Kevlar Reinforced Polymer Matrix Composite for Structural Application

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Abstract: In any structural systems, the material properties play a major role in their behavior when subjected to different loadings. The present work focuses on the development of novel hybrid polymer based composite in which Kevlar and Kevlar with graphene was used as filler material in L-12 epoxy resin to enhance mechanical properties of Kevlar reinforced polymer composite. Kevlar because of its distinguished mechanical properties such as high strength to weight ratio and resistance to impact loading has wide variety of applications. Reinforcement at varied proportions in the range of 0.1 to 0.4 wt % has been used to determine the optimum performance in-terms of load bearing capacity for the modified composite. Further the performance of hybrid composite with varied Kevlar dosage from 0.1 to 0.4wt% and a constant dosage of 0.3wt% of graphene has been investigated. The results of modified beams are compared with unmodified beams to check the efficacy of the reinforcement for the intended application. SEM and EDX were conducted to determine the dispersion state of Kevlar pulp in the holding matrix, behaviour of Kevlar with graphene in the matrix and to study the effect of impurities on the mechanical properties under study. The Kevlar reinforcement showed appreciable increase in mechanical properties.

Key words: Kevlar, epoxy, hybrid, composite, SEM, EDX, Kevlar pulp.

1. Introduction

A composite is a heterogeneous material consisting of two or more distinct materials bonded together which has better properties than any of its constituents. The properties of these composites vary considerably from point to point in the material depending upon the material phase in which the point is located. The base matrix can be of three types that are metal matrix, ceramic matrix and polymer matrix and reinforcement are mainly of two types fibers and particulates, the combination of these are limitless and have infinite applications. Composite materials used for structural applications are best classified as high performance systems and are made of synthetic materials that have high strength-to-weight ratios, but often demands controlled manufacturing environments for optimum performance. Further, a composite can be tailor made to suit specific mechanical needs for any given project, which in turn achieves far better efficiency towards end applications. The most common fibers used in recent times are glass fibers, carbon fibers, aramid fibers and natural fibers, next to which are the nylon-and polyester fibers.

Short fiber reinforced epoxy resin composites possess significant mechanical properties they have various applications in fields such as chemical engineering, sporting goods automotive industry,
aerospace industry, defense industry and friction materials. Kevlar pulp is a kind of short fiber which is tough resistant to impact loading and has high strength to weight ratio.

2. Literature review

Simona Matei et al [1] researched on obtaining characteristics and physical-mechanical properties of the composites with short fibers reinforced epoxy matrix. Fibers used in the study are glass fiber and kevlar fiber. They observed that glass fiber reinforced composites have much better properties than compared to kevlar reinforced composites.

Yahaya et al [4] studied the mechanical properties kenaf-kevlar fiber reinforced composites and concluded that Kevlar fiber reinforced composite has higher flexural and tensile properties than kenaf reinforced composites.

K.K.Herbert et al[5] investigated the mechanical properties which included tensile, compressive and flexural strength and modulus of Kevlar-49 thermoplastic based composites were experimentally obtained and compared with the theoretical predictions. They observed that theoretical values are higher than experimentally determined values.

Prashanth S et al[9] studied the various properties of different synthetic fibers such as glass fiber, carbon fiber and kevlar fiber which also includes the study of the respective fiber reinforced composites. The study concluded that Kevlar is more resistant to fatigue, while carbon and glass are not totally sensitive to fatigue. Kevlar has strong abrasion resistance, while carbon and glass fibers are less resistant to abrasion. Carbon fiber is highly stable and is relatively non-sensitive to chemical degradation.

3. Materials and Methodology

3.1 Matrix Material

Base Matrix for holding the reinforcement materials are varied in nature akin to metals, ceramics and polymers. Epoxy resin was purposely selected since its exclusive nature of outstanding bonding to a vivid fiber diversity, besides providing the modified samples superior mechanical and electrical properties at high temperatures. All these advantages make L-12 as a suitable candidate for the base matrix in the present research study. The L-12 epoxy resin (Figure 1) and the corresponding hardener K-6 were obtained from Atul India Ltd. Table 1 shows the significant properties of epoxy.

Table 1: Properties of Epoxy resin L-12

| Material                  | Epoxy resin |
|---------------------------|-------------|
| Trade name                | Lapox, L-12 |
| Chemical name             | Diegycidyl Ether of Bisphenol A (DGEBA) |
| Epoxide equivalent        | 182-192     |
| Density, kg/m³            | 1162        |
Supplier | Atul industries limited, Gujarat, India
Parts by weight | 100

| Material | Hardener |
|----------|----------|
| Trade name | K-6 |
| Chemical name | Triethylene Tetro amine (TETA) |
| Epoxide equivalent | - |
| Density, kg/m$^3$ | 954 |
| Supplier | Atul industries limited, Gujarat, India |
| Parts by weight | 10 |

**Table 2: Properties of Hardener K-6**

3.2 Filler Material-1: Kevlar

There are different grades of Kevlar available. For this study Kevlar 29 pulp is used and the properties of these are listed in the following table.

**Table 3: Properties of different grades of Kevlar pulp**

| Fiber type | Density, (g/cm$^3$) | Tensile Strength, MPa | Modulus, GPa | % Elongation |
|------------|---------------------|-----------------------|--------------|-------------|
| Kevlar 149 | 1.47                | 3450                  | 179          | 1.5         |
| Kevlar 29  | 1.44                | 2920                  | 83           | 3.5         |
| Kevlar 49  | 1.44                | 3600                  | 124          | 2.9         |

![Figure 2. Kevlar 29 pulp](image)

3.3 Filler Material-2: Graphene

Graphene is chosen as the nano filler due to its excellent mechanical properties. Graphene with 95wt% purity that is industrial grade which is used to produce composites. The following table shows the properties of graphene.

**Table 4: Properties of the Graphene used for study**

| Specifications | Dimensions |
|----------------|------------|
| Diameter       | 10–20 (micron) |
| Purity         | 96.99%     |
| Surface area   | 323-600m$^2$/g |
| Bulk density   | 0.231g/cc  |
| Fibre thickness| 3-6nm      |
| Oxygen content | <4%        |
3.4 Methodology
For the plane Kevlar samples Kevlar pulp is mixed with 10-40 ml Ethanol and sonicated for 10 minutes in probe sonicator to help in uniform distribution of Kevlar pulp in the matrix. The sonicated mixture is added to matrix and again sonicated for 20 minutes at 80°C to evaporate all the alcohol content in the mixture. It is cooled to room temperature and 10wt% of Hardener is added and sample is poured into the mould.

For the samples with graphene as nano filler Kevlar pulp is mixed with 10-40 ml Ethanol and sonicated for 10 minutes in probe sonicator to help in uniform distribution of Kevlar pulp in the matrix. The sonicated mixture is added to a mixture of matrix and 0.3wt% graphene and sonicated for 20 minutes at 80°C to evaporate all the alcohol content in the mixture. It is cooled to room temperature and 10wt% of Hardener is added and sample is poured into the mould.

![Figure 3](image-url)

**Figure 3.** Procedure followed for conduction of experiment

**Table 5:** Details of the test specimen.

| Sample number | Sample code | Composition (wt %) |
|---------------|-------------|--------------------|
|               |             | Kevlar | Graphene |
| 1             | PE          | -      | -       |
| 2             | A1          | 0.1    | -       |
| 3             | A2          | 0.2    | -       |
| 4             | A3          | 0.3    | -       |
| 5             | A4          | 0.4    | -       |
| 6             | S1          | 0.1    | 0.3     |
| 7             | S2          | 0.2    | 0.3     |
| 8             | S3          | 0.3    | 0.3     |
| 9             | S4          | 0.4    | 0.3     |
4. Results and Discussion

4.1 Tensile test:
Tensile test is carried out to determine the force required to break the composite specimen and to know the amount of extension of the same at the breaking force. This data helps to determine the yield strength and the modulus of elasticity of the test specimen. Tensile test was performed on the composites developed using UTM as shown in Figure 4, with specimen of the size 250 mm x 25 mm x 2.5 mm used. To achieve experimental precision, ASTM D2344M was followed to attain the statistical accuracy of the tensile test of the polymer beams tested. The specimen size and sort of the test conducted is shown in Table 6. Specimens were approximately rectangular shaped based on the ASTM norms for random dispersed and disoriented fillers in the holding matrix condition as shown in Figure 5.

| Characteristics of specimen | Particulars                          |
|-----------------------------|--------------------------------------|
| Size                        | 250(mm) x 25(mm) x 2.5(mm)          |
| Epoxy resin                 | L-12                                 |
| Hardener                    | K-6                                  |
| Kevlar                      | Untreated                            |
| Amount of graphene          | 0, 0.3 by Weight of epoxy            |

Figure 4: UTM machine
Figure 5. Tensile and bending test samples

Table 7: Tensile test results:

| Sample | Ultimate load (KN) | Yield strength (MPa) | Modulus of elasticity (E) (GPa) |
|--------|---------------------|----------------------|---------------------------------|
| PE     | 1.5                 | 24.00                | 3.75                            |
| A1     | 2.51                | 40.16                | 1.5896                          |
| A2     | 2.86                | 45.76                | 1.8498                          |
| A3     | 3.26                | 52.16                | 2.6752                          |
| A4     | 1.76                | 28.16                | 2.3416                          |
| S1     | 2.78                | 44.48                | 2.817                           |
| S2     | 2.62                | 41.92                | 1.305                           |
| S3     | 2.95                | 47.2                 | 2.822                           |
| S4     | 0.68                | 10.88                | 1.590                           |

Figure 6. Load and deflection graph for bending test of samples
Figure 7. Tensile strength of composites

The graph shows that for the modified beams elongation has increased up to 0.2 wt% dosage and decreased with further increase in kevlar pulp dosage. For 0.2 wt% dosage the deflection is highest that is 4.7 mm which indicates increase in ductility but load carrying capacity of the sample with 0.3 wt% dosage is higher than 0.2 wt% and the ductility is comparable. For the hybrid composites deflection is highest in the 0.2 wt% dosage which is 6.1 mm and it is maximum. We can say that ductility has increased but load carrying capacity has decreased when compared to Kevlar pulp reinforced composites. The load carrying capacity is maximum for sample A3 and it has increased by 113% compared to plane polymer. The results show that the tensile strength increases with increase in Kevlar pulp dosage only up to 0.3 wt% and decreases with further increase. Tensile strength is maximum for the dosage of 0.3 wt % of Kevlar pulp which is 52.16 MPa. It has increased by 117% when compared to plane polymer. When 0.3 wt% of graphene was added with varying dosage of Kevlar pulp from 0.1 wt% to 0.4 wt% the tensile strength shows no trend but the maximum among hybrid composite is 47.2 MPa which is less compared to Kevlar pulp reinforced composite. This may be due to improper distribution and poor interfacial adhesion between Kevlar and graphene.

4.2 Bending test

This test determines the flexural properties of the test specimen. Three point bending test was performed on the composites developed using bending test setup as shown in Fig. 8 with specimen of the size 40 mm x 12 mm x 6 mm used.

Table 8: Specimen characteristics of three-point bending test

| Characteristics of specimen | Particulars          |
|-----------------------------|----------------------|
| Size                        | 40(mm) x 12(mm) x 6(mm) |
| Epoxy resin                 | L-12                 |
| Hardener                    | K-6                  |
Table 9: Bending test results

| Sample | Maximum load (kN) | Maximum Deflection (mm) | Flexural strength (MPa) |
|--------|-------------------|-------------------------|------------------------|
| PE     | 0.5               | 3.9                     | 69.44                  |
| A1     | 0.70              | 2.56                    | 97.22                  |
| A2     | 0.55              | 1.64                    | 76.38                  |
| A3     | 0.74              | 2.31                    | 102.77                 |
| A4     | 0.56              | 0.86                    | 77.77                  |
| S1     | 0.54              | 1.29                    | 75                     |
| S2     | 0.50              | 1.25                    | 69.44                  |
| S3     | 0.6               | 1.93                    | 83.33                  |
| S4     | 0.38              | 1.31                    | 52.77                  |
Figure 9. Load and deflection graph for bending test of samples

Figure 10. Flexural Strength of composites
The graph indicates that flexure strength is maximum for 0.3wt% of plain Kevlar pulp which is 102.77MPa. Further increase in dosage percentage decreases the flexural strength. The flexural strength has increased by 48% for sample A3 which is maximum among all the samples and for the hybrid composites it has increased by 20%, which is less when compared to Kevlar pulp reinforced composites. This maybe due to poor adhesion of Kevlar and graphene.

4.3 Microscopic images

Figure 11. 0.1wt% kevlar

Figure 12. 0.2wt% Kevlar

Figure 13. 0.3wt% kevlar

Figure 14. 0.4wt% Kevlar

Figure 15. 0.1wt% kevlar + 0.3wt% graphene

Figure 16. 0.2wt% kevlar + 0.3wt% graphene

Figure 17. 0.3wt% kevlar + 0.3wt% graphene

Figure 18. 0.4wt% kevlar + 0.3wt% graphene
Microscopic study is done to know the distribution of the fillers in the matrix. These images show that there is uniform distribution of the filler materials into the matrix.

4.3 Thermal gravimetric analysis (TGA)

![Figure 19. TGA of graphene reinforced composites](image)

TGA of samples is conducted up to 700°C with rate of change of temperature 10°C. TGA of the samples with graphene is shown above which indicates that there is 6.446% of volatile content, 80.90% of polymer (L12 and K6) and 12.654% is the remaining ash. At 104.91°C the volatile content starts to evaporate and completely evaporates at 165.54°C, losing up to 6.445% of its weight. The remaining sample is stable up to 330.38°C and begins decomposing thereafter. The sample completely decomposes and burns at 407.69°C losing up to 80.90% of its total weight. All the samples are stable up to 330°C.
4.4 Fourier Transform Infrared Spectroscopy (FT-IR)

The wave number corresponding to the most noticeable broad peak is 3435.75 which corresponds to stretching of O-H intermolecular bond which is present in alcohol, epoxy. The next significant peak is 1607.44 which corresponds to bending of amine bond which is present in Kevlar. The next peak is 1566.2 which corresponds to stretching of cyclic alkene bond which is present in Kevlar and graphene. This confirms that the sample composition has not changed and also the absence of impurities.

5. Conclusion:
- Tensile strength is maximum for 0.3wt% of plain Kevlar pulp which is 52.16MPa.
- The incorporation of Kevlar pulp into epoxy has increased the tensile strength by 117% and load carrying capacity by 113% for sample A3 compared to plane polymer.
- The strength of the hybrid composite which consists of Kevlar and graphene as reinforcements has increased considerably by 97% but it is less compared to modified beams. This shows that strength has increased and load carrying capacity of the material has also increased.
- Flexure strength is maximum for 0.3wt% of plain Kevlar pulp which is 102.77MPa.
- The flexural strength has increased by 48% for sample A3 which is maximum among all the samples and for the hybrid composites it has increases by 20%.
- Spectroscopic analysis such as FTIR and thermal analysis such as TGA were conducted to study the micro structural and polymer behavior to thermal degradation, which indicated that the samples are stable up to 330°C.
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