of g-C3N4
Erosion wear behavior of g-C3N4 particulate composites with different filler to epoxy ratios at an impact velocity of 119.2 m/s is presented. From figure 2, it is shown that the sand impact angle considerably affected the rate of erosion. From 30° to 45° sand impact angles the maximum erosion wear occurred in the composites irrespective of the percentage of filler in Epoxy. If any material has a maximum erosion at 0° to 45° impact angles shows a ductile behavior [13,14], and if it has maximum erosion rate between 60° to 90° shows a brittle nature [13,14]. From the graphs, it is evident that these g-C3N4/Epoxy composites showed a maximum erosion from 45° to 60° which concludes that the composites are semi-ductile in nature. The rate of erosion decreases with filler percentage up to 3 wt% and from there onwards a gradual rise in erosion rate is noticed. The rise in erosion rate after 3% is due to a weak bond between filler and epoxy.
Figure 2. Impact angle vs. erosion rate

Figure 2 shows the rate of erosion for the composites reinforced with g-C3N4 in different percentages. The erosion rate is measured in gm/gm and the test is done under a sand impact velocity of 119.2 m/s. The erosion rate of specimens is noted for various impact angles of the sand jet. From the figure 2, it is observed that the highest erosion was occurred for the composite having 1% of g-C3N4 at 45° impact angle and the lowest erosion was occurred for the composite having 3% of g-C3N4 and at 90° impact angle.

Figure 3. Erosion rate vs. percentage of g-C3N4 in Epoxy

Figure 3 shows the erosion rate of composite for various percentages of g-C3N4 in Epoxy. From the graph, irrespective of the impact angle, the lowest erosion rate is recorded for 3% of the g-C3N4 reinforced composite. From figure 2 and figure 3 it is clearly evident that the erosion rate decreases with the addition of g-C3N4 up to 3% and after 3%, with the addition of filler (g-C3N4) the erosion is steadily increasing. It is due to the excessive percentage of filler material may weaken the interaction between epoxy and filler.

3.1. Erosion Surface Morphology

The surface morphology of the eroded part of the specimen is shown in figure 4, which is reinforced with 1% and 3% of g-C3N4 in epoxy. The composites were investigated by a scanning electron microscope at 10 kV. From the morphology of the composite, it is observed that compared to 1% of g-
C3N4 in epoxy, the matrix and filler bonding is relatively better in 3% of g-C3N4 in epoxy, so the erosion is less. In figure 4 (a), chipping out occurred easily due to impingement of sand particles confirms a weak bond between the matrix and filler.

![Figure 4. SEM images for eroded surfaces of a) 1% of g-C3N4 in Epoxy and b) 3% of g-C3N4 in Epoxy](image)

**Conclusion**

Density and void percentage of g-C3N4/epoxy particulate composites increase upon the increase of filler percentage into the polymer. The highest erosion rate occurred between 45° to 60° impact angles for the composites, which confirms the material have semi-ductile behavior. The rate of erosion of the composites decreases with the addition of g-C3N4 up to 3% and after 3% with the addition of filler (g-C3N4) the erosion is steadily increasing. It is due to the excessive percentage of filler material may weaken the interaction between epoxy and filler.

**References**

[1] Qian Li et al 2014 High-Efficiency Photocatalysis for Pollutant Degradation with MoS2/C3N4 Heterostructures. *Langmuir*. 30 (29), 8965-8972
[2] Liu A Y, Cohen M L 1989 *Science*. 245 841–842
[3] Bilyeu, Brostow W, Menard K P 1999 Epoxy thermosets and their applications I: chemical structures and Applications. *J Mater Ed.* 21 281–286
[4] Bilyeu B, W. Brostow, K.P. Menard. 2000 Epoxy thermosets and their applications II.Thermal analyses. *J Mater Ed.* 22 107–130
[5] Bilyeu B, Brostow W, Menard K P 2001 Determination of volume changes during cure via void elimination and shrinkage of an epoxy prepreg using a quartz dilatometry cell. *Polimery.* 46 799–802
[6] Kumar V, Sinha S K, Agarwal A K 2015 Tribological studies of epoxy and its composite coatings on steel in dry and lubricated sliding. *Tribol Mater Surf Interface.* 9 144–153
[7] Mahapatra S S, Patnaik A 2009 Study on mechanical and erosion wear behavior of hybrid composites using Taguchi experimental design. *Mater Des.* 30(8):2791–2801
[8] Biswas S, Debnath K 2011 Effect of alumina particulate on erosion wear behaviour of short bamboo fiber reinforced epoxy composites. In: 11th UNESCO/IUPAC conference workshop and conference on functional polymeric materials & composites.Stellenbosch, South Africa
[9] Bagci M et al 2011 Effects of silicon oxide filler material and fibre orientation on erosive
wear of GF/EP composites. *World Acad Sci Eng Technol* 5:78

[10] Yilmaz MG *et al* 2008 Study of the strength and erosive behaviour of CaCO3/glass fibre reinforced polyester composite. *Express Polym Lett* 2:890–895

[11] Panchal M, Raghavendra G, MO Prakash, Ojha S 2018 Effects of environmental conditions on erosion wear of eggshell particulate epoxy composites. *Silicon*. 10 (2), 627-634

[12] Suresha, Ravikumar B, Venkataramadddy B N, Jayaraju T 2010 Role of micro/nanofillers on mechanical and tribological properties of polyamide66/polypropylene composites. *Mater. Design*. Vol. 31, pp. 1993-2000

[13] Devi L U, Bhagawan S S, Thomas S 1997 Mechanical properties of pineapple leaf fiber-reinforced polyester composites. *Journal of Applied Polymer Science*. vol. 64, no. 9, pp. 1739–1748

[14] Rahman M M *et al* 2013 Effect of NH2-MWCNTs on crosslink density of epoxy matrix and ILSS properties of e-glass/epoxy composites. *Composite Structures*. vol. 95, pp. 213–221