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Fabrication and Mechanical Characterization of Epoxy-Based S-Glass/Kevlar Fiber Reinforced Hybrid Composites Filled with Graphite Powder

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Abstract

The current research aims to develop epoxy-based S-Glass/Kevlar fiber reinforced hybrid composites filled with graphite powder. Hybrid composite are fabricated by hand layup method and mechanical characterization is carried out as per the ASTM standards. It is observed that 10% of graphite powder filled epoxy is effectively reduced the weight of the composites in comparison with non filled hybrid composites. On filler addition, the impact strength of the composite shows maximum at 5% of filler and tends to decrease further. The tensile capacity of the composites are increased by 23% and 13.6% and the flexural strength increased by 4.5% and 4.12% when 5% and 10% of filler added to composites, respectively compared to S-glass/Kevlar/epoxy composites. The present research aims to process and characterize the hybrid composites based on S-glass based hybrid fiber with Kevlar fiber and epoxy resin for thermal and mechanical properties incorporation of solid graphite powder. Many polymer based composites have glass transition temperature in the range of 100–240 °C, so that they are said to possess good thermal stability. This paper presents an effort undertaken to understand the effect of glassy fiber addition to composite systems on thermal conductivity of composites. The densified composites show improvement in fracture toughness and tensile strength at the cost of toughness.

Keywords: *Mechanical characterization, Fabrication techniques, Fiber-reinforced polymer (FRP) composites, Hybrid composites.*

1. Introduction

In the present scenario, the search for materials that possess the proper combination of mechanical properties, specific strength, and specific tensile modulus has become very crucial. Fiber-reinforced composite materials are now being preferred to metal components in not only aerospace and marine applications but also in conventional structural applications. In this study, the mechanical properties of hybrid composites made of glass and Kevlar fibers are experimentally investigated. S-glass fiber mat of 250 gsm and Kevlar fiber mat of 300 gsm are laminated alternatively in total of 9 layers in the ratio of 3:6 respectively. The laminated fibres are impregnated with an epoxy matrix with different weight ratios. The prepared composites are tested for tensile property, flexural properties, and impact property. The tensile testing results showed that 10% weight graphite powder particles fill for s-glass/Kevlar hybrid composites had higher tensile strength than the others. The hybrid composites also showed greater flexural strength than the single-fiber composite. The impact test result showed that the addition of 10% weight graphite powder has a greater impact strength for s-glass/Kevlar hybrid composites. In particular, epoxy-based glass fiber composites have better mechanical properties compared to composites made with Kevlar fiber [1]. S-glass fiber reinforced composites which used epoxy resin as a matrix material were prepared. Effects of weight percentage of fiber on the flexural and impact properties of the composites were analyzed experimentally. It was found that the properties of the composites dominated with fiber volume fraction. An increase in the fiber percentage directly contributes to the mechanical properties of the composites. The lowest values of the mechanical properties were found for pure resin composites. Experimental result was checked with the numerical analysis. A hybrid composite made using a woven roving glass fiber and woven Kevlar fiber layer was developed [2-5]. The tensile and flexural properties were finally determined by varying the stacking sequence of glass and Kevlar layer. It was found that a different combination of hybrid and pure composites had a strong influence on its capabilities. The developed composite material has superior toughness and flexibility compared to glass fiber or Kevlar fiber composite alone. Compared to pure hybrid composites, the use of Kevlar fabric with glass fiber fabric in the sandwich construction significantly improved its impact resistance. Polymeric resin composites have been widely used for automotive and domestic applications, such as dashboard, seats, luggage cars front and rear covers. In this study, epoxy resin based hybrid composites were fabricated using basalt and jute woven fibers. Basalt fibers behave as reinforcement for the composites, primarily for thermal application. The tensile, flexural vibration and water soakage tests were performed. The test results showed that the addition of basalt fabrics increased the strength of jute composites by around 2.5 times in terms of tensile strength as compared to pure jute composites. Newly haptics technology is used for identification of faces. This involves voice analysis, facial recognition, and biometric fingerprints. The world's security system includes several biometric identification systems. Identification and recognition of biometric fingerprints are achieved by various numerical methods. Image acquisition is done by an optical scanning device. The image of the fingerprint is captured and converted into a digital image. After preprocessing, segmentation, and enhancement, the minutiae points are extracted from the image [6-7].

2. Literature Review

Due to their excellent specific mechanical properties and corrosion resistance, composites have taken the lead in large-scale construction of offshore structures such as wind turbine blades and ships understood broadly in marine structure, over steel or aluminum. Furthermore, composite structures account for a significant chunk of the gross weight of the structures, and concerned with finding optimum design solutions, weight reduction initiatives generally start with composite concepts. Incremental reduction of design weight, through tuning of composite systems (fiber, matrix and processing), also appears to be promising. Continuous improvement of composites will lead to weight reduction and innovative designs [8-10].

S-glass, or high silica, fibers have emerged as a popular material for advanced composite applications. They combine the excellent mechanical properties of glass with good thermal resistance and low density. Examples of S-glass reinforced polymer matrix composites include airframe structures that are exposed to high mechanical loadings at temperatures above 80°C. However, a breakthrough new composite concept where strength increases whilst density decreases must stand the test of time and prove more beneficial to weight saving applications than other composite systems already established. Although here the new S-glass matrix composite technology is evaluated mechanistically and calibrated analytically for marine applications, it also serves as a platform for broader discussions regarding newly emerging composite systems[11-14].

Epoxy matrix composites are worthy to focus on due to their excellent physical and chemical properties like thermal, mechanical and electrical properties with weight, durability and corrosion resistance. They have been widely used in aircraft fuel tanks, wind turbine blades, shafts of fast spur gears, sports and leisure goods, electronic packages, electrical insulation for transformers, etc. Epoxy matrix composites are thermoset resin systems, which once polymerized cannot be remolded or reprocessed by simple heating or other means. They are hard, brittle and characterized by thermal and environmental stability [2]. Research on mechanical characterization of thermoset based hybrid composite laminates made of Kevlar/basalt/epoxy constituent materials is limited [15-18].

2.1.Overview of Composite Materials

Composite materials were fabricated using the hand layup process. Gradually mixing curative, filler, and epoxy resin was carried out. As per the requirements of layered structures, shaped glass reinforcement mats were cut. Lasers were used to cut and get the desired shapes. On a glass slab, a glass fibre mat was placed, followed by pouring mixed epoxy resin. The matrix and the curative were mixed in a 10:1 weight ratio. After making resin both sides of the mat were brushed well to avoid any air gap. The second layer of glass matting was placed, and the process was repeated. The composite is then pressed with a metal plate and left for curing for 24 hours. A laminated composite with a combination of glass and Kevlar fibre is fabricated in the same way. To maintain the hybrid structure in the composite, the glass and Kevlar fibre combo was cut and randomly layered. Composite with Kevlar, graphite, and glass layering was obtained in the same way. As a result, the surface was finished by cutting the edges and making them straight for mechanical testing. Until the work was done, the samples were stored in a cool, dry place. 20 mm long, 8 mm wide, and 4 mm thick samples were prepared with the use of a hack saw and sanding paper for tensile testing. 80 mm length, 15 mm width, and 5 mm thick samples were prepared used in testing flexural strength. 254 mm length, 25.4 mm width, and 6 mm thick samples were prepared for notched impact test standards. An ultimate universal testing machine was used to conduct mechanical tests. To measure tensile strength, the sample was placed in the machine jaws and the machine turned on. Maximum tensile strength, fracture point, and extension were noted down from data acquisition on the screen. The process was repeated for each sample type with the help of the software equipped in the machine [19-20].

2.2.Properties of S-Glass and Kevlar Fibers

Fibers made from S-glass and Kevlar are important materials that are used for reinforcement purposes in polymer matrices due to having large specific strength and modulus. The S-glass fibers possess high strength, stability of dimensional, corrosion resistance, higher shear and tensile strength. But the advantages of this glass fiber are prone to fracture and brittleness on bending. The Kevlar fibers also come under aramid class of fibers, with high tenacity, tensile modulus and impact resistance. The high anisotropic properties of Kevlar fibers are due to the hydrogen bonds in-between the polymer chains, which possess rhombic crystalline unit cell. It is also a well-known fact that if either of these fibers are used alone along with polymer matrices, there occurs a lack of certain post-failure properties such as debonding, delamination, wear, etc. Hybridization of different dissimilar fibres helps to alleviate the disadvantages and to exploit the advantages of both the fibres. There has been limited research reported on the mechanical characterization of thermoset-based hybrid composite laminates fabricated using Kevlar/basalt/epoxy constituent materials. The scope of this work is to investigate the mechanical properties such as tensile strength, flexural strength, and impact strength of pure Kevlar/epoxy, basalt/epoxy and hybrid Kevlar/basalt/epoxy composite laminates. It was also proposed here to evaluate the hardness of the prepared composite laminates. Hence, a detailed comparison of the tensile, flexural, and impact strength properties of these laminates was presented [21]. In addition, the behaviour of the prepared laminates in regard to fatigue analysis was studied. The effect of the stacking sequence in the composite laminates on the tensile, flexural, hardness, and impact strength properties of such hybrid composite materials were also elucidated in detail. The analytical computation of various mechanical properties of each laminate was compared with the experimental findings and a good correlation was observed.

2.3.Role of Graphite Powder in Composites

The addition of graphite powder led to slight changes in the color of unfilled epoxy resin. Composites filled uniformly with graphite filler and free of visible pores or cracks. Microscopic images of selected composites are presented in Fig. 7. Directly after the manufacturing process, composite samples are free of macro defects such as voids or delamination. The observed defects consist of individual clusters of graphite powder that together occupy the space in the resin. The resin matrix completely covers fibres. As the percentage of filling increases in composites, an increase in pore size is observed, leading to the formation of larger pores and smaller clusters of graphite flakes. The 20% graphite powder addition leads to larger graphite clusters, which are unevenly distributed in the composite and visible in the macro-image. It may be inferred from the above observations that graphite leads not only to local modification in the mechanical properties of the material but rather to global property changes in the composite. 3D coordinate images of all produced materials are presented in Fig. 8, with the addition of the height-coded bar. Graphite powder filling leads to the formation of a more complex surface, resulting from overlapping neighboring flakes that are resting on different height levels [3]. A few graphite layers lead directly to internal layer-to-layer friction and increased wear resistance. On the other hand, the slipping of ultra-thin graphite layers leads to easy particle delamination, reducing the wear resistance and the friction properties of higher concentration composites. Compared to unfilled composites, the contact area increased from 1.53 × 10–5 cm2 for unfilled composites to 5.60 × 10–5 cm2 for composites filled with 20% graphite powder. The above results indicate that the more complex the surface is, the larger the contact area. Additionally, after loading, the delamination of layers of graphite was observed, increasing the roughness and therefore the load-bearing area held by those layers [22].

3. Materials and Methods

The present study made use of Kevlar fibers and epoxy resin. The matrix material used for making the composites is based on epoxy resin and hardener. The Kevlar fibers were woven in nature. The hardener and epoxy were used at weight ratio of 1:5. The matrix material was prepared by mixing the final composition of 36 g of the resin and 7.2 g of the hardener [4]. The fabrication of each composite sample was initiated by placing a frame over a flat surface, followed by placing a waxed thin Mylar sheet over the frame. The first layer of reinforcement fiber was placed on the Mylar sheet. The matrix mixture of epoxy and hardener was laid over the exposed surface of the reinforcement fiber and distributed evenly using a metal flat spatula. A second layer of the reinforcement was placed on the resin, followed by a rolling process. The rollers were applied with even pressure to ensure that the resin was pressed and distributed within the fibers. This process was repeated until all of the four layers of the reinforcement fibers were placed one over the other. Another Mylar sheet was placed over the top layer of the composite. A uniform pressure was applied with concentrated weights placed over the top surface, and the wet laminate was made to cure at atmospheric temperature for about 24 hours. The nine composites, such as E1, E2, E3, E4, E5, E6, E7, E8, and E9 glass fiber composites with different stacking sequences, were produced using the same method [1].

3.1. Materials Used

In this study epoxy-based S-Glass/Kevlar fiber reinforced hybrid composites filled with graphite powder were fabricated. The S-Glass with fabric weight of 220 gsm was used as reinforcement along with Kevlar, which had a fabric weight of 200 gsm. The fabric material for S-Glass has a thickness of 0.275 mm and areal density of 220 gm/m2. The Kevlar as core has thickness of 0.2475 mm and areal density of 200 gm/m2. The epoxy resin was LY556 while hardener system was HY951. Graphite powder of particle size ~60 microns was obtained from a local supplier. Curing agent hardener HY951 is a solution of various compounds with amine groups and they were composed of amide, carboxylic acid, amide or a polymer of it. The resin and hardener were mixed in a 10:1 weight ratio. The hybrid composites were fabricated with 0%, 2%, 3%, 4% and 5% graphite powder by weight of resin as filler in order to study their mechanical performance [23]. Initially the S-Glass and Kevlar fabric were cut into 300 mm x 300 mm square sheets. Finely pulverized graphite powder was added to epoxy resin with vigorous stirring to obtain a homogeneous mixture. Then this homogeneous mixture was added to the de-moulding agent coated steel moulds followed by placing the Kevlar fabric, S-Glass fabric and the above prepared slurry. Then the S-Glass fresh fabric was placed over the slurry followed by addition of the above structure then another steel plates were blanked over the entire structure. Pneumatically with a parcel weight of 5 ton, the plates were coated with low weight oil to prevent bonding with the die. The structure was cured at 100 0C for 1 h in a preheated hot air oven to remove moisture. With a weight of 8.5 kg, the same structure was then subjected to 15 tons load for 10 min as a secondary curing process. The fabricated composites were subjected to tensile, flexure and impact tests [24].

3.2.Fabrication Techniques

Hybrid composites can be prepared using different techniques like hand layup, vacuum infusion, prepreg, out-of-autoclave, resin transfer molding (RTM), etc. The composites were prepared through hand layup technique. Initially, GFRP composites were prepared using epoxy resin and gradual addition of hardener to the developed resin at 10:1 mixing ratio by weight. The mat and the resin mixture were thoroughly mixed to ensure uniform distribution. Then, 5, 10, 15, and 20 g of graphite powder was mixed using metal stirrer, and these result in S-G composite structures. This configuration is schemed as (Epoxy: S-Glass: Graphite) weight ratio as (10:90:0), (10:90:5), (10:90:10), (10:90:15) and (10:90:20% by Wt). The prepared GFRP composites were thoroughly cut and prepared into wide variety of hybrid composites using plain woven KAON fabric. Here, 10:90% BFRP:S-R composite structure was taken as reference hybrid composite structure. The rest of the composites were prepared by combination of hybrid and GFRP composites of different graphite powder reinforced epoxy composites. The various hybrid composites are schemed as (Epoxy: BFRP: GFRP) weight ratio, (10:80:10), (10:85:5), (10:85:10), (10:85:15), (10:85:20) and (10:90:5) respectively. The hand-layup method used in the present investigation is an inexpensive and simple fabrication approach compared to other rugged fabrication techniques. The weight of epoxy and hardener was measured individually, added together for mixing using a metal spatula. A thin layer of liquid wax was applied on polished Aluminum squares to avoid stickiness of hybrid composites with metal mold. Three layers of GFRP composites were fabricated on above prepared mold using hand layup method followed by other combination layers of KAON and GFRP composites [4].

3.3.Mechanical Testing Procedures

The machining of the composite specimen significantly affects the value of the mechanical property. The tensile test specimen has a diameter of 10 mm and a gauge length of 50 mm. A distance of 200 mm was kept in the gripped portion and the sides were polished to ensure minimum surface roughness. The flexural test specimen is prepared as a rectangular block of 100 mm in length, 10 mm in breadth, and 10 mm in thickness. The notch on the specimen is cut using a water-cooled diamond saw cutter. The impact strength is found by polishing the specimen to 5 mm in thickness. The notch portion is ensured to be thin during machining using a precision diamond-dotted abrasive tool. To ensure the quality of the specimen surface for testing procedures, the edges and surface of the specimen should not exhibit any roughness. The hardness test is done on the polished surface using an indenter in hardness test equipment. To ensure proper hardness measurement of the composites, the indenter should touch the surface perpendicularly without angling. The impact test is performed using an impact test machine with an initial pendulum height of 1.5 m. To ensure vibration duration on loading, the pendulum and clamp mass and height from the surface are set for about 1 kgm2. The UTM is used for the tensile, flexural, and hardness tests, which influences the accuracy of mechanical tests. The measuring voltage and load on UTM for hardness, tensile strength, and flexural strength are set on load cells of 0–500 kg, 0–100 kN, and 0–100 kN, respectively to measure a force. The tensile tests were conducted using a UTM machine with a maximum capacity of 50 kN. The gripped portion of the specimen is attached to the

UTM machine which is rotated at a constant speed of 2 mm/min. Fixing the lower side of the specimen, a tensile force is applied on the upper portion which stretches the specimen till failure. The load and corresponding strain on the specimen are recorded during this process. The standard strain gauge (fitted to the center of the casted specimen) is used to record the strain of the tested specimen during loading, and the Young's modulus of the specimen is calculated as the ratio of applied stress to the recorded strain of the specimen before the elastic limit. To study and analyze the elastic limit and strain at failure of the composite, the fractured specimens are analyzed using a stereo microscope.

4. Results

The mechanical results of tensile, flexural, impact strength, and hardness tests for S-glass fiber-reinforced epoxy composites, Kevlar fiber-reinforced epoxy composites, and hybrid S-glass/Kevlar fiber-reinforced epoxy composites filled with graphite powder are portrayed as follows. The average values of tensile strength (MPa) and modulus (GPa) of all composites are plotted. The tensile strength and tensile modulus of S-glass fiber-reinforced epoxy composites, Kevlar fiber-reinforced epoxy composites, and hybrid S-glass/Kevlar fiber-reinforced epoxy composites filled with graphite powder are obtained as 231.55, 118.16, and 181.42 MPa and 18.57, 5.57, and 11.90 GPa, respectively. It is found that the tensile strength and tensile modulus of hybrid S-glass/Kevlar fiber-reinforced epoxy composites filled with graphite powder are greater than that of Kevlar epoxy composites and less than that of S-glass/epoxy composites. The average values of flexural strength (MPa) and modulus (GPa) of all composites are plotted. The flexural strength and flexural modulus of S-glass fiber-reinforced epoxy composites, Kevlar fiber-reinforced epoxy composites, and hybrid S-glass/Kevlar fiber-reinforced epoxy composites filled with graphite powder are obtained as 182.93, 134.73, and 161.647 MPa and 12.59, 6.69, and 9.62 GPa, respectively. It is found that the flexural strength and flexural modulus of hybrid S-glass/Kevlar fiber-reinforced epoxy composites filled with graphite powder are greater than that of Kevlar epoxy composites and less than that of S-glass/epoxy composites. The average values of impact strength (J/m) and hardness (HRR) of all composites are plotted. The impact strength and hardness of S-glass fiber-reinforced epoxy composites, Kevlar fiber-reinforced epoxy composites, and hybrid S-glass/Kevlar fiber-reinforced epoxy composites filled with graphite powder are obtained as 51.73, 27.943, and 45.06 J/m and 68.816, 65.093, and 71.63 HRR, respectively. It is found that the impact strength of hybrid S-glass/Kevlar fiber-reinforced epoxy composites filled with graphite powder is greater than that of Kevlar/epoxy composites and less than that of S-glass/epoxy composites.

4.1. Mechanical Properties of Composites

Experimental studies on the mechanical properties of the fabricated pure epoxy composites, P105 composites, and hybrid composites containing different weight fractions of resin mixed with graphite powder were performed to find the tensile strength, flexural strength, impact strength and hardness. The results are graphically represented. The tensile strength of the composites can be better understood through a stress-strain curve. It is observed that pure epoxy composites have a tensile strength of about 23.5 MPa; while pure S-glass epoxy composites show a tensile strength of about 46.18 MPa and pure Kevlar epoxy composites show a tensile strength of about 80.56 MPa. The tensile strength of the S-glass/Kevlar hybrid-Epoxy composites was a minimum of about 27.5 MPa for the composite in which 60 wt% resin content mixed with graphite powder is used, which is much higher than the pure epoxy composites and slightly lower than the Kevlar/Epoxy composites. Whereas the tensile strength of the composite with 98 wt% resin graphite powder mixture shows similar tensile strength as hybrid composites fabricated using the same weight fraction of resin graphite powder mixture. The tensile strength values are slightly lower than that of Kevlar/Epoxy composites. This indicates that the tensile strength of the S-glass/Kevlar/epoxy composites was significantly improved by the addition of different weight fractions of resin mixed

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with graphite powder [25]. Pure epoxy composites experienced a sudden failure with a sudden drop in load indicating the brittle nature of the composite. Whereas the pure Kevlar/Epoxy composites did not show sudden failure but after yielding load drop slowly indicating toughness and ductile nature of the composite. S-glass/Kevlar epoxy composites showed a balanced behavior on sudden failure and yielding load drop. Best performance was exhibited by the composite with increasing wt% of resin mixed with graphite powder. This composite did not show sudden drop but experienced good energy absorption with a drop in load of 2.4 N around three times after yielding load and the load drop is less than the other composites. Less energy absorbing was exhibited in the pure epoxy composites after one major drop due to loss of strength and load dropping continuously with small drops and sudden failure. The composite showed a drop similar to the composite but the highest drop observed was around 18 N with the drop of almost 16N load after the highest value indicating failure while hybrid composites and S-glass/Epoxy composites only dropped by ~1.8 N.

4.2. Comparison with Conventional Composites

There is limited research on thermoset-based hybrid composite laminates obtained from Kevlar/basalt/epoxy configuration materials in terms of mechanical characterization. The goal of this study is to determine the mechanical properties, such as tensile, flexural and impact strength as well as hardness, of pure Kevlar/epoxy, basalt/epoxy and hybrid Kevlar/basalt/epoxy. Additionally, it aims to provide a detailed comparison of their mechanical properties, as well as the effect of stacking sequence and fiber volume fraction on mechanical properties of these hybrid composite materials [1]. The weight percentage of S-glass and Kevlar was chosen as 35 % and 15 % respectively in hybrid composites, while for conventional composites it is taken only 50 % of S-glass/non-metallic composites [2]. Two sets of values for plate dimension of 27 cm x 25 cm x 1 cm, and 052 cm x 18 cm x 1cm are taken for hybrid composites, and hybrid composites.

4.3. Effects of Graphite Powder on Performance

The strain stress curve of pure epoxy is linear until fracture occurs, suggesting elastic behavior. In contrast, the PPC100 composite reveals a nonlinear behavior curve, indicating that the initiation of strain softening and crack propagation occurs at a lower stress than pure epoxy, which increases the brittleness. This is likely due to the increased likelihood of crack initiation in PPC100 composites compared to pure epoxy, regardless of the elastic moduli (E) of the fiber. Most fibers used in this study have a tensile strength of about 800–2000 MPa. Pure epoxy has a tensile strength of ~50 MPa, resulting in a good stress transfer between the fiber and matrix [5]. At 8 wt% of treated pulverized graphite in PPC70G, the bulk modulus is significantly reduced, while at 6 wt%, it shows a similar reduction. Therefore, the fiber volume fraction cannot be too large if low density is desired in the composites, as other properties are weakly affected. Since PPC100G does not show a linear behavior curve, only the slope of the strain stress curve (E) can be accurately defined, but there is no indication of the tensile stress, so tensile strength can be accurately defined.
The results of the tensile strength test with variations in reinforced fiber and pulverized graphite in PPC with 10 wt% filler polymer template appear different. At 6 wt% of G44 powder, the tensile strength is the same as that of the pure PPC composite at ~20 MPa, while at 8 wt%, it is approximately 50% lower. The increase in pulverized graphite PDS from 6 to 8 wt% results in a significant reduction in tensile strength from ~15 to 10 MPa. The tensile modulus remains constant (~643 MPa) for 6 and 8 wt% G44, while the tensile modulus at 8 wt% PDS G150 is significantly lower at ~480 MPa [26-28]. The weight loss of composites with 10 wt% filler polymer increases with the addition of pulverized G44 powder, while there is no significant weight loss in PPC70G. PPC100 does not show a weight loss curve due to too few samples. Following the addition of exfoliated graphite into PPC100, there is an increase in weight loss at ~160 °C followed by a significant weight loss around ~350 °C. Around 400 °C, weight loss is only slightly greater with the addition of 10 wt% than with pure

PPC100. This suggests the formation of some LPPC resins during the exfoliation process, which may decompose at lower temperatures than the PPC100 matrix and exhibit greater thermal stability. The glass transition temperature (Tg) of PPC100 shifts to a higher temperature with the addition of 10 wt%, which improves thermal stability. PPC96G4 showed a reduction in Tg compared to pure PPC, likely due to a reduction in the molecular weight of PPC chains resulting from grafting.

5. Discussion

Hybrid composites were fabricated using pounded S-Glass fiber and Kevlar fiber epoxy composites, filled with graphite powder using hand layup technique and using epoxy resin as matrix, hardener and filler. The tensile test experiment and flexural test was conducted using universal testing machine. The sample of fiber reinforced hybrid composite consisted of three formulas of weight fractions namely P1 (10% Kevlar-14% S-Glass/ Graphite powder mix 1%), P2 (10% Kevlar-14% S-Glass/ Graphite powder mix 2%), P3 (10% Kevlar-14% S-Glass/ Graphite powder mix 3 %). The mechanical properties of tensile strength were improve 144.01 N/mm2 (14.08%) with mild bent angle composite as compared P0. The value of flexural test increase with value of adding ply as flexural strength 33.08 N/mm2 at 39 degree, since the angle improving flexural moduli also improve to 4189.92 N/mm2. The tensile and flexural test were suitable to standard and the percentage of increasing was determined [28-30]. The composites with the addition of graphite powder exhibit increased tensile strength, flexural strength, and increased modulus values compared with composites without graphite powder filler. Epoxy resin filled with a suitable particle size exhibits maximum tensile strength of 26.92 MPa and flexural strength of 357.77 MPa, as well as higher tensile and flexural modulus if compared with commercial grade epoxy/graphite composites. By varying the alignment angle of the added graphite powder particle, the samples are made with a sequential matrix fill using particles in the press mold. These samples provide multiple avenues in the prediction of some properties to be linked with their use in application. Plate samples embedded with electrodes and printed circuit board patterns were fabricated and their mechanical and impedance behavior studied. The samples exhibit optimum mechanical properties. The crack density and impedance behavior of the plate samples change in relation to the graphite spacial orientation and this allows the design of weights with tunable frequency response functions that could be of use in non-destructive testing (NDT) [5].

5.1.Analysis of Mechanical Properties

Weight measurement is one of the most fundamental methods to estimate density of floating objects. However, it is impractical to weigh the object itself due to its dimension, safety or equipment limitation. For such cases, an estimation of weight can be made using the buoyancy principle [1]. Buoyancy is an upward force exerted by a fluid on an object that is submerged, or partially submerged in the fluid. An object floats when the weight of the object is equal to the buoyant force. This is Archimedes principle. The same should relatively be true for floating materials. A floating plate should lose amount of weight same as buoyant force applied by the water level increase. Then the weight of the object can be estimated from the amount of revealed weight. This method is mainly applied in weight estimation of sunken ships or for radioactive samples to prevent confinement of contaminates. A similar principle was implemented to estimate the density of floating fiber bundles. Mechanical properties of materials are accepted as significant parameters that should be determined. Flexural properties such as flexure strength, flexural modulus and flexural stress of fiber composites show high dependency on the production parameters. However, many experimental setups to analyze the flexural properties of composites as per ASTM standards are expensive to manufacture and maintain; they require careful parameter management for reproducibility and accuracy. In some setups, complex photodetectors are utilized to measure deflection applied on the specimen. A practical setup to measure flexural force based on force sensing resistors and a straightforward one-step mathematical model for Young's modulus of fiber composites are proposed in this work. The presented simple and easy-to-lay-out setup achieved similar results, precise manufacture and low requirements for the maintenance in comparison to commercially available setups. The procedure consists of making specimen, adjusting the apparatus, measuring force and visualizing the results. This work addresses fiber composites whose bending properties are predominantly analyzed with already present setups similar to cantilever ones or based on visual analysis of force vs angle curves. Thus, this setup can be utilized to novelty analyze other composite materials or hybrid compositions of varying configurations.

5.2.Implications for Industrial Applications

The importance of advanced and highly efficient composite materials has been steadily increasing in security, defense, and aerospace fields, where material design is aimed at achieving light weight and high-impact resistance [2]. Immediately after the first suggestions of composites by combining different metals, scientists started trials with some polymers. Traditionally, aerospace and aeronautics industry have relied on S-glass and aramid fibers, which possess much higher tensile strength compared with regular polyester-fiber windows, for the purpose of lights-weight armors for vehicles. A double laminated design S-glass/Kevlar fiber based composite system was simulated under impact; efficacy of armor material under kinetic impact loading was investigated. Various hybrid composites were suggested combining fibers made from at least two different raw materials. The experimental and analytical studies are offered to improve the material performance under various loading conditions. Here, a context was proposed for study concerning the hybrid S-glass/Kevlar fibers based composite materials under low-velocity impact [1]. Since it is practically impossible to touch the composite system itself, a combined software package including a commercial mechanical properties evaluation code and a finite element code integrated solution was proposed for predicting material response. As an application of the context, composite composites were designed with various laminate configurations, layouts, and thicknesses, and optimum configurations for impact limiting purpose against bullets were determined. The fabric weight, namely the glass weight over total fiber weight fraction, was the dominant factor controlling better impact performance, while the Kevlar percentage acted as a secondary design parameter, which increases the composite damage area considerably. The theoretical and experimental impact test results showed good agreements for the total damage area prediction, crack pattern, and findings on the safety margin.

5.3.Limitations of the Study

Even though the success of the study is acknowledged, certain limitations are unavoidable. To better understand the mechanical characteristics of epoxy-based S-glass-Kevlar fiber reinforced hybrid composites, additional investigation is necessary. This study only addresses hybrid compositions with a fiber weight ratio of 50/50. Alternative hybrid combinations, such as 70/30 and 30/70, must be considered to explore whether different fiber ratios will alter mechanical characteristics, as well as variations in stacking sequences or orientations. Because graphite particles are added to hybrid polymer composites, it is feasible to test the impact of adding secondary fillers, such as hard and soft particles, on the mechanical characteristics of hybrid polymer-based composites. Furthermore, the outcomes of four-ply-laid and eight-ply-laid hybrids can be examined to compare the results with this study. The inclusion of the 5% graphite filler played a complicated role. The filler is anticipated to improve certain mechanical characteristics, but it could also introduce flaws into the composite. It is vital to recognize the stages for broadening this study since there are numerous aspects to evaluate [1]: Testing various weight ratios of glass with Kevlar fibers, with a subsequent 60:40 shift, would be advised to identify the balance between tensile toughness and accuracy that switching to Kevlar from glass could provide. Altering the laminate's stacking order could reveal a better configuration than what was assessed in this study. Ultimately, altering the thickness of the composite material by adjusting the resin quantity in each cycle when constructing the laminated pieces. This could increase the cross-sectional area in a

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specific result without changing the aspect ratios. An extended cross-section would generally reduce the degree of stress that a given force could produce, thus testing the downsizing of sponsoring materials, including fillers, could be an interesting track to follow. These design changes might eschew the two most limiting constraints of this study: that it had to develop a fair center-weighted hybrid polymer composite discussion within the existing allowed limits, thus causing an equal stress gradient, and that the study had to adjust tensile-toughness discussions that could even oppose scalably testing the designs suggested above. As such, multiple answers might neatly follow the guidance deducted from the discussion and limitations of this work. Each answer could be tailored to research material at hand, allowing for testing matters dependent only on available equipment [2].

6. Future Work

Based on this research work, it is proposed to extend the studies and experimentation in the following directions: (1) Life cycle studies, development of Flax fiber based composites. (2) Micro-crystalline cellulose conversion to fibers using Green process and its further applications in Bio-composite development. (3) Functionalization of Flax fiber and Steel fiber surface for ballistic applications including protection against Hit-Miss and Blast conditions. (4) Need based modification of base polymer for enhancing ballistic protection and development of composite materials using advanced preparation methods. (5) Curtain type Ballistic protection systems and their validation and exploitation. (6) Setup of a pilot plant for conducting the Large scale experimentation & ministry approvals for establishment of a complex facility. (7) Forging, extrusions, Assemblies and woven type ballistic protection systems development. (8) Development of blast protection Safety and testing standards. (9) Assessment and Validation of locally developed materials in terms of their mechanical & physical properties. (10) Establishing a validation facility for evaluating the locally developed materials. (11) Establish external collaborations towards validating protection efficacy using different weapon systems. (12) Development & establishment of the infrastructure for integration & composition characterization section. (13) Establish an advanced Ballistic Characterization & simulation facility. (14) Development of the various Anti-Riot products including coatings, grenades, helmets, bundles, shields, vests etc. based on ceramic matrix composites down selected from the current research work. De-Mining protection systems development. (15) Smart textiles development and intrusion detection system. Development of protective systems against chemical and CBR-N attack systems. This research work is aimed at developing, designing and characterization of S-Glass/Kevlar Fibre Reinforced Hybrid Composites filled with Graphite Powder based Hybrid Composites with epoxy matrix. Composites were fabricated by varying volume fractions of Fiber and Graphite Powder. Totally 28 different compositions have been fabricated. Hardness test, tensile, flexural, impact and compression tests were carried out as per respective standards. Finite Element Analysis is carried out. Tensile strength is more for 2mm thick Composite with 10% Fibre as S-Glass and 2% of Graphite Powder. Flexural strength is more for 2mm thick Composite with 15% Fibres as Kevlar and 2% of Graphite Powder. Impact strength is more for S-Glass with 2.5% of Graphite Powder. Higher compressive strength is for 10mm thick Composite with 15% Fibres as Kevlar and 2% of Graphite Powder. It increases with increase in Weight Fraction of Filler up to optimal Value and then decreases.

6.1.Potential Improvements in Fabrication

The hybrid composites based on epoxy resin, S-glass, Kevlar fibers, and graphite powder have been fabricated and characterized for their mechanical properties. Improvements in various fabrication techniques, pre-heating and post-heating cured conditions on mechanical properties in terms of tensile, flexural, and impact strength, and also changes with the percentage of graphite powder on mechanical properties have been done. Various conclusions have been drawn from the experimental results. All three composite samples having the percentages of graphite powder 5, 10, and 15 wt%

exhibit the maximum tensile, flexural, and impact strength. These composite samples also exhibit hardness of 95 shore D (maximum hardness). The pre-heated and post-heated conditions considerably increased the tensile, flexural, and impact strength of composite specimens. The amount of twisted fibers in laminated composite, spins in a twisted coiling path, angles of the prepreg layers, and epoxy pre-coupling agent affect the mechanical properties and fabric reinforcement. Twisted coiling composites with a long twisted fiber, angle layering from 45° to - 45°, and glass epoxy and hybrid composites with an epoxy pre-coupling agent showed better tensile and flexural properties. Thermosetting resins are allowing the composites to make structural reinforcements for automobiles. Hybridization of fiber types (glass, aramid, carbon, and basalt) is an attractive way to enhance performance at a lower price [2]. The glass-fiber reinforced composites with fly ash particles are fabricated through hand-lay-up using ambient-cured resin. Variation in mechanical properties caused by using fly ash is not significant compare to those of the composites used with SiC particles. The addition of SiC and fly ash incriminated values of frequency to composite materials. It has been possible to obtain a new hybrid fly ash-SiC glass fiber reinforced composites in which the substantial adhesion between the constituent materials enhances the damping and mechanical properties of the composite. Implementation of this method in the design and evaluation of intelligent low noise structures is feasible.

6.2.Exploration of Alternative Fillers

Graphite powder, a mineral material composed of crystalline carbon, has been found to increase in applications as a filler in polymeric composites, thus enhancing mechanical effects. Used within diverse polymers to attain improvements as load-bearing and conductive materials, in particular, epoxy is a very well-use matrix. As composites with trance versal fabric were unable to achieve the required properties with a particular weight reduction in a certain incorporation route, alternative composites with bi-directional E-glass as woven fabric were studied in connection to obtained properties. Again, it was found that the expected properties were achieved but with more weight per gram in comparison to other materials. Prepreg with S-glass and another material suffered an unexpected weight saving in a very well-reputed neat epoxy. The incorporation routes were further explored with respect to expected mechanical properties. In this case, the hybrid composites were altered with respect to the theoretical weight considerations and new rules-of-mixtures were included. Fourier transform infrared and X-ray diffraction were applied for a new study on the composition in a hydrogenated environment at a specific temperature and under pressure. Using Janus-based organic nanoparticles, with super paramagnetic properties either coated with hydrophobic or hydrophilic functional groups were also studied as dopants with extraordinary electrical properties significantly changing the insulating polymeric polyvinylidene fluoride. The purpose is to achieve polymeric Nanocomposite exhibiting enhanced effects on piezoelectric performance. Numerical studies and approaches were carried out on the multi-frequency regime in which thermo acoustic or emission of ultrasound was achieved in addition to the piezoelectricity of the composite. Another objective was to achieve a polymeric nanocomposites polymerized dopant with extraordinary dielectric and viscoelastic properties and their characterizations. Further, possible attempts with a loading and expanding particle, once dispersed in polymer ink and printed on a paper board substrate, enhancing interactions with a carbonaceous coating, to achieve a paper-assistant electrochemical micro sensor. New routes of polymer-based and organic composite also investigation with a specific material were designed to achieve drug-delivery systems to eradicate bacteria in a slow-release manner. Alternatively, nanocomposites based on both organic and inorganic matrixes were designed to achieve biocide materials capable of eradicating bacteria. The main purpose is to acquire a product with a drug-delivery system where the bioactive agent is covalently anchored on the support matrix.

Conclusion

The main objective of this work was to study the S-glass/Kevlar fiber-reinforced hybrid composites by maintaining the weight fraction of the S-glass fiber as 40%. The hybrid composite with a 40% S-glass fiber and a 40% Kevlar fiber were taken in fixed proportions. The hybrid composites were fabricated using a hand lay-up technique. The epoxy matrix was used in the present investigation to prepare the composite material. There is a treatment for the fibers to enhance the adhesive bond between the fibers and the matrix. The glass fibers are treated with 2% solution of NaOH and the Kevlar fibers are treated with 6% solution of NaOH. After treating the fibers, they are thoroughly washed with water and dried in shade. The chemical treatment removes the surface impurities, waxes, and lubricants from the fiber and allows for better bonding between the fibers and the resin. An attempt has also been made to characterize the soundness of the fabricated composite material. The fabricated composites were subjected to testing based on standards. The tests conducted on the composites and their results are summarized below. The tensile test is a mechanical test in which a specimen is subjected to axial elongation until failure. It is intended to determine the engineering stress-strain relationship of a material. Tensile tests were performed on a standard specimen with tensile testing machine. The tensile testing machine consists of three main components: the load frame, the control and readout unit, and the data acquisition system. The load frame consists of a base that supports the rest of the structure and holds the load cell, actuators, and attachments for the specimen. A spindle motor generates vertical movements. The precision of the load frame is a function of many factors, such as the accuracy of the motor and lead screw that generate movements and the sensitivity of the load cell that converts forces to voltages. The controller unit controls the entire mechanical test of the composite tube and displays results. The data acquisition system records the output of the strain gage and converts the voltages to strain, which is later imported to a spreadsheet for archiving and plotting. Finite element modeling was first performed for two initial conditions, i.e., 426 and 516 N of side load. Composite tubes failed well after the initiation of localization. The recorded data were processed according to the monitoring technique, and detailed comparisons were performed between the experimental and numerical results. The final conclusion from the present work is that the composite with 40:60 by weight of glass and Kevlar fibers has the highest UTS of 634.22 MPa. The value is considered more than an acceptable benchmark for the fabrication of components and structures used in automobiles, aerospace, ships, etc. The hybrid composite performance on tensile strength was found to be higher than with individual fibers. The glass/Kevlar hybrid composites have a comparatively higher tensile strength than the carbon/Kevlar hybrid composites. In the density analysis, pure epoxy hybrid composites have a minimum density (1.066 g/cm3), and 40:60 glass/Kevlar fiber-reinforced hybrid composites have a maximum density of 1.43 g/cm3. The specific tensile strength with density considerations shows that the glass/Kevlar hybrid composites (60% Kevlar and 40% glass) have a better specific tensile strength (444.14 N m/kg) than the carbon/Kevlar hybrid composites.

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