Effect of Multi walled Carbon Nano Tube reinforcements on Mechanical Properties of Hybrid (Aramid/Carbon) Fiber Composite

A Project Report submitted in fulfillment requirements

For the award of the Degree of

BACHELOR OF ENGINEERING

IN

MECHANICAL ENGINEERING

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SANGIVALASA, VISAKHAPATNAM – 531162

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CERTIFICATE

This is to certify that the Project Report entitled **"EFFECT OF MULTI WALLED CARBON NANO TUBE REINFORCEMENTS ON MECHANICAL PROPERTIES OF HYBRID (ARAMID/CARBON) FIBER COMPOSITE"** being submitted by BANISETTY VINAY (317126520122), THIPPAGUDISA VINAY BABU (318126520L27), SYED ABDUL KALEEM (317126520174), GEDDA CHANDRA SEKHARA NAIDU (317126520131), PUKKALLA SRINIVASA RAO (317126520164) in partial fulfillments for the award of degree of **BACHELOR OF TECHNOLOGY** in **MECHANICAL ENGINEERING, ANITS**. It is the work of bona-fide, carried out under the guidance and supervision of **MR.K. NARESH KUMAR**, Assistant Professor, Department Of Mechanical Engineering, ANITS during the academic year of 2017-2021.

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DECLARATION

We, the undersigned, hereby declare that this "**Experimentation"** under the title of **"Effect of Multi-Walled Carbon Nanotube Reinforcements On Mechanical Properties of Hybrid (carbon/aramid) Fiber Composite" s**ubmitted by me for the award of Degree of "**Bachelor of Technology**" in Mechanical Engineering at ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY & SCIENCES (A), Visakhapatnam, is a record of original research work carried out by us. This work has not been submitted to any University or Institution in India or abroad, for the award of any degree

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We present this report on **"Effect of Multi walled Carbon Nano Tube reinforcements on Mechanical properties of hybrid (Aramid/Carbon) Fiber composite"** in the partial fulfillment of the requirement for the award of BACHELOR OF ENGINEERING in MECHANICAL ENGINEERING.

We intend to express our thanks with sincere obedience to **Prof. T. V.Hanumantha Rao,** Principal, ANITS and **Prof. B. Naga Raju,** Head of the Department, Mechanical Engineering, ANITS for providing this opportunity to express our deep and sincere thanks to our esteemed guide **Dr. K. Naresh Kumar,** Assistant Professor, Mechanical Engineering Department, ANITS, A source of constant motivation and best critic, for his inspiring and infusing ideas in getting our project done successfully.

Lastly we are grateful to one and all who have contributed either directly or indirectly in the completion of the project.

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ABSTRACT

Aramid fiber reinforced composites are widely used in ballistic protection in marine applications. The components such as bullet proof vests, helmets, rigid vehicles and all type of cable reinforcements are manufactured by using aramid fiber reinforced composites. Where as carbon fiber composites are being used in aerospace, sports equipment, automobiles etc because of its outstanding mechanical and tribological properties. In this work, an attempt was made in this work to study the combined behaviour of these two fibers with polymer matrix epoxy resin. A die of size 25cm x 25cm x1.2 cm is made using wood material and external side supports are made by using mild steel. Four composite sheets (HY1, HY2, HY3, HY4) are fabricated by varying the content of MWCNT from (0.1% to 0.4%). The content of carbon 5 wt% and aramid 5 wt% are taken in equal ratio i.e. (2 aramid sheets are combined with 5 carbon sheets). The content of Polymer matrix epoxy resin is taken as 89%. Fabrication was done using hand lay up method. The specimens are cut according to ASTM standards to evaluate mechanical and properties of the composites. It was observed from mechanical properties results that, HY3 (Hybrid fiber reinforced composite with 0.3wt% multi walled carbon nano tubes) exhibited better mechanical properties compared to other formulations of materials.

Key Words: Aramid fiber, Carbon fiber, Epoxy Resin, Multi walled Carbon nanotubes, Mechanical Properties.

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INTRODUCTION

INTRODUCTION

1.1 History of composite materials

The first uses of composites date back to the 1500s B.C. when early Egyptians and Mesopotamian settlers used a mixture of mud and straw to create strong and durable buildings. Straw continued to provide reinforcement to ancient composite products including pottery and boats. Later, in 1200 AD, the Mongols invented the first composite bow. Using a combination of wood, bone, and “animal glue,” bows were pressed and wrapped with birch bark. These bows were extremely powerful and extremely accurate. Composite Mongolian bows provided Genghis Khan with military dominance, and because of the composite technology, this weapon was the most powerful weapon on earth until the invention of gunpowder. The modern era of composites did not begin until scientists developed plastics. Until then, natural resins derived from plants and animals were the only source of glues and binders. In the early 1900s, plastics such as vinyl, polystyrene, phenolic and polyester were developed. These new synthetic materials outperformed resins that were derived from nature. However, plastics alone could not provide enough strength for structural applications. Reinforcement was needed to provide the strength, and rigidity. In 1935, Owens Corning introduced the first glass fiber, fiber glass. Fiber glass, when combined with a plastic polymer creates an incredibly strong structure that is also lightweight. This is the beginning of the Fiber Reinforced Polymers (FRP) industry as we know it today.

1.2 Scope of the composite material

Over the last four decades, Composite materials technology has experienced a rapid development. Steel fiber reinforced polymer composite materials have been recently introduced as an alternative to conventional glass and carbon fiber reinforced polymer composites. Further the research activities aimed to expand the applications in composite industry must be addressed to improve manufacturing composite technology through a better integration of product and process design, to develop a new constituent material. The focus of this research work was on the characterization of hybrid composite material, but still there exists thrust areas where the scope can be extended in future.

- Hybrid sandwich composite can also be a thrust area for investigating the mechanical and damage behavior of composites.
- Effect of environment on the mechanical and fracture behavior may be taken up to study the response of hybrid composite materials under various corrosive environments.
- Investigations with respect to varied stacking sequence can also be taken up to characterize the mechanical behavior of hybrid composite material.

Today, composites research attracts grants from governments, manufacturers and universities. Two applications that continue to experience innovative growth are airplane composite materials and composite sheets for marine use. Other materials such as environmentally-friendly resins incorporating recycled plastics and bio-based polymers meet the demand for stronger, lighter and environmentally friendly products.

1.3 Introduction to composite materials

A typical composite material is a system of materials composing of two or more materials (mixed and bonded) on a macroscopic scale. For example, concrete is made up of cement, sand, stones, and water. If the composition occurs on a microscopic scale (molecular level), the new material is then called an alloy for metals or a polymer for plastics. Generally, a composite material is composed of reinforcement (fibers, particles, flakes, and/or fillers) embedded in a matrix (polymers, metals, or ceramics). The matrix holds the reinforcement to form the desired shape while the reinforcement improves the overall mechanical properties of the matrix. When designed properly, the new combined material exhibits better strength than would each individual material.

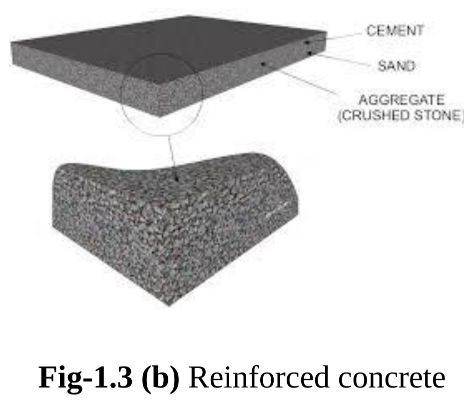


Fig-1.3 (a) Wood

Fig-1.3 (b) Reinforced concrete

Other matrix materials can be used and composites may also contain fillers or nano-materials such as graphene. The many component materials and different processes that can be used make composites extremely versatile and efficient. They typically result in lighter, stronger, more durable solutions compared to traditional materials.

1.3.1 Characteristics of composites

Composites, known also as fiber-reinforced plastics (FRP), are defined as materials which are a combination of reinforcements and matrix. Neither of these are well suited for construction purposes on their own, but when combined result in a very strong and rigid material. Composites can be divided roughly into two groups: synthetic materials reinforced with short fibers, and synthetic materials reinforced with long (continual) fibers. In fiber reinforced plastic materials, the properties of the fibers are used to resist tensile and compressive loads, while the plastic – the matrix material – transfers shear. Composite materials stand out through a wide diversity in their behaviors' born of an association of fibers and resin. The amount of fibers, the type of reinforcement and their fiber orientation are determining elements that may lead to materials with completely different characteristics.

Composites have the following characteristics :

i. Microscopically it is non-homogeneous material and has distinct surface interface. There are big differences in the performance of composite materials.
ii. The formed materials should have a great improvement in performance. Volume fraction of components is larger than 10%.
iii. Tensile strength of composites is four to six times greater than that of
iv. Conventional materials like steel, aluminium etc.
v. Improved torsion stiffness and impact properties.
vi. Higher fatigue endurance limit (up to 60% of the ultimate tensile strength)
vii. Composites are less noisy while in operation and provide lower vibration transmission.
viii. Composites are more versatile and can be tailored to meet performance needs and complex design requirements.

1.3.2 Classification of composites

The classification of composite materials is clearly explained in the form of a diagram.

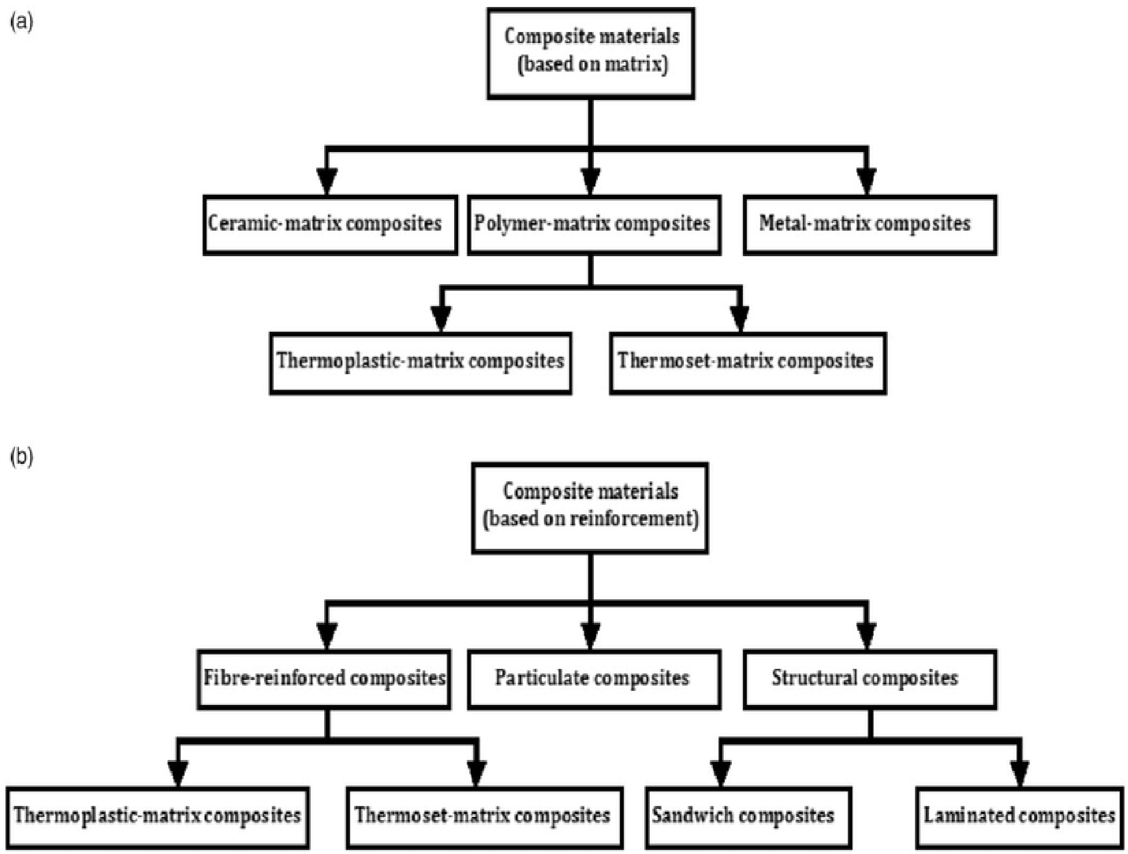


Fig 1.3.2 Classification of composites based on matrix and reinforcement

The composite materials are of numerous types, and classifications are done on the following basis:

Based on fiber reinforcement of the materials

a) Continuous-Fiber Reinforced composites

The fibers in a continuous fiber reinforced composite may not actually be "continuous" in the strictest definition of the word. In actuality they vary from as short as several feet in length to several thousand feet in length. Everything in this wide range is generally called continuous because the length of the fibers tends to be orders of magnitude larger than the width or thickness of the raw composite material. Raw continuous fiber composites can come in many forms (pultruded rods, woven mats, etc.), but we will concentrate on "tape". This tape can be thermoplastic or thermoset. It is created by impregnating the continuous fibers with the desired matrix and forming this combination into a thin, wide and long geometry. Continuous fiber composite tapes tend to be 0.005″ to 0.030″ thick, 0.063″ to several feet wide and up to several thousand feet long. The wide spools of tape are generally slit down to narrower widths for final processing. When continuous fibers are processed into the composite tape they are unidirectional and run longitudinally. In other words all of the fibers run in the long direction of the composite tape. As a group, continuous fiber reinforced composites tend to be more expensive than short or long fiber reinforced composites but offer significantly improved performance.

b) Short-Fiber Reinforced composites

Fiber reinforcement in thermoplastics has three basic forms; short fiber reinforcement, long fiber reinforcement and continuous fiber reinforcement. In general, with short fiber reinforcement, the fiber length is on the order of 100 times the fiber OD. Since most fibers are much smaller in diameter than a human hair, short fibers look more like powder to the unassisted eye. Short fiber reinforced thermoplastics tends to be manufactured by mixing the fibers into the molten thermoplastic. The fiber length and random orientation within the matrix make it relatively easy to achieve a good wet-out (i.e. completely encase all fibers with matrix) with this method. When compared to long and continuous fiber reinforcements, short fibers composites are the easiest to manufacture, but offer the smallest increase in mechanical properties. Short fiber composites tend to be formed into final parts with a molding and/or extrusion process. These processes require that the thermoplastic flow predictably to fill in molds and/or dies, and the short fibers do not interfere (much) with that process.

*B*ased on the constituent of matrix of the materials

a) Matrix constituent

I. Organic Matrix Composites: These consist of polymers and resins that have organic origins, and have thermosets and thermoplastics under their banner. They are very cheap to manufacture, and we can fine-tune the characteristics of these composites by carefully choosing (or even manufacturing) the component materials in the first place. This is something that other forms of composites do not offer.

II. Metal Matrix Composites: Although these are not as widely used as their plastic counterparts (which come under organic composites), they are widely known for their high strength, tensile nature, toughness and stiffness: something which organic matrix polymers do not possess. Since these are metals and have very high melting points, they can withstand high temperatures and sustain their shape under adverse conditions. They are resistant to corrosion and non-reactive in most cases (as opposed to the individual metals that form the components). Some common metal components used are Titanium, Magnesium and Aluminum, which have major applications in aerospace industry.

III. Ceramic Matrix Composites: Ceramics are usually sturdy solids that have strong ionic bonding, or in a few cases, strong covalent bonding as well. They have some very good properties such as very high melting point, superior corrosion resistance, stability and compressive strength in adverse situations, and the like. Thus, ceramics are materials which are preferred if the operating temperatures could get as high as 1500 degrees Celsius.

b) Reinforcements

The composites might need reinforcements, which could be fibers, or particles of fibers, or whiskers. Fibers are materials that have a thin and long structure, where one axis is long while other is circular or almost circular in nature. The following classifications are possible:

I. ***Fiber reinforced composites***: Fibers are very good components and transfer strength and other desirable properties to the composites. Fibers are not very ideal for use in composites, as the properties that they bring to the composite material can depend on their length, shape, orientation and composition, and these vary a lot. Especially, orientation of fibers can matter a lot in strength of the composite. During formative stages of the matrix, there can be some randomness and optimum strengths might not be reached.

II. ***Laminar composites***: These are present in “lamina”, that is, layers of material bonded together. They are used in clad and sandwich laminate formats, which have numerous applications.

III. ***Particulate reinforced composites***: These are microstructures of metal and ceramic composites, which have one phase of material strewn into another, to form numerous particles, which may have different shapes like triangle, square and the like. The dispersed size of these particles is of the order of few microns, and they can get in volumes of as much as 28%.

IV. ***Whiskers***: These are single crystals with almost no defects in their structure. They are not continuous, and are short in structure, and made from materials such as graphite, silicon carbide, and the like. The lengths of these whiskers is of the range of 3 to 55 nanometers. They have a length to width ratio greater than one, and therefore, are elongated, as opposed to the particles.

V. ***Flakes***: These can be used in place of fibers, and can usually be densely packed into the composite. They can provide numerous characteristics to the composite. Metal flakes can make the material conductive, while mica and glass flakes can make it highly resistive. Although these are very helpful, flakes can fall short in case of uniformity of the material. They can have differing shapes and sizes, and can have notches or cracks, etc.

VI. ***Filled composites***: They come by adding filler material to plastic components, to change the properties of the composite. They enhance the properties and reduce the weight as well, as they are simply filler materials that “fill” up the space.

VII. ***Cermets***: These are composites composed of ceramics and metals. They take up the best properties of each, such as high strength, high tolerance to temperature, better stability, and the like. They are usually used to manufacture resistors, capacitors and numerous electrical components that have specific properties, and might have to work under high temperatures. They are used in dentistry for filling the tooth cavities and the like, as well as in machining and cutting tools. They are somewhat pricier than the other composites.

VIII. ***Hybrids***: A composite can be stated as a hybrid when two or more type of fibers is used in a combined matrix to produce a composite that will reflect the benefit of each of the individual fiber used. This will finally provide a synergetic response to the whole structure. Such a composite of concrete is termed as the Hybrid Fiber Reinforced Concrete (HFC).

1.3.3 Advantages of composite materials

- Design Flexibility –Composites give designers nearly unlimited flexibility in designing shapes and forms. They be molded into the most intricate components and can be made a wide range of densities and chemical formulations to have precise performance properties.
- Low cost per cubic inch – When comparing costs based on volume, composites have lower material costs than traditional materials such as wood, engineered thermoplastics and metals. In addition, because composites have a low petroleum-based content, they are not subjected to the price fluctuations experienced in petroleum-based products.
- Lower material costs – Because composites can be precisely molded, there is little waste and therefore significantly lower overall material costs than metals products.
- Improved productivity – Industrial Designers and Engineers are able to reduce assembly costs by combining several previously assembles parts into a single component. Also, inserts can be molded directly into the part during the molding process thereby eliminating the need for a post-process. In addition, composites do not usually require additional machining, thereby reducing work-in-process and time to market.

Other key advantages of composites include:

a) Molded dimensional accuracy
b) Tight tolerance, repeatable moldings
c) Low-post mold shrinkage
d) Chemical Resistance
e) Consolidated Parts and Function
f) Corrosion Resistance
g) Design Flexibility
h) Durable
i) High Flexural Modulus to Carry Demanding Loads
j) High Impact Strength
k) High Performance at Elevated Temperatures
l) Heat Resistance, Molded-in Color,Molded in inserts
m) Outstanding Electrical Insulation,Arc and Track Resistance,Ability to Quench
n) Naturally Flame Retardant

o) Creep Resistance
p) Mechanical Property Retention
q) Superior Thermal Stability
r) Lighter Weight than Metal
s) Lower Costs vs. Die Cast
t) Low Petrochemical content
u) Better cost stability than commodities
v) Lower Cost per Cubic Inch as compared to Thermoplastics

1.3.4 Disadvantages of composite materials

- Perhaps the biggest disadvantage of composite materials for aircraft and component manufacturers is their higher initial cost compared with metals.
- The greater cost is largely due to the price of the fibers and the complicated process required to make the finished materials. It can be difficult to analyze the interior structure of a composite aircraft piece which has been damaged. The inspections are also difficult and more costly.
- One issue that comes up during inspections is delamination when layers of composites separate. The biggest cause of delamination is an impact to the composite piece. Water can infiltrate a piece that has experienced delamination, and the problem will get worse as the water freezes and thaws. Standard aircraft composite materials do not conduct electricity and so, unlike aluminum, cannot prevent lightning from being directed to a plane's fuel tanks. That problem was corrected for the 787 by incorporating wire mesh into the composite.
- Finally, the resin used in composite materials weakens at temperatures as low as 150 degrees Fahrenheit, and a temperature above 300 degrees might result in aircraft failure. When a composite material burns, they give off toxic fumes and micro-particles into the air, causing health risks. For all of those reasons, fire prevention is crucial on planes built with composites.

1.3.5 Applications of composite materials

Composites are used in a wide variety of markets, including aerospace, architecture, automotive, energy, infrastructure, marine, military, and sports and recreation. Each year, fiber-reinforced polymer composites (FRPs) find their way into hundreds of new applications, from golf clubs and tennis rackets to jet skis, aircraft, missiles and spacecraft. FRPs offer designers an increasing array of potential uses as a material and system solution.

- Aerospace

  Major OEMs such as Airbus and Boeing have shown the potential for large-scale composite applications in aviation, and NASA is continually looking to composites manufacturers for innovative space solutions for rockets and other spacecraft.
- Architecture

  The architecture community is experiencing substantial growth in the understanding and use of composites. Composites offer architects and designer performance and value in large-scale projects and their use is increasing in commercial and residential buildings.
- Energy

  New advancements in composites, particularly those from the U.S. Department of Energy, are redefining the energy industry. Composites help enable the use of wind and solar power and improve the efficiency of traditional energy suppliers.
- Automotive

  As the largest composites market, the automotive industry is no stranger to composites. Composites help make vehicles lighter and more fuel efficient.
- Infrastructure

  Composites are used all over the world to help construct and repair a wide variety of infrastructure applications, from buildings and bridges to roads and railways.
- Marine

  The marine industry uses composites to help make hulls lighter and more damage-resistant. Composites can be found in many more areas of a maritime vessel, including interior moldings and furniture on super yachts.
- Pipe & Tank

Fiber-reinforced polymer composite pipes are used for everything from sewer upgrades and wastewater projects to desalination, oil and gas applications. When corrosion becomes a problem with pipes made with traditional materials, FRP is a solution.

- Sports & Recreation

  From football helmets and hockey sticks to kayaks and bobsleds, carbon fiber and fiberglass composite materials help athletes reach their highest performance capabilities and provide durable, lightweight equipment.

- Transportation

  While FRP in cars gets most of the attention, composites can also play a big role in increasing fuel efficiency in trucks. A number of U.S. state Departments of Transportation are also using composite to reinforce the bridges those trucks travel on.

The future of the advanced composite materials is extremely bright. Aerospace and defense are just two of the many market segments that will see a large increase in the use of these materials. As time progresses, these weigh lighter, incredibly strong materials will dominate the materials used in almost any given industry.

(a)

(b)

Fig-1.3.5 Applications of composite materials

1.3.6 Fiber Reinforced Composite

Fiber-reinforced composites are composed of axial particulates embedded in a matrix material. The objective of fiber-reinforced composites is to obtain a material with high specific strength and high specific modulus. Hence, interfacial bonding is important. Classic examples of fiber-reinforced composites include fiberglass and wood.

Based on fiber geometry

Some common geometry for fiber-reinforced composites:

i) ***Aligned***

The properties of aligned fiber-reinforced composite materials are highly anisotropic. The longitudinal tensile strength will be high whereas the transverse tensile strength can be much less than even the matrix tensile strength. It will depend on the properties of the fibers and the matrix, the interfacial bond between them, and the presence of voids.

There are two different geometries for aligned fibers:

a) **Continuous and aligned:** The fibers are longer than a critical length which is the minimum length necessary such that the entire load is transmitted from the matrix to the fibers. If they are shorter than this critical length, only some of the load is transmitted. Fiber lengths greater than 15 times the critical length are considered optimal. Aligned and continuous fibers give the most effective strengthening for fiber composites.

b) **Discontinuous and aligned:** The fibers are shorter than the critical length. Hence discontinuous fibers are less effective in strengthening the material, however, their composite modulus and tensile strengths can approach 50-90% of their continuous and aligned counterparts. And they are cheaper, faster and easier to fabricate into complicated shapes.

c) **Random:** This is also called discrete (chopped) fibers. The strength will not be as high as with aligned fibers, however, the advantage is that the material will be isotropic and cheaper.

d) **Woven**

The fiber are woven into a fabric which is layered with the matrix material to make a laminated structure.

A variety of moulding methods can be used according to the end-item design requirements. The principal factors impacting the methodology are the natures of the chosen matrix and reinforcement materials. Another important factor is the gross quantity of material to be produced. Large quantities can be used to justify high capital expenditures for rapid and automated manufacturing technology. Small production quantities are accommodated with lower capital expenditures but higher labour and tooling costs at a correspondingly slower rate.

Many commercially produced composites use a polymer matrix material often called a resin solution. There are many different polymers available depending upon the starting raw ingredients. There are several broad categories, each with numerous variations. The reinforcement materials are often fibers but also commonly ground minerals. The various methods described below have been developed to reduce the resin content of the final product, or the fiber content is increased. As a rule of thumb, lay up results in a product containing 60% resin and 40% fiber, whereas vacuum infusion gives a final product with 40% resin and 60% fiber content. The strength of the product is greatly dependent on this ratio.

Table-1.3.6 (a) Properties of various materials (Ref. B.D. Agarwal [2015])

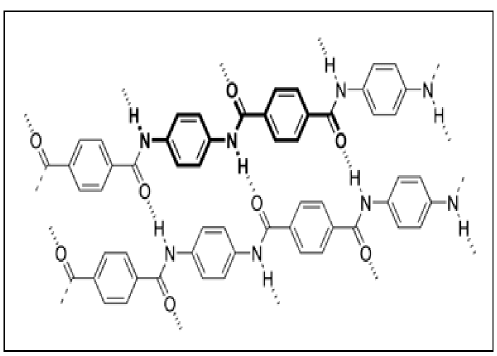
Material	Tensile modulus(E) [Gpa]	Tensile strength [Gpa]	Density(p) [g/cm3]	specific Modulus (E/p)	Specific strength (σ_u/ρ)
E-glass	72.4	3.5	2.54	28.5	1.38
S-glass	85.5	4.6	2.48	34.5	1.85
Graphite (High modulus)	390	2.1	1.9	205	1.1
Graphite (High tensile strength)	240	2.5	1.9	126	1.3
Boron	385	2.8	2.63	146	1.1
Silica	72.4	5.8	2.19	33	2.65
Tungsten	414	4.2	19.3	21	0.22
Beryllium	240	1.3	1.83	131	0.71
Kevlar49 (Aramid fiber)	130	2.8	1.5	87	1.87

Table-1.3.6(b) Properties of various conventional materials (Ref. B.D.Agarwal [2015])

Conventional material	Tensile modulus(E) [Gpa]	Tensile strength [GPa]	Density(p) [g/cm3]	Specific modulus (E/p)	Specific strength (σ_u/ρ)
Steel	210	0.34-2.1	7.8	26.9	0.043-0.2
Aluminium alloys	70	0.14-0.62	2.7	25.9	0.052-0.2
Glass	70	0.7-2.1	2.5	28	0.28-0.8
Tungsten	350	1.1-4.1	19.3	18.1	0.057-0.2
Beryllium	300	0.7	1.83	164	0.38

1.4 Aramid Fiber

Aramid fibers are a class of heat-resistant and strong synthetic fibers. They are used in aerospace and military applications, for ballistic-rated body armor fabric and ballistic composites, in bicycle tires, marine cordage, marine hull reinforcement, and as an asbestos substitute. The name is a portmanteau of "aromatic polyamide". The chain molecules in the fibers are highly oriented along the fiber axis. As a result, a higher proportion of the chemical bond contributes more to fiber strength than in many other synthetic fibers. Aramids have a very high melting point (>500 °C). Aramid fiber is a man-made organic polymer (an aromatic polyamide) produced by spinning a solid fiber from a liquid chemical blend. The bright golden yellow filaments produced can have a range of properties, but all have high strength and low density giving very high specific strength. All grades have good resistance to impact, and lower modulus grades are used extensively in ballistic applications. Compressive strength however is only similar to that of E glass. Although most commonly known under its Dupont trade name 'Kevlar', there are now a number of suppliers of the fiber, most notably Akzo Nobel with 'Twaron'. Each supplier offers several grades of aramid with various combinations of modulus and surface finish to suit various applications. As well as the high strength properties, the fibers also offer good resistance to abrasion, and chemical and thermal degradation. However, the fiber can degrade slowly when exposed to ultraviolet light.



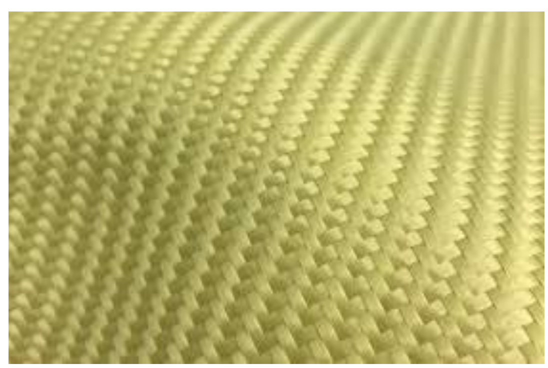


Fig-1.4(a) Structure of Twaron and Kevlar

Fig-1.4(b) Aramid fiber sheet

1.4.1 History of aramid fiber

Aromatic polyamides were first introduced in commercial applications in the early 1960s, with a meta-aramid fiber produced by DuPont as HT-1 and then under the trade name Nomex. This fiber, which handles similarly to normal textile apparel fibers, is characterized by its excellent resistance to heat, as it neither melts nor ignites in normal levels of oxygen. It is used extensively in the production of protective apparel, air filtration, thermal and electrical insulation, as well as a substitute for asbestos. Meta-aramid is also produced in the Netherlands and Japan by Teijin Aramid under the trade name Teijinconex in Korea by Toray under the trade name Arawin, in China by Yantai Tayho under the trade name New Star, by SRO Group (China) under the trade name X-Fiber, and a variant of meta-aramid in France by Kermel under the trade name Kermel. Based on earlier research by Monsanto Company and Bayer, para-aramid fiber with much higher tenacity and elastic modulus was also developed in the 1960s and 1970s by DuPont and AkzoNobel, both profiting from their knowledge of rayon, polyester and nylon processing. In 1973 DuPont was the first company to introduce a para-aramid fiber, which it called Kevlar, to the market; this remains one of the best-known para-aramids and/or aramids. In 1978, Akzo introduced a similar fiber with roughly the same chemical structure, which it called Twaron. Due to earlier patents on the production process, Akzo and DuPont engaged in a patent dispute in the 1980s. Twaron subsequently came under the ownership of the Teijin Company. In 2011, Yantai Tayho introduced similar fiber which is called Taparan in China. Para-aramids are used in many high-tech applications, such as aerospace and military applications, for "bullet-proof" body armor fabric. Both meta-aramid and para-aramid fiber can be used to make aramid paper. Aramid paper can be used as electrical insulation materials and construction materials to make honeycomb core. Dupont made aramid paper in 1960s, which is called Nomex paper. Yantai Metastar Special Paper introduced aramid paper in 2007, which is called metastar paper. Both Dupont and Yantai Metastar can make meta-aramid and para-aramid paper.

The Federal Trade Commission definition for aramid fiber is: A fiber manufactured in which the fiber-forming substance is a long-chain synthetic polyamide in which at least 85% of the amide linkages, (−CO−NH−) are attached directly to two aromatic rings.

1.4.2 Applications of aramid fiber

Aramid fiber applications are divided into two categories:

A) Reinforcement in composites like sport goods, aircraft, military vehicles and many other.

B) Fabrics in clothing such as fire protection clothes or bullet proof vests. More elaborative uses of aramid are:

a) Various forms of composite materials
b) Sail cloth
c) Snowboards
d) Protective gloves, helmets, body armor
e) Filament wound pressure vessels
f) Flame and cut resistant clothing
g) Asbestos replacement
h) Ropes and cables
i) Optical fiber cable systems
j) Jet engine enclosures
k) Tennis strings and hokey sticks
l) Wind instrument reeds
m) Reinforcement for tyres and rubber goods
n) Circuit board reinforcement
o) Ballistic protective applications such as bullet proof vests
p) Protective apparel such as gloves, motorcycle protective clothing and hunting gaitors, chaps and pants.
q) Sails for sailboats, yachts etc
r) Belts and hosing for industrial and automotive applications
s) Aircraft body parts
t) Boat hulls
u) Fiber optic and electromechanical cables
v) Friction linings such as clutch plates and brake pads

w) Gaskets for high temperature and pressure applications

x) Adhesives and sealants

y) Although every application meets its own requirements, almost all of them share aramid's major characteristics: high strength, high modulus, high toughness, thermal dimensionality stability, low creep and light weight.

(a) (b)

(c)

Fig-1.4.2(a-c) Application of Aramid fibers in various industries

1.4.2.1 Remaining applications of aramid fiber

- The market for aramid fiber is expected to witness a CAGR of over 5% during the forecast period. Major factor driving the market studied is the increasing demand from the aerospace sector. On the flipside, the availability of alternatives with better properties is expected to hinder the growth of the market studied.
- The aerospace and defense sector dominated the aramid fibers market and is expected to grow at a fastest rate during the forecast period.
- Emerging applications in the optical fiber industry are likely to act as an opportunity in the future.
- Europe dominated the global aramid fiber market followed by North America and Asia-Pacific worldwide, with the largest consumption coming from countries, such as United States, Germany, and the United Kingdom, among others.

1.4.3 Types of aramid fibers

There are two main types of aramid fiber

1. Meta- aramid
2. Para- aramid

The term meta and para refers to the location of chemical bonds in the structure of aramid fibers. The chemical bonds of a para-aramid fibers are more aligned in the long direction of the fibers. The meta-aramid fibers are not aligned they are in zigzag pattern.

1. Meta-aramid: Fibers made from the meta aramid have the excellent thermal, chemical and radiation resistance and are make the fire retardant textiles such as outer wear for fire fighters and racing car drivers. Nomex and teijiconex are examples of meta aramids.
2. Para-aramid: Fibers which are made from the para-aramid have higher strength. These are more commonly used in fibers reinforcement plastics for civil engineering structures, Stress skin panels, and other highly tensile strength applications. Ex: Kevlar and technora

1.4.4 Different trade name of aramid fibers

Aramid fibers are available with different trade names. There properties are determined by the manufacturing process, conditions in which fibers are prepared and end uses. Different trade names of aramid fibers are Kevlar, Technora, Tawron, Nomex etc. (Aramid Fibers, trade names).

Table 1.4.4 Typical properties of aramid fibers

Property [Units]	**Kevlar 29**	**Kevlar 49**	**Kevlar 129**	**Kevlar 149**
Diameter [µm]	12	12	----	----
Density [g/cm3]	1.44	1.44	1.44	1.44
Tensile strength[Mpa]	2760	3620	3380	3440
Tensile modulus [Gpa]	62	124	96	186
Elongation [%]	3.4	2.8	3.3	2.5
Coefficient of thermal expansion (0-100°C), (m/m/°C) In axial direction In radial direction	 -2×10^{-6} 60×10^{-6}	 -2×10^{-6} 60×10^{-6}	 -2×10^{-6} ------	 -2×10^{-6} ------

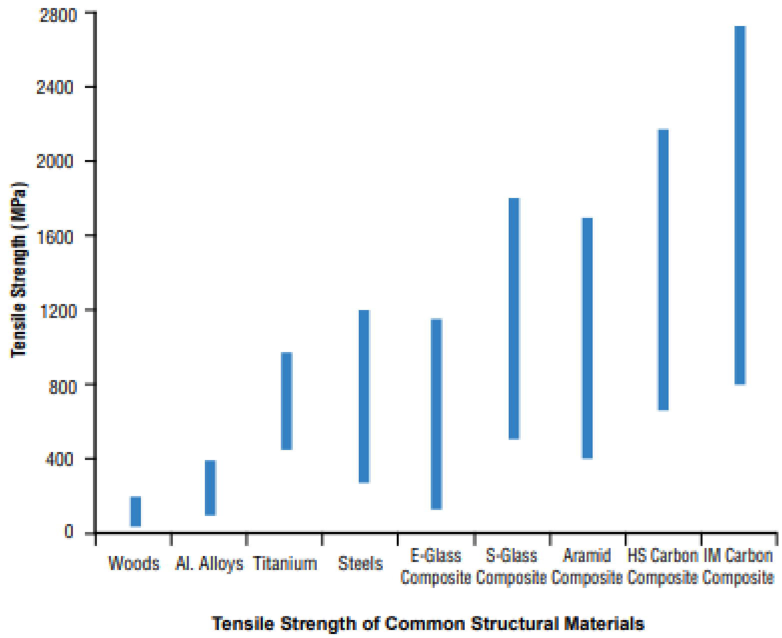


Fig1.4.4 (a) Comparison of tensile strengths of different materials(Ref Guide to Composites)

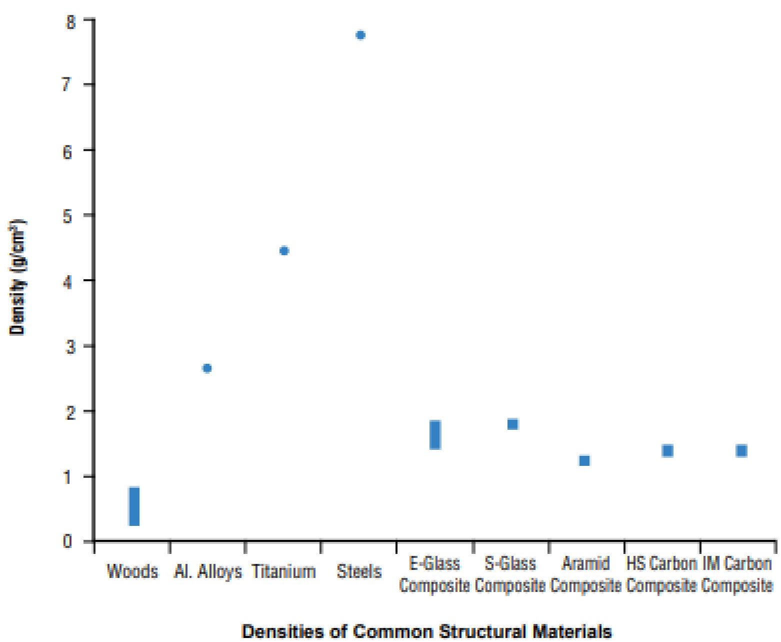


Fig1.4.4 (b) Comparison of densities of different materials (Ref Guide to Composites)

The above figures clearly show the range of properties that different composite materials can display. These properties can best be summed up as high strengths and stiffnesses combined with low densities. It is these properties that give rise to the characteristic high strength and stiffness to weight ratios that make composite structures ideal for so many applications. This is particularly true of applications which involve movement, such as cars, trains and aircraft, since lighter structures in such applications play a significant part in making these applications more efficient.

The strength and stiffness to weight ratio of composite materials can best be illustrated by the following graphs that plot 'specific' properties. These are simply the result of dividing the mechanical properties of a material by its density. Generally, the properties at the higher end of the ranges illustrated in the previous graphs are produced from the highest density variant of the material.

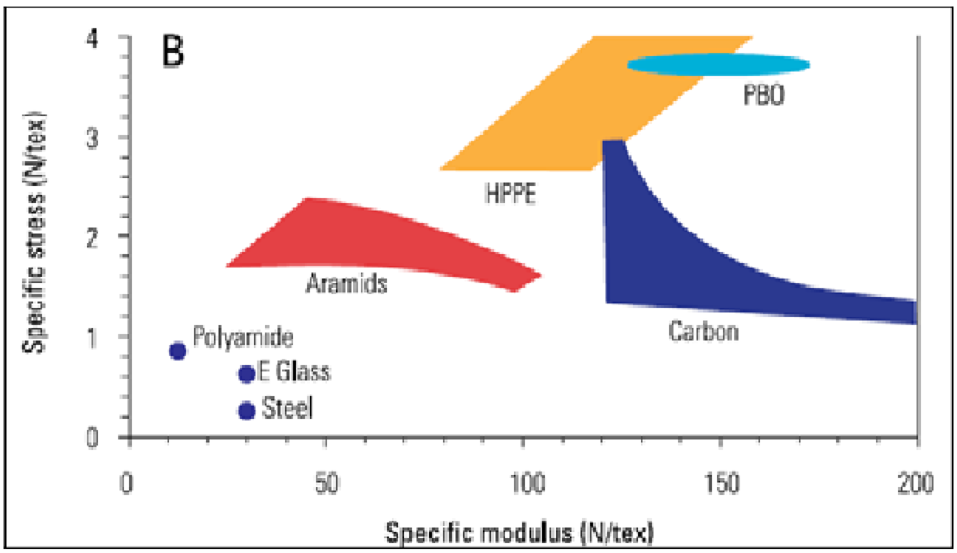


Fig-1.4.4(c) Comparison of Strength and modulus of different fibers (Ref Research gate)

1.4.5 Properties of aramid fibers

I. Fiber structure : A series of synthetic polymers in which repeating units containing large phenyl rings are linked together by amide groups. Amide groups (CO-NH) form strong bonds that are resistant to solvents and heat. Phenyl rings (or aromatic rings) are bulky six-sided groups of carbon and hydrogen atoms that prevent polymer chains from rotating and twisting around their chemical bonds.

II. Fiber properties: They are characterized by medium to ultra-high strength, medium to low elongation and moderately high to ultra-high modulus with the densities ranging from 1.38g/cm3 to 1.47g/cm3. Heat-resistant and flame-resistant aramid fibers contain high proportion or meta-oriented phenylene rings, whereas ultra-high strength high-modulus fibers contain mainly para-oriented phenylene rings.

III. Chemical properties: All aramids contain amide links that are hydrophilic. However, not all aramid products absorb moisture the same. The PPD-T (poly-phenylene terephthalamide) fiber has very good resistance to many organic solvents and salt, but strong acids can cause substantial loss of strength. Aramid fibers are difficult to dye due to their high Tg. Also, the aromatic nature of para-aramid is responsible for oxidative reactions when exposed to UV light, that leads to a change in color and loss of some strength.

IV. Thermal properties: Aramid fibers do not melt in the conventional sense but decompose simultaneously. They burn only with difficulty because of Limited Oxygen Index (LOI) values. It should be mentioned that at 300 degrees Celcius some aramid types can still retain about 50% of their strength. Aramids show high crystallinity which results in negligible shrinkage at high temperature.

V. Mechanical properties: Aramid yarn has a breaking tenacity of 3045 MPa, in other words more than 5 times than this of steel (under water, aramid is 4 times stronger) and twice than this of glass fiber or nylon. High strength is a result of its aromatic and amide group and high crystallinity. Aramid retains strength and modulus at temperatures as high as 300 degrees Celcius. It behaves elastically under tension. When it comes to severe bending, it shows non-linear plastic deformation. With tension fatigue, no failure is observed even at impressively high loads and cycle times. Creep strain for aramid is only 0.3%.

To sum up, aramid general characteristics are:

- High strength
- Resistance to absorption
- Resistance to organic solvent, good chemical resistance
- No conductivity
- No melting point
- Low flammability
- Excellent heat, and cut resistance
- Sensitive to acids and ultraviolet radiation

Aramid fibers also have outstanding mechanical properties. This includes a high strength-to-weight ratio outstanding abrasion resistance and tenacity.

Table-1.4.5 Mechanical properties of various fibers [Ref B.D.Agarwal Analysis of fiber composites]

Item	Material	Matrix	Fiber Weight Fraction	Laminate Specific Gravity	Tensile Strength lb/in^2	Tensile modulus lb/in^2 x 10^6	Specific Tensile Strength	Specific Tensile Modulus	Compressive Strength lb/in^2	Compressive Modulus lb/in^2 x 10^6
1	E-glass mat	Polyester	0.29	1.42	12,050	0.87	8,486	0.61	16,675	0.81
2	E-glass mat	Polyester	0.33	1.44	13,630	1.08	9,465	0.75	17,690	1.04
3	E-glass W.R.	Polyester	0.50	1.63	27,550	1.99	16,902	1.22	21,750	2.03
4	S-glass W.R.	Polyester	0.50	1.64	63,800	2.90	38,902	1.77	30,450	–
5	Aramid K49, woven	Polyester	0.44	1.31	62,350	3.77	47,595	2.88	16,675	2.36
6	Carbon fiber, woven	Polyester	0.40	1.40	66,700	4.35	47,643	3.11	–	–
7	Aramid K49, woven	Epoxy	0.55	1.31	65,250	4.35	49,810	3.32	24,940	–
8	Carbon fiber, woven	Epoxy	0.59	1.47	79,750	7.98	54,250	5.43	52,200	–
9	K49/ E-glass hybrid (C72/K200)	Polyester	0.40	1.46	34,800	1.81	23,835	1.24	24,650	2.14
10	K49/ E-glass hybrid (C77K/200)	Polyester	0.45	1.49	36,400	2.05	24,430	1.38	22,185	2.29
11	Kevlar 49 (1350)	Polyester	0.42	1.293	53,850	2.80	–	–	16,675	2.60
12	Kevlar 49 (1350S, Twill weave)	Polyester	0.42	1.30	55,610	3.47	–	–	16,460	2.80
13	Aramid 900S (Twill weave)	Polyester	0.48	1.294	64,165	3.86	–	–	14,865	2.80
14	E-glass cloth, woven	Polyester	0.56	1.71	48,285	2.20	28,237	1.29	–	–
15	K49/E-glass hybrid (no mat)	Polyester	0.44	1.50	42,780	2.42	28,520	1.61	–	–

1.4.6 Production of aramid fiber

Aramid fiber is a man-made organic polymer (an aromatic polyamide) produced by spinning a solid fiber from a liquid chemical blend. The bright golden yellow filaments produced can have a range of properties, but all have high strength and low density giving very high specific strength. All grades have good resistance to impact, and lower modulus grades are used extensively in ballistic applications. Compressive strength, however, is only similar to that of E glass. The polymer poly-metaphenyleneisophthalamide is used to make meta- aramids and the polymer p-phenyleneterephthalamide to make para-aramids. Because the aramids decompose before they melt they are produced by wet and dry spinning methods. Sulphuric acid is the normal solvent used in the spinning processes. In wet spinning a strong solution of the polymer, which also contains inorganic salts, is spun through a spinneret into weak acid or water. In this bath the salts leach out. In the dry spinning process the salts are more difficult to remove and this process is only used to produce the weaker meta-aramid fibers. In both processes post treatment of the fibers by additional drawing is used to optimize fiber properties. Aramid products are available as filament yarn, staple fiber or pulp.

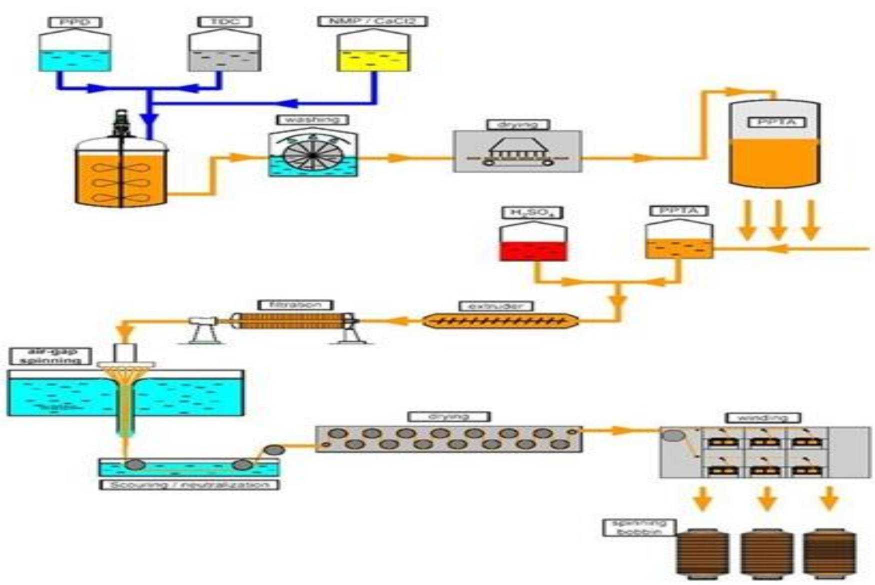


Fig 1.4.6 Aramid fiber production process (Ref textile leaner. BlogSpot)

1.4.7 Fabrication methods of aramid fiber

Aramid and Kevlar fibers are compatible or can be used with many types of resin systems. The best choice of resin system is epoxy as it adheres best to the fiber surface. Vinyl ester, and isophthalic polyester may also be used. Orthopthalic polyester should be avoided as it does not provide sufficient adhesion to the fiber.

- Hand Lay-up: Lay-up is performed in the following steps: Pigmented gel coat is first applied by brush or spray. After gel coating, a thin coat of resin (usually polyester) and a thin layer of reinforcement are placed on, and worked by hand with brushes and rollers, so the resin fully impregnates the fabric. Other layers (usually chopped strand mat) follow, until the desired thickness and strength are achieved. After cure, the component is pulled out of the mold (or released) and trimmed. Post-curing at elevated temperatures in or out of the mold may also take place. The mold is cleaned, re-released (if no multiple release agent is used) and returned to use.
- Vacuum Bagging: The previous process can be greatly improved by vacuum bagging, with a small increase in capital investment. The gel coat and impregnating procedure is the same, but before cure, the component is sealed on the mold under a vacuum bag. The air is drawn and the component is compressed by the atmospheric pressure against the mold surface by the vacuum bag (serving as the "upper tool".)
- Vacuum Infusion: Similar to vacuum bagging, with the difference that reinforcement is laid on the mold dry. The mold and the reinforcement are sealed and vacuum is drawn from one side. Once air-tightness is assured resin and hardener are mixed and introduced in the dry reinforcement by the sucking power of vacuum. A special "flow fabric" and network of "spiral tube" facilitate the procedure and make sure that resin travels fast everywhere in the mold cavity, and fully impregnates all the layers or dry reinforcement.
- RTM (Resin Transfer Moulding): Sometimes called injection molding, this capital intensive process employs a coupling (male and a female) metal mold that is heated. The reinforcement is cut with precision and placed in the mold cavity. Usually instead of laying the pieces of reinforcement fabric one by one, a preform is used (many different layers of reinforcement are pre-cut and held together in particular pattern, according to the shape of the mold, with the help of a "binder". This way loading the reinforcement in the mold can

be done with one move.) After loading the reinforcement the two matching molds are closed tightly and catalyzed resin is pressed inside through the carefully positioned openings or injection “gates”. The air is expelled through other carefully positioned openings, the “vents”, and the reinforcement is saturated. The whole process can be assisted by vacuum (Vacuum Assisted RTM.)

- RTM light : This process is a conjunction of RTM and resin infusion. Like RTM we have two matching molds, but here they are made out of composites. Usually upper one is thinner and more flexible than the lower. The two molds are closed (or sealed) air tightly by vacuum pressure alone or vacuum and other mechanical claming. Catalyzed resin is pressed inside the mold. Injection pressure is much lower that in RTM, where metal molds are used. Heat may be applied, but usually, again, much lower than in RTM.
- Press molding: Like RTM, two matching metal molds are heated. Instead of dry reinforcement, prepregs or pre-impregnated preforms are used. Prepregs are fabrics that are pre-impregnated with resin (sometimes resin and fillers) and treated with temperature in such a way that are partially cured (the so called “B stage” of cure.) When reheated in hot press molding, the resin becomes liquid again, and finally cures.
- Filament winding: It is a capital-intensive process used mainly to manufacture small and large diameter tubing and pressure tanks in medium to high production volume. As the name implies, it involves the winding of continuous, pre-saturated reinforcing filaments around a rotating mandrel, until the whole surface is covered at the desired depth. The filaments are saturated as they pass through a resin bath just before they meet the mandrel. The winding, depending on the complexity of the machine, can be performed in two or more angles. Also, towpreg or pre-impregnated, B stage filament can be used (prepreg winding). After cure, at the final stage of production the mandrel has to be removed, usually with the help of a hydraulic extractor.
- Pultrusion: It is a sophisticated, continuous, high capital and material intensive process for the manufacture of composite profile. Unlike filament winding which mounts reinforcement in the transverse (or circumferential) direction of the mandrel, pultrusion places the primary reinforcement in the longitudinal direction. As a principle, it is similar to the production of aluminum profile (although aluminum extrusion is a pushing action.) It is performed by pulling continuous filaments together with chopped strand mat tapes

through a resin bath to a heated metal die cavity of the desired cross section and shape. This die serves as the mold and the curing oven at the same time.

1.4.8 Advantages of aramid composites

The mainadvantages of aramid fiber are

- High strength and low weight.
- Like graphite, it has a slightly negative axial coefficient of thermal expansion, which means aramid laminates can be made thermally stable in dimensions. Unlike graphite, it is very resistant to impact and abrasion damage.
- It can be made waterproof when combined with other materials like epoxy.
- It can be used as a composite with rubber retaining its flexibility.
- High tensile modulus and low breakage elongation combined with very good resistance to chemicals make it the right choice for different composite structural parts in various applications.

1.4.9 Disadvantages of aramid composites

On the other side, aramid has a few disadvantages. The fibers absorb moisture, so aramid composites are more sensitive to the environment than glass or graphite composites. For this reason, it must be combined with moisture resistant materials like epoxy systems. Compressive properties are relatively poor too. Consequently, aramid is not used in bridge building or wherever this kind of resistance is needed. Also, aramid fibers are difficult to cut and to grind without special equipment (e.g. special scissors for cutting, special drill bits). Finally, they suffer some corrosion and are degraded by UV light. For this reason they must be properly coated.

In this chapter , the history of aramid fiber composites are discussed initially and further the applications of aramid fiber composite in various industries are elaborated and the properties of aramid fiber are compared with other various materials. The production method for manufacturing of aramid fiber is explained. The advantages and disadvantages of aramid fiber are also discussed. In the next chapter, the detailed review carried in the research area of aramid fiber composites is explained and the scope of work is presented.

1.4.10 Carbon Fiber

Among the fiber-reinforced composites, carbon fiber (CF)-reinforced composites are used widely in the aerospace, automobile, sports, medical instrument, and construction industries as well as in the military because of their high mechanical properties, impact resistance, thermal resistance, chemical stability, and lightweight nature.

Carbon fibers about 5–10 micrometres in diameter and composed mostly of carbon atoms. Carbon fibers have several advantages including high stiffness, high tensile strength, low weight, high chemical resistance, high temperature tolerance and low thermal expansion. These properties have made carbon fiber very popular in aerospace, civil engineering, military, and motorsports, along with other competition sports. However, they are relatively expensive when compared with similar fibers, such as glass fibers or plastic fibers.

Carbon fiber is defined as a fiber containing at least 92 wt % carbon, while the fiber containing at least 99 wt % carbon is usually called a graphite fiber . Carbon fibers generally have excellent tensile properties, low densities, high thermal and chemical stabilities in the absence of oxidizing agents, good thermal and electrical conductivities, and excellent creep resistance. They have been extensively used in composites in the form of woven textiles, prepregs, continuous fibers/rovings, and chopped fibers. The composite parts can be produced through filament winding, tape winding, pultrusion, compression molding, vacuum bagging, liquid molding, and injection molding.

1.4.10.1 Classification and types of carbon fibre

Based on modulus, strength, and final heat treatment temperature, carbon fibers can be classified into the following categories:

a) **Based on carbon fiber properties, carbon fibers can be grouped into**:

- Ultra-high-modulus, type UHM (modulus >450Gpa)
- High-modulus, type HM (modulus between 350-450Gpa)
- Intermediate-modulus, type IM (modulus between 200-350Gpa)
- Low modulus and high-tensile, type HT (modulus < 100Gpa, tensile strength > 3.0Gpa)
- Super high-tensile, type SHT (tensile strength > 4.5Gpa)

b) Based on precursor fiber materials, carbon fibers are classified into:

- PAN-based carbon fibers
- Pitch-based carbon fibers
- Mesophase pitch-based carbon fibers
- Isotropic pitch-based carbon fibers
- Rayon-based carbon fibers
- Gas-phase-grown carbon fibers

c) Based on final heat treatment temperature, carbon fibers are classified into:

Type-I, high-heat-treatment carbon fibers (HTT), where final heat treatment temperature should be above 2000°C and can be associated with high-modulus type fiber.

Type-II, intermediate-heat-treatment carbon fibers (IHT), where final heat treatment temperature should be around or above 1500°C and can be associated with high-strength type fiber.

Type-III, low-heat-treatment carbon fibers, where final heat treatment temperatures not greater than 1000°C. These are low modulus and low strength materials.

1.4.11 Properties of carbon fibre:

Carbon Fiber has High Strength to Weight Ratio (also known as specific strength) Strength of a material is the force per unit area at failure, divided by its density. Any material that is strong AND light has a favourable Strength/weight ratio. Materials such as Aluminium, titanium, magnesium, Carbon and glass fiber, high strength steel alloys all have good strength to weight ratios.

(i) Carbon Fiber is very Rigid.

Rigidity or stiffness of a material is measured by its Young Modulus and measures how much a material deflects under stress. Carbon fiber reinforced plastic is over 4 times stiffer than Glass reinforced plastic, almost 20 times more than pine, 2.5 times greater than aluminium.

(ii) Carbon fiber is Corrosion Resistant and Chemically Stable.

Although carbon fiber themselves do not deteriorate, Epoxy is sensitive to sunlight and needs to be protected. Other matrices (whatever the carbon fiber is imbedded in) might also be reactive.

(iii) Carbon fiber is Electrically Conductive.

This feature can be useful and be a nuisance. In Boat building It has to be taken into account just as Aluminium conductivity comes into play. Carbon fiber conductivity can facilitate Galvanic Corrosion in fittings. Careful installation can reduce this problem.

(iv) Fatigue Resistance is good

Resistance to Fatigue in Carbon Fiber Composites is good. However when carbon fiber fails it usually fails catastrophically without much to announce its imminent break. Damage in tensile fatigue is seen as reduction in stiffness with larger numbers of stress cycles, (unless the temperature is hight) Test have shown that failure is unlikely to be a problem when cyclic stresses coincide with the fiber orientation. Carbon fiber is superior to E glass in fatigue and static strength as well as stiffness.

(v) Carbon Fiber has good Tensile Strength

Tensile strength or ultimate strength, is the maximum stress that a material can withstand while being stretched or pulled before necking, or failing. Necking is when the sample cross-section starts to significantly contract. If you take a strip of plastic bag, it will stretch and at one point will start getting narrow. This is necking. It is measured in Force per Unit area. Brittle materials such as carbon fiber does not always fail at the same stress level because of internal flaws. They fail at small strains.

(vi) Fire Resistance/Non Flamable

Depending upon the manufacturing process and the precursor material, carbon fiber can be quite soft and can be made into or more often integrated into protective clothing for firefighting. Nickel coated fiber is an example. Because carbon fiber is also chemically very inert, it can be used where there is fire combined with corrosive agents. Carbon Fiber Fire Blanket excuse the typos.

(vii) Thermal Conductivity of Carbon Fiber

Thermal conductivity is the quantity of heat transmitted through a unit thickness, in a direction normal to a surface of unit area, because of a unit temperature gradient, under steady conditions. In other words its a measure of how easily heat flows through a material.

Because there are many variations on the theme of carbon fiber it is not possible to pinpoint exactly the thermal conductivity. Special types of Carbon Fiber have been specifically designed for high or low thermal conductivity. There are also efforts to enhance this feature.

(viii) Low Coefficient of Thermal Expansion

This is a measure of how much a material expands and contracts when the temperature goes up or down. Units are in Inch / inch degree F, as in other tables, the units are not so important as the comparison. In a high enough mast differences in Coefficients of thermal expansion of various materials can slightly modify the rig tensions. Low Coefficient of Thermal expansion makes carbon fiber suitable for applications where small movements can be critical. Telescope and other optical machinery is one such applications.

Chapter 2

Literature Review

2.1 LITERATURE REVIEW

M.Goodarz, S.HajirBahrami, M.Sadighi et al 2019 provided a response of epoxy laminates containing nano-interlayers with different amounts of the thickness and various stacking configuration. The results show that the concept of incorporating nano fibers interfacial makes composite able to absorb significantly higher impact energy in comparison with laminates without any nanofibers. This also indicate that the limit of applicability of quasi-static analysis for the dynamic problem is also at this impact energy level.[1]

KyarikiGoulouti, Julia De Castro et al 2015 studies about the energetically weak points in thermally insulated building envelopes are formed by thermal breaks that are implemented to structurally connect external balconies to internal slabs. The study shows that the thermal and structural concept of a new highly insulated balcony thermal break is presented, together with the short and long-term experimental evaluation of the load-bearing prototype components.[2]

Seung Yoon On, Moo Sun Kim, SeongSu Kim et al 2017 studied about the mismatch in the coefficient of thermal expansion between adherends and adhesives is one of the main reasons for the fracture and failure of adhesive bonding structures. The post treated meta fiber mate exhibited an effectively, reduced CTF and increased adhesion strength. The results show that the post treatment methods for nano fiber reinforcement were introduced to enhance the strength of single lap adhesive joints.[3]

Lixin Xing, Liliu, Yudong Huang et al 2014 studied about scanning electron microscopy was employed to characterize the surface morphology of DAF12 (aramid fiber-12) and high energy irradiated fibers and composites de-bonding section. These changes investigated via X-ray Photoelectron spectrometer verified the increase polar groups on fiber surface caused by high energy irradiation. The studies shows that high energy irradiation onto DAF12 can improve the interface properties between fiber and epoxy resin. In addition, high energy irradiation can satisfy the needs of large low fiber surface treatment without any difficulty to treat interior fibers in bundles.[4]

M.Khafidh, D.J.Schipper, M.A.Masen et al 2019 worked on wear reduction of elastomers can be achieved by minimizing the propagation of cracks in the elastomer during sliding contact. The results shows that the coefficient of friction of the composites consists of different stages, these stages are influenced by the wear processes during sliding. A mechanism of wear process of shortcut aramid fiber reinforced elastomers and its relation to friction behaviours was proposed.[5]

Nannan Ni, Yuefang Wen, Delong He et al 2015 studied about the composite damping behaviours were experimentally investigated using single cantilever beam vibration test and dynamic mechanical analysis, and the influence of the aramid non woven fabrics interlayers on the composite mechanical properties was investigated.The research results indicated that the addition of ANF into the composites can significantly improve the damping properties through forming some resin zones with higher loss factor in the composites.[6]

E.Tapie, V.P.W.Shim, Y.B.Guo et al 2015 studied that aramid fibers are used in high performance fabrics and yarns for dynamic loading applications, because of their high strength and stiffness, and stiffness, and good energy absorption. It also explores the influence of the weaving process on the mechanical response of aramid yarns. The results show that the quasi static and dynamic tensile properties of vergin and woven TwaronTioyo were characterized and compared to examine the influence of weaving on the resulting mechanical properties.[7]

MulatAlubelAbtew, FrancoisBoussu, Pascal Bruiaux et al 2018 conducted research on mechanical and moulding properties of 2D woven and non woven fabrics. These also presents investigation of tensile, bonding and moulding behaviours of in orthogonal warp interlock fabrics with different fabric densities. The results show that four different types of 3D woven fabrics made of same fiber types but different fabric density were designed and manufactured using dobby weaving loom.[8]

M.M.Moure, I.Rubio, J.A.Loya et al 2011 analysed the behaviour of aramid composite plates subjected to low and medium impact energies. The results revealed that there is a greater energy absorption capacity in thin plate than in thick plate for low impact energy values.[9]

Xiangyu Xu, Boming Zhang, Liying Xing, Kai Liu, Ming Bai et al 2009 subjected the composites to microwave radiation of different power densities. The equilibrium temperature, power thresholds and damage morphologies of quasi isotropic laminates were compared. The obtained results indicate that for the same thickness the quasi isotropic laminates have better resistance to microscopic radiation as compared to unidirectional composites.[10]

Kazuto Tanaka, Kohji Minoshima, WitoldGrela, Kenjiro et al 2004 investigated concerning the influences of stress waveform and wet environment of the fatigue fracture behaviour of aramid single fiber. Fatigue tests were conducted under sinusoidal, negative pulse and positive pulse waveforms for the fiber preconditioned in laboratory air and wet air. The fatigue strength tested in wet air was lower than that in laboratory air, and the fatigue strength in laboratory air under negative pulse waveform was higher than those under two waveforms.[11]

KrystynaImielinska, Laurent Guillaunat et al 2004 worked on water immersion ageing followed by instrumental low velocity impact testing. The maximum water absorption and water diffusion coefficient were found to be only slightly affected by the absorbed water. Due to low fiber matrix adhesion the prevailing failures modes at low impact energy were fiber debonding and interfacial cracking.[12]

Kazuto Tanaka, Kohji Minoshima et al 2002 worked on single fiber pull out tests and investigated the influence of water absorption on the interfacial properties of aramid composite. The study shows that the fiber interfacial strength was severely decreased. The pulled-out fiber specimens were smooth. Insite observations of interfacial crack propagation by a video microscope and an analysis of acoustic emission(AE) signals showed that AE obtained during the pull-out process were classified according to fracture models.[13]

Pieter.J.de Lange, Peter.G.Akker, Edith Mader et al 2006 investigated the effect of oily finish components on the interphase strength of aramid epoxy composites.Variations in the macroscopic composite properties as a fraction of the amount of oil are very well predicted by micro mechanical adhesion results from single filament pull out measurements and Raman spectroscopy.[14]

X.Wang, B.thi, Y.Feng,F.Liang et al 2007 determined the effect of fiber arrangement in 3D woven hybrid composites in their low velocity impact properties, aramid basalt fibers and epoxy resin were used to fabricate interplay hybrid composite in which different layers and interply hybrid composite in which each layer was composed of two types of alternatively arranged yarns. The interply showed higher ductile indices, lower peak load and higher specific energy absorption in both wrap and weft directions.[15]

J. Parthenios, D.G. Katerelos, G.C. Psarras et al 2002 examined the use of aramid fibers as laser Raman stress/strain sensor in full composites . Three different case studies were investigated. The obtained strain profiles provide important information concerning the crack growth characteristics and the consequent strain transfer through the load-bearing elements, which are the glass fibers.[16]

Thomas Ø. Larsen , Tom L. Andersen , Bent Thorning et al 2007 performed tests on friction and wear properties of an epoxy resin (EP) reinforced by either a glass fiber weave (G/EP) or a carbon/aramid hybrid weave (CA/EP) . The coefficient of friction furthermore seems to be roughly independent of p and v. CA/EP shows superior wear behaviour at the six mildest pv conditions with the wear rate an average factor of 22 lower than the G/EP rates. At the three roughest pv conditions CA/EP shows complete failure, while G/EP shows a relatively steady tribological behavior despite decomposition and development of larger-scale cracks.[17]

D.H. Gordona, S.N. Kukurekaa, et al 2009 tested the Polyamide 4,6 (PA46) and its aramid fiber composites (6 wt.%, 12 wt.% and 15 wt.%) as candidate materials for tribological applications using a twin-disc wear test rig, built in our laboratories, to measure their wear and frictional properties under variations of number of cycles (103 to 106), applied load (300–600 N) and applied velocity (500, 1000 and 1500 rpm), all at a slip ratio of 2%.Over the range of tests, the average coefficient of friction results showed that the PA46 + 15% aramid fibers generally had the lowest values compared to the other types of samples; however they generally had the highest steady wear rates, especially at higher loads and velocities.[18]

Ha Na Yu, SeongSu Kim et al 2009 investigated the failure of large aramid/glass reinforced phenolic composite journal bearings for marine applications by the finite element method for stress analysis. The stress analysis results show that the maximum compressive stress in the hoop direction occurred at the groove for oil passage due to the interference fit amount. By adjusting the ratio of the two kinds of bearing materials and giving the optimal interference amount, the new design reduced the maximum compressive stress by 60% and the shear stress at the interface by 70% at 33^{o} C.[19]

O.A. Khondker*, T. Fukui, M. Inoda, A. Nakai, et al 2014 studied about aramid/nylon knitted composites as the 'one unity' composites, which were fabricated by varying molding time. Mechanical properties of aramid/nylon and aramid/epoxy composites were investigated. Tensile strength of the reinforcing aramid fiber decreased significantly with increasing time of heat exposure, whereas tensile modulus of aramid fiber was insensitive to heat exposing time.[20]

2.2 SCOPE OF THE WORK

Based on literature, it was observed that many researchers are worked on aramid fiber reinforced composites for sustaining high impact loading conditions and components requiring high thermal resistance such as in military applications. Many researchers worked on CF reinforced composites for many applications in industry and automobiles. In this work an attempt was made to study the behavior of hybrid fiber combining aramid and carbon in equal proportion with polymer matrix epoxy resin. The content of MWCNT inclusion in the hybrid fiber is taken as a challenge to study the mechanical properties of the composite. The content of MWCNT inclusions are varied from 0.1 to 0.4 wt% and the best ingredient wt% is observed from after performing mechanical properties evaluation for all the composite specimens. This ingredient of MWCMT along with hybrid fiber can have the possibility to use in advanced applications to improve strength of the composite.

Chapter-3

FABRICATION OF HYBRID FIBER REINFORCED COMPOSITES

FABRICATION OF HYBRID FIBER REINFORCED COMPOSITES

The materials that are used in fabrication of hybrid fiber reinforced composites and the process that was followed is discussed in this chapter.

3.1 Selection of materials required for fabrication

1. Aramid fiber
2. Cabon fiber
3. Epoxy resin with hardener and accelerator
4. Multi-walled carbon nano tubes

3.1.1 Aramid fiber

Aramid fiber is a man-made organic polymer (an aromatic polyamide) produced by spinning a solid fiber from a liquid chemical blend. The bright golden yellow filaments produced can have a range of properties, but all have high strength and low density giving very high specific strength. All grades have good resistance to impact, and lower modulus grades are used extensively in ballistic applications. Aramid fiber is purchased from Mumbai.

3.1.2 Carbon fiber

Carbon fibers about 5–10 micrometres in diameter and composed mostly of carbon atoms. Carbon fibers have several advantages including high stiffness, high tensile strength, low weight, high chemical resistance, high temperature tolerance and low thermal expansion. These properties have made carbon fiber very popular in aerospace, civil engineering, military, and motorsports, along with other competition sports. However, they are relatively expensive when compared with similar fibers, such as glass fibers or plastic fibers

3.1.3 Epoxy resin

Epoxy resins are polymeric or semi-polymeric materials whose applications are extensive and include coatings, adhesives and composite materials such as those using aramid fiber and fiber glass reinforcements. In general epoxies are known for their excellent adhesion, chemical and heat resistance, good-to-excellent mechanical properties and very good electrical insulating properties.

- **Hardener**

  Hardener is high viscous liquid material mixed with resin in suitable proportion during the process of preparation of composites which helps in the solidification of the wet, smooth composite. It is used to harden the smooth composite hence it is called as hardener.

- **Accelerator**

  Accelerator is a substance that increases the rate of a reaction by providing a low energy shortcut from reactants to products. In some cases, reactions occur so slowly that without a catalyst, they are of little value. Nearly all reactions that occur in living cells require catalysts called enzymes without them life would be impossible.

3.1.4 Multi-walled carbon nano tubes

Multi-walled carbon nano tubes (MWCNTs) are elongated cylindrical nano objects made of SP^2 aramid. Their diameter is 3–30 nm and they can grow several cm long, thus their aspect ratio can vary between 10 and ten million. They can be distinguished from single-walled aramid nano tubes on the basis of their multi-walled Russian-doll structure and rigidity, and from aramid nano fibers on the basis of their different wall structure, smaller outer diameter, and hollow interior.

3.2 Method of fabrication

There are different types of fabrication methods for hybrid fibers which can be seen in the first chapter.Thus, we selected the wet/hand lay-up method.

3.3 Wet/Hand lay-up

- Hand lay-up technique is the simplest and oldest open molding method of composite fabrication process.
- In this work the content of MWCNT is varied from (0.1 to 0.4 wt%) and keeping the remaining ingredients such as aramid fiber , carbon fiber and epoxy resin constant.
- Carbon fiber and aramid fiber content is taken in equal weight proportions.
- 2 sheets of aramid fiber is combined with 5 sheets of carbon fiber. The weight percentage of these fibers are taken as 10 wt%.Resin content is taken as 89% along with required quantity of accelerator and hardener
- After the preparation of composite sheets, the composite sheets are cured for 24 to 48 hrs. After curing and drying in outside atmosphere, the specimens were cut according to ASTM standards from each composite sheet to evaluate mechanical properties of the composite.

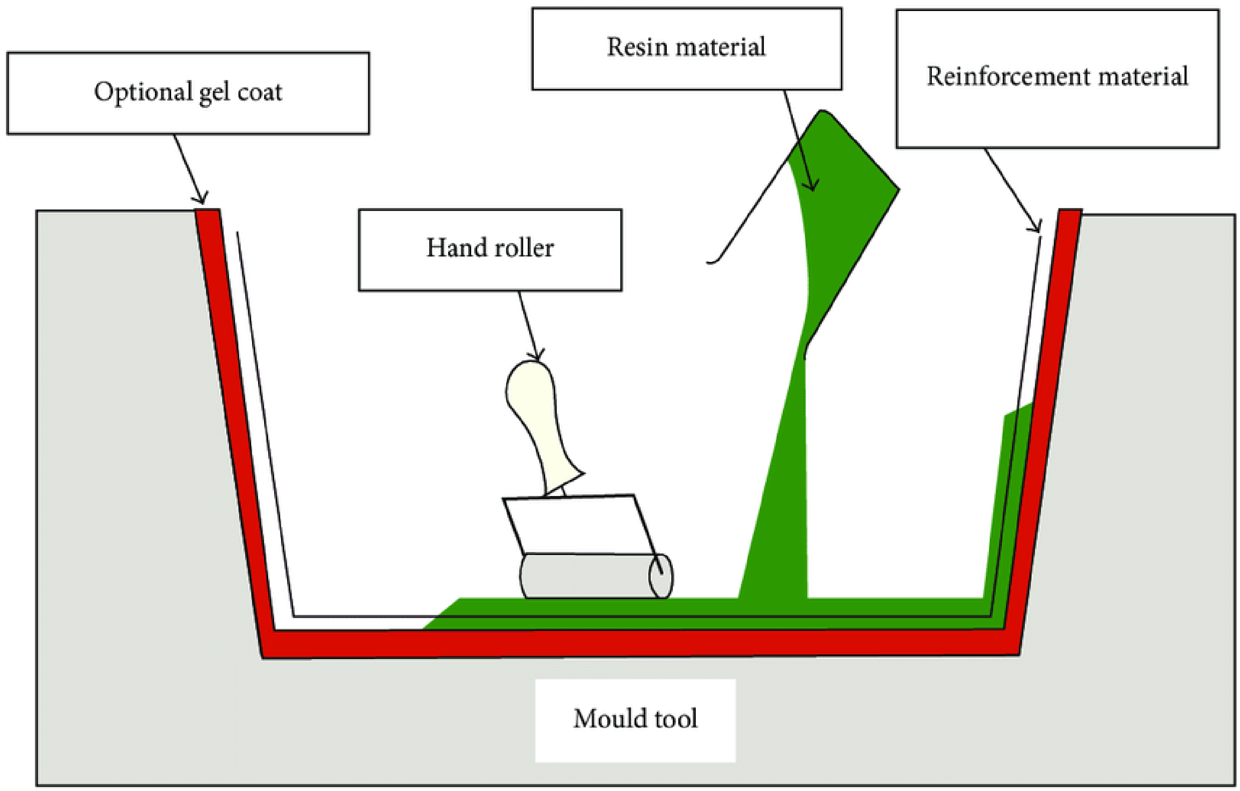


Fig-3.3 Hand lay-up method

- ➢ Simple, single cavity molds of fiberglass composites construction are generally used.

Advantages

a) The process results in low cost tooling with the use of room- temperature cure resins

b) The process is simple to use.

c) Any combination of fibers and matrix materials are used.

d) Higher fiber contents and longer fibers

e) Design flexibility

Disadvantages

a) Since the process is worked by hands, there are safety and hazard considerations.

b) The resin needs to be less viscous so that it can be easily worked by hands.

c) The quality of the final product is highly skilled dependent of the labour.

d) Uniform distribution of resin inside the fabric is not possible. It leads to voids in the laminates.

e) Possibility of diluting the contents

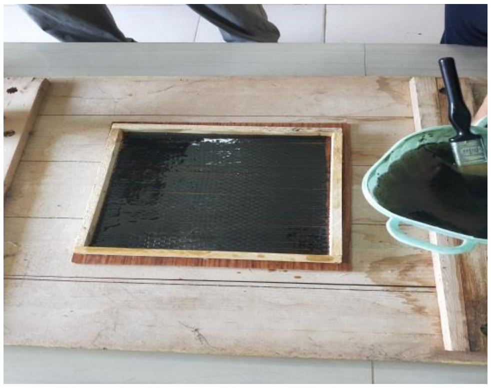
3.4 Fabrication of composite material with hand lay-up method

Hand lay-up technique is the simplest and oldest open molding method of composite fabrication process. In this work, multi-walled carbon nanotubes of different weight percentages is mixed with epoxy resin, hardener and fiber reinforcements. The thickness of the composite sheet to be fabricated is controlled by the layers placed on the mould. After the preparation of composite sheets, the work pieces are cured for 24 to 48 hrs. So that work pieces will get hard. After this, the specimens are cut according to ASTM standard.

Steps involved in fabrication process

1. Aramid fiber sheets,carbon fiber sheets is cut into 30 square centimeters as shown in fig (a).
2. The content of MWCNTs is varied in wt%(0.1 to 0.4) and the remaining ingredients are kept constant .Uniform mixing of all the ingredients was done by using a foculator. Mould releasing agent of candle wax is rubbed on the table for ensuring easy removal of the sheet after curing process. Initially resins along with all ingredients are taken and aramid fiber and carbon fiber sheets were placed layer by layer and uniform pressure is applied through rolling process to remove the gases present during fabrication . This is shown in fig (c)
3. Remaining the other ingredients same but changing the proportions of Carbon nano tubes the resin mixture is applied to other similar four sheets and dried it for 24 hours as shown in fig 3.4(a-d).

(a) **(b)**



(c) **(d)**

Fig-3.4 (a,b,c,d) Steps involved in fabrication

Table-3.4 Material Selection for different composite sheets formulation

Ingredients (wt%)	**Type of composite**			
	HY1	**HY2**	**HY3**	**HY4**
Hybrid fiber (CF+AF)	10	10	10	10
Epoxy Resin	89	89	89	89
MWCNT	0.1	0.2	0.3	0.4
Accelerator and hardenor	Balance	Balance	Balance	Balance

CHAPTER - 4

TENSILE BEHAVIOUR OF HYBRID FIBER COMPOSITES

TENSILE BEHAVIOUR OF HYBRID FIBER COMPOSITES

4.1 INTRODUCTION

In this chapter the tensile behaviour of different samples of hybrid fiber composites are presented. The Tensile test was carried out on computerized UTM, as per ASTM standards. The four specimens were subjected to tensile test and their values were reported.

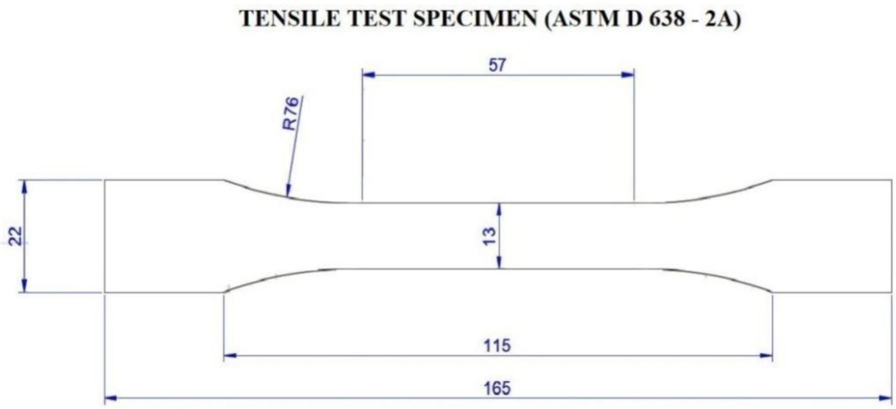
4.2 EQUIPMENT FOR TENSILE TESTING

A Computerized UTM Test is used to find the tensile properties of the composites. Operation of the universal testing machine is by hydraulic transmission of load from the test specimen to separately housed load indicator. The system is ideal since it replaces transmission of load: through levers and knife edges which are prone to wear and damage due to shock on rupture of test pieces. Load is applied by a hydrostatically lubricated ram. Main cylinder pressure is transmitted to the cylinder of the pendulum dynamometer system housed in the control panel. The cylinder of the dynamometer is also of self-lubricating design. The load transmitted to the cylinder of the dynamometer is transferred through leverage to the pendulum. Displacement of the pendulum actuates the rack and pinion mechanism which operates the load indicator pointer and the autographic recorder. The deflection of the pendulum represents the absolute load applied on the test specimen**.**

(Fig-4.2) Tensile testing machine

4.3 METHOD OF TENSILE TESTING

Tensile test is the basic important test to evaluate the strength of any material. The machine is equipped with advanced load cell technology for faster testing and reduction of inertia errors. Tensile test is performed based on ASTM D638-02a standard. The specimens before test and after test are indicated below.



(Fig-4.3) Tensile test specimen with ASTM standards in CAD

Initially, the specimens are fixed between two clamping jaws firmly and loaded gradually with incremental load until failure takes place. The values of deformation against each load value are noted and tabulated. The breaking load for each specimen is noted and ultimate tensile strength values of all the samples with varying inclusions of (wt% of Sic and rubber powder) are observed for all the four specimens.

Fig-4.3.1 Tensile Test Specimens before failure

Fig-4.3.2 Tensile test specimen after failure

4.4 RESULTS OF TENSILE TEST:

- Tensile test is the basic important test to test the specimen and evaluate its mechanical properties to assess the performance of composite material required for particular applications. In this test four specimens HY1, HY2, HY3 and HY4 are loaded in the computerized universal testing machine and the deformation and stress values are observed with incremental of gradual application of load on the specimens. The load at break and corresponding tensile strength values are given in table 4.4

Table 4.4 Tensile test results

Sample	Max Tensile Load(KN)	Ultimate Tensile Strength(KN/mm^2)	Percentage Elongation
HY1	17.75	13.65	5.8
HY2	8.75	67.3	7
HY3	18	130	8.2
HY4	3.5	26.9	6.4

Table4.4

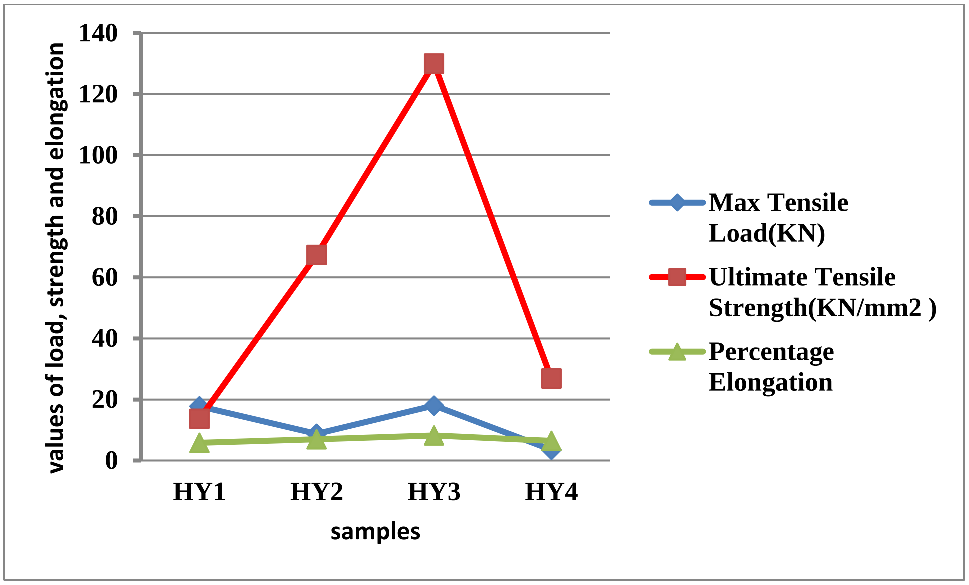


Fig - 4.4 Bar graph showing the tensile strength of hybrid fiber specimens by variation of MWCNTs

It was observed from fig 4.4 that, HY3 sample specimen containing MWCNT (0.3 wt%) exhibited best result of tensile strength of value 130 KN/mm^2 compared to remaining formulations of materials . It was also observed from the graph that, MWCNT beyond 0.3 wt % observed to be decrease in tensile strength values. The grain distribution and uniform distribution of all the ingredients can be analyzed.

CHAPTER – 5

FLEXURAL BEHAVIOUR OF HYBRID FIBER COMPOSITES

FLEXURAL BEHAVIOUR OF HYBRID FIBER COMPOSITES

5.1 INTRODUCTION

In this chapter the flexural behaviour of different samples of Hybrid fiber reinforced composites with different compositions is presented. The flexural test was carried out on computerized UTM as per the ASTM standards. The test specimens are prepared as per ASTM D 790. The four specimens were subjected to flexural test and their values were reported.

5.2 Equipment for flexural testing

A 10-ton capacity computerized UTM was used for conducting flexural test. The instrument is equipped with integrated computer compatible software in order to display various graphical results. And a special three-point loading attachment is provided for conducting flexural test.

Fig - 5.2 Flexural Testing Apparatus

5.3 Methods of flexural testing

There are three basic methods which cover the determination of flexural properties of the polymer.

Method 1: It is basically a three-point loading, utilizing center loading on a simply supported beam. A bar of rectangular cross section rests on two supports and is loaded by means of a loading nose at the center. The maximum axial fiber stress occurs on a line under the loading nose.

Method 2: In this method a four-point loading system is utilized. Two load points equally spaced from their adjacent supporting points, with a distance between loading points equal to one third of the support span. In this test, the bar lies on two points each at an equivalent distance from the adjacent support points.

Either method can be used for conducting the experiment. Method 1 is used for materials that break at relatively at low loads. Method 2 is used particularly for those materials that undergo large deflections during testing. Standard test method ASTM D790, for flexural properties of reinforced polymer composites has been used to test the composites.

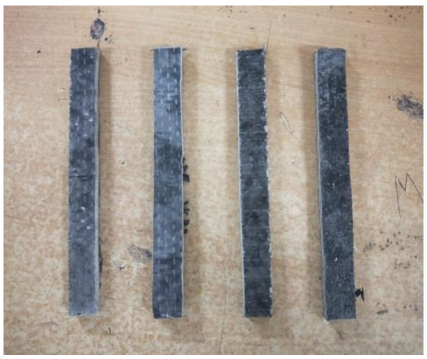


FIG-5.3.1 Flexural test Specimens **FIG-5.3.2 Specimen after performing Flexural Test**

5.4 RESULTS OF FLEXURAL TEST

The flexural test results are tabulated below

Table Flexural strengths of different specimens.

Sample	Flexural Load(KN)	Flexural Strength(KN/mm^2)
HY1	0.5	18
HY2	1	36
HY3	1.75	63
HY4	0.75	27

Table 5.4

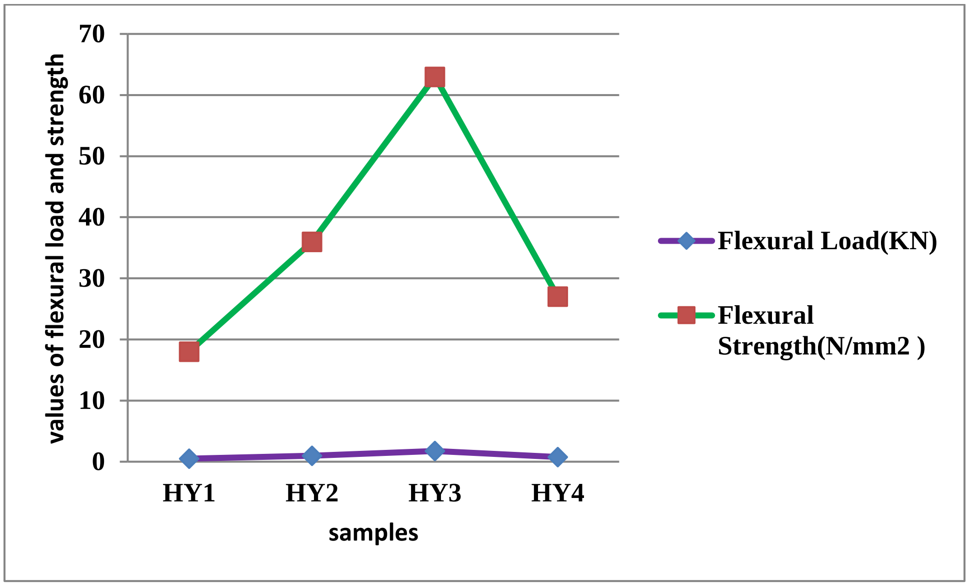


FIG-5.4 Bar graph showing the flexural strength of the Hybrid fiber specimens

Fig 5.4 represents bar graph showing flexural strengths of all specimens. It is observed from the bar graph that, HY3 specimen exhibited higher flexural strength value of 63 KN/ mm2 compared to remaining formulations of materials. The flexural strength value tried to decrease with increase in MWCNTs inclusions to 0.4 wt%. Therefore, the optimum value of achieving higher flexural strength is considered as 0.3 wt% .

CHAPTER-6

IMPACT BEHAVIOUR OF HYBRID FIBER COMPOSITES

CHAPTER-6

IMPACT BEHAVIOUR OF HYBRID FIBER COMPOSITES

6.1 INTRODUCTION

In this chapter the impact behaviour of different samples of Hybrid fiber composites is presented. The Impact test was carried out on Charpy Load Impact testing machine as per the ASTM standards. The test specimens are prepared as per ASTM D256 (8mm × 4mm × 4mm). The four specimens were subjected to Impact test and their values were reported.

The equipment and the method for impact testing are discussed below. The analysis on the results of the experimental investigations for the impact strength various samples of hybrid fiber reinforced polymer resin matrix composites of different weight ratios is presented.

6.2 EQUIPMENT FOR IMPACT TESTING

An analog load impact tester is used to find the impact strength of hybrid fiber reinforced polymer resin matrix composite specimens. The equipment has working range from 0-300 with a minimum resolution of 0.2J. In this equipment the value of 1 Division is equal to 2 Joules.

Fig - 6.2 Impact testing Machine

Fig - 6.2.1 Impact test specimens

Fig - 6.2.2 Impact test specimens after failure

6.3 METHOD OF IMPACT TESTING

Impact test is conducted as per ASTM D256 standards specimen cut in to 8 x 4 x 4 mm. The capacity of material to withstand such blows (impact or shock loads)without fracture is called impact strength. The material with high toughness will generally exhibit greater impact strength. Dynamic tests have been developed to establish impact resistance by using a notched specimen. The specimen is held in an anvil and is broken by a single blow of the pendulum, which falls from a fixed height (hl). After breaking the specimen, the pendulum continues to swing on the other side through a height(h2), if the weight of the hammer is W. then the energy delivered to the specimen to break it is W(hl-h2). The pendulum type impact machine is provided with scales and pointer, and scales are usually calibrated to read energy required to break the specimen in KJ.

Impact strength = Energy in fracture / cross−section area at notch

6.4 RESULTS OF IMPACT TEST

The impact test results are tabulated below

Sample	Energy absorbed (J)
HY1	36
HY2	30
HY3	40
HY4	34

Table 6.3

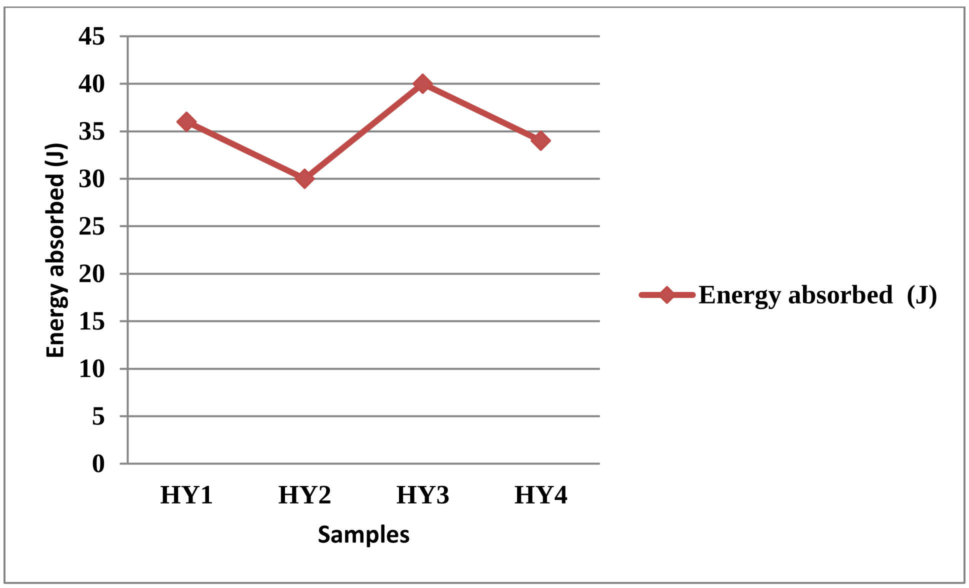


FIG-6.4 Bar graph showing the impact strength values of the hybrid fiber specimens

It was also observed from fig 6.4 that, impact strength of HY3 sample specimen was superior compared to remaining formulations of materials.

CHAPTER 7

HARDNESS MEASUREMENT

CHAPTER 7

HARDNESS MEASUREMENT

7.1 Introduction

Hardness is a measure of the resistance to localized plastic deformation induced by either mechanical indentation or abrasion. In general, different materials differ in their hardness; for example hard metals such as titanium and beryllium are harder than soft metals such as sodium and metallic tin, or wood and common plastics. Macroscopic hardness is generally characterized by strong intermolecular bonds, but the behavior of solid materials under force is complex; therefore, there are different measurements of hardness: scratch hardness, indentation hardness,and rebound hardness.

Hardness depends on elasticity, stiffness, , plasticity, strain, strength, toughness, viscoelasticity, and viscosity.

7.2 Methods of hardness measurement

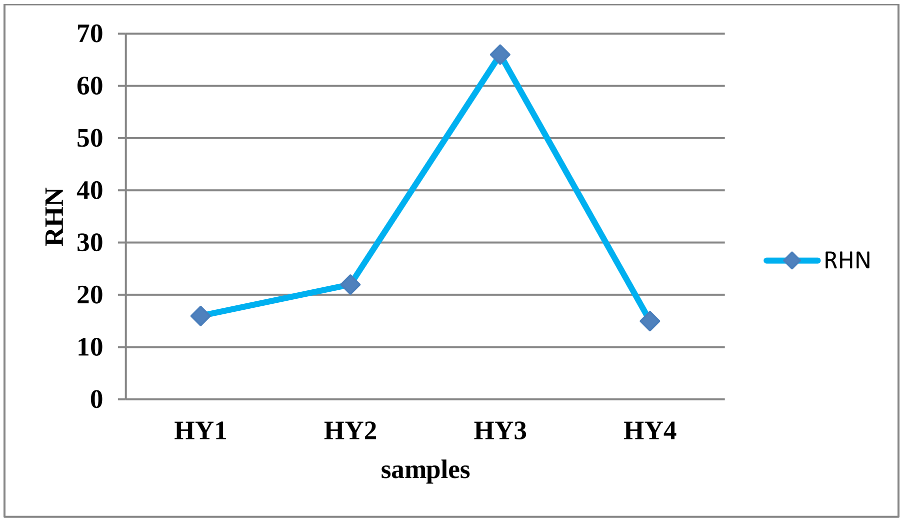
The **Rockwell scale** is a hardness scale based on indentation hardness of a material. The Rockwell test measuring the depth of penetration of an indenter under a large load (major load) compared to the penetration made by a preload (minor load). There are different scales, denoted by a single letter, that use different loads or indenters. The result is a dimensionless number noted as HRA, HRB, HRC, etc., where the last letter is the respective Rockwell scale (see below). When testing metals, indentation hardness correlates linearly with tensile strength. The composite specimens RHN is determine by using B scale for a load of 60Kgf applied for 20 seconds. The direct reading observed on the dial gives the value of RHN for the specimens. Rockwell hardness testing machine used for calculating the RHN is shown below.

Fig(a)7.2

7.3 Results of hardness measurement

Sample	RHN
HY1	16
HY2	22
HY3	66
HY4	15

Table(a)7.3



Fig(b)7.3

CHAPTER - 8

CONCLUSIONS

CONCLUSIONS

8.1 INTRODUCTION

Hybrid fiber reinforced composite materials are fabricated by varying the content of multi-walled carbon nanotubes and keeping remaining ingredients as constant. Four different formulations of composite material with varying weight percentages of filler inclusions are fabricated. Mechanical results are performed as per ASTM standards.

8.2 CONCLUSIONS FROM TEST RESULTS

The results obtained from different tests are presented as per the order discussed in this report i.e., Tensile, Flexural,Impact and Hardness.

8.2.1 CONCLUSIONS DRAWN FROM TENSILE TEST RESULTS

a) The maximum tensile strength is obtained for sample HY3 among all the samples.

b) It was observed that the sample HY3 having (130 KN/mm^2) exhibits good tensile strength properties compared to remaining samples.

c) It was observed that the tensile strength is increasing from sample HY1 to HY3.

8.2.2 CONCLUSIONS DRAWN FROM FLEXURAL TEST RESULTS

a) The maximum flexural strength is obtained for sample HY3 (63 KN/mm^2) among all the samples.

b) It was observed that the flexural strength is increasing from sample HY1 to HY3.

8.2.3 CONCLUSIONS DRAWN FROM IMPACT TEST RESULTS

a) The highest impact strength is obtained for the sample HY3 (40J).

b)) It was observed that the impact strength is increasing from sample HY1 to HY3.

After performing mechanical properties evaluation HY3 composite containing 0.3 wt% of MWCNT inclusions along with remaining ingredients exhibited better properties compared to remaining formulations of materials.

8.2.4 CONCLUSIONS DRAWN FROM HARDNESS TEST RESULTS

The HY3 sample specimen possess better grain distribution among the sample and uniform distribution of all the ingredients compared to the sample AF 3.

8.3 SCOPE FOR FUTURE WORK

This work can be extended for evaluation of wear properties of all the sample specimens and determination of surface roughness values . The bonding behavior of the Aramid fiber reinforced composite can be further clearly estimated to know the distribution of ingredients. Experimental methods can be used for actual evaluation of materials subjected to dynamic loads.

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