Fabrication And Experimental Investigation on Mechanical Behaviour of Hybrid Composite with And Without Surface Modification

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ABSTRACT:
This paper gives an investigation into the morphological analysis of boron carbide and mechanical properties of the Jutton-Glass hybrid polymer nano composite. As reinforcements, hybrid nanoparticles comprising of boron carbide and graphene nano platelets were used. For laying the composites, the vacuum bagging technique was used with the composition of hybrid nano-material taken as 0, 0.25, and 0.5 wt. % of Gr and B_4C) and the samples were testing for mechanical properties as per ASTM standards. The samples prepared have been subjected to various testing's and the results are reported. Prior to the preparations of composites, the polymer is mixed with surface modified nanomaterial and stability tests were conducted to assess uniform dispersion the aid of U.V. spectroscopy, and the outcomes showed that the samples had been exceptionally uniform over a period of time. It is determined that the mechanical behaviour of hybrid composites, which include 0.5% B_4C and Gr, shows more improved properties than 0.25% B4C and Gr. But the multi-layered samples with graphene also showcased encouraging mechanical properties like hardness and tensile strength.

Keywords: Stability, Boron Carbide (B_4C), Scanning Electron Microscopy (SEM), Morphological Analysis, Mechanical Properties.

1. INTRODUCTION:

The growth of composites and their applications in manufacturing is a brilliant development in the history of materials. Composites are used in numerous fields with mechanical and biological backgrounds for unique applications. When two or more materials with different properties are mixed, a composite material is created. The presence of particles in a composite material adds to its mechanical properties, which include hardness, tensile and flexural strength. Depending on the type of matrix, composites can be categorized into 3 types: Metal matrix composites, ceramic matrix composites, and polymer matrix composites.

1.1 About polymer composites:

Polymer matrix composites (PMCs) are composite materials in which a polymer matrix is strengthened by including high-strength fibers or particulate elements. The incorporation of the polymer matrix and reinforcing materials yields a composite material that demonstrates improved mechanical, thermal, and occasionally electrical characteristics in comparison to the separate constituents. The properties of polymer matrix composites are determined by three constitutive factors: the type of reinforcements (particles and fibers), the type of polymer and the interface between them. Nowadays, these composites are used in various sectors such as automotive, marine, aerospace and many others due to their high specific stiffness and strength.
Fiber-polymer composites, also known as fiber-reinforced polymer (FRP) composites, are composite materials consisting of a polymer matrix reinforced with high-strength fibers. These composites combine the favorable properties of both the polymer matrix and the reinforcing fibers, resulting in materials with enhanced mechanical, thermal, and sometimes electrical characteristics.
A fiber is characterised by the fact that its length is much greater compared to its cross-sectional dimensions. The properties of the matrix, the fiber and its interface significantly influence the properties of composites. Fibers in polymer composites can be either synthetic/man-made fibers or natural fibers. Commonly used synthetic fibers for composites include glass, aramid, carbon fibers, etc., while natural fibers include jute, banana, cotton, flax, hemp, etc. Depending on the application, there are different types of glass fibers, e.g. E-glass fibers for electrical applications, C-glass for corrosive environments and S-glass for structural applications and high temperatures. Glass fibers are available in various forms, including continuous fibers, chopped fibers and woven fibers. When the fibers are derived from natural sources such as plants or other living organisms, they are referred to as natural fibers. The properties of some of these fibers can be found in Table 1. Composites made from the same reinforcing material may not perform better because they are exposed to different loading conditions during their lifetime. To solve this problem, hybrid composites are the best solution for such applications. A hybrid composite material is a combination of two or more different fiber types, where one fiber type

compensates for the deficiency of another fiber type. The concept of hybridization offers the designer the flexibility to tailor the material properties according to the requirements.

1.2Nano-composites:

Fiber-reinforced polymer nanocomposites (FRPNCs) are a sophisticated type of composite materials in which durable fibers are incorporated into a polymer matrix that is additionally strengthened with nanoscale fillers or nanoparticles. The utilization of both macroscopic reinforcement (fibers) and nanoscale reinforcement (nanoparticles) enables the augmentation of mechanical, thermal, and barrier properties to a greater extent than what can be achieved with traditional fiber-reinforced polymer composites.

These composites can be categorized as unintercalated, interposed, exfoliated, and are produced using various techniques such as intercalation of polymer, in-situ polymerization, and melt compounding. Biomedical Nano-composites are specifically designed for dental treatments, bone tissue engineering, and drug delivery in cancer treatments and wound dressings. Moreover, the optical properties of composite materials can be improved by embedding a transparent matrix material. Certain Nano-composites, including CNTs, Graphene and its oxides, and MoS2/Graphene, have shown promising optoelectronic properties for photonic applications.

Table 1. Physical properties of various fibers.

Type of Fiber	Tensile strength (MPa)	Young's modulus (GPa)	Elongation at break (%)	Density (g/cm^3)
Megass	292	17.5	----	1.26
Willow	221	11.5-18.2	-----	0.61-1.12
Musa Paradisiac	501	13.2	5.93	2.32
Coir	178	4.4-8.1	30.5	1.21
Gossypium	564	5.52-13.63	8.1-9.2	1.41-1.62
Linum	1039	28.62	2.72-3.32	1.52
Cannabis	690	73.1	1.61	1.47
Corchorus	392-778	26.52	1.51-1.82	1.20
Hibiscus Cannabinus	935	53.5	1.62	----
Agave Sisalana	521-643	9.41-23.1	2.1-2.51	1.61
E-glass	3412	73.4	------	2.51

a. Graphene:

Graphene is an allotrope of carbon, composed of hexagonally arranged carbon atoms in a layered structure. A single layer of carbon atoms isolated from the bulk graphite structure is called "graphene". The carbon atoms in a graphene layer form three robust in-aircraft bonds per atom, which in turn ends in the formation of a hexagonal planar layer with a honeycomb-like atomic association.

b. Boron Carbide:

B_4C possesses a range of notable properties, including a high melting point, a high hardness, a low density, exceptional deterioration and rusting confrontation, and more. Currently, this material is garnering significant attention in the field of nano-composites research owing to its distinct somatic, chemical, and electric characteristics, which position it as a foremost challenger amongst the constituents with potential for high-performance applications [53–65]. The micro-sized boron carbide powder is sourced from a specialized supplier and subsequently transformed into nano-sized particles.

1.2.1 Study on natural Fiber based Polymer Composites:

Natural-based polymer composites have been used more frequently in recent years because of their many benefits, including biodegradability, flexibility, availability, affordability, and light-weight nature. Many studies have been carried out by researchers to improve the mechanical properties of these composites. Gowda et al., for instance, found that composites made of jute fibers have stronger properties than those made of wood. In unsaturated polyester resin, Chawla and Bastos investigated the impact of fiber volume fraction on the mechanical characteristics of untreated jute fibers. According to Schneider and Karmaker[], composites made with jute fibers have better mechanical qualities than those made with kenaf fibers.

1.2.2. Study on non-natural Fiber based Polymer Composites:

A significant extent of research has been conducted by numerous researchers on polymer composites based on artificial fibers. *Huang et al.*(20) investigated the impact of water absorption on the mechanical properties of glass/polyester composites. It was determined that the breaking strength and tensile strain of the composites gradually decreased with increased immersion time in water, as the bonding between the fiber and matrix weakened. *Yuan et al. (21)* examined the reinforcing effects of modified jute fiber on the mechanical properties of timber-flour/polypropylene composites and discovered that the addition of Kevlar fiber enhanced the mechanical trends of the materials. Wang et al.'s studies (22) into the mechanical traits of composites strengthened with woven Kevlar and fiberglass found that the sort of fiber utilized had a great impact on the fibers mechanical behavior. At the same time as Cho et al. (23) seemed into the mechanical conduct of carbon fiber/epoxy composites, they discovered that the composites reinforced with nanoparticles had better mechanical traits, along with better shear and compressive strengths.

1.2.3 Impression on Hybrid Fiber based Polymer Combinations:

Hybrid fiber composites are composed of a mixture of natural and/or synthetic fibers, that may encompass highly-priced materials including glass, carbon, and boron fibers. Several studies have examined the mechanical behaviour of hybrid composites based on different fiber combinations, along with jute and oil palm fiber or glass and jute. Those investigations have proven that using hybrid structures can effectively beautify the tensile and dynamic mechanical performance of composites because of stepped forward fiber/matrix interface bonding. Moreover, remedies such as the conduct of jute cloth were determined to enhance the performance characteristics. Notch sensitivity has also been studied in untreated woven jute and jute-glass cloth reinforced polyester hybrid composites, with jute composites showing higher sensitivity than jute-glass hybrids. The impact of stacking sequence on mechanical features has additionally been experimentally investigated in interlaced jute and glass material bolstered polyester hybrid composites.

1.2.4.Dispersion of Nanomaterials in polymer:

Achieving uniform dispersion of nanoparticles within the polymer matrix is crucial. Agglomeration of nanoparticles can lead to uneven properties and compromise the performance of the nanocomposite. Modifying or functionalizing nanoparticles on the surface can increase their stability in the polymer, leading to better dispersion. The compatibility of nanomaterials with the polymer matrix can be improved by applying surface treatments or coatings. This is achieved by utilizing surfactants, coupling agents, or other chemical treatments to alter the surface energy and facilitate greater dispersion. These agents can help stabilize the nanomaterials in the polymer matrix and prevent agglomeration. The dispersion stability of nanomaterials in the polymer prior to preparation of fiber reinforced polymer nanocomposites is a vital step. To assess the stability, UV Visual spectroscopy is normally employed.

*1.3*Present work and Novelty:

This research aims to examine the investigation, evaluation, and mechanical performance of jutton/glass fiber-strengthened epoxy hybrid composites with Nano fillers such as graphene and boron carbide. The study investigates the impact of B_4C size, with and without surface modification, on tensile and hardness properties. Additionally, the morphological and mechanical behaviour as well as the stability of the composite polymer were analysed using micrographs. Jutton fibers offer several benefits, including improved performance, enhanced durability, and resistance, quick drying, reduced shrinkage, and cost efficiency.

2 Materials and Methods:

This phase provides an overview of the processing information for the composites and the experimental procedures conducted to characterize and test the composite specimens. The raw materials utilized in this study are

- **2.1 Materials:**

Reinforcements / fibers: Jutton fibers (Jute + Cotton), Glass fiber
Matrix / Resin: Epoxy (LY556) with hardener (Hy951)
Nano-fillers: Boron Carbide, Graphene
Type of method: Stability, Surface modification.
Fabrication Technique: Vacuum Bagging Technique

The bast fiber with the highest production extent is jute, which is likewise one of the most low-cost natural fibers. Jute plants can grow up to 2–3.5 m in height; however, their fibers are brittle and feature low extension to break due to their high lignin content material (12–16%). However, jute fibers have less resistance to moisture, acid, and UV light. On the other hand, cotton fibers are soft, cool, and can hold water 24-27 times their own weight. They are also resistant to abrasion, wear, and high temperatures. A visual representation of diverse varieties of jute fibers is shown in the figure.

Fig:1. 50:50 Jute and Cotton Fiber (Jutton fiber)

Jutton fibers are acquired from plant life and are a mixed form that comprises fibers of jute and cotton. At present, in the jute sector, it has been used and improved to a satisfactory level for use in diverse regions, particularly ground coverings, technical textiles, household textiles, handicrafts, etc. It emphasizes combining and growing the best qualities while at the same time minimizing the wicked qualities of the fibers. Mixing jute with cotton fiber may be an acceptable process of jute diversification, with the aid of which value-added merchandise may be produced. As a result, the techniques of softening and mixing have established a new class of jutton-based products. S2 Glass offers substantially greater power than conventional glass fiber, better fiber durability, modulus of resistance, impact deformation, and green processing. This has the capacity of composite parts to face up to high stages of concern and flexural fatigue. Epoxy LY556 is Araldite LY556 is a medium-viscosity, unmodified epoxy base on bisphenol-A. It possesses tremendous mechanical properties and resistance to chemical compounds, which can be modified within wide limits by way of the use of HY951 hardener as well as fillers. Epoxy LY556, which specifies LY as bisphenol-A, and 556 is a five-vicosity code, five-performance grade. 6-curing time(seconds).

Nature of Epoxy resin LY-556:

1.Visual issue - self-evident, light yellow fluid
2. Viscosity@ 250 C - 10000-12000 MPa
3. Thickness , 250 C - 1.15-1.20 gm/cm3
4. Streak factor - 1950 C

What's more, hardener HY951 which indicates HY as Araldite and 951 is nine-thickness code,5-execution code,1-relieving time(in seconds). homes of hardener HY-951:

1. Thickness = 0.95 gm/cm3
2. Liquefying factor = 120 C (lit.)
3. Edge of boiling over = 266-2670 C (lit.)
4. Water solubility= Dissolvable
5. Streak point = 143.330C

2.2 Characterization:

2.2.1 Scanning-Electron-Microscopy (SEM)

It is used to study the morphological characterization of the composite and powder particles. SEM images have been taken of synthesized boron carbide during the milling process, with variations in timing. As the dimensions of the matters approached the nanoscale and the percentage of fragments on the surface decreased relative to the total number of molecules, the properties of the substances changed. The figure shows smaller, more uniform, spherical particles, as well as heavily agglomerated debris within the powder.

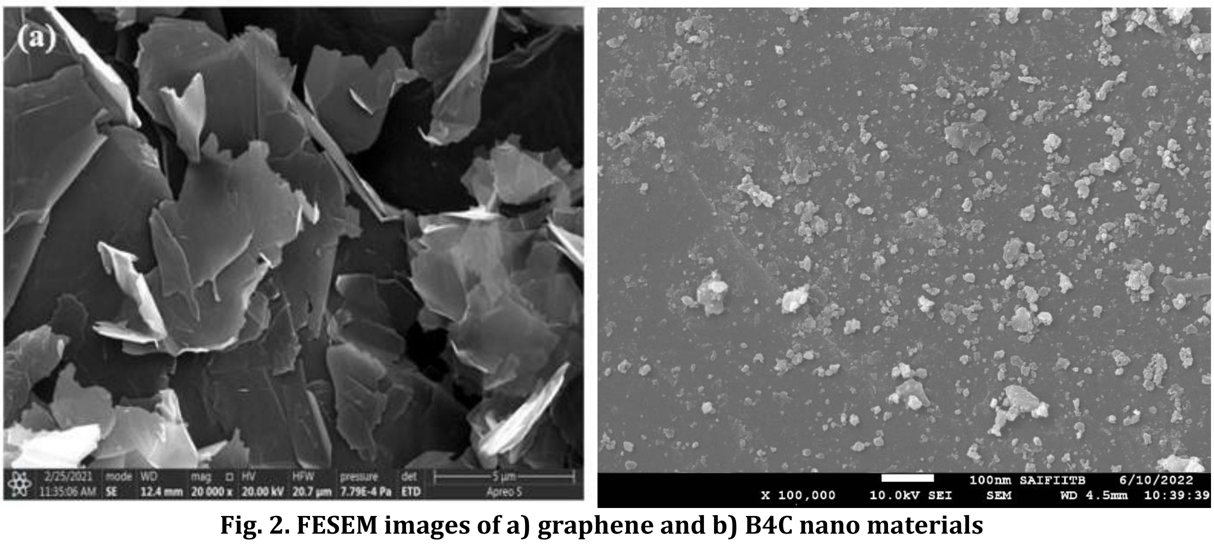


Fig. 2. FESEM images of a) graphene and b) B4C nano materials

2.2.1 Surface modification:

The hybrid composites [14, 22] have been extensively studied and it has been found that the composites with a jutton-to-glass ratio of 3:2 exhibit superior mechanical properties, including tensile strength and hardness, compared to untreated jutton composites. To further enhance these properties, the jutton and glass fibers are exposed under varying intensities of UV radiation. The UV-pretreated jutton and glass fiber (3:2) composite, at the most optimal intensities, demonstrates the highest mechanical properties when compared to untreated jutton and glass-based hybrid composites.

2.3 Preparation of the Composite

2.3.1 Preparation of polymer and its stability:

The stability of polymer dispersed with nanomaterials as reinforcements is a crucial aspect that determines the performance of nanocomposites and their suitability for various applications. Proper dispersion of nanofillers within the polymer matrix is crucial. The clustering of nanoparticles can result in non-uniform characteristics and jeopardize the stability of the nanocomposite. Methods such as sonication and melt mixing are frequently used to attain homogeneous dispersion. The resilience of the interface between the polymer matrix and nanofillers is crucial during the creation of nanocomposites. Enhancing the interfacial adhesion between the matrix and the filler is crucial for effectively transferring stress, hence enhancing the mechanical characteristics and stability of nanomaterials.

The ultra-sonication technique affects the surface and structure of nanoparticles and prevents the agglomeration of particles to form solid fluids. Adequate dispersion of short Jutton-glass fibers in a resin can be achieved without sonication. However, due to the clinginess of graphene and boron carbide, the degree of dispersion of graphene and B_4C in the resin mixture can be improved by sonicating a suspension of nanoparticles. The reasonable dispersion is much greater and effects the size of the nanopowder agglomerates.

2.3.2 Assessment of stability of polymer dispersed with nanomaterials

To assess the stability, UV Visual spectroscopy is normally employed. UV-Visible (UV-Vis) spectroscopy is a method employed to evaluate the durability of nanoparticles in polymers before creating polymer nanocomposites. UV-Vis spectra are collected in order to observe any alterations in the absorption characteristics of the polymer that is distributed with nanoparticles. The UV stability assessment primarily focuses on the UV range, which spans from 200 to 400 nm. UV-Vis spectra can detect absorption bands linked to the polymer and nanomaterials included within it. Alterations in these bands can signify the clustering and sedimentation of nanomaterials. Prior to subjecting the polymer dispersed with nanoparticles to UV radiation, a baseline UV-Vis spectra of the parent polymer is acquired. This spectrum functions as a benchmark for comparison and aids in the detection of any alterations in the absorption properties of the material.

2.3.3 Preparation of composite with vacuum bag method:

Vacuum bag molding is a highly effective technique utilized in composite manufacturing to produce laminated structures. This technique applies pressure to the laminate throughout its action cycle, serving various purposes.

- Efficiently removes any trapped air among the layers of fabric.
- Compacts the layers of fibers, ensuring sturdy bonding between them and preventing any distortion at some stage in the preparation system.
- Facilitates reducing humidity ranges.
- And most importantly, the vacuum bagging technique complements the integration of the fiber and resin in the composite.

The key to accomplishing those advantages lies in maximizing the ratio of fiber to resin. It is vital to observe that the reinforcement within the fabric industry. Moreover, thermosetting resins like polyester and epoxy can end up brittle if they're not properly strengthened in the course of the curing process. If there is extra resin inside the laminate, it'll showcase extra habitations of the resin as opposed to the desired composite. Conversely, if there is too little resin, areas in which the reinforcement is dry will have susceptible spots. To optimize the resin content, it is essential to absolutely saturate the entire reinforcement with resin while minimizing any excess content. The essential principle in the back of the vacuum bagging technique is to "squeeze out" any excess resin so as to obtain a maximized fiber-to-resin ratio.

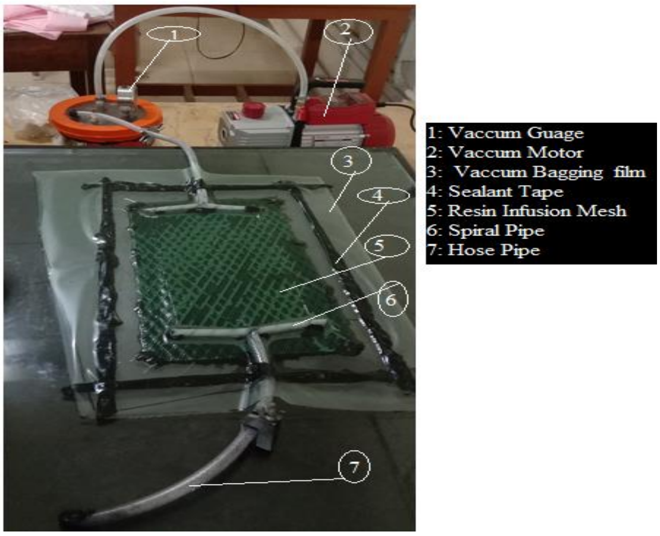


Fig:3. Experimental Setup

2.4Hardness Measurement:

Hardness tests are a degree of resistance to indentation and are amazing for being rapid, clean and non-destructive. A force is applied to an indenter, together with a metal ball and the resulting size or depth of the indentation inside the base of the material is measured the use of a microscope. Digital Rockwell hardness testing machine is the device used to measure the hardness. Lower numbers indicate the material is easily scratched, while higher numbers suggest more resistance to indentation. Hardness is frequently related to tensile energy. Resin composite fillings in functional areas are more susceptible to abrasion. However, a significant effect of 300000 load cycles on the hardness is observed. This projected completely different behaviour when compared. At the same time, this gives an indication of higher longevity, which must be considered. The relationship between the effect of size and hardness, with and without surface modification vs hardness is further investigated.

2.5 Tensile test:

The tensile test measures the energy needed to fracture a sample work and the level to which it elongates before contravention. This test generates a stress-strain curve that is utilized to determine the tensile modulus. The resulting data from this testing aids in identifying the most effective materials to withstand application forces and provides crucial quality control tests for materials. The ASTM D3039 tensile test is conducted using an Instron device, which performs the test and measures the force required to break the polymer composite. Typically, the tensile test is performed on a plane specimen [28–30]. In this test, a uniaxial load is applied to both ends. The tensile test is performed on a specimen of bi-directional jutton/glass FRHC with a choice of nano fillers.

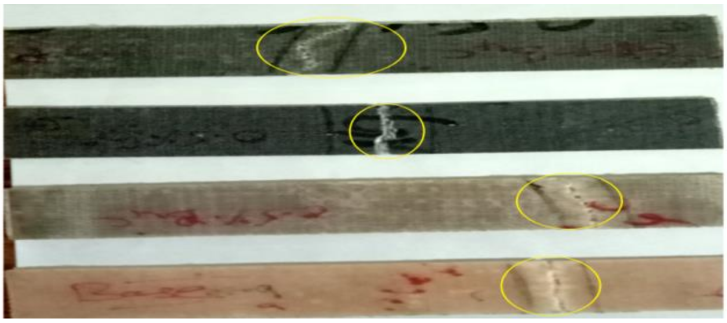


Fig: 4. Tensile specimen

3 **Results and Discussion**:

The obtained solid laminates are cut as per ASTM standards, and various characteristics are being analyzed. Stability tests for the resin samples with various volume percentages of nanoparticles were performed, and the results were analysed

3.1 Polymer and its Stability:

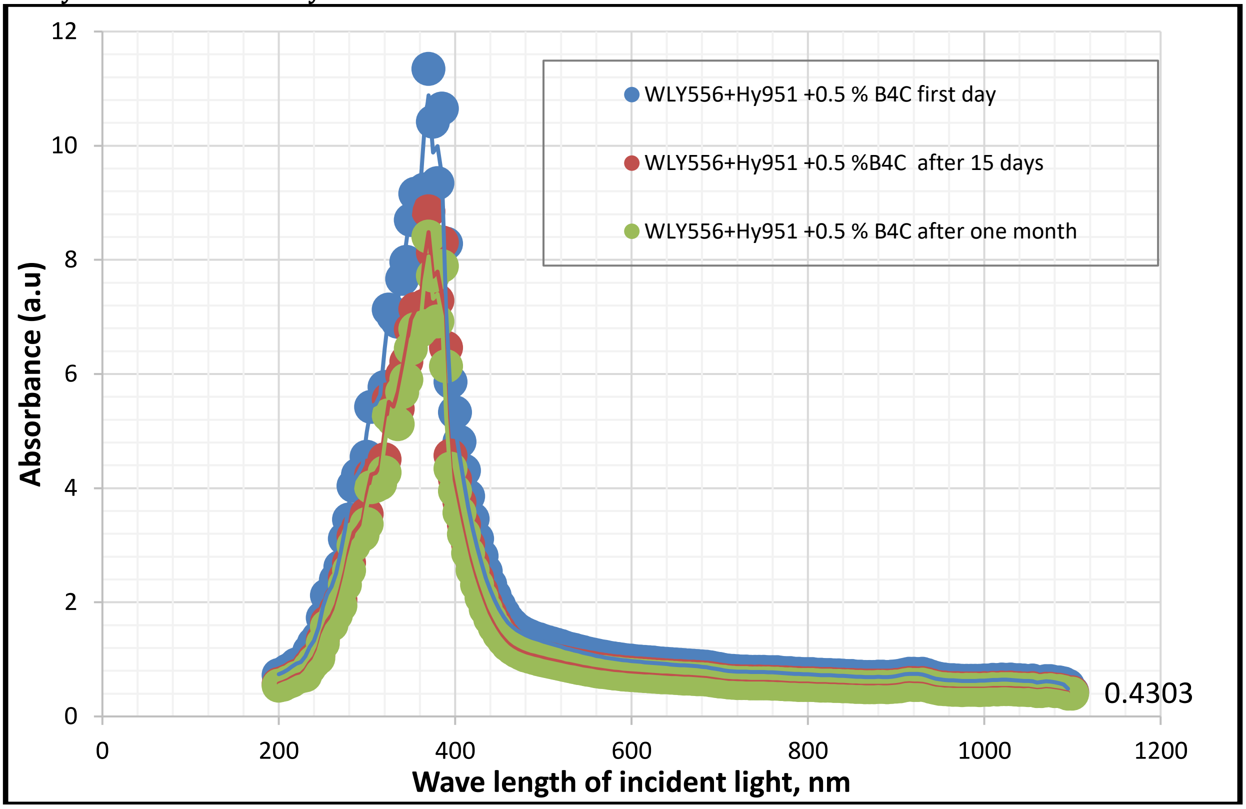


Fig.5 Absorbance vs. Wavelength of incident light

Figure 5 shows the absorbance vs. wavelength of incident light of the epoxy-B4C substance. If the wavelength of incident light increases, the absorbance in the respective substance reaches its maximum value and then decreases as shown in table 2.

Table:2 Peak Absorbance

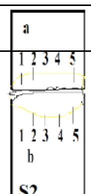
S.No	No.of Days	Peak Absorbance(a.u)
1	1 st Day	11.345
2	After 15 Days	8.845
3	After One month	8.403

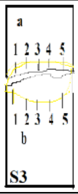
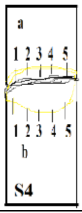
3.2 Effect of surface modification on the hardness of composites:

3.2.1 Hardness Test: Hardness test without and with surface modification:

The hardness tests were performed randomly on the surfaces in each sample, and mean values are reported. Hardness is found for four samples at five distinct locations in each sample, i.e., hardness above break point (a) and below break point (b). The hybrid composite is subjected to surface modification, for which enhanced properties were obtained. There is a substantial increase in the value of hardness. The values of hardness without and with surface modification are shown in Table 4.

Table:3 Digital Rockwell Hardness test (HRC values) for surface modification specimen

Sample Name	Digital Rockwell Hardness test (HRC values) @ near breaking points				Pictorial Representation
	Without surface modification		With surface modification		
	(a) Above	(b) Below	(a) Above	(b) Below	
S1: Base	306.2	325.4	- NA -		
	318.3	241.1			
	268.8	297.5			
	364.9	212.6			
	313.4	311.2			
	384.5	514.7	518.5	514.7	

S2: B_4C	420.5	320.7	520.5	520.7	
	325.1	419.0	525.1	519.0	
	216.1	311.9	516.1	511.9	
	405.0	210.5	505.0	510.5	
S3: Gr	329.5	305.8	521.7	518.1	
	339.6	419.7	512.2	519.9	
	384.4	327.9	514.0	527.0	
	362.3	439.2	514.4	539.5	
	321.1	358.3	521.6	518.0	
S4: B_4C+Gr	346.6	399.5	543.5	529.5	
	448.8	323.8	542.6	541.5	
	343.4	448.6	545.4	548.3	
	449.2	345.8	549.2	543.0	
	346.4	354.7	541.8	533.2	

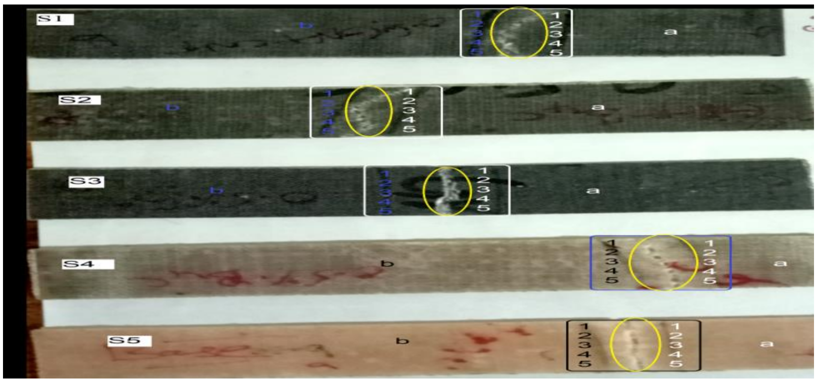


Fig:6. Hardness test @ various breaking points of specimen

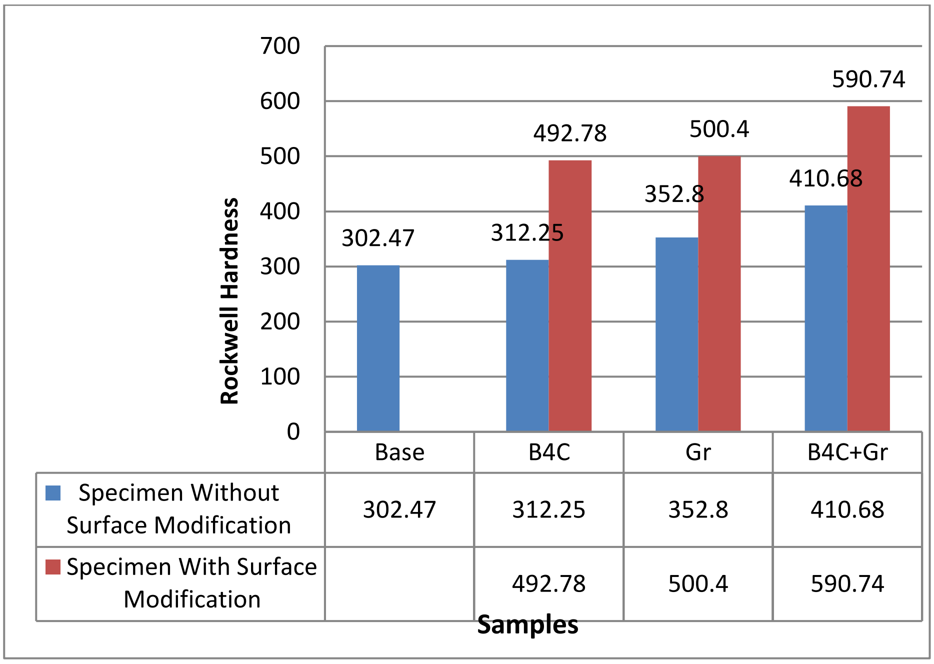


Fig.7: Hardness values without & with Surface modification

Fig. 9 shows the Rockwell hardness values of the composite without and with surface modification. In this, it is evident that the hardness of the samples has increased at a greater rate. The sample B_4C+Gr has attained the highest value of 590.74 HRC with surface modification. The surface morphology in general is normal, and lower hardness was obtained as compared to the base in the heat-affected region due to the sonication process. Due to the agglomeration formed and the uneven particle distribution, the hardness obtained is not uniform. The Rockwell hardness values of the composite without surface modification of the B_4C+Gr sample give a higher value of 410.68 HRC in comparison with other compositions of samples. It concludes that sample B_4C+Gr with surface modification has 31% increased hardness compared to without surface modification.

3.5 Effect of surface modification on tensile strength

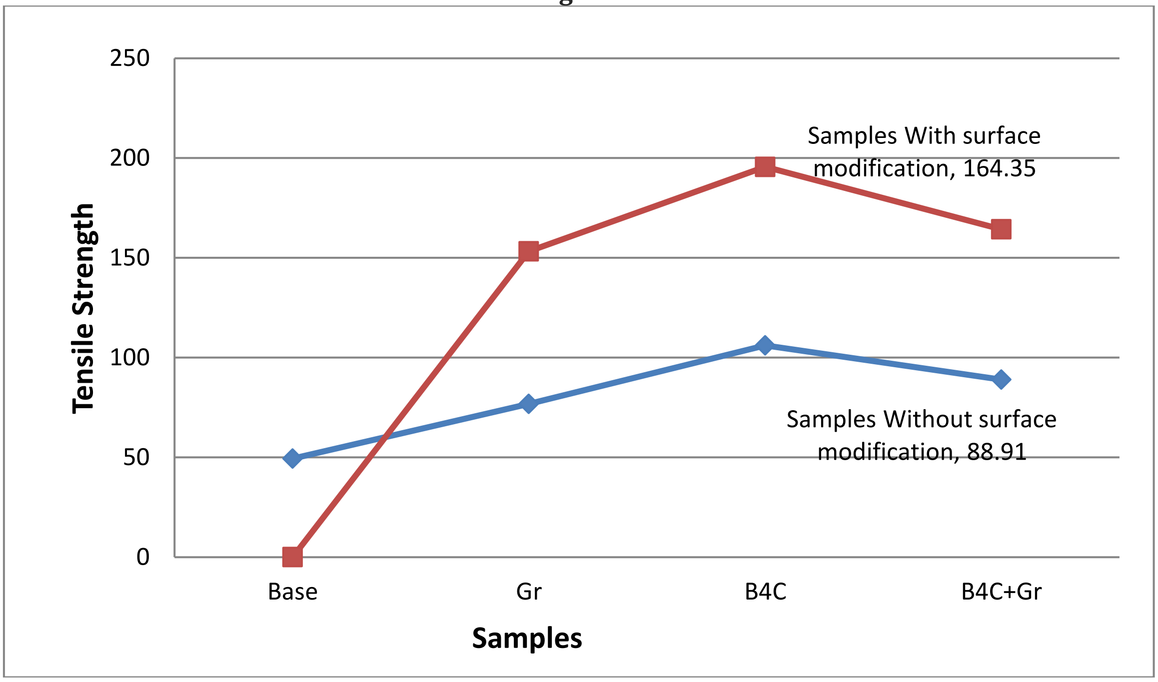


Fig.8: Tensile strength with and without surface modification

The effect of with and without surface modification of Gr and B_4C nano particles on GFRP hybrid composite as shown in Figure 10, due to the strong filler / matrix and good particle dispersion, which led to an efficient stress regulator, the addition of nanoparticles considerably will increase the tensile strength of composite. Subsequently, the expansion of nanoparticles essentially improves the rigidity of the composite. As per the results, the composite specimen containing B_4C+Gr particles shows the high tensile strength of 195.63 MPa with surface modification sample and its tensile strength variation became more than that of other compositions. Beginning with a composite specimen filled of B_4C, the tensile strength is 160.35 MPa to decline. The above figure is evident of tensile strength with surface modification of the specimen is more than 51% when compared to without surface modification of the specimen.

4. CONCLUSION:

Based on the results and discussion, it can be concluded that

- The production of nano-sized B_4C particles from commercially available (10-um) boron carbide was successful. The particle size steadily declined and achieved a minimum size after 30 hours of milling..
- The stability of the particles is uniform, as evidently showcased in the absorbance, i.e., if the wavelength of incident light increases, the absorbance in the respective substance reaches its maximum value and then decreases.
- Mechanical properties like tensile strength and hardness increased tremendously at a greater rate when subjected to surface modification.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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