TRIBOLOGICAL BEHAVIOR OF MULTI WALLED CARBON NANO TUBE REINFORCED ARAMID/EPOXY COMPOSITE

A Project Report submitted in Partial fulfillment requirements

For the award of the Degree of

BACHELOR OF ENGINEERING

IN

MECHANICAL ENGINEERING

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CERTIFICATE

This is to certify that the Project Report entitled **"TRIBOLOGICAL BEHAVIOUR OF MULTI WALLED CARBON NANO TUBE REINFORCED ARAMID/EPOXY COMPOSITE"** being submitted by VADAMUDULA SANJAY MOULIK (317126520055), BORA BINDU MADHAVI (317126520007), POTHURAJU RESHMA (317126520042), BUDDHA RAJ KUMAR (317126520010), BATTINA SATYARAO (317126520004) 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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We present this report on **“Tribological behaviour of Multi walled Carbon Nano Tube reinforced Aramid/Epoxy composite”** in the partial fulfillment of the requirement for the award of BACHELOR OF ENGINEERING in MECHANICAL ENGINEERING.

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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. The poor ability of aramid fiber with polymer matrix limits its usage for wide range of applications. Hence, within in this work an attempt was made to include multi walled carbon nano tubes in the base matrix of epoxy resin to improve mechanical and bonding properties of the composite. Composite sheets having dimensions of 25cm x 25 x 0.6 cm are fabricated by using hand layup method. Five composite sheets (AF1, AF2, AF3, AF4, AF5) are fabricated by in terms of wt% keeping 80% epoxy resin, 0.2 % rubber powder, 0.2% graphite powder, 0.2% BaSo4, and 1.5 % fiber content as constant for each sheet and varying the content of multi walled carbon nano tubes from (0.1% to 0.5%). The specimens are cut according to ASTM standards to evaluate mechanical and thermal properties of the composites. Scanning electron microscope images (SEM) are observed for two samples. The uniform distributions of grains across the composite are observed through SEM images. It was observed from mechanical properties results that, AF4 (aramid fiber reinforced composite with 0.4wt% multi walled carbon nano tubes) along with remaining ingredients exhibited better mechanical and thermal properties compared to other formulations of materials.

Key Words: Aramid fiber, Epoxy Resin, Multi Walled Carbon nanotubes, Tribological 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

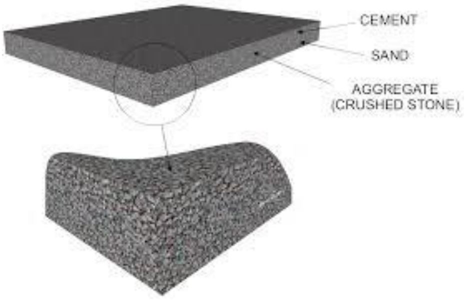


Fig-1.3 (b) Reinforced concrete

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.

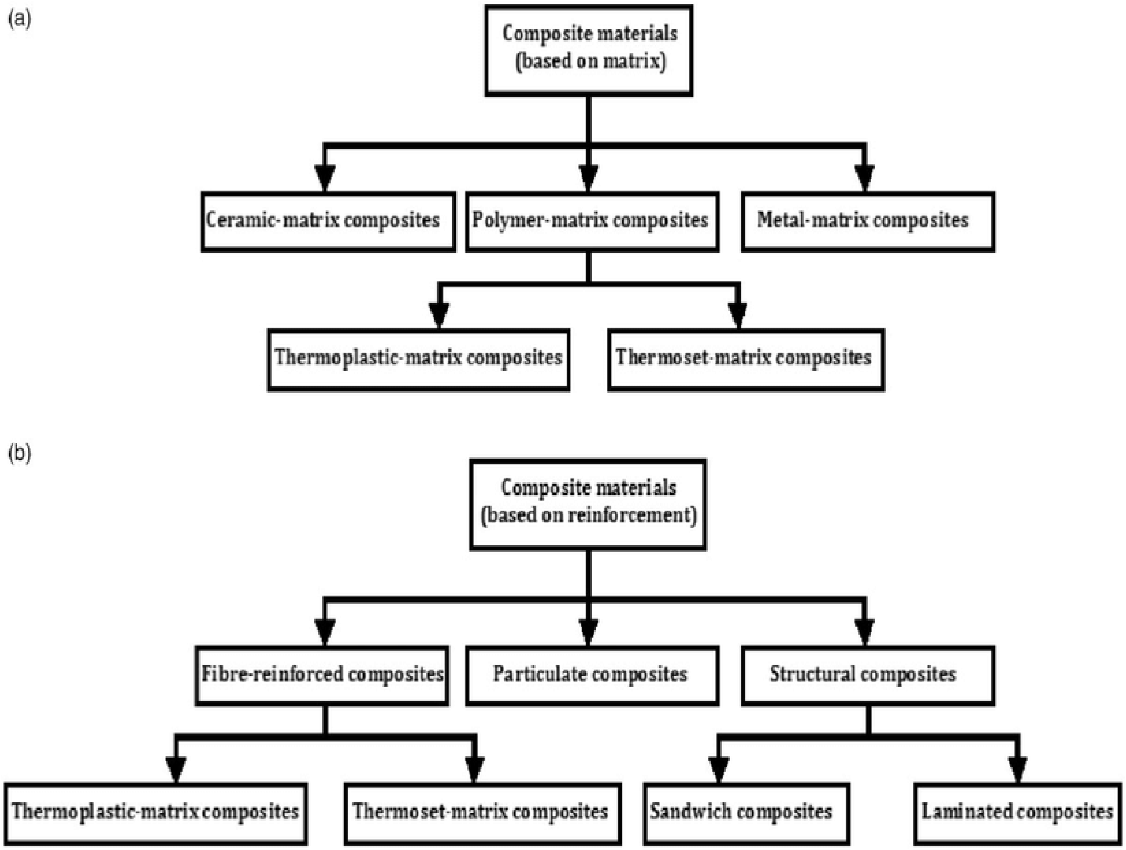


Fig 1.3.2 Classification of composites based on matrix and reinforcement

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

1. ***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.

2. *Based 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.

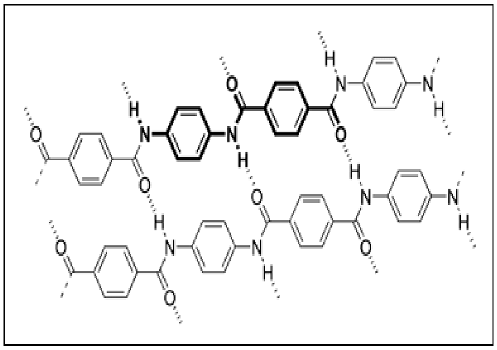


Fig-1.4(a) Structure of Twaron and Kevlar

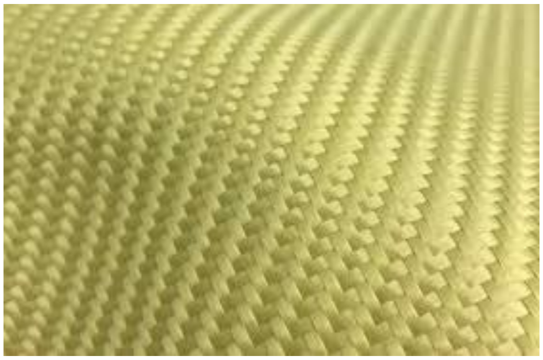


Fig-1.4(b) Aramid fiber sheet

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	-2×10^{-6}	-2×10^{-6}	-2×10^{-6}	-2×10^{-6}
In radial direction	60×10^{-6}	60×10^{-6}	------	------

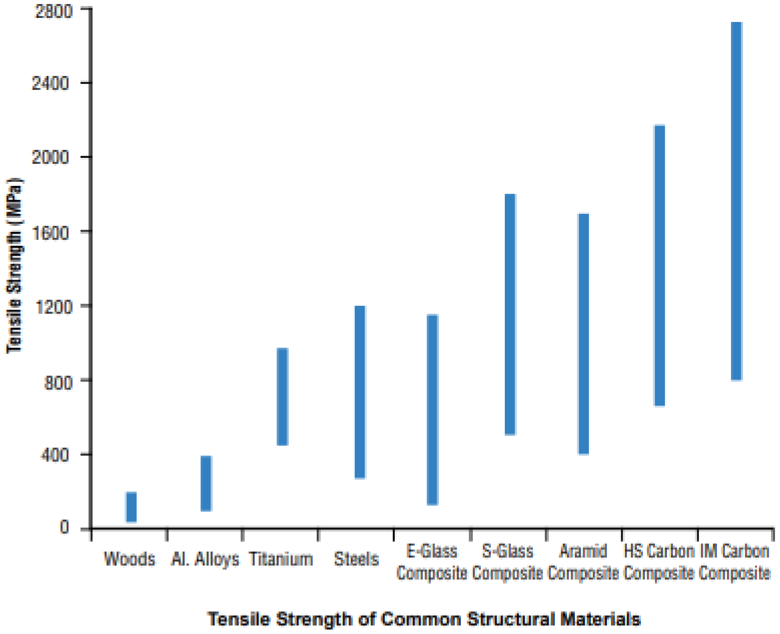


Fig1.4.4 (a) Comparison of tensile strengths of different materials(Ref Guide to Composites)

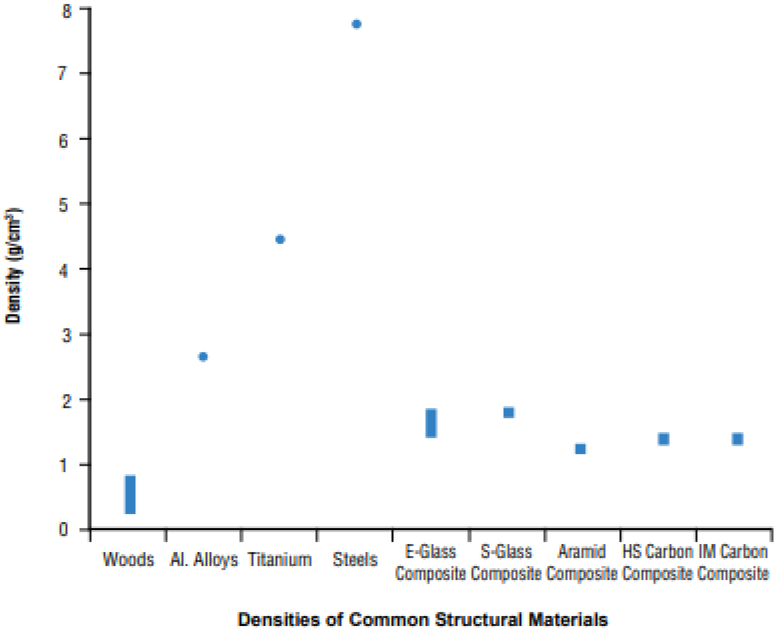


Fig1.4.4 (b) Comparison of densities of different materials (Ref Guide to Composites)

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.

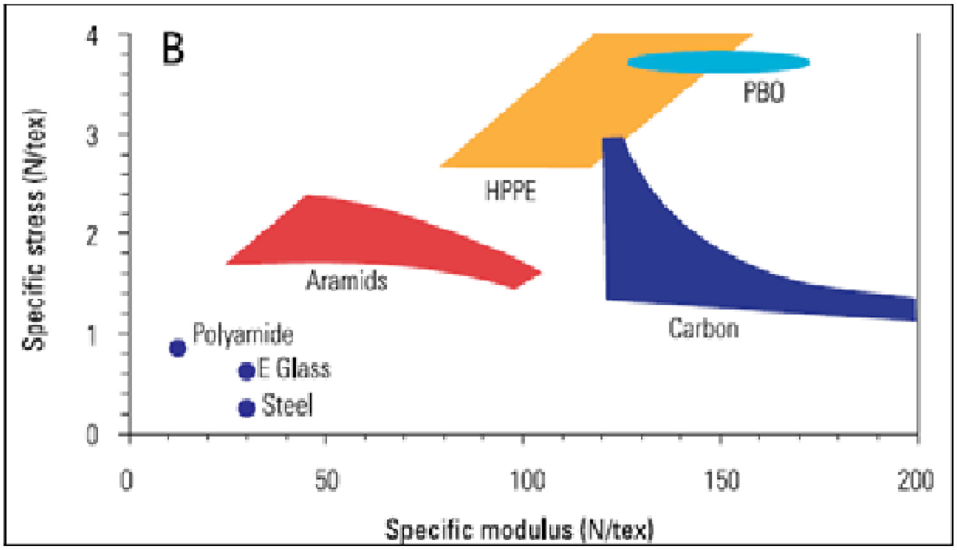


Fig-1.4.4(c) Comparison of Strength and modulus of different fibers (Ref Research gate)

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%.

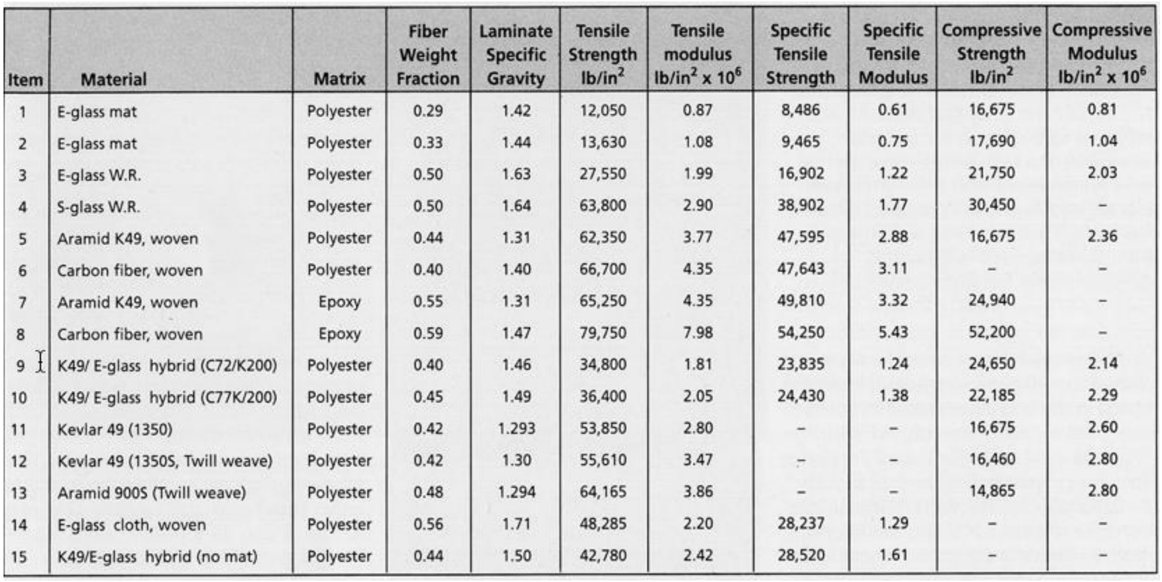
To sum up, aramid general characteristics are:

- 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.

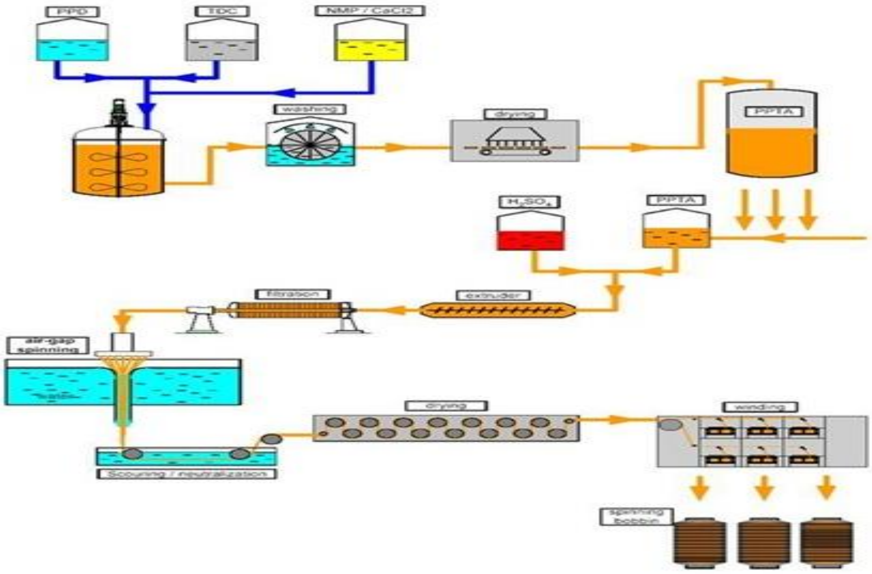


Fig 1.4.6 Aramid fiber production process (Ref textile leaner. BlogSpot)

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.

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. The poor ability of moisture absorption is taken as an objective in this work. An attempt was made to improve interfacial adhesion between fiber and matrix and thermal resistance of the composite by inclusion of multi walled carbon nano tubes in the base polymer matrix of epoxy resin along with other ingredients. The content of MWCNT is varied from (0.1wt% to 0.5 wt%) and five composites sheets are fabricated. Mechanical and thermal properties are evaluated and the best configuration of MWCNT reinforcement is selected to use aramid fiber more effectively for engineering and industrial applications.

Chapter-3

FABRICATION OF ARAMID FIBER REINFORCED COMPOSITES

FABRICATION OF ARAMID FIBER REINFORCED COMPOSITES

The materials that are used in fabrication of aramid 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. Epoxy resin with hardener and catalyst
3. Barium sulphate
4. Multi-walled aramid nano tubes
5. Rubber powder
6. Graphite powder

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 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.

- **Catalyst**

  Catalyst 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.

3.1.3 Barium sulphate

Barium sulfate is the inorganic compound with the chemical formula BaSO4. It is a white crystalline solid that is odorless and insoluble in water. It occurs as the mineral barite, which is the main commercial source of barium and materials prepared from it.

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.

3.1.5 Rubber powder

Micronized rubber powder (MRP) is classified as fine, dry, powdered elastomeric crumb rubber in which a significant proportion of particles are less than 100 µm and free of foreign particulates (metal, fiber, etc.). MRP particle size distributions typically range from 180 µm to 10 µm.

3.1.6 Graphite powder

Graphite is a sub metal, which is derived from aramid rocks that are metamorphosed. It is derived in a flaky form from these rocks. It is one of the softest metals, and is aramid in its stable form. It is true that powdered graphite flakes are mainly referred to as graphite powder. This powder is also used to increase the aramid content in certain metals like steel. It also makes a good lubricant that can protect surfaces against friction and related damage.

3.2 Method of fabrication

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

3.3 Wet/Hand lay-up

- Fibers are first put in place in the mould. The fibers can be in the form of woven, knitted, stitched or bonded fabrics. Then the resin is impregnated.
- The impregnation of resin is done by using rollers, brushes or a nip-roller type impregnator.
- The impregnation helps in forming the resin inside the fabric. The laminates fabricated by this process are then cured under standard atmospheric conditions.
- The materials that can be used have, in general, no restrictions.
- One can use combination of resins like epoxy, polyester, vinyl ester, phenolic and any fiber material.

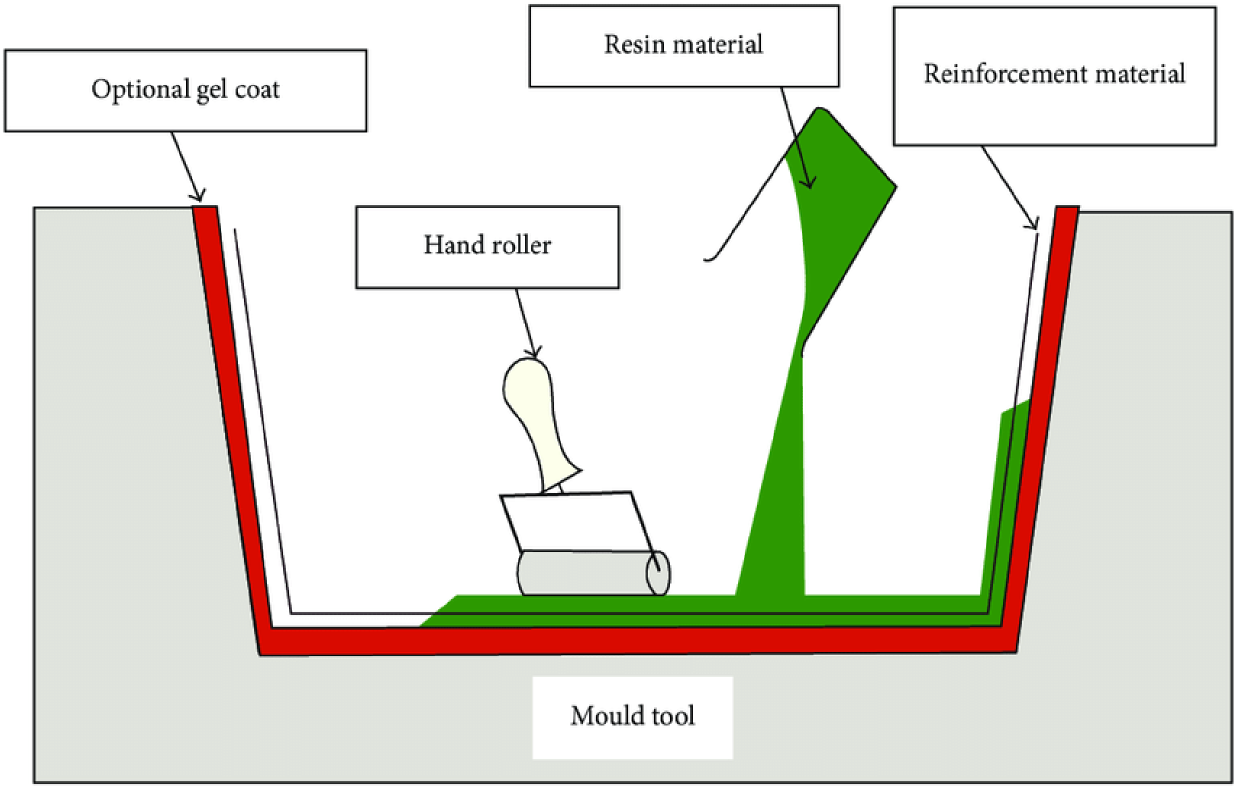


Fig-3.3 Hand lay-up method

- Simple, single cavity molds of fiberglass composites construction are generally used.
- Molds can range from small to very large and are low cost in the spectrum of composites molds.

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

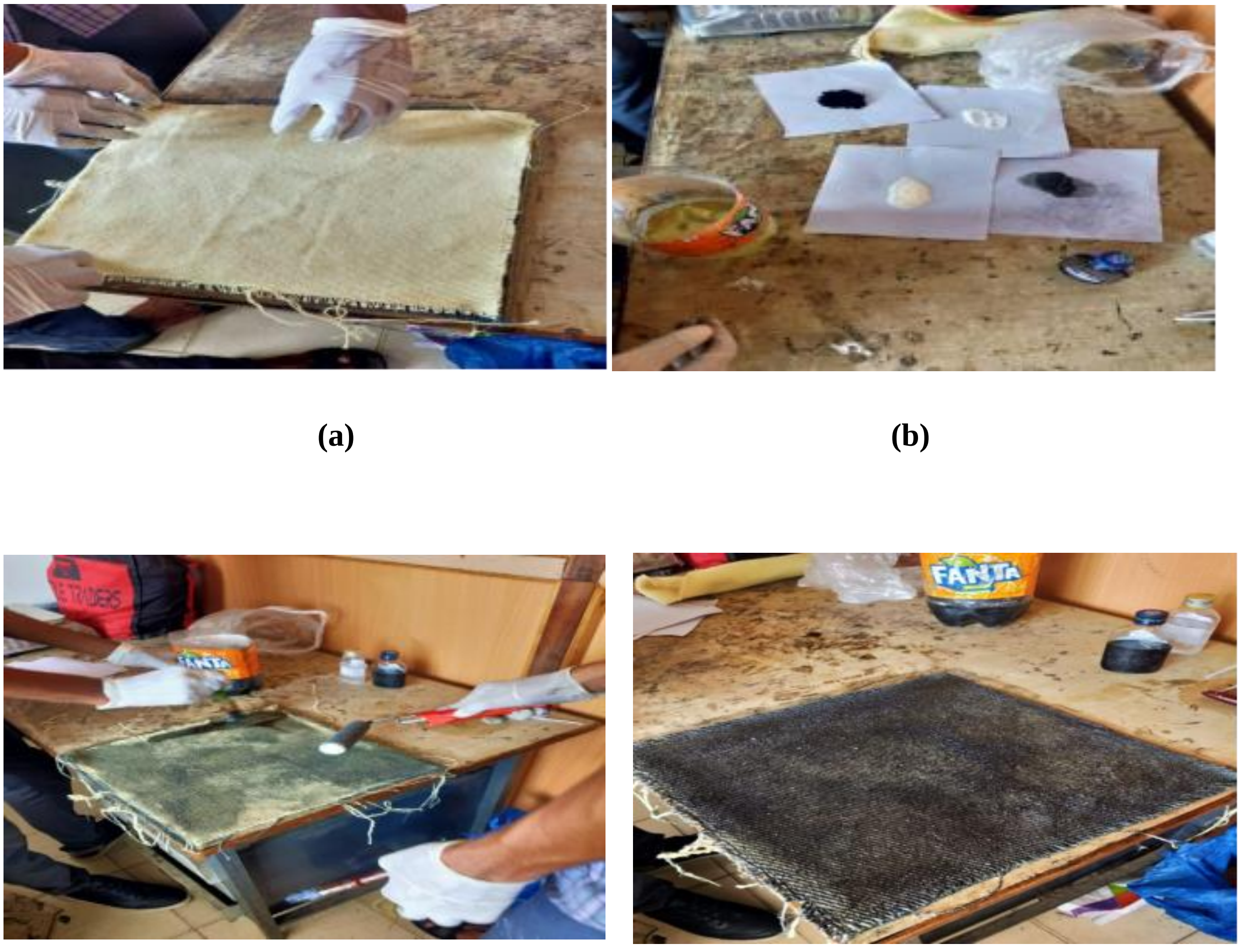
Hand lay-up technique is the simplest and oldest open molding method of composite fabrication process. In this work, Silicon carbide, rubber powder of different weight percentages is mixed with epoxy resin, hardener and fiber reinforcements. The thickness of the composite sheet to be fabricated is controlled 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 sheet is cut into 30 square centimeters as shown in fig (a).
2. Ingredients such as Carbon nano tubes, Barium Sulphate, Graphite powder, Rubber powder are added in small proportions in 700ml resin as shown in fig (b).
3. The content of MWCNTs is varied in wt%(0.1 to 0.5) and the remaining ingredients are kept constant .Uniform mixing of all the ingredients was done by using a foculator. Mould releasing agent of heavy duty silicon spray is sprayed on the table for ensuring easy removal of the sheet after curing process. Initially resins along with all ingredients

are taken and each aramid fiber sheet was placed and uniform pressure is applied through rolling process to remove the gases present during fabrication . This is shown in fig (c)

4. Remaining the other ingredients same but changing the proportions of Carbon nano tubes the resin mixture is applied to other similar five 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**				
	AF1	**AF2**	**AF3**	**AF4**	**AF5**
Aramid fiber	15	15	15	15	15
Epoxy Resin	80	80	80	80	80
Rubber Powder	0.2	0.2	0.2	0.2	0.2
Barium Sulphate	0.2	0.2	0.2	0.2	0.2
Graphite Powder	0.2	0.2	0.2	0.2	0.2
MWCNT	0.1	0.2	0.3	0.4	0.5
Accelerator and hardener	Balance	Balance	Balance	Balance	Balance

CHAPTER - 4

PIN ON DISK EQUIPMENT

PIN ON DISK EQUIPMENT

4.1 APPARATUS

4.2 WHY TESTING USING PIN-ON-DISK?

Currently, there is a trend to reduce the size of machine elements, increase power, reduce maintenance and improve reliability. These requirements push the design limits and require innovative solutions. Testing these solutions on a scale of a full machine would be too expensive, but also time consuming. Therefore the universal experimental set-ups are often used to perform tribological research on a prototyping phase, prior to full scale tests.

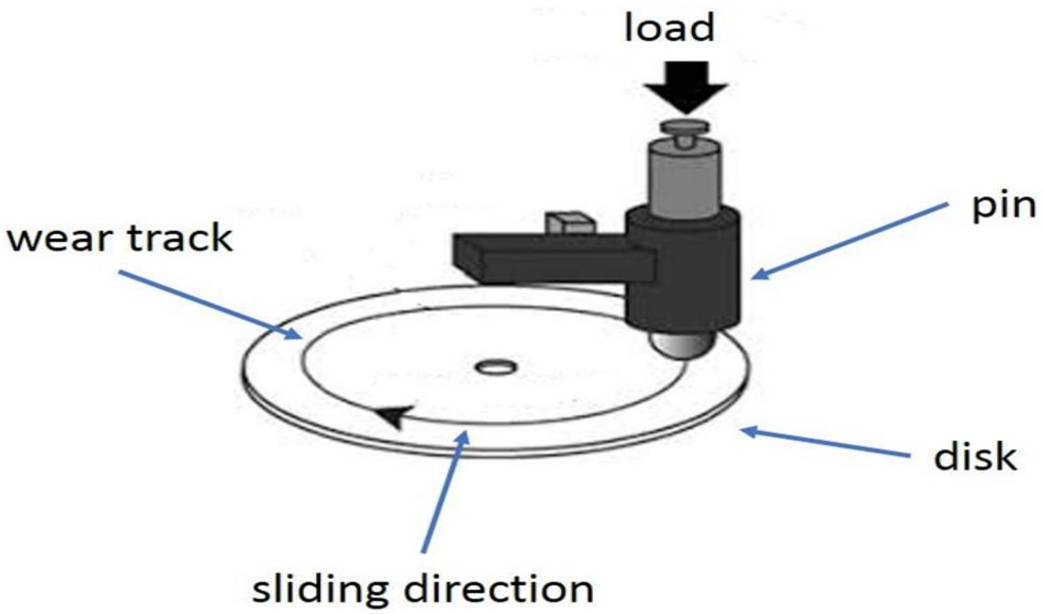
4.3 PIN ON DISK TEST

Friction and wear (typically wear rates and wear resistance) characterization of materials is typically performed using various types of **tribometers**, while pin on disk test being probably one of the most common.

The popularity of the method is due to its relative simplicity and abundance of the tribological contacts that can be well described by the a simple pin on disk motion: from dry contacts of bolt screws.to rail wheels to rail contact and to lubricated contact of biological implants.

The test typically allows to test several motion modes, such as unidirectional, fretting modes and recently any other complex motion patterns. Typically, the tests are performed under the following testing standards: ASTM G99, ASTM G133 and ASTM F732. Further information on the tribology testing standards can be found **here**.

Direction of load applied on the rotating disc

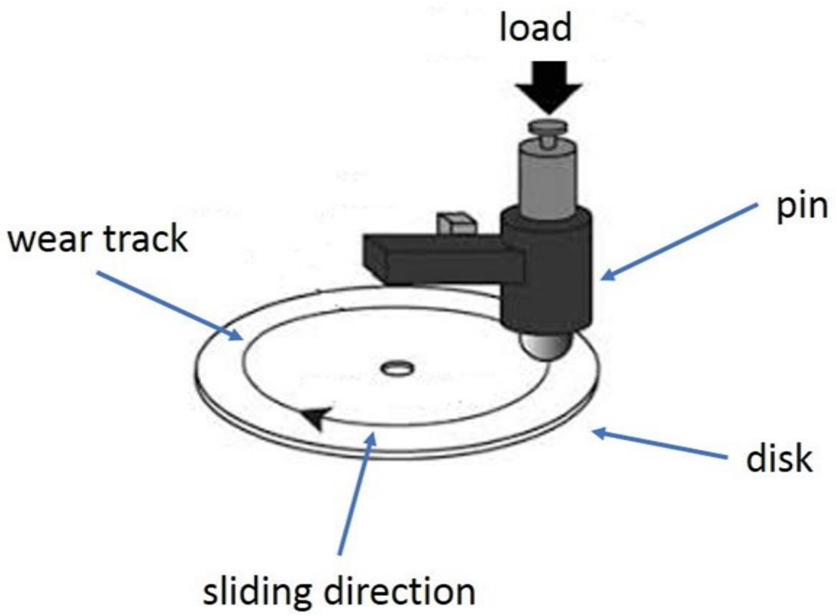


Pin on disk tribometer

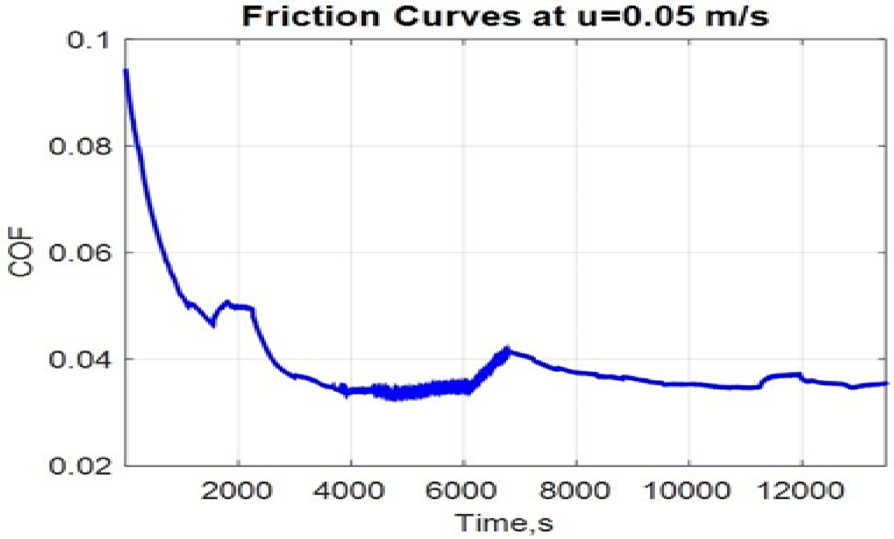
- Schematically, the pin on disk test is depicted in the figure . The stationary pin is pressed against rotating disk under the given load.

- The pin can be of any shape, however, the most popular shapes are spherical (ball or lens) or cylindrical due to ease of alignment of such pins.

- During the test, the friction force, wear and temperature are continuously monitored.



A typical friction curve measurement recorded on a pin on disk apparatus is shown in the figure :



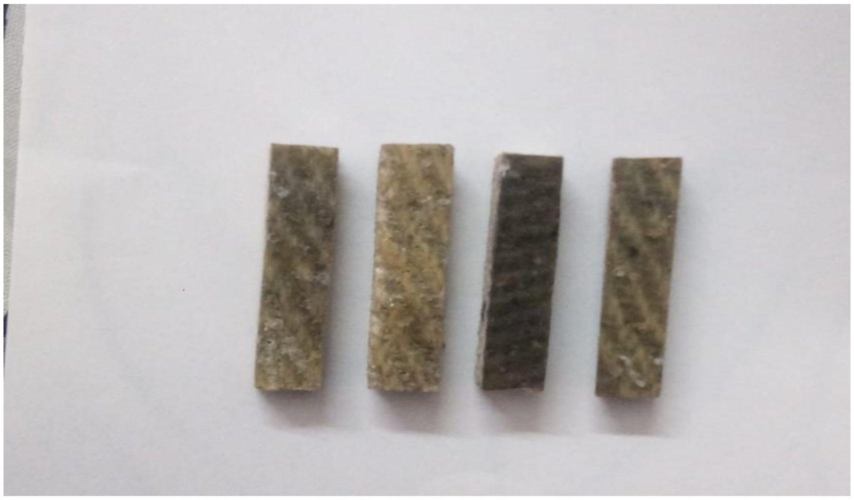
- As can be seen form the figure, at the start of the test, the measured coefficient of friction (COF) is high and with further progress drops.
- This behavior is typical friction measurements and is attributed to a running-in phenomenon.

- During the running-in, the surface topography changes, chemical reactions takes place until the system comes to a steady-state state. This steady state COF is then usually reported.

CHAPTER 5

SPECIMENS FOR CONDUCTING WEAR TEST

5.1 SPECIMENS FOR CONDUCTING WEAR TEST



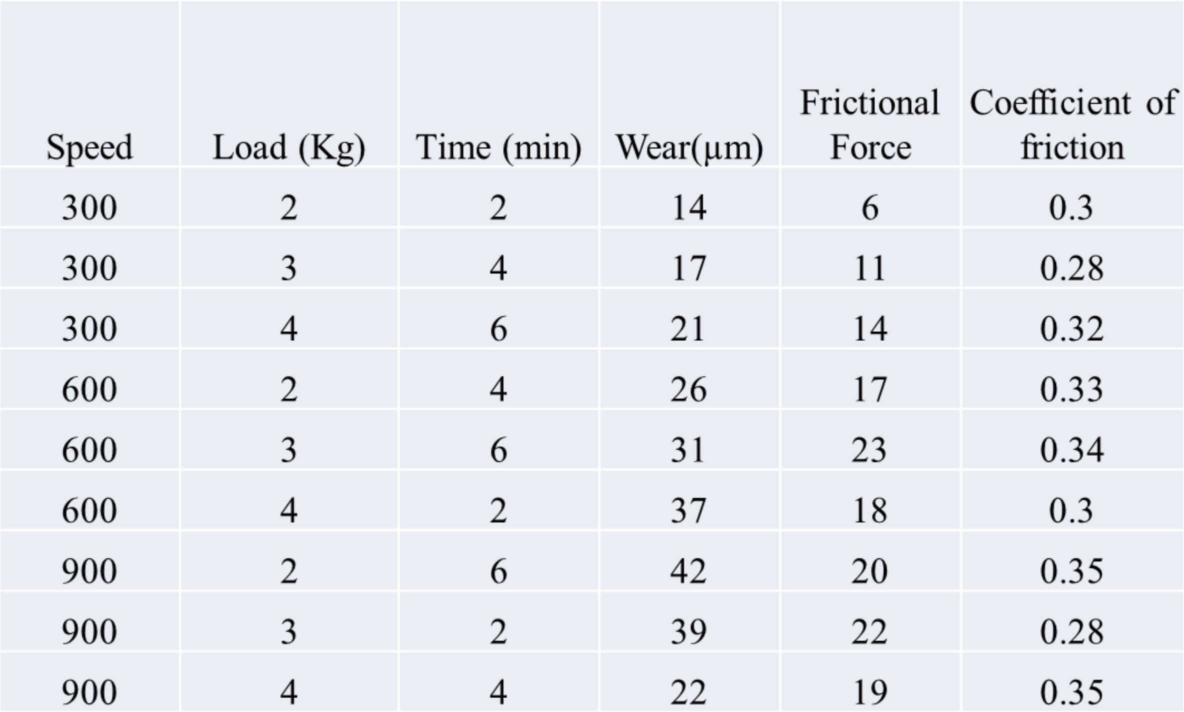
5.2 WEAR TESTING PARAMETERS

Speed	Load (Kg)	Time (min)
300	2	2
600	3	4
900	4	6

Wear and Coefficient of friction results for sample AF1

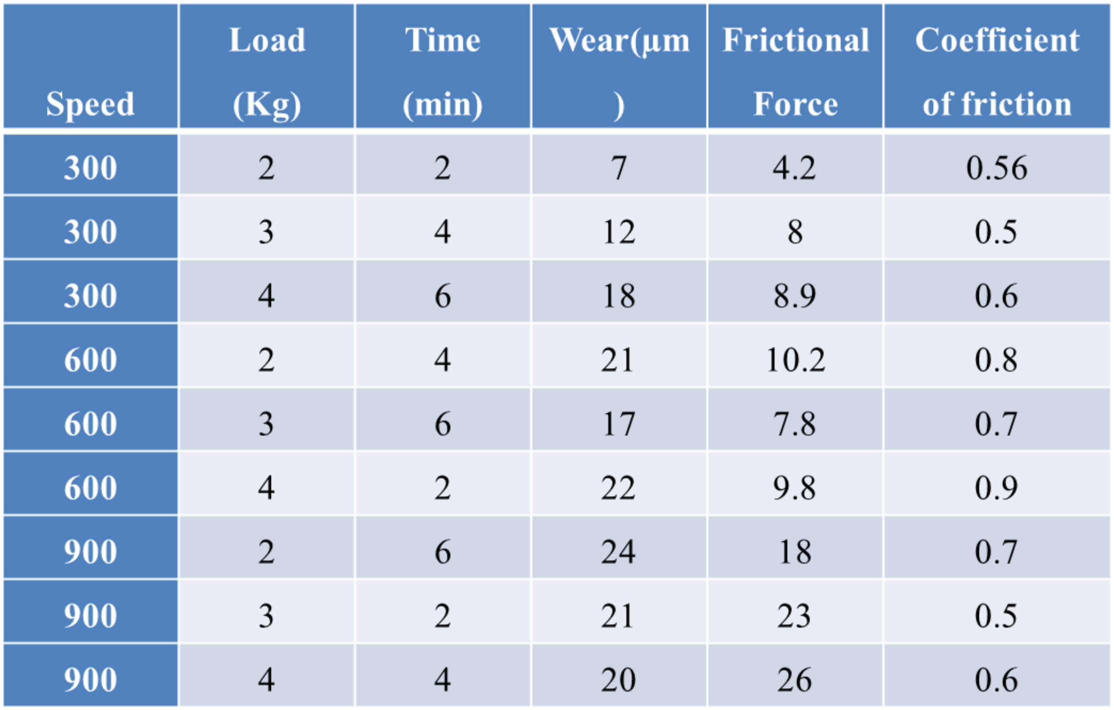
Speed	Load (Kg)	Time (min)	Wear(μm)	Frictional Force	Coefficient of friction
300	2	2	18	7	0.3
300	3	4	22	12	0.4
300	4	6	24	16	0.38
600	2	4	28	18	0.42
600	3	6	33	9	0.45
600	4	2	45	20	0.5
900	2	6	63	22	0.72
900	3	2	40	24.8	1.2
900	4	4	80	20.5	0.8

Wear and coefficient of friction results for sample AF2



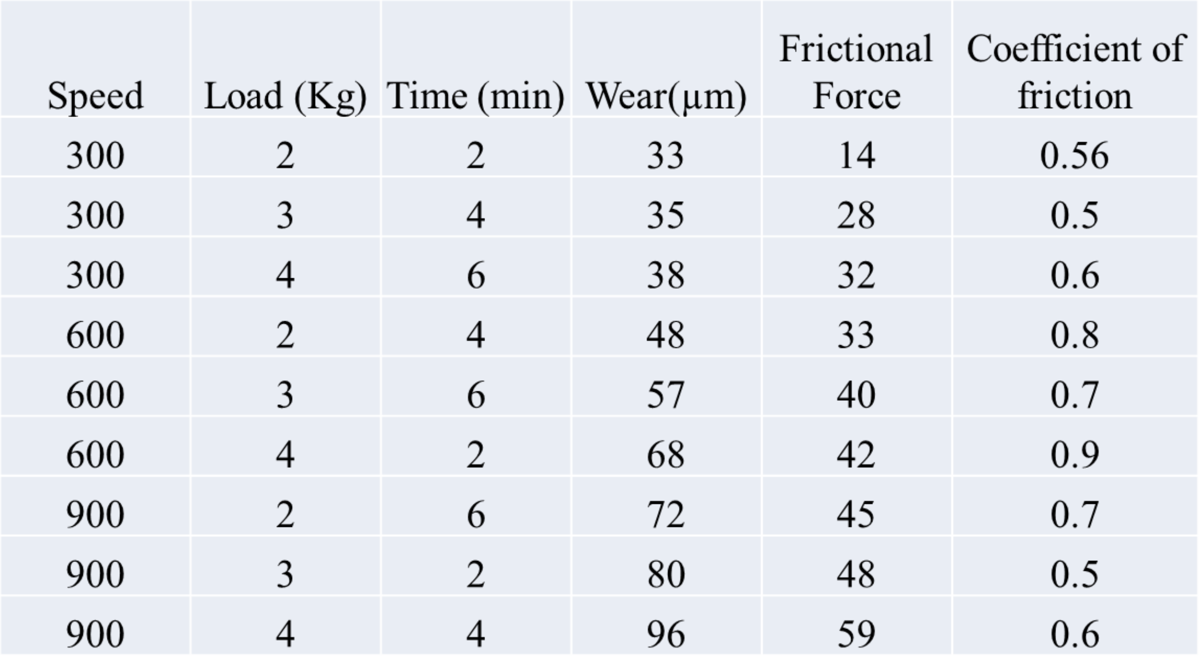
Speed	Load (Kg)	Time (min)	Wear(µm)	Frictional Force	Coefficient of friction
300	2	2	14	6	0.3
300	3	4	17	11	0.28
300	4	6	21	14	0.32
600	2	4	26	17	0.33
600	3	6	31	23	0.34
600	4	2	37	18	0.3
900	2	6	42	20	0.35
900	3	2	39	22	0.28
900	4	4	22	19	0.35

Wear and coefficient of friction results for sample AF3



Speed	Load (Kg)	Time (min)	Wear(µm)	Frictional Force	Coefficient of friction
300	2	2	7	4.2	0.56
300	3	4	12	8	0.5
300	4	6	18	8.9	0.6
600	2	4	21	10.2	0.8
600	3	6	17	7.8	0.7
600	4	2	22	9.8	0.9
900	2	6	24	18	0.7
900	3	2	21	23	0.5
900	4	4	20	26	0.6

Wear and Coefficient of friction results for sample AF4

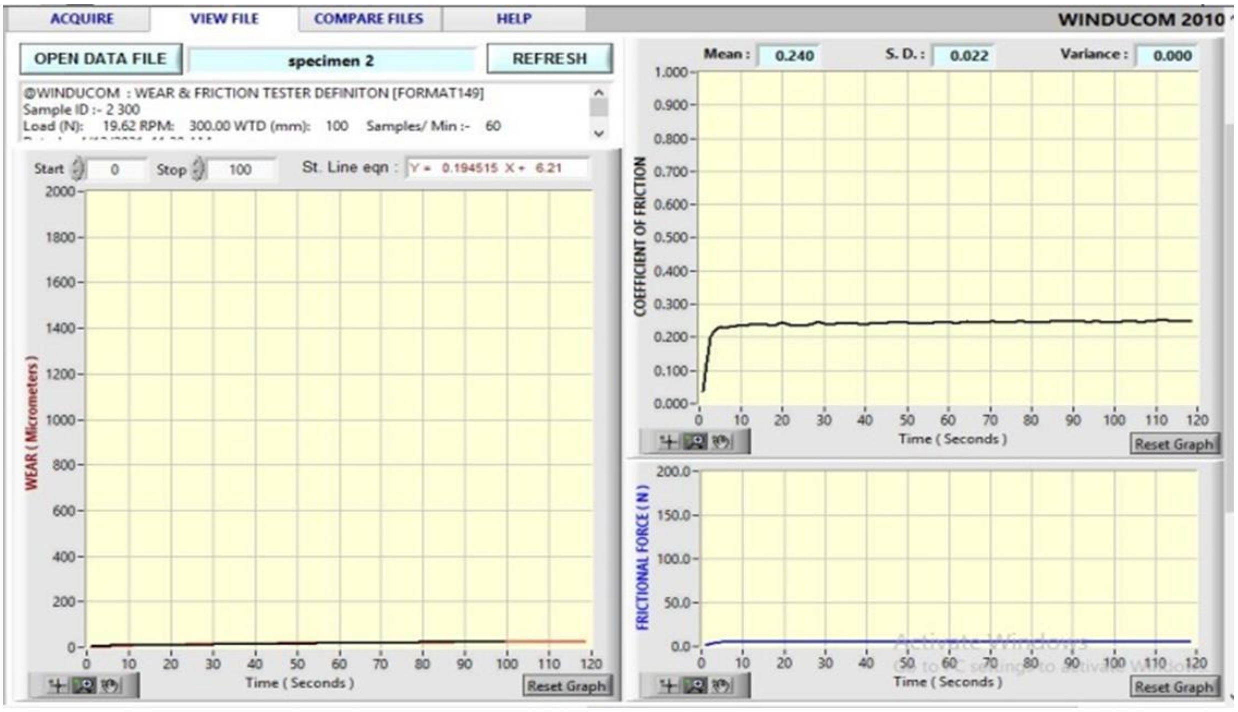


Speed	Load (Kg)	Time (min)	Wear(μm)	Frictional Force	Coefficient of friction
300	2	2	33	14	0.56
300	3	4	35	28	0.5
300	4	6	38	32	0.6
600	2	4	48	33	0.8
600	3	6	57	40	0.7
600	4	2	68	42	0.9
900	2	6	72	45	0.7
900	3	2	80	48	0.5
900	4	4	96	59	0.6

5.3 EXPERIMENTAL RESULTS DEPICTED IN GRAPH

Variation of Wear , Frictional resistance ,Coefficient of friction with respect to time from experimental results depicted in graphs as Follows :

Experiment 1:



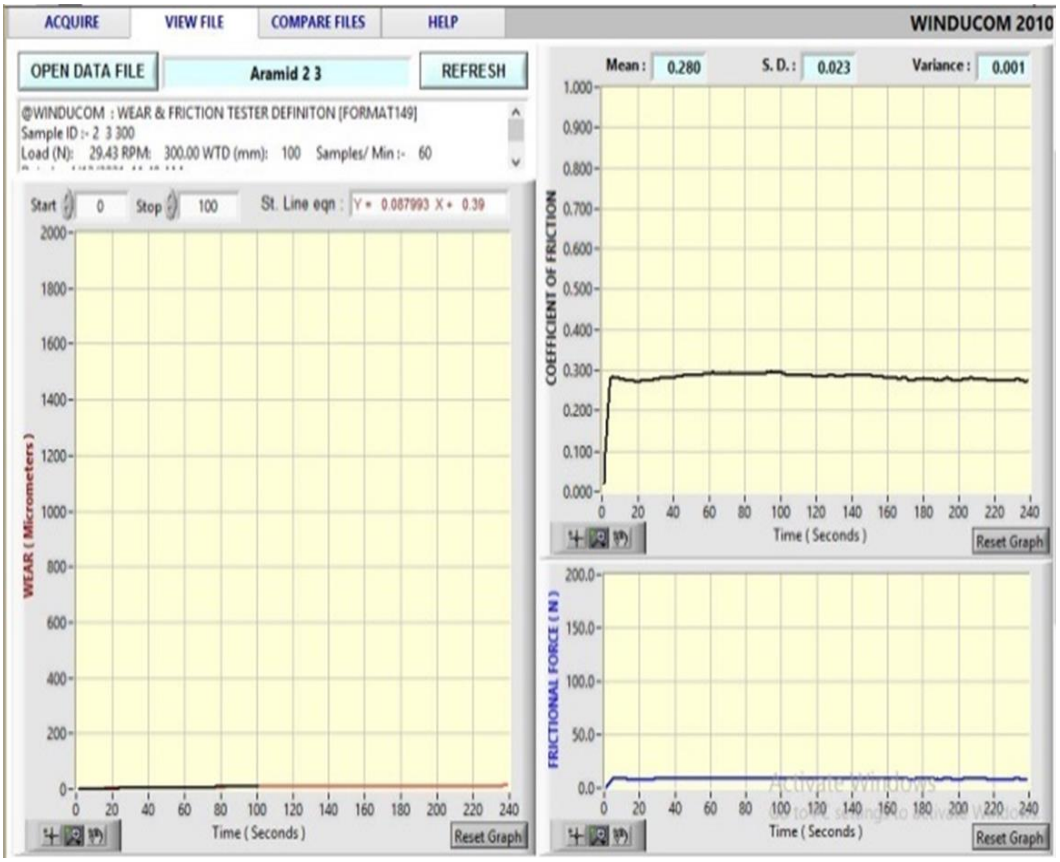
specimen 2

@WINDUCOM : WEAR & FRICTION TESTER DEFINITON [FORMAT149]
Sample ID :- 2 300
Load (N): 19.62 RPM: 300.00 WTD (mm): 100 Samples/ Min :- 60

Start 0 Stop 100 St. Line eqn : Y = 0.194515 X + 6.21

Mean : 0.240 S. D. : 0.022 Variance : 0.000

Experiment 2:



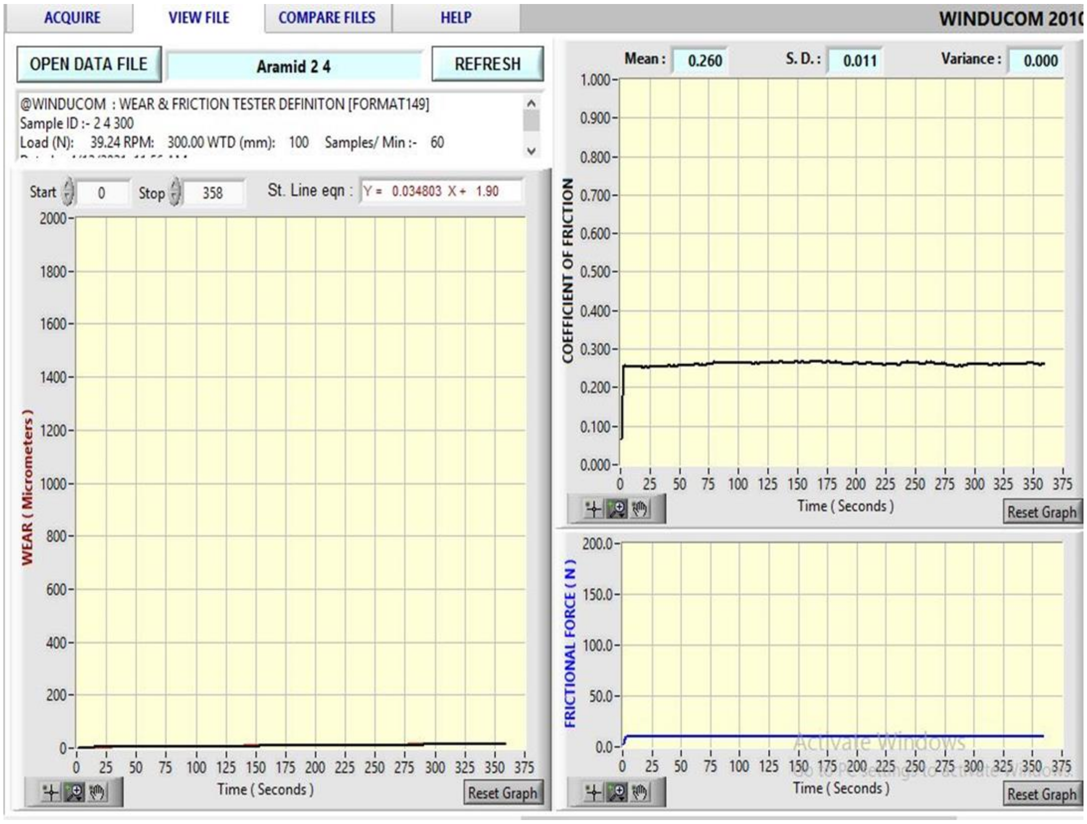
Aramid 2 3

@WINDUCOM : WEAR & FRICTION TESTER DEFINITON [FORMAT149]
Sample ID :- 2 3 300
Load (N): 29.43 RPM: 300.00 WTD (mm): 100 Samples/ Min :- 60

Start 0 Stop 100 St. Line eqn : Y = 0.087993 X + 0.39

Mean : 0.280 S. D. : 0.023 Variance : 0.001

Experiment 3:



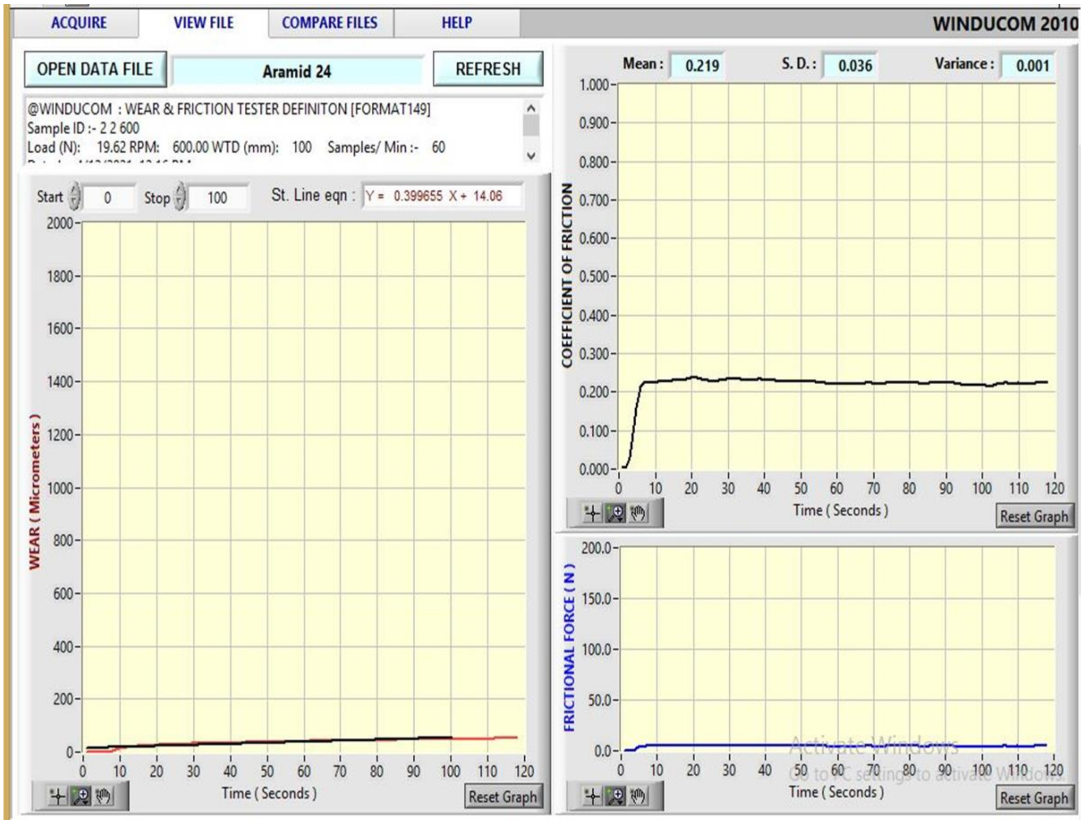
Aramid 2 4

@WINDUCOM : WEAR & FRICTION TESTER DEFINITON [FORMAT149]
Sample ID :- 2 4 300
Load (N): 39.24 RPM: 300.00 WTD (mm): 100 Samples/ Min :- 60

Start 0 Stop 358 St. Line eqn : Y = 0.034803 X + 1.90

Mean : 0.260 S. D. : 0.011 Variance : 0.000

Experiment 4:



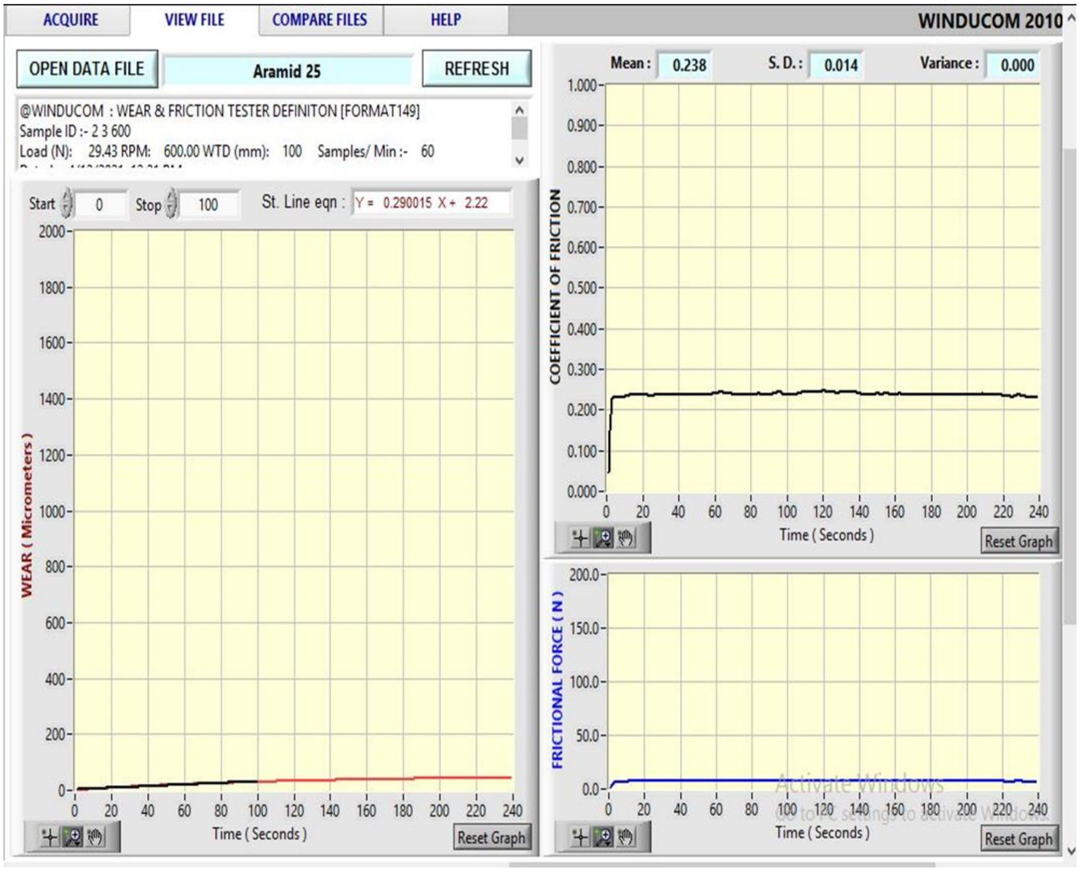
Aramid 24

@WINDUCOM : WEAR & FRICTION TESTER DEFINITON [FORMAT149]
Sample ID :- 2 2 600
Load (N): 19.62 RPM: 600.00 WTD (mm): 100 Samples/ Min :- 60

Start 0 Stop 100 St. Line eqn : Y = 0.399655 X + 14.06

Mean : 0.219 S. D. : 0.036 Variance : 0.001

Experiment 5:



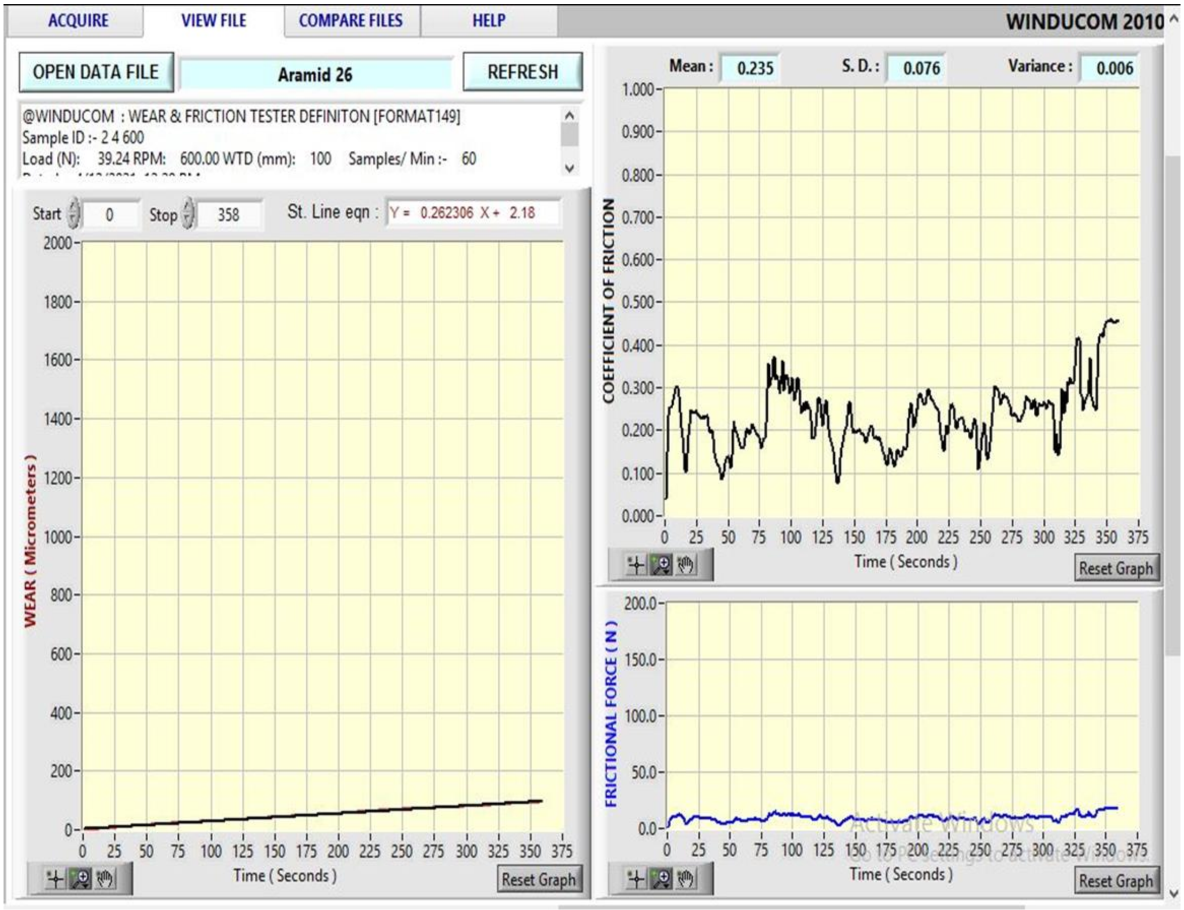
Aramid 25

```
@WINDUCOM  : WEAR & FRICTION TESTER DEFINITON [FORMAT149]
Sample ID :- 2 3 600
Load (N):    29.43 RPM:    600.00 WTD (mm):    100    Samples/ Min :-    60
```

Start 0 Stop 100 St. Line eqn : Y = 0.290015 X + 2.22

Mean : 0.238 S. D. : 0.014 Variance : 0.000

Experiment 6:



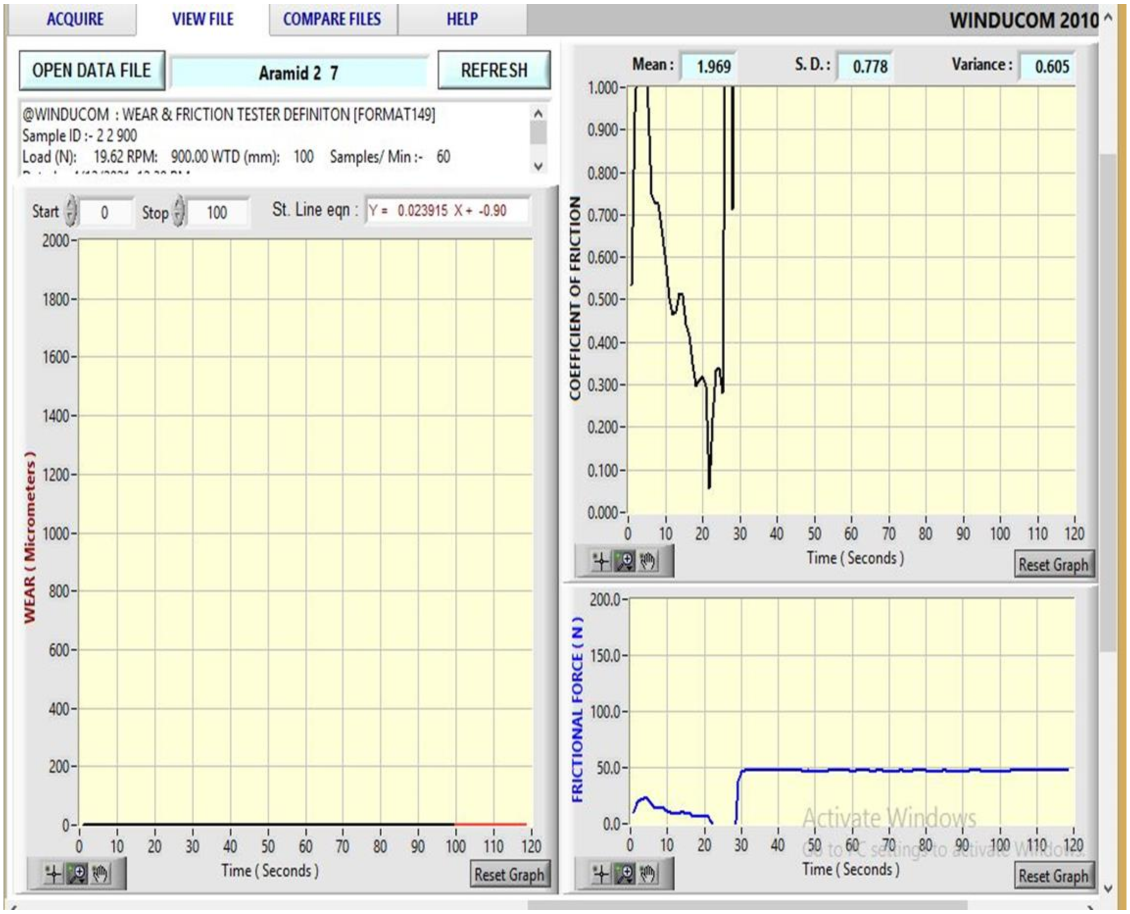
Aramid 26

@WINDUCOM : WEAR & FRICTION TESTER DEFINITON [FORMAT149]
Sample ID :- 2 4 600
Load (N): 39.24 RPM: 600.00 WTD (mm): 100 Samples/ Min :- 60

Start 0 Stop 358 St. Line eqn : Y = 0.262306 X + 2.18

Mean : 0.235 S. D. : 0.076 Variance : 0.006

Experiment 7:



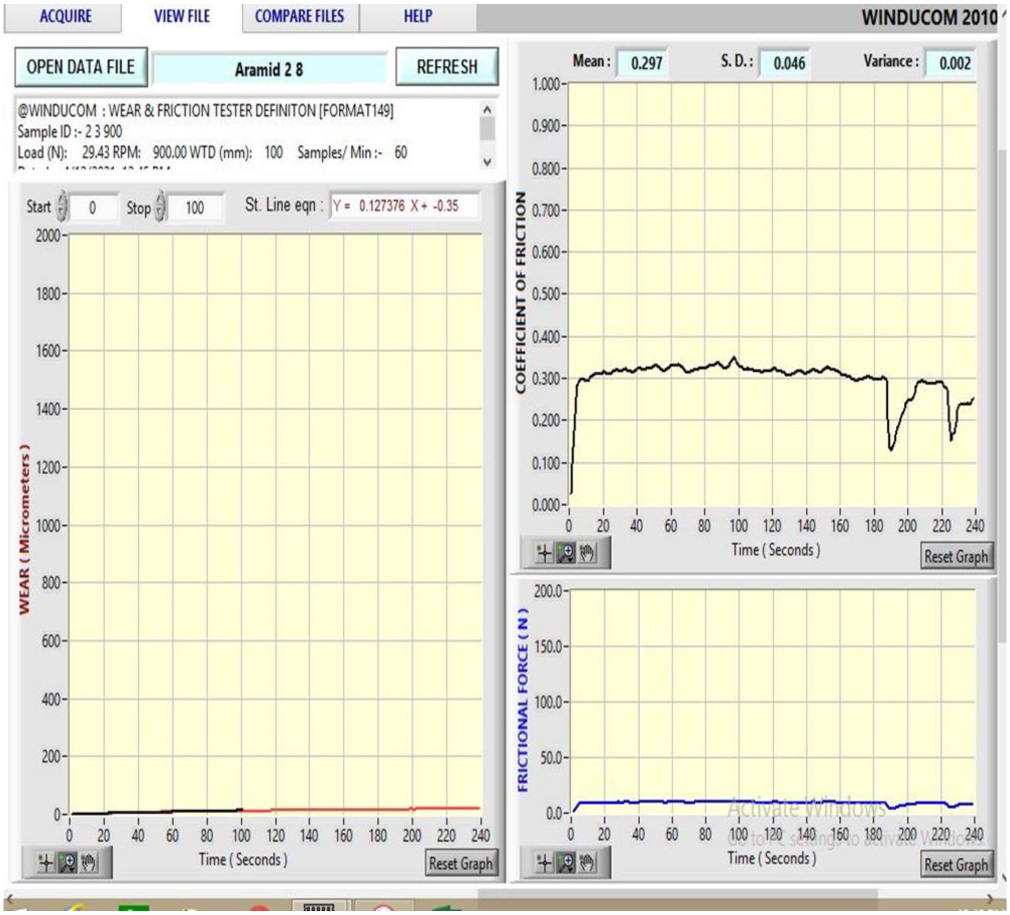
Aramid 2 7

@WINDUCOM : WEAR & FRICTION TESTER DEFINITON [FORMAT149]
Sample ID :- 2 2 900
Load (N): 19.62 RPM: 900.00 WTD (mm): 100 Samples/ Min :- 60

Start 0 Stop 100 St. Line eqn : Y = 0.023915 X + -0.90

Mean : 1.969 S. D. : 0.778 Variance : 0.605

Experiment 8:



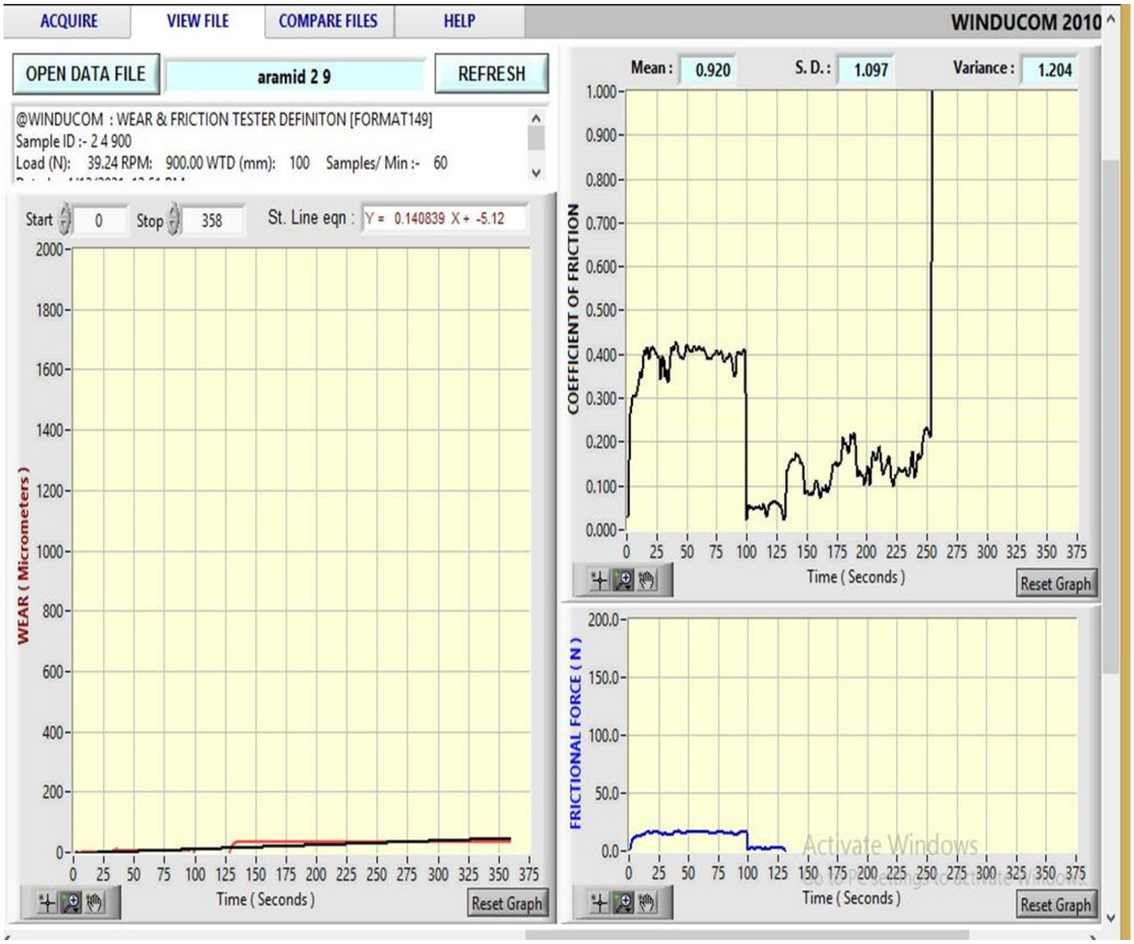
Aramid 2 8

@WINDUCOM : WEAR & FRICTION TESTER DEFINITON [FORMAT149]
Sample ID :- 2 3 900
Load (N): 29.43 RPM: 900.00 WTD (mm): 100 Samples/ Min :- 60

Start 0 Stop 100 St. Line eqn : Y = 0.127376 X + -0.35

Mean : 0.297 S. D. : 0.046 Variance : 0.002

Experiment 9:

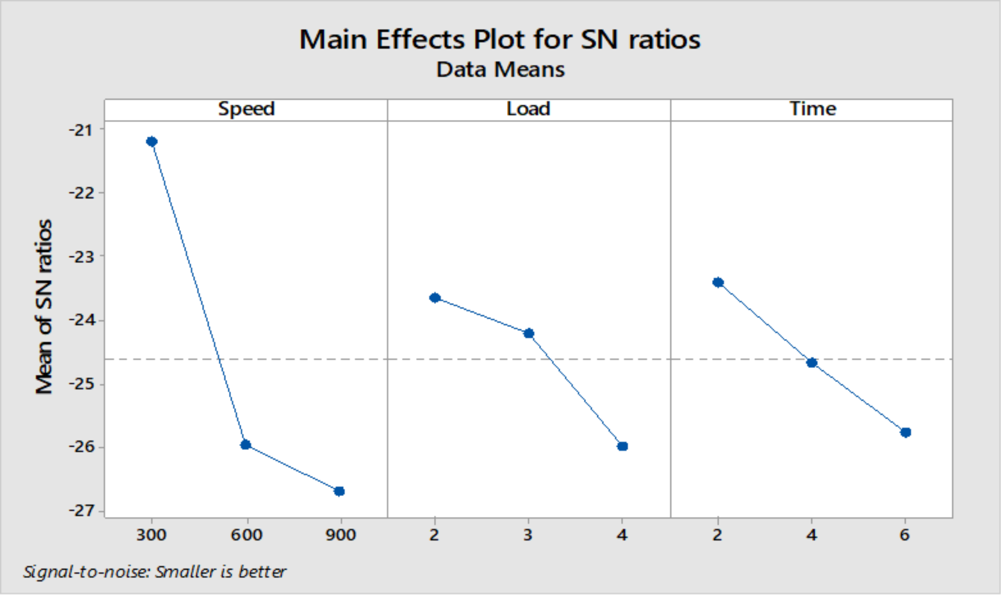


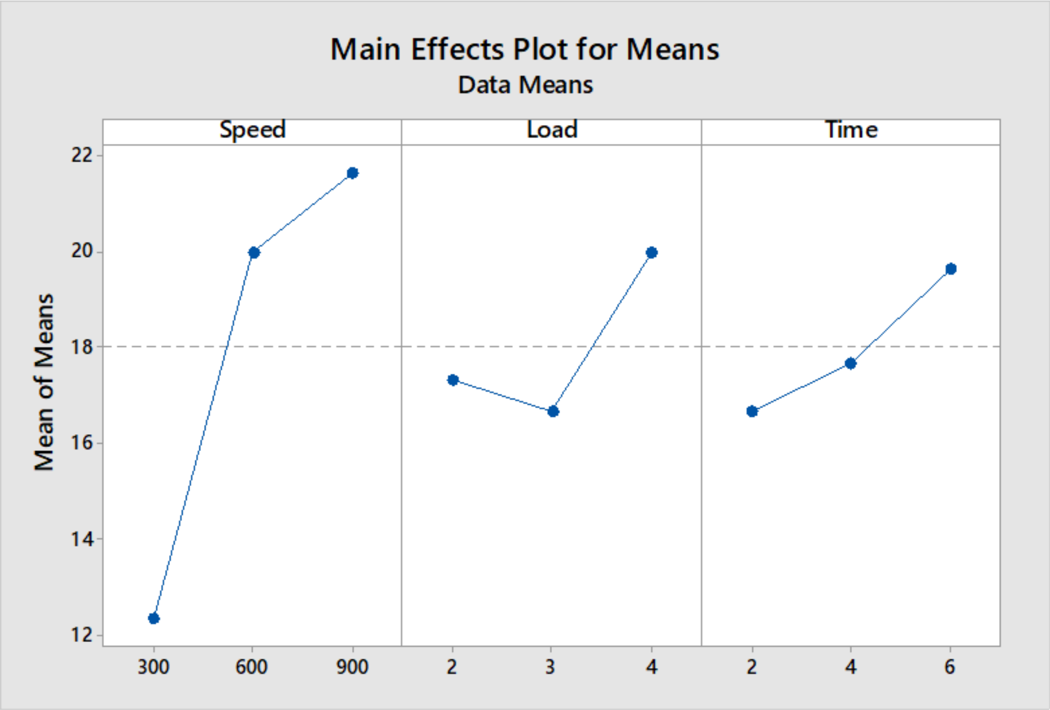
aramid 2 9

@WINDUCOM : WEAR & FRICTION TESTER DEFINITON [FORMAT149]
Sample ID :- 2 4 900
Load (N): 39.24 RPM: 900.00 WTD (mm): 100 Samples/ Min :- 60

Start 0 Stop 358 St. Line eqn : Y = 0.140839 X + -5.12

Mean : 0.920 S. D. : 1.097 Variance : 1.204





Response Table for Signal to Noise Ratios
Smaller is better

Level	Speed	Load	Time
1	-21.20	-23.65	-23.40
2	-25.97	-24.21	-24.68
3	-26.69	-25.99	-25.77
Delta	5.49	2.34	2.37
Rank	1	3	2

Response Table for Means

Level	Speed	Load	Time
1	12.33	17.33	16.67
2	20.00	16.67	17.67
3	21.67	20.00	19.67
Delta	9.33	3.33	3.00
Rank	1	2	3

Regression Analysis: Wear(µm) versus Speed, Load, Time

Analysis of Variance

```
Source      DF  Adj SS  Adj MS  F-Value  P-Value
Regression   3  154.83   51.61     3.34    0.113
  Speed      1  130.67  130.67     8.47    0.033
  Load       1   10.67   10.67     0.69    0.444
  Time       1   13.50   13.50     0.87    0.393
Error        5   77.17   15.43
Total        8  232.00
```

Model Summary

```
      S    R-sq  R-sq(adj)  R-sq(pred)
3.92853  66.74%     46.78%       0.00%
```

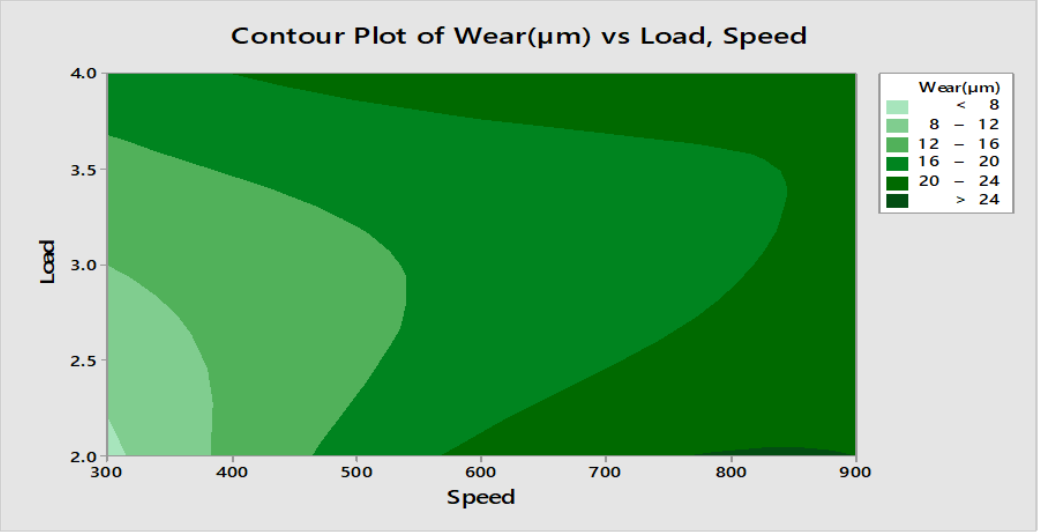
Coefficients

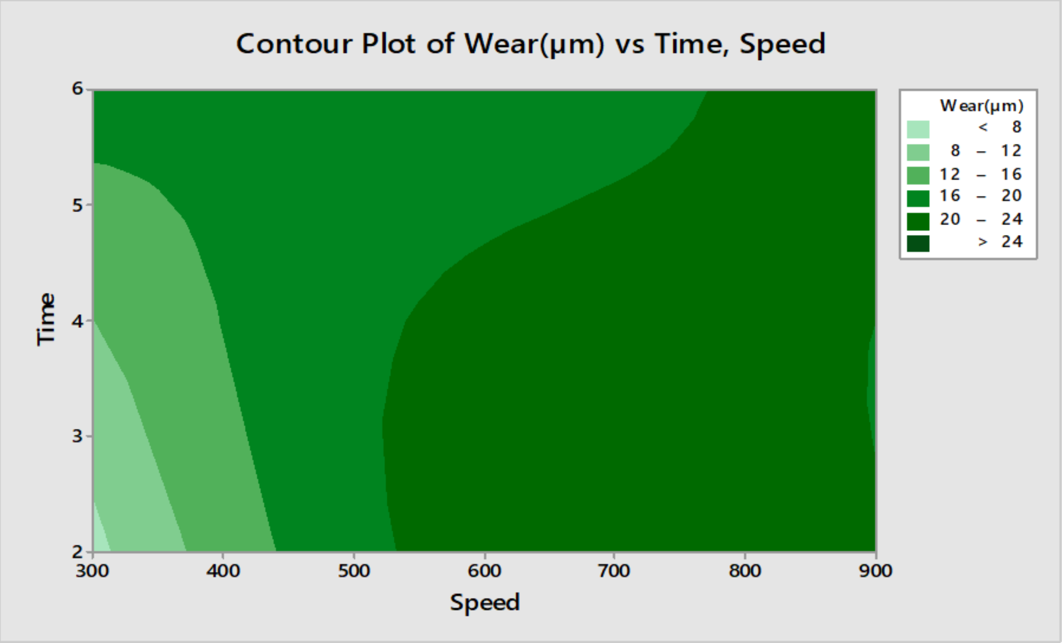
```
Term        Coef  SE Coef  T-Value  P-Value   VIF
Constant    1.67     6.74     0.25    0.815
Speed    0.01556  0.00535     2.91    0.033  1.00
Load        1.33     1.60     0.83    0.444  1.00
Time       0.750    0.802     0.94    0.393  1.00
```

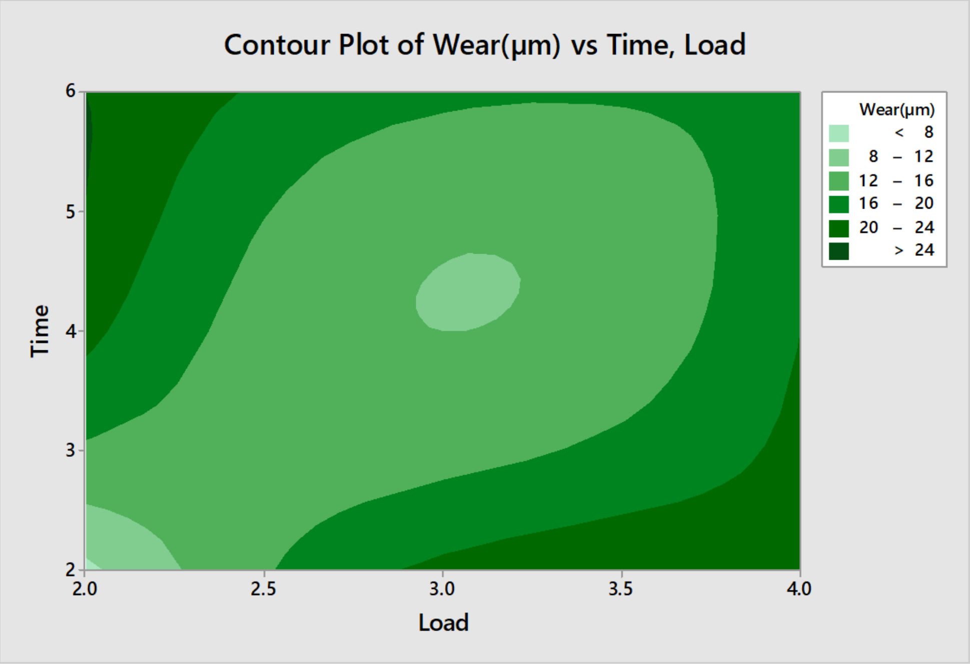
Regression Equation

```
Wear(µm) = 1.67 + 0.01556 Speed + 1.33 Load + 0.750 Time
```

Wear=1.67+0.0155(300)+1.33(4)+0.750(6)=23.58microm


Contour Plot of Wear(µm) vs Load, Speed
Load
4.0
3.5
3.0
2.5
2.0
Speed
300
400
500
600
700
800
900
Wear(µm)
< 8
8 – 12
12 – 16
16 – 20
20 – 24
> 24


Contour Plot of Wear(µm) vs Time, Speed
Time
6
5
4
3
2
Speed
300
400
500
600
700
800
900
Wear(µm)
< 8
8 – 12
12 – 16
16 – 20
20 – 24
> 24


Contour Plot of Wear(μm) vs Time, Load
Time
Load
6
5
4
3
2
2.0
2.5
3.0
3.5
4.0
Wear(μm)
< 8
8 – 12
12 – 16
16 – 20
20 – 24
> 24

CHAPTER - 6

CONCLUSIONS

CONCLUSIONS

6.1 INTRODUCTION

Aramid fiber reinforced composite materials are fabricated by varying the content of carbon nanotubes and keeping remaining ingredients as constant. Four different formulations of composite material with varying weight percentages of filler inclusions are fabricated. Mechanical and damping results are performed as per ASTM standards. SEM images are observed to assess the uniform dispersion of ingredients. TGA results are also observed.

6.2 CONCLUSIONS FROM TEST RESULTS

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

6.2.1 CONCLUSIONS DRAWN FROM TENSILE TEST RESULTS

a) The maximum tensile strength is obtained for sample AF 4 among all the samples.

b) It was observed that the sample AF 4 having (48.97 N/mm^2) exhibits good tensile strength properties compared to remaining samples.

c) It was observed that the tensile strength is increasing from sample AF 1 to AF 4.

6.2.2 CONCLUSIONS DRAWN FROM FLEXURAL TEST RESULTS

a) The maximum flexural strength is obtained for sample AF 4 (37.98 N/mm^2) among all the samples.

b) It was observed that the flexural strength is increasing from sample AF 1 to AF 4.

6.2.3 CONCLUSIONS DRAWN FROM IMPACT TEST RESULTS

a) The highest impact strength is obtained for the sample AF 4 (0.26J/mm^2).

b)) It was observed that the impact strength is increasing from sample AF 1 to AF 4.

After performing mechanical properties evaluation AF4 composite containing 0.4 wt% of MWCNT inclusions along with remaining ingredients exhibited better properties compared to remaining formulations of materials.

6.3 CONCLUSIONS DRAWN FROM SEM IMAGES

The AF 4 sample specimen possess better grain distribution among the sample and uniform distribution of all the ingredients compared to the sample AF 3.

6.4 CONCLUSIONS DRAWN FROMTHERMO GRAVIMETRIC ANALYSIS

Based on TGA and SEM results, it was also observed that AF4 composite exhibited lower weight loss of 2.32 mg after increase of temperature to 600 degree centigrade. The grain distribution is also uniform for sample AF4 compared to remaining samples.

Hence, this method of incorporation of MWCNT in the base polymer matrix can decrease the moisture absorbing capability and also increases the strength of the composite to greater extent and enables to use this method widely for many engineering applications.

6.5 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 impact and dynamic loads.

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