ANALYSIS OF MECHANICAL PROPERTIES IN HIGH SILICA FIBER GLASS - SIO2 NANO COMPOSITE MATERIALS

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Abstract

This study presents an experimental analysis of the mechanical properties of high silica fiber glass-SiO_2 nano particle hybrid composite materials. The objective of this research was to investigate the effect of nano particle content on the mechanical properties of the composite materials. The composite materials were prepared by mixing high silica fiber glass and SiO_2 nano particles at different weight percentages. The resulting materials were characterized for their tensile strength, hardness, and impact resistance. The results showed that the addition of SiO_2 nano particles led to an improvement in the mechanical properties of the composite materials. The study concluded that the high silica fiber glass-SiO_2 nano particle hybrid composite materials have the potential to be used in aerospace and automobile industries.

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1. Introduction

The aerospace industry is constantly working to improve the efficiency of both commercial and military aircraft by developing better high-performance structural materials. The thrust-to-weight ratio, which is a key factor in aircraft performance, is being optimized by making the aircraft lighter even though the materials used in the body are typically heavy. The use of composite materials, which are created by combining two or more elements to create a stronger material, is allowing for the construction of more fuel-efficient aircraft [1]. The aviation industry is able to benefit from composites in many ways, such as their excellent impact resistance, thermal stability, stress resistance, and resistance to corrosion, which make them perform better in accidents. As composite technology improves and becomes more affordable, the use of composite materials in aerospace industry will become more widespread [2].

Fiberglass is a popular material used in the aerospace manufacturing industry due to its various properties that are beneficial for aircraft construction. They are used in the construction of fins, propellers, flaps, rotor blades, and air brakes. It also saves on fuel consumption. One of the key advantages of fiberglass is its lightweight nature. This makes it an ideal choice for aircraft manufacturers, as weight reduction is a crucial factor in the design of aircraft. The lightweight nature of fiberglass also helps to improve fuel efficiency, making it a cost-effective solution for airlines. Additionally, fiberglass is highly durable and resistant to weathering and corrosion, making it suitable for use in harsh environments. It is also flexible, allowing it to bend and deform under stress without breaking, which is important for withstanding the extreme conditions encountered during flight. In conclusion, fiberglass is an effective material for aerospace manufacturing due to its lightweight, durability, resistance to corrosion, and flexibility [3].

High Silica Fiberglass offers a wide range of applications and is known for its high strength and simple processing. It serves as a material for heat insulation, high temperature resistance, and ablation resistance. The product's thickness ranges from 0.6mm to 1.35mm. The content of silica is more than ninety-six percent [4]. It is affordable, immune to corrosion, has a strong structural foundation and an outstanding proportion for strength-to-weight. Its disadvantages include, poor abrasion resistance, adhesion difficulties, and inhaling glass fibers can cause deadly cancerous development in the lungs. These characteristics make high silica fiberglass ideal for use in a variety of high-temperature and harsh environment applications, including in the aerospace and defense industries.

2. Literature Review

Adam Quilter's paper on "Composites in Aerospace Applications" discussed the usage of composites in the aerospace industry, its advantages, and the benefits of it on the aircraft design and several aircrafts such as the A380, Boeing 777 and several more [5]. K. Balasubramaniam, Mohamed T.H. Sultan, N.Rajeswari in their paper on "Manufacturing Techniques of Composites for Aerospace Applications" delivers an intricate insight into all the manufacturing processes used for producing composites. The paper concludes that composites that are made using a method that can handle a lot of fiber will be stronger [6].

Fiber glass is combined with oxides, which softens and increases the material's resistance to heat. The material's limited thermal conductivity and modest thermal expansion necessitate some adjustments. Awan et al. looked at the tensile characteristics of a polyester resin composite reinforced with fiber glass at various ply sheets. The impact behavior of GF-reinforced epoxy composite interwoven mats with weaving angles of 20 degrees, 30 degrees, 45 degrees, 60 degrees, 75 degrees, and 90 degrees C, respectively. Impact energy absorption efficiency of the composite increased when the weaving angle inside interlacing threads was decreased [7].

Kakur Naresh, Shankar Krishnapillai, Velmurugan Ramachandran's "Comparative Study of a Neat Epoxy and Unidirectional Carbon/Epoxy Composites under Tensile and Impact Loading" shows that numerous experiments on neat epoxy and various stacking configurations of UD CFRP composites are used to examine the tensile and impact characteristics. The tensile characteristics of a pristine polymer are used to determine its shear properties. It was investigated how fiber orientation affected chopped strand and roving fiberglass reinforced polymeric composites. The results showed that the density and hardness of the composite were unaffected by the orientation of the chopped fibers. Impact resistance and degradation tests were performed on E-glass-reinforced polyester resin composites with various laminate depths. Investigations were done on the mechanical characteristics of composites made of polyester and fiberglass with various fiber contents. [8].

Ganesh R. Chavan, Lalit N. Wankhade's "Improvement of the mechanical properties of hybrid composites prepared by fibers, fiber metals, and nano-filler particles" explains that recent findings show that hybrid fiber-reinforced polymer composites are widely used in a variety of fieldS. One of the most effective methods for improving the mechanical properties of composite material laminates is hybridization [9]. Giuseppe Nardoni, Pietro Nardoni, Sara Zanoletti, Luca Beccalossi, Mario Turconi, Franco Monti examine in their paper "Acoustic Emission Monitoring of Fiberglass and Composite Material under Stress" how carbon fiber and fiberglass type materials respond to progressive stress and how acoustic emission can be used to emphasize material changes [10]. The first phase of the research program focused on a sail made of fiberglass that was used to harness tidal current energy. The usage of carbon fiber materials in aeronautical components was the subject of the second phase.

The mechanical properties of epoxy composites reinforced with nano-SiO2 particles and MWCNTs were studied by Xiao, C and et al. for mechanical properties and strengthening mechanism of epoxy resin reinforced with nano-SiO2 particles and multi-walled carbon nanotubes. The results showed that the mechanical properties of the composites were greatly improved, with nano-SiO2/MWCNTs/EP composites exhibiting the best properties. The synergistic strengthening mechanisms of nano-SiO2 and MWCNTs on the EP included the micro plastic deformation effect, micro-cracks and their divarication effect, and the pull-out effect of MWCNTs in the EP matrix, which reduced stress concentration and increased energy absorption [11].

In a study by Wang, X. and et al. for the use of unmodified SiO2 as nanofiller to improve mechanical properties of polymer-based nanocomposites shows the improvement of mechancial properties by the addition of Sio2. The aim of the study was to improve the mechanical properties of a polymer-based nanocomposite, methyl methacrylate (MMA), by copolymerizing it with a small amount of cationic functional comonomer 2-(methacryloyloxy)ethyltrimethylammonium chloride (MTC) and using unmodified SiO2 nanoparticles. The chemical structure and interaction of P(MMA-co-MTC)/SiO2 were characterized, and the morphology and mechanical properties were studied in detail. The results showed that P(MMA-co-MTC)/SiO2 was successfully synthesized and had improved mechanical properties, especially the flexural property, due to better dispersion and stronger interfacial adhesion achieved through electrostatic interaction. The optimal mechanical properties were obtained with 10 wt% MTC and 1.0 wt% SiO2, with a 20.7% increase in tensile strength and a 140.7% improvement in flexural strength compared to PMMA. The method does not require surface modification, making it convenient and cost-effective.

In a study conducted by Jotiram, G.A and et al. on investigating mechanical strength of a natural fibre polymer composite using SiO2 nano-filler, analyzed the effect of introducing nano-SiO2 filler in kenaf fibre polymer composite on their mechanical characteristics. The results showed that the strength of the composite improved proportionally with the increment in nano-filler content until the addition of 2% and then, the improvement was not impressive. The maximum enhancement in tensile, compressive, and impact strength was attained with 2% fraction of nanofiller in the composite with an improvement of 20.61%, 23.71%, and 22.88% respectively [13].

3. Methodology

A. Hand layup method

The hand lay-up method is a manual process used to create composite structures, by layering resin and reinforcement materials. The process typically involves laying alternating layers of reinforcement material and resin on a mold, and then manually compacting the layers to remove any air pockets and ensure a uniform distribution of the reinforcement material. The mold is then placed in a controlled environment to allow the resin to cure and form a solid, integrated structure.

Hand lay-up is one of the most basic and least expensive methods of making composite structures, and it is well-suited to low-volume production runs, or to the creation of one-off or prototype parts. The method is relatively simple, requiring only a mold, resin, reinforcement materials, and basic tools such as rollers and brushes. The major disadvantages of hand lay-up include the relatively long curing time required and the need for skilled labor to ensure consistent quality [14].

B. Process of specimen preparation

The process of specimen preparation of composite material using high silica fiber glass, resin, and SiO_2 nano filler is a critical step in the testing of composite materials and can have a significant impact on the accuracy of the test results. The first step is to obtain a representative sample of the high silica fiber glass. This can be done by cutting a piece of the material using a suitable cutting tool such as a saw or a sharp knife. The size of the sample should be in accordance with the standard test procedures and should be suitable for the type of test being performed. Once the sample has been obtained, the surface of the composite material must be prepared. This may involve sanding, grinding, or polishing the surface to remove any surface defects, such as cracks, inclusions, or roughness. The surface should be free of any contaminants, such as oil, grease, or dirt, and should be clean and dry. Next, the sample must be mixed with the resin and SiO_2 nano filler to create the composite material. The resin and nano filler should be mixed according to the manufacturer's instructions to ensure a homogeneous mixture. The high silica fiber glass must be added to the mixture and carefully mixed to distribute the fibers evenly throughout the resin. The mixture must then be cast into the required shape and size, typically using a mold or a pre-made form. The composite material must be allowed to cure and during the curing process, the resin and nano filler will bond to the high silica fiber glass, forming a composite material [15].

C. Specimen preparation- Abrasive Water Jet Cutting

Once the composite material has fully cured, it must be cut into the required specimen shape and size. This is typically done using water jet cutting machine, and the specimen should be cut with a clean and sharp blade to avoid any deformation of the material. The specimen should be carefully marked to indicate the orientation of the fibers and the location of any defects. Abrasive Water Jet cutting machine is a mechanical instrument that can cut a variety of materials by applying water pressure to a material with grating. It is frequently used in sectors for cutting and molding since it is the most common and advantageous technology from an environmental standpoint for reducing a material's size or slicing it into a form. The heat source was used to slice the materials using a variety of techniques, which created a substantial threat to the workplace and made it challenging to work without jeopardizing the precise form and size, leading to an increase in waste. In this process, a cutter is connected to a high-pressure water pump, and the water jet released from the nozzle cuts it through material by spraying it quickly [16].

4. Testing Methods

1. Compression Test

One of the most essential kinds of mechanical testing is compression testing. Compression tests are used to assess how a material will respond to crushing loads and are often carried out by applying comprehensive forces to a test specimen. The test's objective is to identify a material's behavior or response to a comprehensive load by measuring key parameters such as strain, stress, and deformation. A material's maximal stress tolerance under a constant or progressive load is evaluated. The samples are manufactured with a size of 3 x 3 x 3 cm.

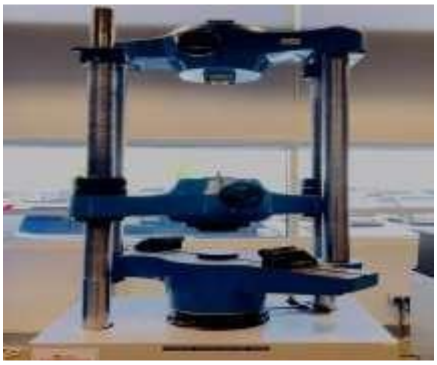

Fig 1: Compression Testing Machine

2. Hardness Test

A material's resistance to permanent deformation brought on by the introduction of another harder substance is measured by its hardness. An indenter is pushed into a material's surface to gauge its hardness. To determine the hardness, measurements of the indenter's penetration depth or the size of the indenter's print are taken. Hardness testing may be used to evaluate a material's properties, such as strength, ductility, and wear resistance, and it helps determine if a material is suitable for its intended usage. The samples are manufactured with a size of 3 x 3 x 1 cm.

Fig 2: Brinell Hardness Testing Machine

3. Impact Test

Impact tests are performed to determine the greatest force necessary to cause the material to fully deform. The marked side of the sample is pressed up against the marked edge of the pendulum. The pendulum can freely strike the sample without any restrictions. If the rupture does not happen, the hammer is broken by using a heavier one. The samples are manufactured with a size of 8 x 1 x 0.4 cm.

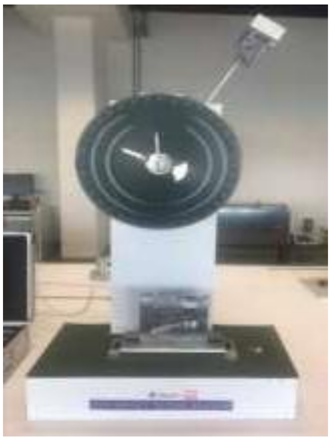

Fig 3: Izod Impact Testing Machine

5. Material selection

1- Resin: UPR resin

UPR resin refers to Unsaturated Polyester Resin, which is a type of polymer made from unsaturated polyester and a reactive diluent like styrene. It is widely used in the manufacture of a variety of products, including fiberglass reinforced plastics, composites, and laminates. The chemical properties of UPR are what make it so useful for these applications. One key property of UPR is its ability to undergo polymerization. This reaction transforms the liquid resin into a solid matrix that provides strength and rigidity to the composite material. The solid matrix created by the polymerization of UPR makes it an ideal material for reinforcement in a variety of applications, such as boat and pool construction, and building and infrastructure projects. Another important chemical property of UPR is its strength, toughness, and resistance to weathering and chemical degradation. These characteristics allow UPR to withstand exposure to a wide range of environmental conditions, making it a versatile material that can be used in a variety of industries [17].

2. Hardener: AKPEROX A50

Unsaturated resins are cured at room temperature using a combination of MEKP in Di Methyl Phthalate solution; 1% to 2% of resin is advised. This kind of hardener was chosen since it can be used safely at room temperature and has a long shelf life. It has a viscosity of 24 mPa.s. and a density of 1.18 gr/cm^3 at 20^{0}C. From a mechanical perspective, the AKPEROX A50 hardener is known for its ability to increase the crosslinking density of the resin. This leads to an increase in the hardness and rigidity of the final product, making it suitable for applications that require high mechanical strength. From a chemical perspective, the AKPEROX A50 hardener is formulated to ensure a fast curing process for the resin. It is also designed to be resistant to moisture, which helps to prevent premature curing or degradation of the resin during storage. Additionally, the AKPEROX A50 hardener is resistant to a variety of chemicals, including solvents, acids, and bases. This makes it suitable for use in a wide range of industrial applications [18].

3. High Silica Fiber Glass

High silica fiber glass fiber is a type of fiberglass that contains a higher percentage of silica, typically around 96-98%. This high silica content gives the fiber improved mechanical and thermal properties, making it suitable for use in high-temperature and high-strength applications. Some common uses of high silica fiber glass include reinforcement of high-temperature composites, thermal insulation, and electrical insulation. It is also used in the production of high-performance materials such as ceramic matrix composites and aerospace composites. High silica fiber glass is more expensive than traditional fiberglass, due to the higher cost of silica raw materials, but its superior properties make it a popular choice for many high-performance applications [19].

4. SiO_2 Nano filler

According to studies, adding silicon dioxide (SiO_2) nanoparticles to the manufactured membranes has a good impact, reducing surface roughness and increasing hydrophilicity. Compared to other inorganic nanoparticles like TiO_2, Al_2O_3, ZrO_2, and Fe_3O_4, the SiO_2 nanoparticles with their plentiful resources are more practical and less expensive. Incorporating SiO_2 nanoparticles into a polymeric membrane is favorable due to their abundance of hydroxyl groups, wide surface area, and tiny and narrow particle size distribution. Additionally, due of their improved hydrophilicity, SiO2 infused membranes can reduce membrane fouling and increase water permeability. SiO_2 integrated membranes have more potential than membranes without incorporated nanoparticles in terms of mechanical qualities. It has a melting point of 1710°C and a density of 2.65 g/cm³ [20].

6. Results & Discussion

Two samples of high silica fiber glass have been prepared for conducting mechanical tests. The first sample is a high silica fiber glass sandwich composite, while the second sample is a composite that includes SiO_2 nano-fillers in addition to the high silica fiber glass.

a. Results of Compression Test

Data Received during the compression test of the two samples are as follows:

Table 1: Hardness Test Data for Specimen I & Specimen II

Constraints	Specimen I	Specimen II
Maximum Load ; F_m	74150 N	78150 N
Displacement at F_m	5.5 mm	4.6 mm
Maximum Displacement	8.3 mm	6.8 mm
Cross sectional Area; S_o	900 mm^2	900 mm^2
Compressive Strength	82.389 N/mm^2	86.833 N/mm^2

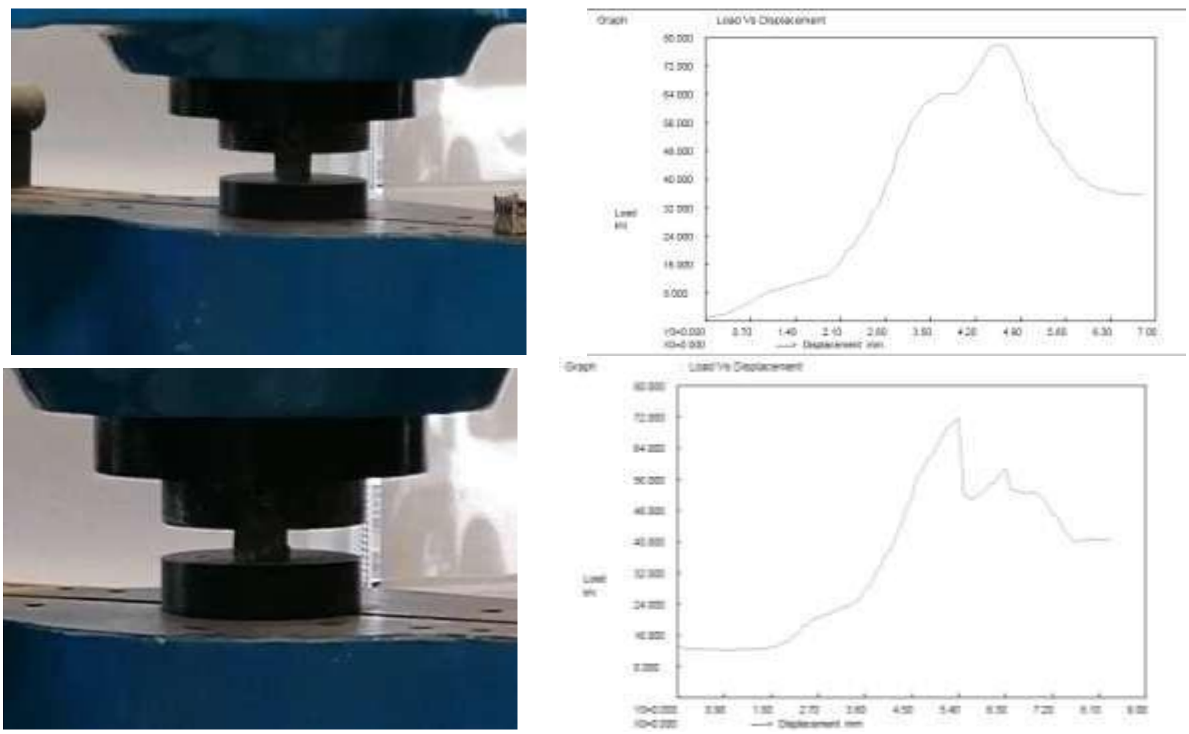

Fig 5: Compression Test of Specimen I & Specimen II

The material's strength was evaluated by subjecting it to a 78KN force. Although it held up for a period during the test, it ultimately broke. The graph of load vs displacement reveals how the specimen's movement changes as the load increases and steadily increases. The peak represents the specimen's ability to withstand force and the maximum pullout strength. A comparison of the two graphs illustrates that the addition of SiO_2 nano filler enhances the material's load-bearing capacity, resulting in an improvement in its ability to bear load.

b. Result of Izod Impact Test

Data Received during the Izod Impact test of the two samples are as follows:

Table 2: Izod Imapct Test Data for Specimen I & Specimen II

Constraints	Specimen I	Specimen II
Cross Sectional Area; A	3.2 mm	3.2 mm
Impact Energy Absorbed by the material; K	0.15625 KJ	0.23828 KJ
Izod Impact Strength; I	0.0488 KJ/mm^2	0.0745 KJ/mm^2

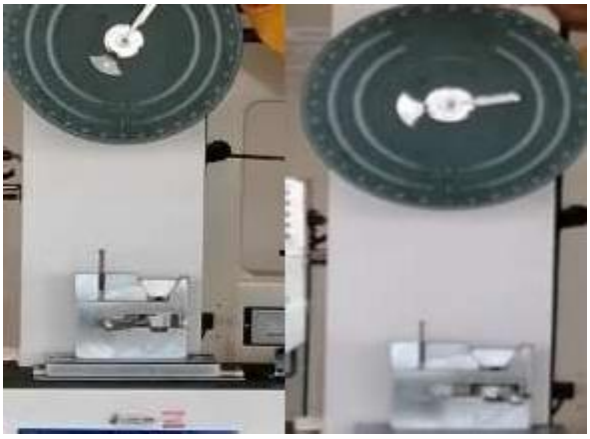

Fig 6: Izod Impact Test of Specimen I & Specimen II

A force of 11J was used to perform the Izod impact test. The moment the rod contacted the specimen, it promptly broke. The data indicates that the Specimen II has higher impact strength than the specimen I.

6.3 Result of Hardness Test

The material's hardness was evaluated using a B hardness test scale with an applied force of 612.9N. The rod was pressed against the material for a duration of ten seconds to assess its hardness

Fig 6: Brinell Hardness Test of Specimen I & Specimen II

The hardness of the samples can be determined by using a Brinell Hardness Testing machine and applying the formula $HBW=0.102\frac{2F}{\pi D(D-\sqrt{D^2-d^2})}$.

The data received through the Brinell Hardness Test are as follows:

Table 3 : Hardness Test Data for Specimen I & Specimen II

Constraints	Specimen I	Specimen II
Force Exerted; F	612.9 N	612.9 N
Outer Diameter; D	2.55 mm	2.55 mm
Inner Diameter; d	1.07 mm	0.94 mm
HBW	66.3 kPa	86.911 kPa

7. Conclusion

According to the observed data, the Specimen II is a superior material in aviation and a better material for aerospace applications in terms of compressive strength, hardness, and impact strength. High hardness materials are better able to withstand erosion, penetration, and permanent deformation. This property is also important in aerospace applications where materials are subjected to harsh environmental conditions, including extreme temperatures, high pressures, and exposure to abrasive materials. Specimen II has a higher compressive strength, which means it is better able to maintain its structural integrity and safety under heavy loads and stresses such as during takeoff, landing, and maneuvers. This is crucial in aerospace applications where the safety of aircraft and spacecraft is paramount. Impact strength is the ability to resist the sudden force. Considering impact is very important as, damage control and fracture resistance are the key consideration when choosing, materials in aviation. Materials with high impact strength are more resilient and less likely to experience damage or fracture, ensuring the safety of the aircraft or spacecraft and reducing the risk of catastrophic failure. Overall, the combination of high compressive strength, hardness, and impact strength makes Specimen II a desirable material for aerospace applications, as it is better able to withstand the harsh conditions and stresses of flight. By adding SiO_2 nano filler into the composite material, the strength and durability of the material are further enhanced, making it an even more attractive option for use in aerospace engineering.

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