The Investigation of General Properties of Carbon Fiber (CF) Composites - Preliminary Study

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Abstract

The most commonly used materials in the production of high-performance CFs are cellulose, polyacrylonitrile, and pitch. Polyacrylonitrile (PAN)-based fibers dominate the market (representing nearly 90% of total CF production), with some companies producing more than 10,000 tons per year. However, the current technique's high cost (the combined cost of the precursors and stabilization accounts for 70% of the total CF synthesis cost) limits the technology's applicability. Carbon fiber manufacturing is characterized by a high energy demand due to long processing times and energy-intensive thermal processes. PAN-based CFs are difficult to commercialize due to the time-consuming pre-oxidation step,which significantly raises the manufacturing cost. As a result, advanced processing technologies aimed at reducing CF production costs should be developed. They were consisting of a thin but strong crystalline filament ofcarbon. This experimental study was to learn the mechanical properties of carbon fiber using Universal Testing Machine (UTM). There was a section where we made a phone case out of Polyacrylonitrile (PAN) carbon fiber and compared it to other materials for phone cases. The phone cases of carbon fiber composites as the one example of consumer products made from woven carbon fiber then were hardened by hard epoxy mixed with resin epoxy. Then, the phone cases were tested with UTM machine to compare the tensile strength and high modulus. Other than that, there were a few samples with different compositions of PAN powder mixed with different compositions of sodium thiocyanate. The results of the testing show that the carbon fiber had a high tensile strength than the other materials of phone cases which were silicone and thermoplastic polyurethanes (TPU). The microstructure of carbon fiber has a significant impact on its mechanical properties.

Keywords: *Mechanical, Carbon fiber, Phone case, Polyacrylonitrile*

1. Introduction

Devices, items, commodities, or merchandise of regular or frequent use that are typically purchased by individuals or households for private consumption from a retail outlet or otherwise received or delivered directly to the consumer are referred to as consumer products. Consumer goods are items purchased by the ordinaryperson for personal consumption. Consumer products, also known as final goods, arethe product of production and manufacturing and are what a customer will see on the store shelf. Consumer goods include things like clothing, food, and jewellery.

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Manuscript History:
Received 14 March, 2023, Revised 6 April, 2023, Accepted 6 April, 2023, Published 30 April, 2023

https://doi.org/10.33736/jaspe.5528.2023

e-ISSN: 2289-7771

One of the newest trends in engineering materials is natural fiber reinforced composites (NFCs). The most important factor in engineering product manufacture iscost-effectiveness. These NFCs are favored in most applications because they are less polluting and have a larger fiber content for equal performance, reducing the use of more polluting base polymers [1-2]. Carbon fiber reinforced composite materials that were developed in the 1950s as a reinforcement for high temperatures molded plastic components on missiles. Carbon fiber was produced mostly 90% Polyacrylonitrile and 10% Rayon or Petroleum pitch. Carbon fiber is one of the polymers and it is a strong material, but it is lightweight [3]. They were consisting of a thin but strong crystalline filament of carbon. The carbon fiber was made from a process that is part chemical and part mechanical. The carbon atoms in carbon fiber are bonded together in microscopic crystals [4]. The crystal alignment will make the fiber incredibly strong. Carbon fiber was classified by the tensile modulus of the fiber [5]. Tensile modulus is a measure of how much pulling force a certain diameter fiber can exert without breaking. Carbon fiber is always used in part of automobiles, aeroplanes, and recreational products and because of its uniqueproperties, it is also used to make a phone case [6].

Carbon fiber manufacturing is characterized by a high energy demand due to long processing times and energy-intensive thermal processes. However, they are relatively expensive when compared with similar fibers, such as glass fibers or plastic fibers. The most common materials used to make high-performance CFs are cellulose,polyacrylonitrile, and pitch. Polyacrylonitrile (PAN)-based fibers dominate the business (representing almost 90% of total CF production), with some companies having annual capacity surpassing 10,000 tons. However, the high cost of the currently utilized technique (the combined cost of the precursors and stabilization accounts for 70% of the total CF synthesis cost) limits the technology's usability.

The scope of this study is divided into a few parts. The first part of the study is to prepare the carbon fiber using a PAN as a precursor. In this part, there will be a few processes involved in the making of PAN carbon fiber such as the polymerization of PAN, carbonization, stabilization and more [7]. There will be a part of making a phone casing using the PAN carbon fiber. The next part is to study the mechanical properties mentioned in the objectives of thestudy, which are the tensile strength and high modulus. Other mechanical properties that have been known would not be covered in this study.

The last part is to compare the tensile strength of the carbon fiber phone cases with the normal ones. This research is significant because, despite its widespread popularity, carbon fiber has never been properly investigated as a fine fiber material for consumer products. Aside from the dearth of studies on this fiber's impact on consumer products, there have also been few investigations in this field.

A substantial amount of effort has been expended in relating fiber structure to properties and translating the relationship into production in order to reduce production costs or improve fiber properties. Due to the time-consuming pre-oxidation step, which significantly increases the manufacturing cost, PAN-based CFs are difficult to commercialize. As a result, advanced processing technologies aimed at lowering the cost of CF productionshould be developed.

Therefore the objectives of this study are to learn the mechanical properties of carbon fiber using UTM, to compare the tensile strength of carbon fiber phone cases with the normal phone cases and to investigate the morphologies of the surface of the sample.

2. Materials

There are a few materials that are needed for making up the phone cases. First are existing plastic phone cases that are used to make shapes. Then, the plastic wrap that is used to prevent anything to get dirty and used to create the mold for the cellphone cases. Plaster also needed to become the phone mold and the carbon fiber. Then, 600 g/m² of woven carbon fiber- Fiber Glast 3K weave. Next is the hard epoxy resin which is used to structure your carbon fiber into the shape of the mold also can strengthen the phone cases. The hard epoxy resin used in this project is Fiber Glast 2000 Epoxy Resin and Fiber Glast 2120 Epoxy Cure. Lastly, the shiny epoxy resin that can be used is TAP General Purpose One to One Epoxy Resin/Hardener to give the phone cases a shiny glossy look. All the chemicals and materials were bought from the local supplier.

There was a silicone rubber case and TPU case with the same thickness to be compared to carbon fiber composites. The properties of the material vary depending on the grade of silicone rubber. The distinctive chemical structure of silicon is the cause of its particular material properties. Its backbone is made up of a series of siloxane bonds, which are stronger and more stable than carbon bonds. A polymer with excellent abrasion resistance, biocompatibility, and high ductility is thermoplastic polyurethane (TPU). Products made from TPU typically have elasticity, transparency, and low weight, despite the fact that TPU is made from a variety of materials. TPU can remain strong even when very thin. TPU is a good material for protective cases due to its strength and elasticity. The samples were characterized based on their tensile strengths, densities, surface characterization and functional group.

3. Methodology

The plaster was placed in phone case mold that is wrapped in plastic. The plaster was cured completely inside the mold. For carbon fiber layup, the cellphone mold was placed on the carbon fiber sheet; on the perimeter, leaving approximately an inch extra. The plaster was poured inside the plastic-covered phone case. Paint a good amount of epoxy over the carbon fiber layup. Excess carbon fiber be wrapped on the backside of mold and cut afterwards. The next step, removed the carbon fiber case from the mold.

4. Results and discussion

Each material has a different tensile strength and is determined using a tensile test. The amount of load or stress that a material can withstand before stretching and breaking is referred to as tensile strength. Tensile strength is the material's resistance to tension induced by mechanical loads applied to it, as the name implies. A universal testing machine (UTM) holds a specimen material in place and provides the tensile stress required to determine the breaking point in a material testing laboratory.

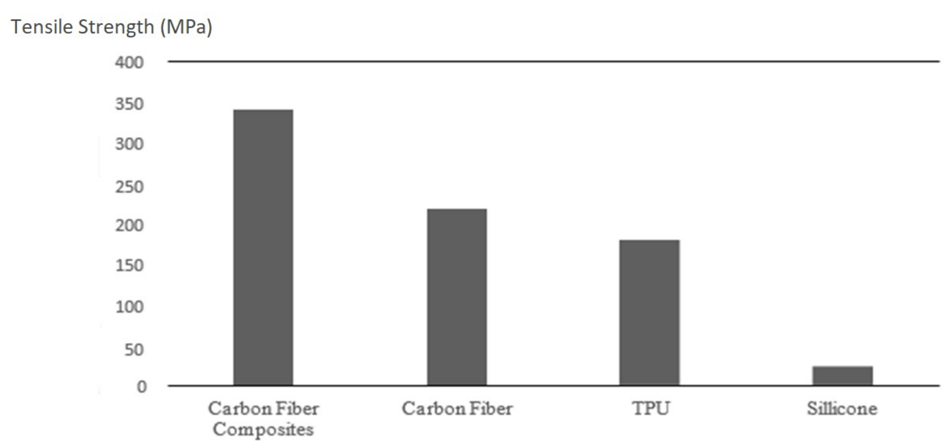

Figure 1. Tensile strength of carbon fiber composites, carbon fiber, TPU and silicone

Figure 1 displays the tensile strength of a few samples that are always used as phone casing which is silicone and TPU other than carbon fiber. The figure shows that carbon fiber had a high tensile strength than other materials. The universal testing machine's tensile strength readings can assist in determining the used material's mechanical properties.

The carbon fiber laminates with the epoxy have high tensile strength than the raw carbon fiber and other materials. Tensile testing of carbon fiber laminates indicates the carbon fiber content for composite fabrication to enhance mechanical strength [8]. Carbon fibers' high modulus is due to their high crystallinity and well-aligned crystals in the fiber direction; however, carbon fibers' strength is primarily affected by fiber defects and crystalline morphologies [9].

Silicone rubbers are more cost-effective, dependable, and long-lasting, even in harsh environments; as well as being simple to process [10]. However, their mechanical strength is low. Park et al., (2008) [11] found that the mechanical properties of silicone rubber foam can be improved by regulating its microstructure. Additionally, pure silicone rubber foam materials have a lower compression resistance than the foam/solid alternating multilayered silicone rubber materials [12].

The TPU is flexible across a wide temperature range, has high wear resistance, and is highly elastic across the entire hardness range. It has characteristics similar to thoseof rubber and plastic. The fact that the material resembles rubber indicates that it is extremely elastic and flexible. TPU exhibits higher strength than silicone. TPU's high-strength composition makes it one of the market's toughest materials. This material is naturally capable of absorbing impacts or shocks due to its high elasticity.TPU has better tensile strength than silicone, but it has the same good properties as silicone.

4.1 Surface structure of samples

Besides that, different samples are examined and analyzed with a digital microscope. A digital microscope displays captured images of small objects on a computer monitor usingan optics and digital camera. High-resolution electron microscopes are useful for observing intricate sample details. The inspection of a sample's surface details is made easier with electron microscopes.

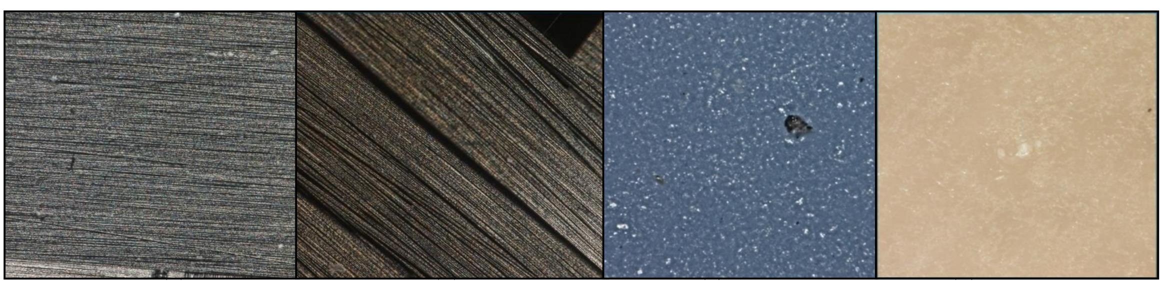

Figure 2. Surface structure of samples (a) Carbon fiber composite (b) carbon fiber (c) silicone (d) TPU

Surface defects and microvoids had an impact not only on the tensile strength and strain of carbon fibers but also on the formation of an interface withpyro carbon. The rearrangement of carbon atoms and the development of carbon fiber surface structure was closely linked to the formation of interfaces in carbon-carbon composites. The defects and edge planes of the graphitic structure at the surface were primarily responsible for the rough surfaces of the investigated carbon fibers. Carbon fibers with relatively high surface roughness contained a variety of microvoids. Rearrangements of carbon atoms may take place at the carbon fiber's outermost surface during the formation of an interface with pyro carbon [13].

It is common knowledge that fiber properties are impacted by microstructure. The precursors and processing conditions determine the microstructure of carbon fiber in Figure 2. Numerous models have been proposed to represent the microstructures. The removal of heteroatoms during heat treatment could result in the formation of pores. By reducing flaw sensitivity and optimizing the microstructure of carbon fiber, strength can be increased. The morphology of the precursor and the conditions of processing determine the microstructure of carbon fiber.

Additionally, the existence of a wrinkled ribbon structure in PAN carbon fibers was supported by TEM-based research [14]. The obtained image in Figure 2(c) is possible to visualize a fairly uniform distribution of silica particles in a matrix of silicone rubber. In contrast to the silicone surface, which appears grainier and rougher and has numerous imperfections, Figure 2(d) shows TPU surface has relatively few features.

4.2 FTIR analysis of PAN carbon fiber

The energy required to start molecular vibrations in a sample is measured using FTIR spectroscopy. In contrast to a dispersive IR spectrometer, which uses a dispersive element to divide the incoming light into its spectral components and measures each one individually, FTIR measures all light frequencies simultaneously. FTIR analysis is an excellent tool for chemical identification because each molecule or chemical structure will produce a distinct spectral fingerprint.

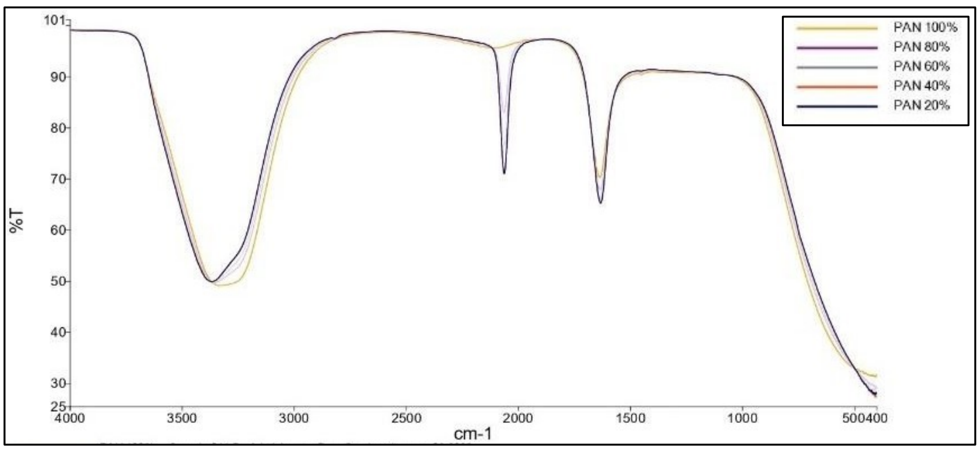

Figure 3. FTIR spectrum of PAN with different percentages

The functional groups found in activated carbon were further identified using FTIR analysis. In addition, the spectrum contained a 3427 cm^{-1} IR band that corresponds toa hydroxyl group vibration stretch, OH. Additionally, the stretching vibrations of the O-H and N-H functional groups are observed at a frequency of 3433 cm^{-1}, as shown in Figure 3. The frequency of the C=O group is also detected at a wavelength of 1720 cm^{-1} w. The vibrations at C-O-C and N-H stretching, respectively, are responsible for 1565 cm^{-1}.

Table 1. Functional group of PAN

Frequency Range (cm^{-1})	Functional Group
3427	OH
3433	O-H AND N-H
1720	C=O
1565	C-O-C AND N-H

4.3 Density of the sample

Lastly, the density was calculated. Density is a physical parameter that indicates the mass of a sample or body divided by its volume: in other words, how tightly the molecules of a substance are packed together in space. Figure 4 shows the reading of density in g/cm^3 of each sample which are Carbon fiber composites, carbon fiber, TPU and silicone. The result shows that the carbon fiber composites has higher density reading than other samples but the carbon fiber composites still has low density. It shown the carbon fiber composites is lightweight material but stronger than TPU and silicone.

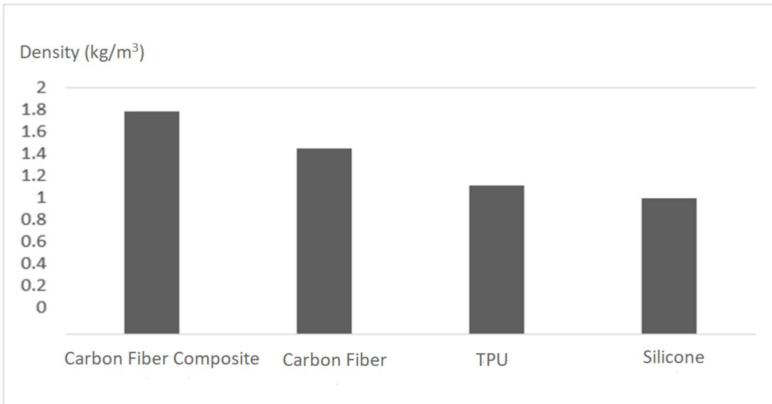

Figure 4. The density of carbon fiber composites, carbon fiber, TPU and silicone samples

A low-density composite is a material that can trap and hold more moisture than a high-density composite [15]. The reason for this is that low-density composites have more voids, porosities, and spaces between their components. Carbon fiber has comparable stiffness and deformation resistance to steel at a fraction of the weight, making it a preferred material when a product must be both strong and lightweight. Carbon fiber, for example, has replaced metal alloys in many aerospace applications, allowing for lighter, more fuel-efficient planes. Carbon fiber is a popular material for bicycle and motorcycle helmets because it provides steel-like protection in a lightweight package.

5. Conclusion

In this study, the mechanical properties of carbon fiber are studied. In particular, the microstructure of carbon fiber has a significant impact on its mechanical properties. The presence of defects has hampered further advancements in the mechanical properties of the fiber. Relationships between fiber structure and properties have been the subject of a great deal of research. By reducing flaw sensitivity and optimizing the microstructure of carbon fiber, strength can be increased. The morphology of the precursor and the conditions of processing determine the microstructure of carbon fiber. Based on the objectives, carbon fiber composite shows high tensile strength, good morphology, have high density compared to other materials studied.

Acknowledgements

The authors would like to thank the Faculty of Applied Sciences and Technology, Universiti Tun Hussein Onn Malaysia for the facilities provided that make the research possible.

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