EXPERIMENTAL ANALYSIS OF THE MECHANICAL PROPERTIES OF HIGH SILICA FIBER GLASS-GRAPHITE NANO PARTICLE HYBRID COMPOSITE MATERIALS

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Abstract

This experimental investigation aims to study the mechanical properties of high silica fiberglass reinforced with graphite nanoparticles. The study will involve the fabrication of composite materials using a combination of high silica fiberglass and graphite nanoparticles. Mechanical tests such as tensile, compression, hardness, and water absorption tests will be conducted to evaluate the strength and stiffness of the composite materials. The results of the study will provide insight into the effect of graphite nanoparticles on the mechanical properties of high silica fiberglass and may have potential applications in industries such as aerospace and construction.

Keywords: High Silica Fiber Glass, Graphite, Tensile Test, Compression Test, Mechanical Properties, Composite Materials, Aerospace

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1. Introduction

Composite materials were initially introduced in the aerospace industry in the 1940s with first-generation composites of glass fibre. Nowadays composite material is frequently used in aerospace due to their high strength-to-weight ratio, damage resistance, corrosion resistance, and high-temperature tolerance [1]. Hence, due to their unique mechanical properties, they can be used in a variety of areas while manufacturing the aerospace vehicles, such as the structure, internal components, internal fittings, and propulsion systems [2].

The most popular type of composite is fiberglass, which was the first composite introduced to the aerospace industry in it initial generation. Fiber-reinforced composite is one of the popular types of fiber glass with a wide range of applications including automotive applications, aviation, mechanical, and structure. It is widely used because it has a high strength to density ratio, high stiffness, chemical resistance and many other enhancements in the mechanical properties [3]. Fibre glass was highly utilized in electrical systems manufacturing caused they appeared to have good electrical insulators and have high temperature tolerance hence why their use has increased dramatically in the development of composites.

The commonly used fiber glass type in aerospace application is the high silica fiber glass a special type of fiberglass used in engineering applications involving due to its resistance to high and extreme temperatures. The composition of this fiberglass is around 96% pure silica (SiO_2). This material due its resistance to extreme environments has its wide applications in the aviation and astronautics engineering industries, chemical industries, building materials and fire safety equipment [4]. Polymer resins doped with Nano silica have an added benefit of being more cost friendly, improved hardness properties, improved corrosion resistance, outstanding tribological characteristics and therefore have a lot of applications in the engineering industries [5].

2. Literature Review

The aerospace industry has seen an advancement in the field of composites due to their explicit properties that contribute in the enhancements of the vehicles. Fibre glass is one of the most used composite material that has a wide range of application. From the year 1939 fibre glass has been in use, they were implemented in naval aircraft as insulators [6]. Few of the most reliable properties of composite fibres are it is considered to have high stiffness rate, it is corrosion and chemical resistant. Due to the high strength to density property fiber glass is considered to be heavy but at the same time it is affordable when compared to other composite materials.

Leaching causes high silica glass fibres containing 95–98 percent SiO2 to become porous. The porous fiber structure of the leached textiles is sintered into a solid silica structure. The high silica textiles that arise may be employed at temperatures ranging from room temperature to 1000°C. However, because to their extremely low strength, even the resulting high silica textiles can only be employed in non-load-bearing applications. From room temperature (0.4 GPa) to 1000C, the strength of pristine fibres falls (0.1 GPa) [7].

Oxides are mixed with fiber glass which makes the material softer and heat resistant. Some modifications are also made as the material has low thermal conductivity and low thermal expansion. The tensile properties of fiber glass-reinforced polyester resin composite at different ply sheets were examined by Awan et al. The impact behaviour of orthogonal and non-orthogonal interwoven mat GF-reinforced epoxy composites with weaving angles of 20 degrees, 30º, 45º, 60º, 75º, and 90º C from the vertical direction, respectively [8]. As the weaving angle inside interlacing threads was lowered, the composite's impact energy absorption efficiency improved.

The impact of fiber orientation on chopped strand and roving fiberglass reinforced polymeric composites was examined. The orientation of the chopped fibers had no effect on the composite's density or hardness, according to the findings. E-Glass-reinforced polyester resin composites with varying laminate depths were tested for impact resistance and degradation. The mechanical properties of fiberglass reinforced polyester matrix composites with varying fiber content were investigated.

The properties of phenolic foam reinforced with glass fiber mat were examined using thermomechanical analysis (TMA) and dynamic mechanical analysis in this work. The control sample was made out of unreinforced phenolic foam. Mechanical testing and scanning electron microscopy were used to validate TMA's findings [9]. The results show that glass fiber mat reinforcement increases the mechanical performance of phenolic foam, while nucleating chemicals improve it even more. The thermal expansion coefficient of phenolic foam reinforced with glass fiber mat is lower than that of unreinforced foam.

Another study was carried out to emphasize the importance of using fiberglass to join the aluminium cabin construction to the heat shield's conical section. The heat transmission from the heat shield to the cabin is reduced by this attachment mechanism, which also provides strain separation between the interior and exterior components. A thermal absorptance-to-emittance ratio of 0.4 on the CM's surface was needed by thermal control standards for missions in outer orbit.

3. Methodology

A. Hand Layup Method
It is one of the most cost-effective composite production techniques. Mould, resin, and hand rollers are the only tools needed for the hand layup process. It's an open-moulding technique that can make a wide range of composites [10]. This technique, however, has a limited manufacturing capacity per mould.

B. Process of Specimen Preparation
A non-hybridized High Silica Fiberglass along with epoxy composite and a hybridized High Silica Fiberglass with graphite reinforced epoxy composite were prepared. A ply was in wax is applied on it is required to place the specimen. For non-hybridized fiber it is placed on the cured wax and the resin that is mixed with the hardener is poured on it. In the same manner the fiber is layered to increase the thickness for testing according to ASTM standards. The specimen was left for curing up to a specific time. For hybridized fiber the structure is made by placing the glass fiber and graphite that is mixed with the epoxy and hardener.

C. Specimen preparation- Abrasive Water Jet Cutting
It's a mechanical device that uses water pressure and a grating substance to cut a range of materials. It is the most popular and environmentally beneficial method for cutting down a material or slicing it into a form, hence it is widely used in industries for cutting and moulding. Different tactics were employed to slice the materials using the heat source, which posed a significant risk to the workplace and made it difficult to operate without compromising the precise form and size, thereby increasing waste. A cutter is attached to a high-pressure water pump in this procedure, and the water emitted from the nozzle slices through the material by spraying it with a high-speed water jet.

4. Testing

A. Tensile Test
The tensile strength of the material can be determined using the tensile test. The composite may crack and delaminate, which allows the researcher to see how the material fails and spreads throughout the system. The nature of the material is absorbed and the maximum load bearing capacity can be determined. The samples are fabricated in the dimensions of 20 x 2 x 1 cm

Fig 1: Tensile Testing Machine

B. Compression Test
It is one of the most important test that is performed on the material. This can be done alone or in conjunction with the flexural test. Pure tensile and compression testing are part of the standard conceptual design procedure for any material. Any flexural loading applied to the structure is fundamentally translated or studied separately as compression or tensile test [11]. Composite materials having two or more phases are scrutinized because they are heterogeneous in nature, resulting in a mix of many diverse qualities rather than a single dominant one.The samples are fabricated in the dimensions of 3 x 3 x 3 cm

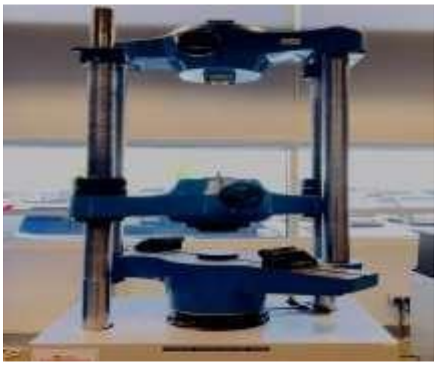

Fig 2: Compression Testing Machine

C. Hardness Test

It is used to determine the toughness of material using indenter. Materials that are hard and think are the ones that are usually tested using hardness. After the indentation is completed, the diameter of the indentation will be measured using the microscope that comes with the equipment. The procedure is held for 10 seconds after the load is applied to produce the appropriate indentation. . The samples are fabricated in the dimensions of 3 x 3 x 1 cm

Fig 3: Brinell Hardness Testing Machine

D. Water absorption Test

Absorption testing is a standard method for determining a material's water-tightness. The volume of water that enters the samples when immersed is measured using this method for determining water absorption. The better the outcome, the lower the absorption rate. The sample must be carefully cleaned to remove tiny particles and debris, drained, and then submerged in purified water at temperatures between 22°C and 32°C with a depth of at least 5cm of water over the basket's top. The trapped air must be removed from the sample immediately after immersion by elevating a basket containing 25mm above the tank's base and letting it to drop 25 times at a rate of roughly one drop per second.

5. Material selection

A. Resin: UPR resin

Is a liquid unsaturated polyester resin used to keep the model solidified in the mould once cured and takes its shape. It was used due to its high strength, durability, compatibility with high silica fibre glass, and its lifespan rate. The resin is categorized under liquid polymers utilized in the industry to enhance the strength of materials and increase their temperature resistance. Furthermore, UPR are considered as good electrical insulators and have high temperature resistance, furthermore, it provides a smooth surface finish which is highly preferable for developing composites using hand-layup method. It is used in the manufacturing of composites as its primary application, wood paints, flat laminated panels and many more applications that involves strength and surface finish. Recommended usage was 2% to 1% of hardener.

B. Hardener: AKPEROX A50

Is a mixture of MEKP in Di Methyl Phthalate solution used to cure unsaturated resins at room temperature, with a recommended usage of 1%to 2% of resin. It has a density of 1.18 gr/cm^{3}and a viscosity of 24 mPa.s. Akperox A50 hardener is a liquid, colourless product that is used in various industrial applications, such as coatings, adhesives, composites, and electrical insulation. Its low viscosity makes it easy to mix and apply, and when combined with epoxy resin, it improves the curing speed and enhances the mechanical and thermal properties of the final cured material. It also has good chemical resistance, making it suitable for use in harsh industrial environments. Additionally, it's known for its good colour stability, low volatility and low exothermal properties, it is recommended for use in situations where high resistance to humidity and water is required. It's commonly used in the manufacturing of flooring, marine and electrical insulation, as well as in the aerospace and automotive industries.

C. High Silica Fibre Glass

High silica fiber glass is a type of fiber glass that is made from silica with a high purity level, typically greater than 96%. This material is known for its excellent thermal stability, high strength, and low thermal expansion. Due to these properties, high silica fiber glass is used in a variety of industrial applications, including high temperature insulation, furnace linings, and heat exchangers. One of the key properties of high silica fiber glass is its excellent thermal stability. It can withstand temperatures up to 1800°C without significant degradation, making it suitable for use in high temperature applications. Additionally, it has high strength, which makes it suitable for use in high-stress environments such as aerospace and automotive applications. High silica fiber glass is a versatile material that is known for its excellent thermal stability, high strength, and low thermal expansion. Its chemical resistance and low smoke generation properties also makes it an ideal material for fire-resistant applications.

D. Graphite Nano filler

Graphite nano filler is a type of nanomaterial made from graphite particles that are typically less than 100 nanometers in size. It has high aspect ratio which makes it a useful additive to improve the mechanical properties of the materials it is added to. It also has high conductivity, lubrication properties and high thermal conductivity which makes it useful in electronic, thermal management and lubrication applications. However, it has low dispersion tendency and is difficult to evenly distribute it in a matrix due to its high aspect ratio and tendency to agglomerate. The physical properties of graphite nano filler include a small particle size typically less than 100 nanometers, a flake or platelet shape, a density of around 2.2 g/cm^3, a high surface area in the range of 10-30 m^2/g, a soft and flexible Mohs hardness of around 1-2, high thermal conductivity in the range of 1000-2000 W/mK, opaque to light optical properties and depends on the number of layers and the degree of ordering within the layers.

6. Results and Discussion

The following two samples were made for conducting mechanical test using High silica fiber glass.

Specimen I - High silica fibber glass sandwich composite

Specimen II - High silica fibber glass sandwich composite with graphite nano filler

6.1 Result of Tensile Test

Data for Tensile Test

The Ultimate Tensile strength of samples can be found by using the formulae S =P/A; whereas P is the Ultimate Force for the sample to break.

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

Constraints	Specimen I	Specimen II
Force; P	9500 N	10400 N
Area ; A	2000 mm^2	2000 mm^2
Tensile Strength; S = P/A	4.75 N/mm^2	5.2 N/mm^2

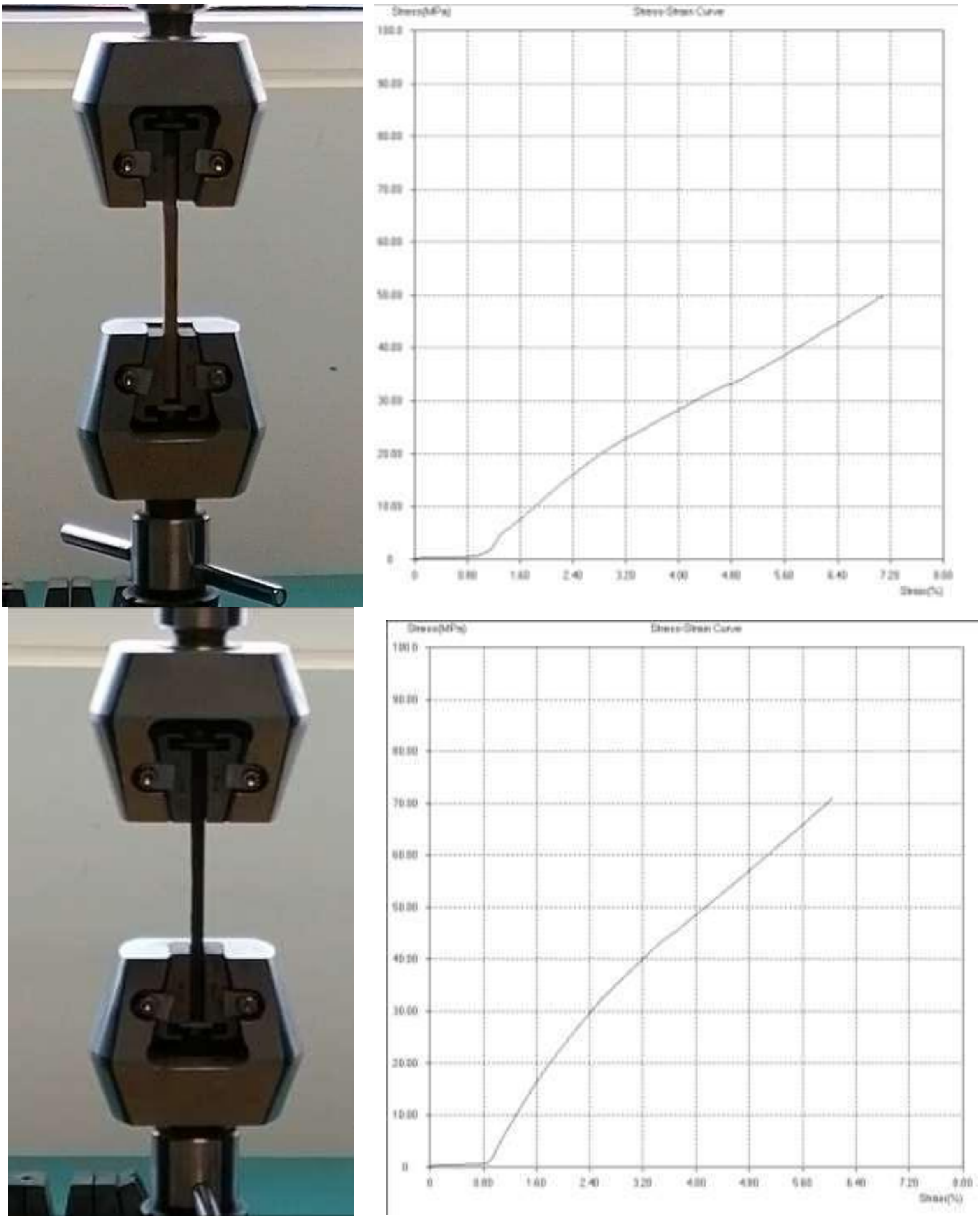

Fig 4 : Tensile Test of Specimen I & Specimen II

The stress-strain graph of specimen I reveals that the elastic limit is increased till 50MPa beyond which immidiately the fracture point was achived and the specimen distorted. For specimen II, the elastic limit is extended upto 70MPa after which immidiately the fracture point was achived and the specimen deformed.

6.2 Result of Compression Test

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

Table 2: Hardness Test Data for Specimen I & Specimen II

Constraints	Specimen I	Specimen II

Maximum Load ; F_m	74150 N	82150 N
Displacement at F_m	5.5 mm	10.8 mm
Maximum Displacement	8.3 mm	14.5 mm
Cross sectional Area; S_o	900 mm^2	900 mm^2
Compressive Strength	82.389 N/mm^2	91.278 N/mm^2

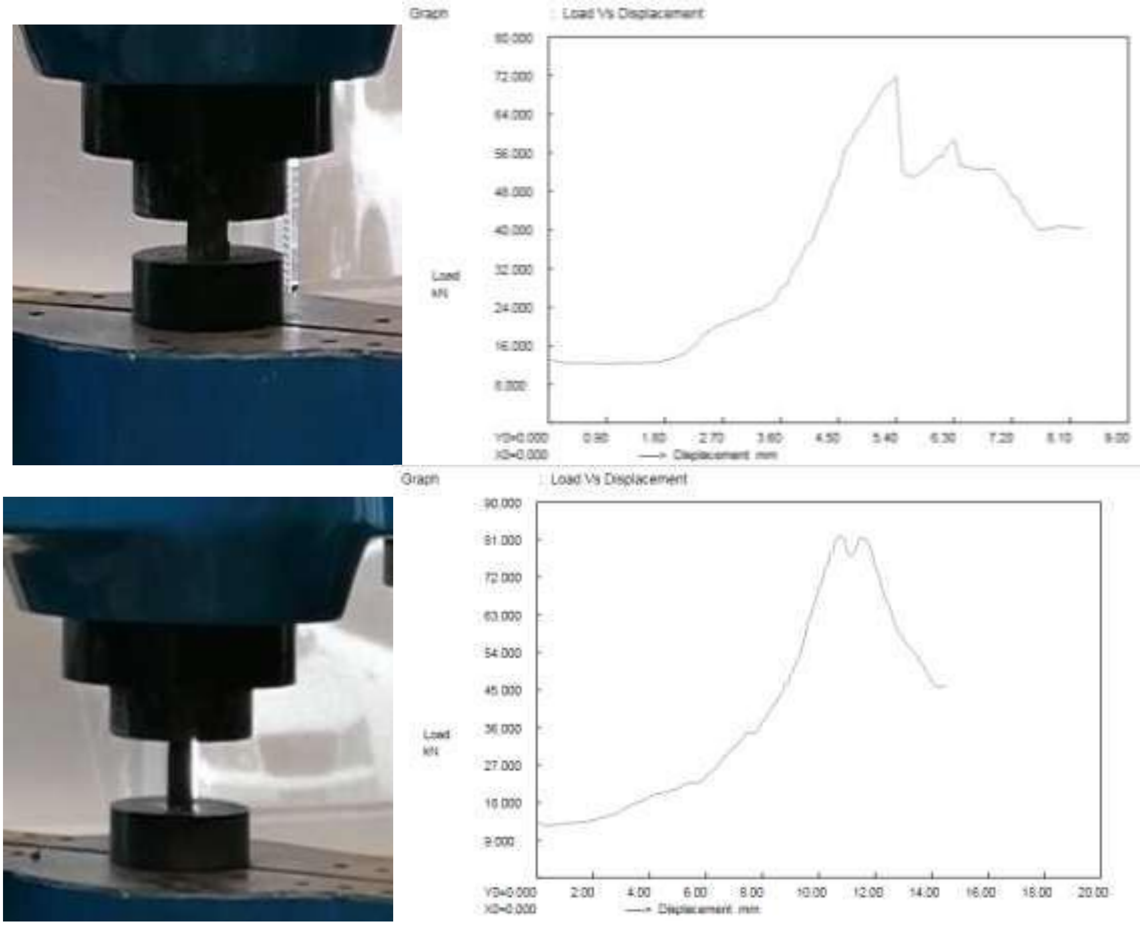

Fig 5: Compression Test of Specimen I & Specimen II

The load Vs Displacement curve depicts the gradual increase of load on the specimen and its displacement as the load increases. The peak shows the maximum pull-out strength and the specimen's capability to withstand the force. When comparing both the graphs it can be noticed that the load bearing capacity is better when graphite Nano filler was added. This has increased the ability to withstand load.

6.3 Results of Hardness Test

A scale B hardness test with a force of 612.9N was done in order to test the hardness of the material. The rod was pressed on the material for 10 seconds to test the hardness.

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

The hardness of the specimens can be calculated using Brinell Hardness Testing machine using 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	0.99 mm
HBW	66.3 kPa	78.03 kPa

6.4 Water Absorption Test

The below image shows the graphite specimen is immersed in water and left for 24 hours. The weight of the specimen before immersed in water and after immersed in water was measured to understand the how much water is absorbed by the material.

Table 4: Water Absorption Test Data for Specimen I & Specimen II

Constraints	Specimen I	Specimen II
Weight before Immersion ; W	17.35 g	18.75 g
Weight before Immersion ; W	17.46 g	18.83 g
Water Absorbed ; W	0.11 g	0.08 g

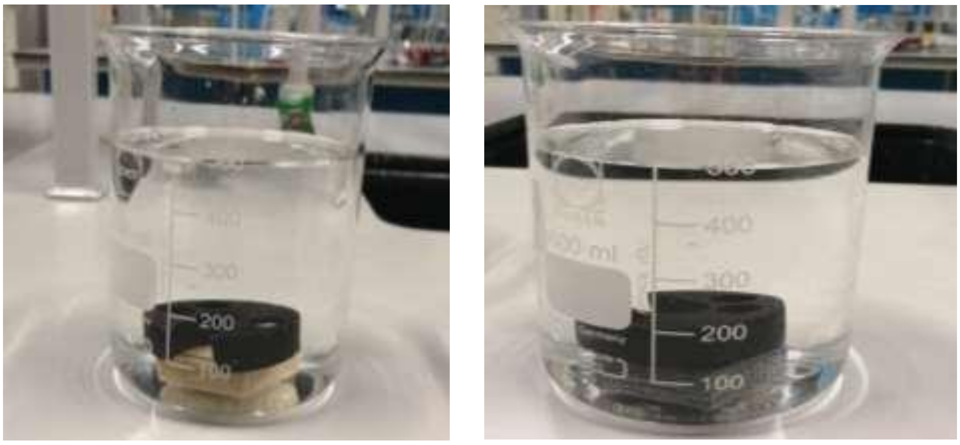

Fig 7: Water absobtion test of Specimen I & Specimen II

7. Conclusion

From the observed data, it is indicated that the Specimen II is a better material for aerospace applications in terms of tension, compression, hardness and water absorption results, which makes it better at withstanding forces on the material. Increase in water absorption degrades the ultimate tensile strength and thereby causes a fatigue life of the composite material. Materials with high hardness has a better ability to resist abrasion, penetration and permanent distortions. Higher tensile strength pf Specimen II indicates that the necking region is further after the necking region of Specimen I, thus delaying plastic deformation. In aerospace applications, materials are often subject to high loads and stresses, so it is crucial that they have a high compressive strength to ensure the safety and integrity of the aircraft or spacecraft. Through these mechanical tests, it was concluded that the composite is strong enough when nano filler graphite was added to it. The material was able to withstand a certain amount of load that was applied on it all though it broke or shattered into pieces. The graph also helped in understanding the elastic limit of the material and fracture point, the point at which the specimen deformed. It is also evident that high silica fiber glass with reinforced graphite epoxy composite is light-weight and stronger than high silica fiber glass composite. Along with the experiments, more mechanical tests may be carried out to comprehend the deep behavior of the composites. The observations from these test show that the hybridized high silica fiber glass with graphite composite has excellent properties, making it suitable for use in aerospace and other industrial applications.

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