

Introduction and Literature review

1.1 Introduction

Human civilization depends on the evolution of materials like the Bricks Age, Middle Ages, Ancient, Brass Age, and Silicon Age etc. This demonstrates the value one place on materials. One will still continue to make efforts to comprehend and alter the environment around us and the materials from which it is produced. Understanding and maximising the relative contributions provided by material combinations rather than focusing on a single substance will be the key to unlocking the next societal frontiers. The enthusiasm around nanotechnology and the nanoscale present exceptional chances to develop novel material assemblages [1-2]. By accessing novel properties and taking advantage of special material synergism it only takes place at the nanoscale, where the length scales of fractography and the underlying physics behind a property converge, these new materials will make it possible to avoid the traditional material performance trade-offs.

The core of the fascinating field of nanoengineered materials is in the development of manufacturing and processing methods that offer combined structural control upon this nano, micro and macro length scales and the convergence of basic understanding of materials at this scale. Explanations of all these materials techniques include multiplying quickly and have an effect on a wide range of commercial and military sectors [3]. Enhancing and improving the qualities of currently existing conventional classes of materials is one way that the state of the art has improved due to nanoscience.

Polymer composites, for instance, have been a backbone of high-performance aircraft [4] for more than 25 years. This provide a wide range of desirable (and adaptable) qualities, for instance, high stiffness and strength, as well as dimensional and thermal stability. Polymer composites may gain in appeal as a result of the development and use of nanotechnology. Polymer nanocomposites will undoubtedly mark the beginning of a new era in the development of materials, just as polymer composites did 25 years ago when they revolutionised the industrial landscape.

Polymer nanoscience is the study of and implementation of nanomaterials to matrices composed of polymer and nanoparticles, where nanoparticles are described as those that have at least one dimension smaller than 100 nm. Changes in both physical and chemical attributes resulted with the shift from micro- to nanoparticles [5]. The increase in the surface area to volume ratio and the increase in particle size are two major factors in this. The behaviour of atoms on the surface of the particle increasingly dominates that of atoms inside the particle as a result of the increase in surface area-to-volume ratio, which increases as the particle size decreases. When particles interact with one another, this has an impact on the properties of the reacting particles.

Due to the higher surface area of the nanoparticles, there is a greater contact between them and the other particles in the mixture, which improves the combination's strength, heat resistance, and other properties [6]. In polymer or copolymer nanocomposites (PNC), nanoparticles or nanofillers are disseminated throughout the polymer matrix. While they can take on a variety of shapes (such as nanofibers, nanotubes, and plate-like filler), at least one of their dimensions must fall within the range of 1-100 nm. These PNCs fall under the umbrella of multiphase systems for instance blends, composites, and foams etc. Controlled mixing and

compounding are necessary for these systems, as well as stability of the acquired dispersion and dispersed phase orientation. All MPS, including PNC, use a similar compounding strategy. As an alternative, polymer can be introduced into one dimensional, two dimensional, or three dimensional preforms to produce nanocomposites of a polymer with a high concentration. Because the orientation of the fibres may be altered, PNCs' characteristics can be precisely adjusted.

PNCs are often categorised depending on the material's physical and chemical properties, such as polymer, metal, or ceramic matrix composites. A noticeable rate of development is being seen in intermetallic matrix composites. Natural fibre reinforced PNCs [7] that are biodegradable and sustainable have received significant interest recently due to their reduced negative environmental effects, including as decreased carbon emissions and fossil fuel usage, lower cost and density, and simplicity of production. Such fibres may provide a hitherto unheard-of balance of stiffness, strength, and Toughness at low density. As a result, natural FRC has the potential to replace glass fibre, carbon fibre, or any synthetic fibre completely or partially in composites that are lightweight and environmentally friendly.

The composite is frequently made from natural fibres such as flax, jute, hemp, banana, ramie, and kenaf. Jute fibres, the second most produced natural fibre after cotton and at least 50% less expensive than flax and other natural fibres, have garnered the greatest attention among these. Jute is mostly produced in Bangladesh, India, and China. The presence of substantial levels (20 wt%–50 wt%) of noncellulosic components, such as hemicellulose and lignin, causes jute fibres to have inferior mechanical characteristics and poor adhesion when supplemented with a matrix [8]. Poor mechanical properties of composites are caused by the inclusion of noncellulosic elements, which result in fibres with poorer crystallinity and hy

drophilicity [9]. However, the strong interfacial bond between the fibre and matrix may be able to enhance the composites mechanical and interfacial properties. The alteration of the surface.

The mechanical characteristics of jute fibre and their composites have been improved using a variety of physical and chemical processes that remove noncellulosic components. The most common surface treatment for removing impurities and noncellulosic elements from the interfibrillar region of jute fibre is the alkali treatment [10]. As a result, this treatment increases the fibrils' capacity to rearrange themselves in the direction of tensile deformation and improves their capacity for load sharing among one another, both of which help to increase stress buildup during the tensile test. The mechanical qualities of jute fibre can be improved by surface treating it for an extended period of time with reduced alkali concentrations.

Other combination surface treatments, such as alkali-silane, alkali-plasma, alkali-beaching, and alkali-acetylation, have also been researched [11]. But the extent to which the mechanical properties could be enhanced by such techniques is constrained, and some of those techniques are costly. Due to its exceptional mechanical characteristics, graphene and its derivatives, such as for high-performance composite applications, graphene flakes (G), graphene oxide (GO), and reduced graphene oxide (rGO) have recently received a lot of interest. In their stable dispersions, GO and rGO might be created in enormous amounts.

These materials intrinsic functional groups also give them good chemical reactivity and handling properties. In addition, the microfluidization technology enables the production of flakes based on graphene that are electrically conductive and can be employed in smart com

posite applications. Previous research have demonstrated a notable increase in the mechanical characteristics and characteristics of composites made on enhanced graphene-jute fiber through the establishment of either mechanical interlocking (G) or bonding (GO) between fibres and graphene-based flakes [12]. Moreover, as evidenced by their success in de-icing and electromagnetic interference shielding, for highest performance composite material used in smart composite applications, jute FRCs based on graphene have already been created. Such advancements could pave the way for the creation of clever and environmentally friendly natural fibre composites for use in cutting-edge, high-performance engineering applications. Even though there have been numerous evaluations that specifically focus on jute fibres and their composites, it remains unclear why jute fiber's physical and chemical improvements, its growth with different materials of graphene, together with their impact on the mechanical as well as multi-functional characteristics of the composites will influence them. Jute fibres, the essential components of which determine their mechanical characteristics and prospective applications, are introduced in this overview.

A summary of several jute fibre surface treatments is presented and how they affect the mechanical properties of composites that are reinforced with jute fibres. Following that, we go into jute fibre surface changes based on graphene and how they affect the interfacial, tensile, and multi-functional properties of fibre reinforced composites [11]. Finally, we discuss our perspectives on potential directions for future study as well as suggestions for creating the smartest, sturdiest, and most environmentally friendly natural fibre reinforced composites possible. Graphene is a single layer made entirely of carbon atoms that are packed closely together and connected by a hexagonal lattice, much like the structure of a honeycomb. Or to put it another way, it is an allotrope of carbon with a plane of sp^2 bound atoms and a bond

length of 0.142 nm. Graphite is created by stacking layers of graphene on top of one another. These layers are separated by 0.335 nm² of interplanar space. For a variety of applications around the world, low density composites and high strength bases are the best options.

The use of fibre reinforced composite materials in the automotive, machine tools, aerospace, and sporting goods is made possible by their special properties, they have strong mechanical properties, good corrosion resistance, high stiffness and specific strength, high absorbency, and minimal thermal expansion. The composites' non-homogeneity, anisotropy, and reinforcement with highly abrasive components make processing them extremely challenging. The cutting tool can sustain substantial damage from the composite work piece, which also has a significant increase of tool wear. In the end, a variety of variables, such as the properties of the material, the proportion of the matrix and reinforcing elements present, and the material's response to the machining operation, all affect the processing of composites [11].

This chapter is divided into three sections to illustrate the areas of literature consulted as shown in *Figure 1.1*. The first section discusses about composites and its types which are the materials that have been used in the present investigation. The second section introduces machining and related parameters and discusses the literature available on methodologies adopted by researchers to investigate the process, their findings and important factors that affect the process, and the product characteristics. The third section discusses about finite element analysis.

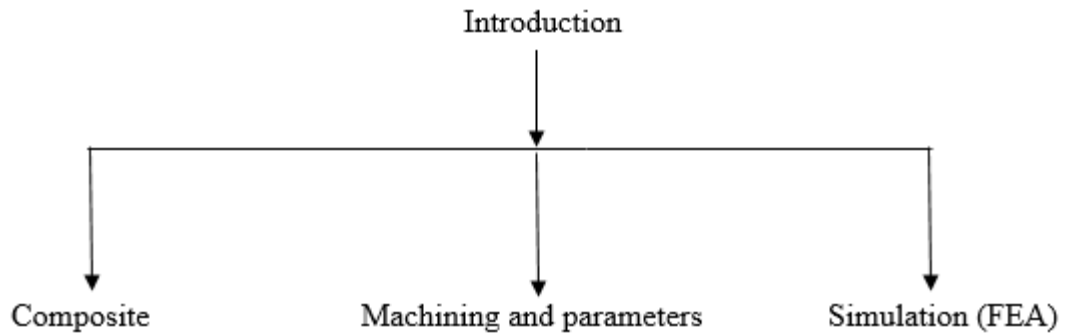


Figure 1.1. Sectors of the introduction.

1.1.1 Composite

whenever two or more components are macroscopically mixed to create a useful third substance known as a composite material. The most important step is a macroscopic inspection of a material in which the individual components can be seen.

1.1.1.1 Types of Composite Materials

On the basis of the matrix material, composite materials may be broadly divided into three classes as shown in Figure 1.2. These are: Polymer Matrix Composites (PMC), Ceramic Matrix Composites and Metal Matrix Composites.

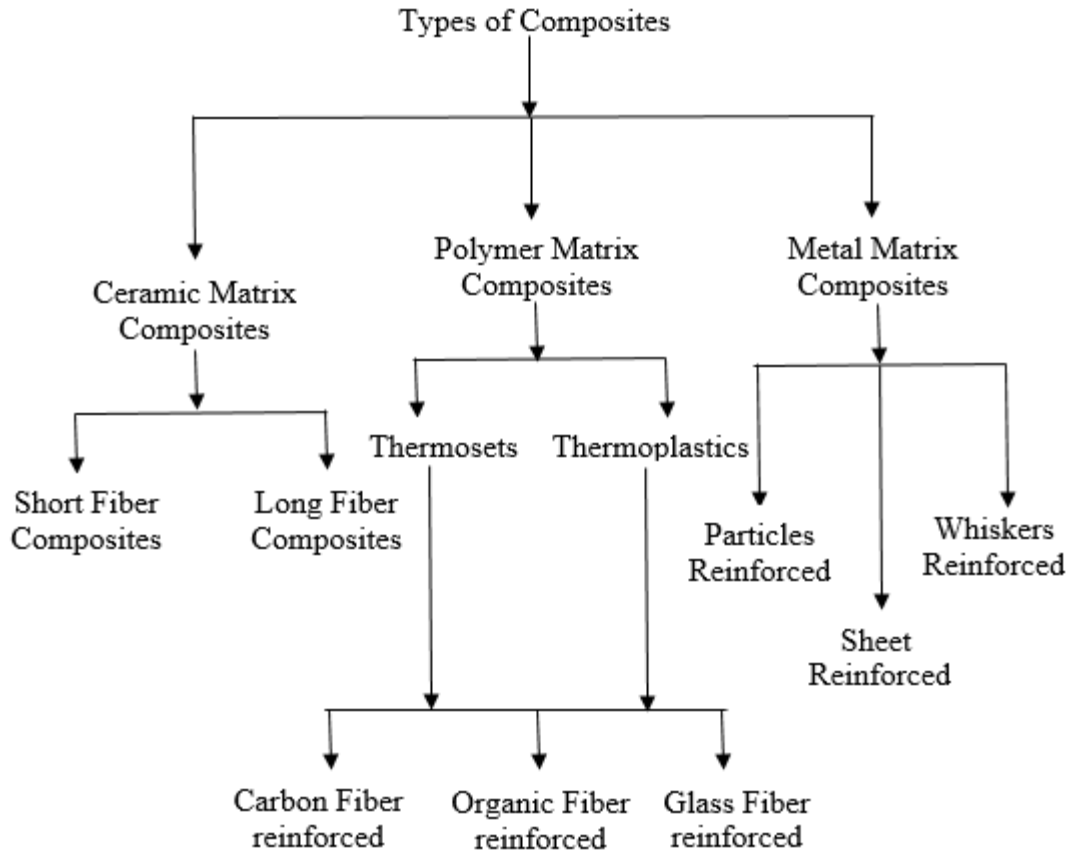


Figure 1.2. Classification of composites.

Polymer Matrix Composites:

Polymeric materials are most frequently employed as matrix materials. Two factors account for this. In general, polymers' mechanical properties particularly their strength and stiffness are insufficient for many structural applications when compared to metals and ceramics. Reinforcing other materials using polymers helps to solve these problems. Second, processing polymer matrix composites need not be done at high temperatures or pressures. Moreover, simpler equipment is needed to produce polymer matrix composites. This led to the quick development of polymer composites, which quickly gained popularity for structural uses. The Schematic diagram is shown in Figure 1.3.

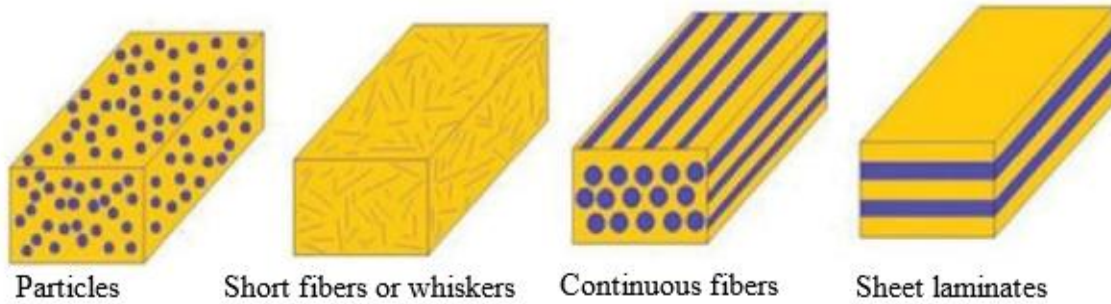


Figure 1.3. Types of polymer matrix composite based on geometry [13].

Ceramic matrix Composites:

Toughness improvement is one of the primary goals while creating ceramic matrix composites. Of course, it is hoped and frequently discovered that the strength and stiffness of ceramic matrix composites will also increase simultaneously. Diagrammatic representation of the various CMC forms, including continuous, discontinuous, and fiber-reinforced CMCs as shown in Figure 1.4.

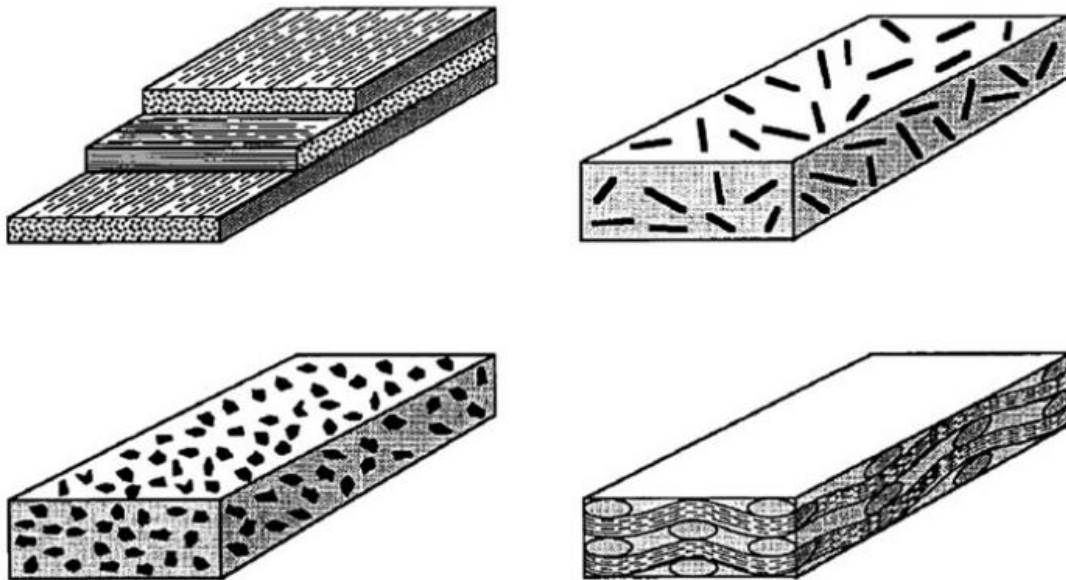


Figure 1.4. Types of ceramic matrix composites based on geometry [14].

Metal Matrix Composites:

In comparison to monolithic metals, metal matrix composites have various benefits, including stronger specific strength, higher specific modulus, better characteristics at high temperatures, and a lower thermal expansion coefficient. These characteristics have led to the study of metal matrix composites for a variety of applications, including heat exchangers, housings, tubes, cables, combustion chamber nozzles (in rockets and space shuttles), and structural components as shown in *Figure 1.5*.

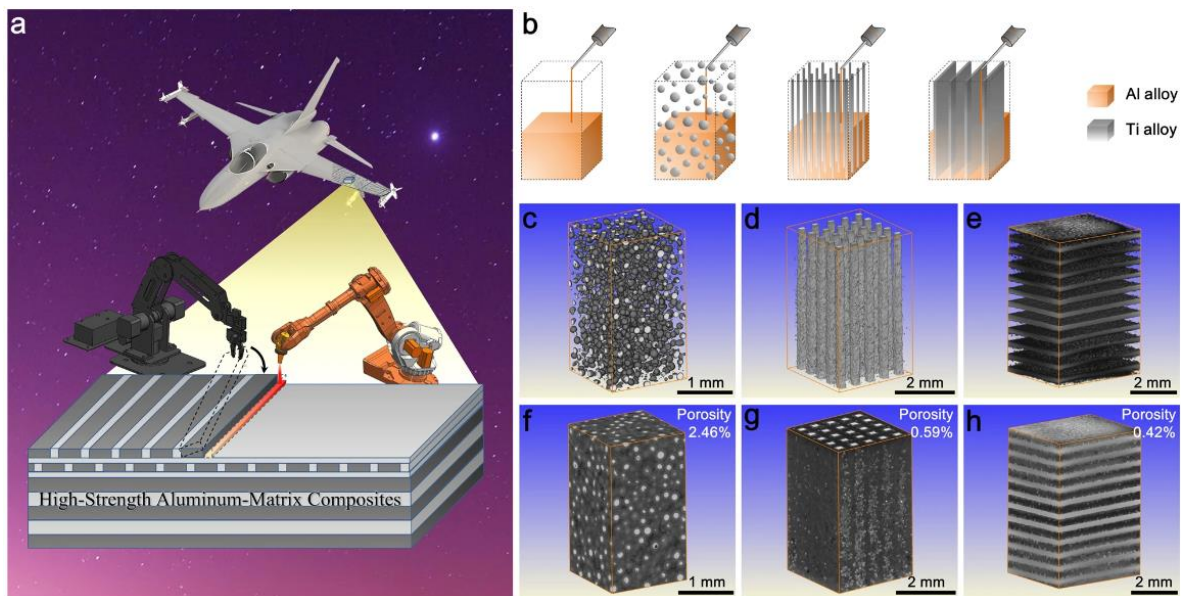


Figure 1.5. Application and fabrication of high-strength aluminum-matrix composites (AMCs) [15].

Hybrid polymer composites

The word "hybrid" in the context of polymeric materials can refer to a type of reinforcement materials that would be blended with several matrices, to two or even more reinforcing materials and additives that have been contained in a single matrix, or even to both of the above approaches. Hybrid effects are variations from the mix rule's expected qualities that might occur when there are more than two stages of reinforcement in a materials as shown in

Figure 1.6. These deviations can be positive or negative. Graphene oxide is a component of the nanocomposite materials in this thesis. The properties of graphene oxide include strong heat stability, which makes it more difficult for cracks to form and increases the strength and Toughness of epoxy matrix composites. By incorporating GO, hybrid epoxy composites may be seen of as novel materials with immense potential for use in a variety of industries, including aerospace, military, automotive, and quick machining.

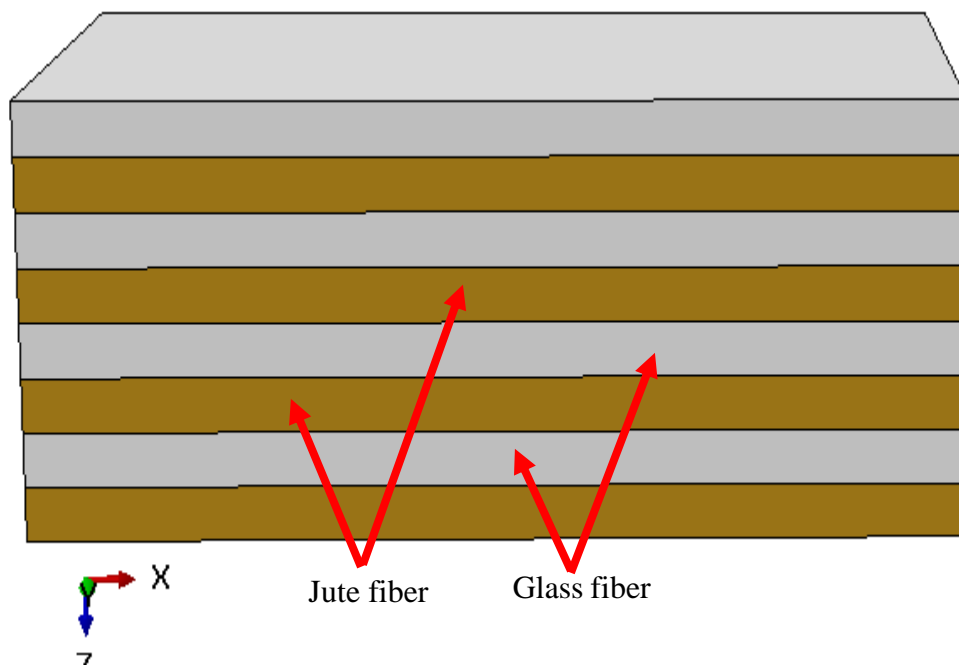


Figure 1.6. Mat fiber reinforced composites (randomly distributed).

1.1.1.2 Fiberglass for reinforcement

Glass is an amorphous substance that is created by chilling a liquid at a pace that prevents the formation of ordered areas, such as crystals. Glass is mostly made of a silica network chemically. Quartz, which is pure silica, must first reach extremely high temperatures in order to melt and pull fibres from it. In order to reduce the viscosity of the glass to a level adequate for melting, homogenising, eliminating gaseous inclusions, and fiberizing, additional chem

ical components are added. The kind and quantity of modifiers modify the final glass's physical qualities to variable degrees. Despite the development of several glass compositions, only a small number of them are being employed in the production of continuous glass fibres. The four major glass forms used are E-glass, S-glass, modified E-glass that is chemical resistant, and high alkali (A-glass).

Table 1.1. Glass composition [16]

Material, percentage weight (%)								
Glass type	Silica	Alumina	Calcium oxide	Magnesia	Boron oxide	Soda	Calcium fluoride	Minor oxides
E-glass	54	14	20.5	0.5	8	1	1	1
Commercial fiberglass used in the present work								
A-glass	72	1	8	4	-	14	-	1
ECR-glass	61	11	22	3	-	0.6	-	2.4
S-Glass	64	25	-	10	-	.3	-	0.7

Table 1.2. Inherent properties of glass fibers [16]

Glass type	Specific gravity	σ_{ult} (MPa)	E_t (GPa)	α ($10^{-6}/K$)	Dielectric constant(a)	Liquidus temperature °C
E-glass	2.58	3450	72.5	5.0	6.3	1065
Commercial fiberglass used in the present work						
A-glass	2.50	6043	69.0	8.6	6.9	996
ECR-glass	2.62	3625	72.5	5.0	6.5	1204
S-Glass	2.48	4590	86.0	5.0	5.1	1454

The variety of glass utilised inside this project is called E-glass, and it is the kind which is most typically employed as a reinforced material for purposes in both plastic and textile items made of fibreglass. Table 1.1 lists the typical chemical compositions of these four varieties

of glass, whereas Table 1.2 lists their intrinsic characteristics.

1.1.1.3 Natural Fiber Reinforced Polymer Composites



Figure 1.7. Natural fiber reinforcements [17].

Natural composites have qualities that combine those of polymers and natural fibres. Because of their non-conductive and heat-resistant qualities, phenol- or melamine formaldehyde resins were created and utilised in electrical applications around the turn of the 20th century. It is currently common practise to add natural fibres Figure 1.7 to polymers to enhance their mechanical qualities. Mechanical properties such as UTS and modulus of elasticity are enhanced in the completed products (composites) because as fibres in composites affect the UTS and modulus of elasticity of the materials [18]. The automobile industry, where natural fibres are advantageously employed due to their low density and rising environmental concerns, is one of the main global markets for recent growth in natural fibre plastic composites.

Where load bearing capability and dimensional stability under humid and high heat conditions are of secondary relevance, natural fibre composites have found applications.

For instance, flax fibre reinforced polyolefin is widely employed in the automobile sector today, although the fibre mostly serves as filler material in interior non-structural panels [19]. It is possible to employ natural fibre composites for structural applications, but these materials often include synthetic thermo-set matrix, which obviously limits their environmental benefits [20]. Due to their high aspect ratio, high specific strength, and high stiffness, plant fibres like hemp, flax, and wood offer a lot of promise as reinforcement in structural materials [21]. Natural fibres also include cheap cost, environmentally friendly manufacturing, less tool wear, no skin problems, and strong acoustic and thermal insulating characteristics. These are additional benefits of adopting natural fibres that are important to mention. In addition to possessing strong mechanical characteristics specifically and having a favourable influence on the environment, these benefits exist. Production of door from hemp fibre as shown in Figure 1.8.

If the matrix material also originates from a renewable resource, a fully biodegradable system may be generated. Lignophenolics, starch, and PLA are a few examples of these materials. Some of these systems provide enticing outcomes. For instance, according to [22], flax fibre composites with PLA matrix may compete with flax/polypropylene composites and even surpass them in terms of mechanical qualities. According to a recent study [23], composites of poly-L-lactide acid (PLLA) reinforced by flax fibres can exhibit a specific tensile modulus comparable to that of composites made of short glass/polyester fibres. Glass/polyester composites had a greater specific strength than flax/polyester composites, which was lower than flax/PLLA composites. Other significant drawbacks that are still present with natural fibre

composites are also linked to their limited utilisation. For effective stress transmission, the fibres often exhibit a limited capacity to cling to common non-polar matrix materials.



Figure 1.8. Manufacturing of door from hemp fibre [24].

Additionally, due to their intrinsic hydrophilicity, fibres are sensitive to water absorption in damp environments. Natural fibre composites have a tendency to absorb a lot of water, which has a detrimental impact on their mechanical qualities, such as stiffness and strength. The natural fibre is not inert, though. Chemical, enzymatic, or mechanical changes can increase the adherence of the fibre to the matrix and decrease the fibre swelling.

Natural fibre composites have several uses in daily life. Jute, for instance, is a popular reinforcing material for composites in India. Buildings, elevators, pipelines, and panels all employ jute fibres with polyester resins [25]. Natural fibre composites are also a very cost-effective material that can be used in wide range of applications, including construction and

renovation (like as walls, ceilings, partitions, window frames), collection (such as bio-gas vessels, post boxes, etc.), household equipment (such as chairs, tables, and equipment), digital (such as the the outside casting of mobile phones), automotive industry and railroad coach interior components (like as internal fenders and bumpers), toy cars, and other a wide range of applications (helmets, suitcases). Several projects have been undertaken in the last few years to develop natural fibre composites in place of the more common synthetic fibre. Hemp, sisal, jute, cotton, and flax are a few examples.

1.1.1.4 Jute Fibers

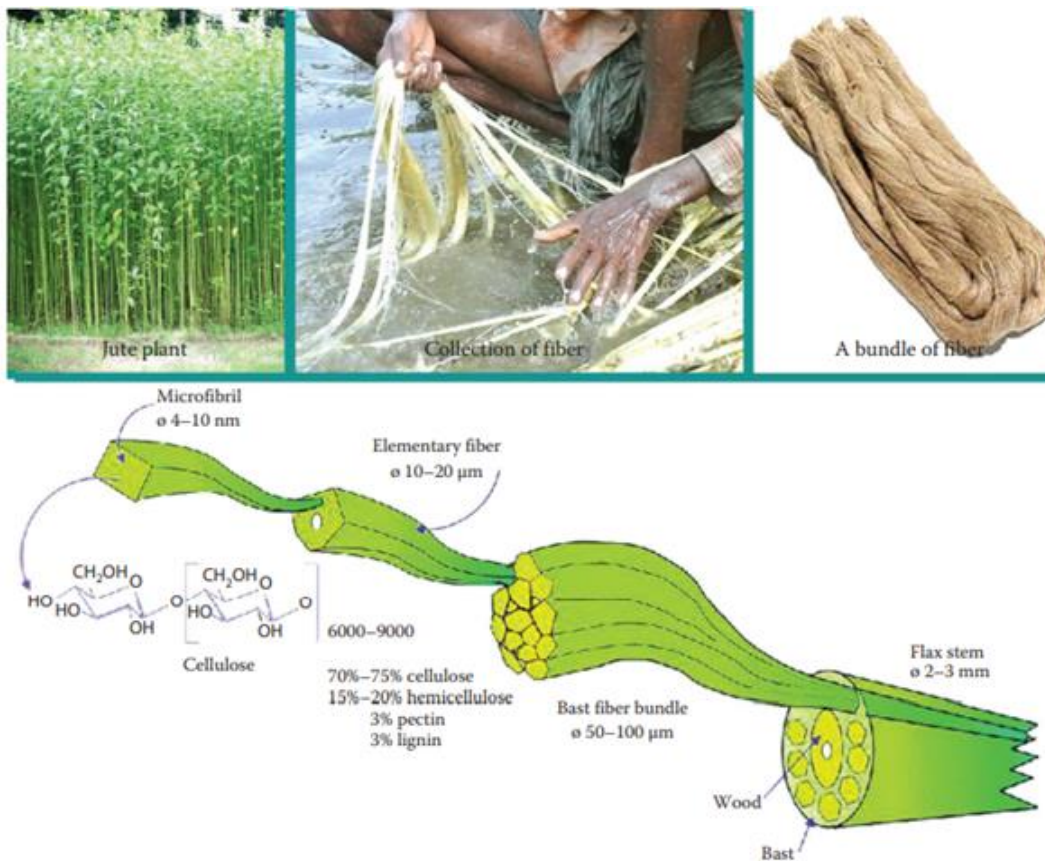


Figure 1.9. Structure of a jute plant and jute fiber [26].

The jute plant, genus *Corchorus*, family *Malvaceae*, is where the fibres are obtained from [27]. The 1-4 m long, off-white to brown jute strands are taken from the plant's bast or skin. Jute has to be grown in an environment that is hot and humid, with temperatures between 200°C and 400°C and relative humidity levels between 70°C and 80°C. Jute needs more rainfall throughout the planting time of 5-8 cm each week. Jute [28] is available in two different colours: white and Tossa. In contrast to the former, the latter is softer, smoother, and more robust. Bengal (India and Bangladesh), the region with the biggest jute production in the world, is where white and tossa jute are grown. It was discovered that jute fibres might take the place of glass fibre, which the European Union has banned for use in vehicles.

Natural fabrics like flax, jute, and hemp are the ideal substitute fibres for making car interiors because they are ductile and have a certain stiffness that is advantageous in side collisions [29]. Since jute is the least expensive plant fibre with a very high tensile strength, it is one of these fibres that is economically feasible. Due to its biodegradable nature, white jute is quickly replacing synthetic materials in many of these applications. To manufacture twine and rope, the fibres are either utilised by themselves or combined with other types of fibres. Tensile strength ranges between 1000 and 480 MPa depending of the fibre thickness, which ranges from 40 to 80 m. Jute fibres can resist air temperatures of up to 100⁰C without decomposing [30].

Surface treatment of jute fiber

The development of composites having superior mechanical characteristics is significantly hampered by the jute fibres' propensity to absorb moisture, as was described in the sections above. By giving the fibre a chemical treatment, this restriction can be overcome. Based upon the type of matrix and reinforcements, as well as the kind of surface processing used, it's been

observed that coupling agents like polyesteramide prepolymer, acrylate and PVC cause the surface treatment of jute fiber to significantly increase the characteristic values of the composites. In the section that follows, several chemical processes are covered.

Silanization

The moisture content at equilibrium in unaltered juteepoxy and jutepolyester composites increases as the fibre quantity. Furthermore, jute-polyester composites processed with polyvinylacetate exhibit improved water resistance. About 20% less moisture was present at equilibrium in composites made with silanized jute fibres [31]. The number of hydroxyl groups that are free to bind moisture and are present on the jute fibres is decreased after silane treatment. These composites exhibit higher (B30%) static characteristic values than unmodified composites at normal humidity thanks to the surface silanes treatment.

Mercerization

Similar to how silane treatment promotes crystallinity and boosts modulus in jute fibres, alkali (NaOH) treatment does the same. Following treatment, the fibres become stronger and exhibit less elongation to break. The interlaminar shear strength of such alkali-treated jute fiber composites rises from 0.238 to 0.2834 MPa, while the modulus rises between 11.9 to 14.7 GPa. Flexural strength of composites is also improved from 199.1 to 238.9 MPa. Depicted in [32] are the load-displacement curves for composite materials comprised of unprocessed and alkali treated jute fiber based composites.

Acetylation

Jute composites made with acetylated jute fibres have better mechanical characteristics, with the extent of the improvement dependent on the amount of jute fibre used and how long it was treated for. Ref [32] provides information on the tensile and flexural strengths of composites made from natural and acetylated jute fibres.

Graft copolymerization

The efficiency of MAH PP as a coupling agent has become the subject of several investigations. For instance, [33] found that applying the coupling agent to the flax fibres prior to processing the composite increased the shear and tensile strengths of flax PP composites by approximately 100% and 25%, respectively. These values were influenced by the application settings, the rate of grafting as well as the graft copolymer's average molar mass. With a PP matrix that has been treated with MAH, similar gains in strength attributes were found [34]. The flax fiber's hydroxyl groups connected chemically and hydrogenally with the MAH coupling agent's acetic anhydride groups, which were securely adhered to the fibre surface by the coupling agent. The MAH PP coupling agent's long PP chain allowed for the adaptation of the significantly dissimilar surface energies of the matrix and reinforcing fibre as well as a satisfactory wetting of the fibre by the viscous polymer. Through an enhanced effort of adhesion, the improved wetness can boost strength. Additionally, it has been established that MAH-modified PP composites reinforced with wheat straw fibres have improved tensile and impact characteristics [35].

1.1.1.5 Graphene-based polymer Nanocomposite materials

One of the well-known developments in polymer science is polymer nanocomposite. When a polymer and a nanoscale substance are combined, the outcome is a unique combination that alters the material's physicochemical properties as well as its structure and morphology [36]. Selecting the right polymers and nanomaterials makes it possible to considerably modify these structural differences and changes in physicochemical qualities. It has been discovered

that adding even a minimal amount (less than five weight percent) of nanomaterial to a polymer matrix can significantly improve the material's characteristics [37]. There are various causes for the resurgence of interest in polymer nanocomposites. First, nanofillers frequently exhibit distinct qualities compared to their bulk equivalents of the same material. For instance, compared to conventional carbon fibres, single-walled carbon nanotubes display much greater strength, stiffness, and strain to failure [38].

Second, compared to their bulk equivalents, these nanoscale fillers have smaller flaws overall. They can delay premature failure, resulting in improved ductility and toughness in nanocomposites. Third, because these nanofillers have high surface-to-volume ratios, they can produce nanocomposites with a lot of interfacial matrix material that has different characteristics from bulk polymer. This interfacial nanopolymer matrix can drastically change the whole nanocomposite's mechanical, thermal, and electrical characteristics. In summary, all these traits offer the chance to make polymer nanocomposites with distinctive properties [39].

Nanomaterial

The word "nanomaterial" often refers to materials having nanoscale internal or exterior dimensions and extra or distinct unique features. According to the ISO, a nanomaterial is a substance having any one dimension in the nanometer scale. Based on their size, there are three major kinds of nanomaterials which are shown in Figure 1.10. Among these, polymer nanocomposites for two dimensional nanomaterials have a special place of their own. On the other hand, other dimensional nanomaterials, for instance, zero dimensional and one dimensional nanomaterials with polymers, can also be used to create nanocomposites [40].

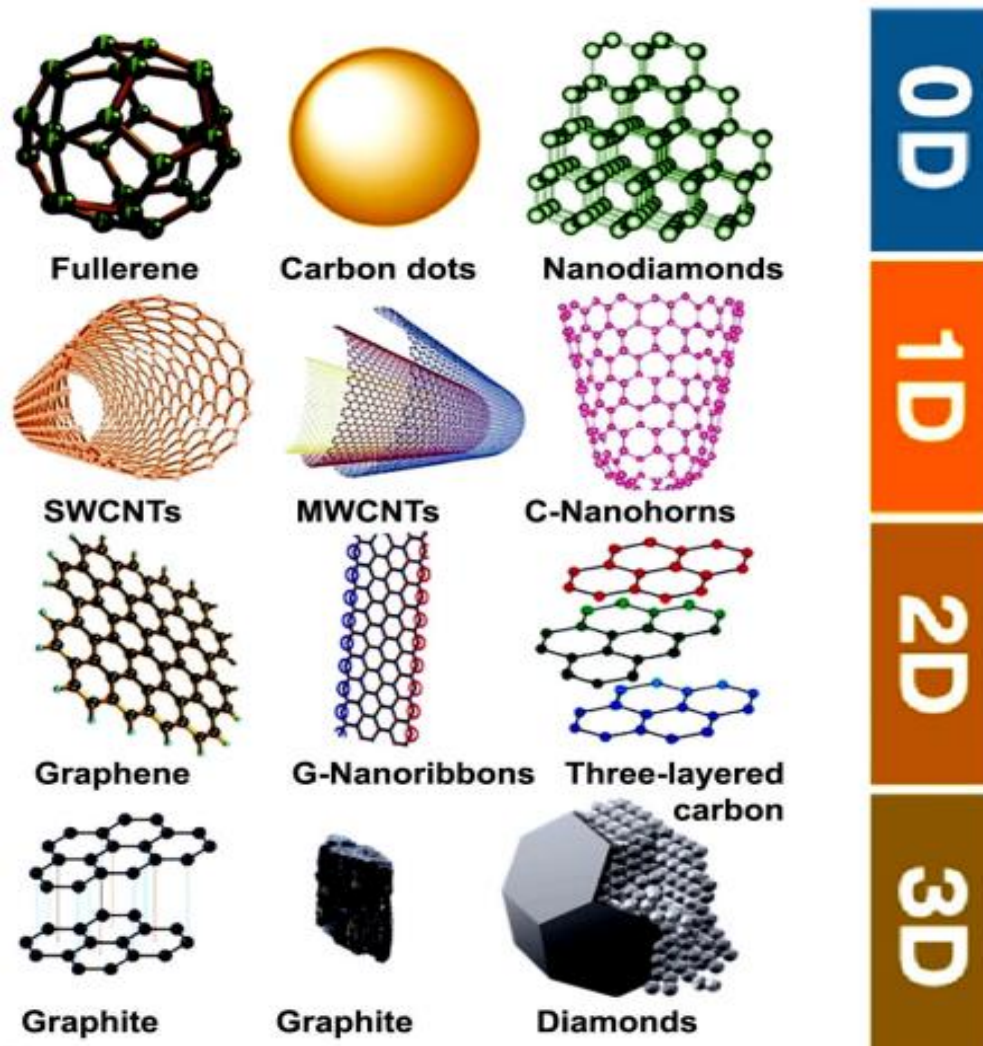


Figure 1.10. Different structures of carbon nanomaterials (CNMs) [41].

Graphene

A layer of 2-D linked carbon atoms that is one atom thick and has a hexagonal honeycomb crystalline structure makes up graphene, also known as mono-layer graphite. The only membrane of carbon atoms tightly packed into a 2D honeycomb crystal lattice [42] having zero-energy band gaps, graphene possesses special properties such as strong mechanical and thermal stability, huge surface area, and high conductivity. Due to its great hydrophobicity and inability to dissolve in a hydrophilic solution, graphene naturally forms huge aggregates by van der Waals and interactions.

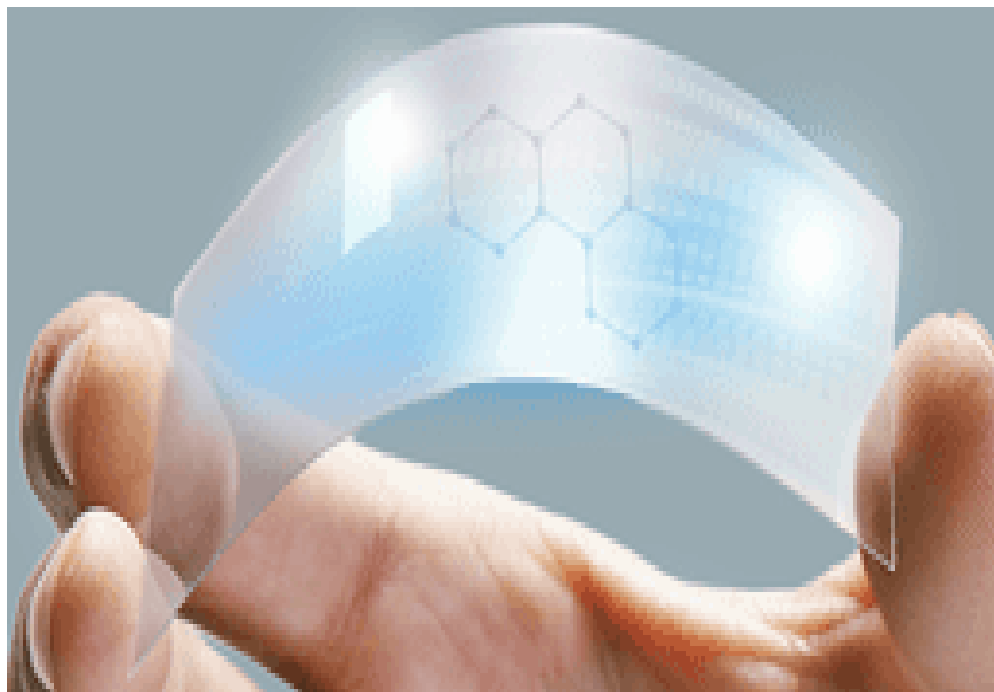


Figure 1.11. Scotch tape method [43].

These qualities make graphene useful in many relevant investigations as a material. The processes and attributes of graphene-based composites with nanoparticles and polymers have recently been the subject of several review publications, with even a passing mention of pote

ntial applications [44]. Numerous applications of graphene have been developed, including corrosion protection films and protective coatings, active sensors, micro - electronic batteries, capacitive electrode materials, faster Gene sequencing, fluorescence biomedical imaging, photocatalytic degradation, gene and bioactive delivery, water purification, and biosensors [45].

Because oxygenated molecules are present, GO becomes more hydrophilic, which typically enables its use in water and other natural environments. For wastewater filtration, a significant amount of graphene and its handmade composites are used. By employing an adsorbent and applying graphene composites, contaminants and poisons such as Medicines, insecticides, toxic metals, pigments, pesticide residues, and medium sized harmful compounds are eliminated [46]. The ideal adsorbents for impurities in water are activated carbon and various carbon allotropes. Graphene also has a large specific surface area for the removal of pollutants.

Glass-Jute hybrid nano-composite

Natural fiber has been used as an alternative material over the previous few decades due to its low cost, eco-friendly, lightweight, renewable nature, maximum mechanical performance, etc. Natural fibers such as hemp, jute, kenaf and bagasse have been used as reinforcement for FRP composite [47]. Polymer composites made from natural fibers have found application in buildings, furniture, impact energy absorption, the automobile industry, naval application, packaging and aeronautics [48]. Low-dimensional carbon nanomaterials, such as carbon nanotubes (CNT) [49], graphene [50], and others, have attracted a lot of attention in recent years from the scientific and engineering sectors. They are appealing reinforcements

for polymers for creating high-performance and useful composite materials because they have distinctive electrical, mechanical, and thermal characteristics [51].

The increased profitability of polymeric materials is due to the inherent infill properties together with their dispersed optimization, ideal interfacial contact, and nanoscale synthetic innovations [52]. [53] Their investigation into the tensile properties of graphene-reinforced composite materials revealed that they had a greater modulus of elasticity than the neat epoxy, at 2.5 GPa (2.3 GPa). To the contrary, increasing the graphene weight fraction (wt%) to 2 wt% causes the composite's Elastic modulus to decrease to 2.3 GPa. A variety of dispersion and alignment technologies can significantly lessen the propensity to aggregate and produce uniform dispersion in order to prevent aggregation [54].

To increase the interfacial strength and compatibility of carbon nanofillers with a polymer matrix, functional surface modification is always performed [55]. Chemical modification, for instance, can greatly reduce agglomeration and evenly distribute nanofillers all across the polymer matrices to give superior load transfer capabilities. With the addition of -COOH functionalization, the elastic modulus of a graphene reinforced composite increased from 3.24 GPa to 3.62 GPa at the same loading (1 wt%) [56]. Another approach to chemical modification that could really stop the formation of permanent aggregates, chemically tailor the mechanical characteristics of the intermediate layer, and significantly improve load transfer and mechanical characteristics in composite materials is the covalent bonding of polymer chains to carbon nanomaterials [57].

For example, when CNT was incorporated in the nylon-6 matrix at 10% by weight compared to pure CNT, [58] discovered that covalent correction increased by 50%. The internal fracture

can degrade material effectiveness without causing obvious damage to the affected surface. As a result, It's crucial to look at the low-velocity influence on composite materials [59]. The impact force and damage process are related, so the researcher must conduct extensive research on the impact behavior of composite materials [60]. Furthermore, the spread of damage is influenced by both material reaction and impact properties. An impactor's velocity, force, and energy are the impact characteristics. The material response is influenced by its strength, energy dissipation, and duration of impact. The design of impactor and its mass will affect the damage characteristics of the sample [61].

The composite materials are brittle, so energy absorption due to impact depends on fiber-matrix debonding, matrix cracks, fiber breakage, and delamination. If delamination occurs between each ply, Progressive failure mode will occur, and the composite will demonstrate the ability to absorb energy. Little work has been performed related to the low-velocity impact on laminated composite. As a result of the necessity to build multifunctional goods, lower manufacturing and operating costs, and boost operational effectiveness, the miniaturization of machined features has emerged as a crucial production demand in contemporary industry. Despite the fact that near-net forms of nano-composite materials may be created, micromachining methods are thought to be essential to guarantee final geometrical precision and dimensional accuracy.

The primary difficulties while cutting materials made of polymers are the high heat created as a result of inadequate heat transmission capacities [62]. Additionally, this might lead to unexpected variations in cutting forces and the accuracy of the final components' dimensions and geometry. Additionally, even though a variety of techniques, particularly those based on lithography, have been used to create composites reinforced with graphene and nano-clay

[63], their use is still challenging, time-consuming, and expensive due to the intricate designs of microdevices [64]. Thus, mechanical micromachining, and particularly micro-milling, appears to be the most appropriate method. Yet traditional materials like metals and alloys are the main subjects of modern research [65]. The necessity to research machinability when micromachining polymer nano-composites reinforced with graphene and nano-clay arises from the need to improve cutting operations as well as to better comprehend the impact of size when downscaling from macro- to micro-machining.

Cutting forces when micromachining polycarbonate (PC) supplemented with a modest volume of GNPs (0.2 wt%) are greater compared to plain PC because of the mechanical enhancements provided by graphene [66]. According to [62], the effective dispersion of smaller GNP particles improved the mechanical characteristics of the nano-composite formed, and larger cutting forces were observed (see Figure 2). When cutting carbon nanotubes (CNTs), especially at high feed rates, this pattern is different from the forces reported [67]. It is also suggested that high heat and molten PC clung to the tool surfaces as a result of the low thermal conductivity of plain PC, which resulted in poor surface quality and bigger burr development.

Additionally, the PC matrix was strengthened with GNPs, which enhanced machinability by reducing surface roughness and burr height and increasing dimensional accuracy. The main difficulties generally facing during machining are heat generation which leads to variation in dimensional or geometrical accuracy, cutting forces, chip formation etc. Metals and alloys have been the subject of recent research [62]. There is a need to study the micromachining specially micro milling of graphene based polymer composites to optimize the machining

parameter by using various techniques such as taguchi, anova etc. also to study the effect of size while downscaling from macro-machining to micro-machining.

Sunil Rawal et. al. [68] found that because of well dispersion of nano particle in the matrix there is a improvement in mechanical property and also higher cutting forces were measured. Due to the poor conductivity of plain matrix there is a excessive heat generation leads results molten material will adhered on tool surface leading burr formation poor surface quality on the other hand using graphene as an additive lead to better dimensional accuracy, improvement in machinability, lower surface roughness.

1.1.1.6 3D Printed CFRT composites

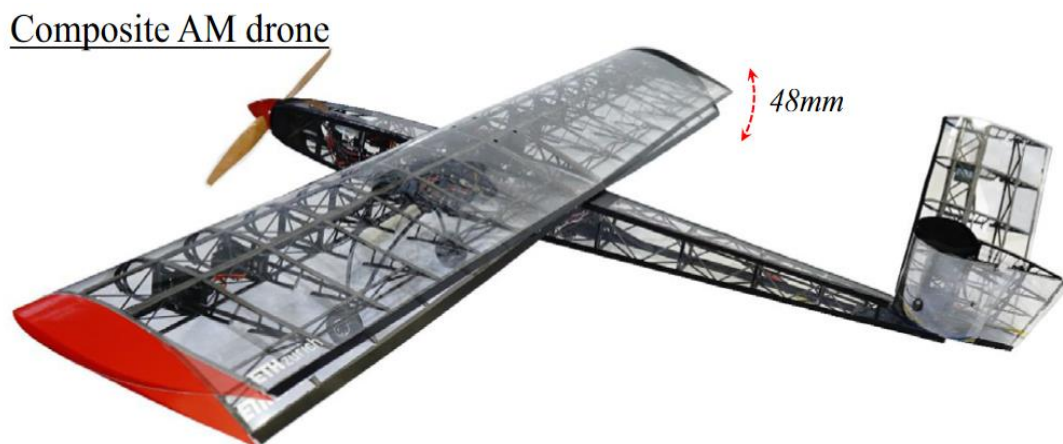


Figure 1.12. Additively manufactured composite drone [69].

The lightweight engineering of aeroplanes and vehicles has recently focused heavily on thermoplastic polymers and composites as shown in Figure 1.12. Among the several 3D printing methods that have been created, FDM has become the most extensively used 3D printing methodology [70] because to its low price and broad availability of components. Furthermore, FDM printed structures made of pristine polymers often have poor mechanical properties and cannot be employed as load-bearing elements. Therefore, by combining polymeric

matrices with fibre reinforcements, or FDM printing composites, many academics and engineers attempt to improve the mechanical qualities of printed structures.

Short-fiber reinforced thermoplastics (SFRT) and continuous-fiber reinforced thermoplastics (CFRT) as shown in Figure 1.13 are the two basic groups into which they may be separated [71]. Multiple attempts have been made to look into printing parameters [72], the porous effect [73], the influence of fibre orientation [74], and the effect of fibre content [75]. For instance, Ref. [76] used FDM printing technique to create composites made of carbon fibre (CF), glass fibre (GF), and polyetheretherketone (PEEK) as well as evaluated their mechanical characteristics. They discovered that the tensile and flexural strength were greatly enhanced with the right kind of fibre addition, but ductility was sacrificed.

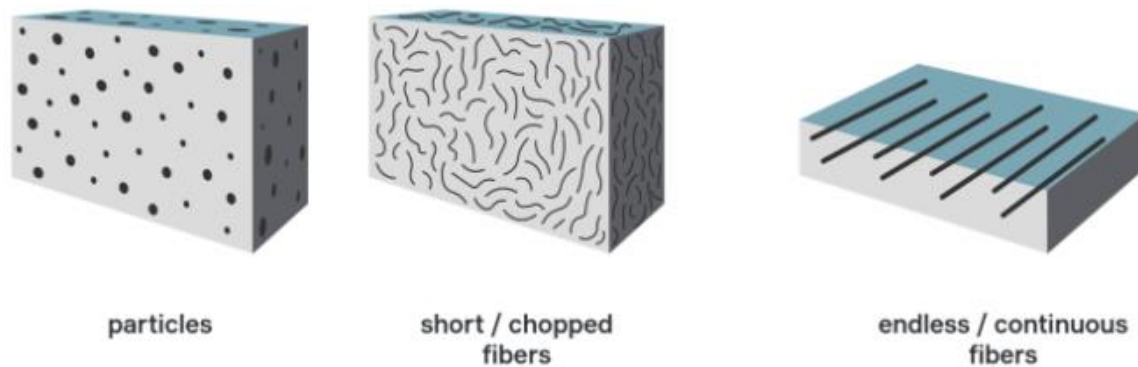


Figure 1.13. Different types of 3D printed composites [77].

The tensile strength was enhanced by around 19% when comparing 5 wt% CF/PEEK with pure PEEK. Additionally, the characteristics can be strengthened by the fibres being aligned along the printing orientation. Using the identical CF/GF-PEEK composites, Ref. [78] looked into the impacts of FDM printing settings. It is discovered that by adjusting the printing speed, layer thickness, nozzle temperature, and platform temperature, the tensile, flexural, and impact strengths may be increased.

The advancements are modest, though. For instance, even after the process parameters were optimised, the tensile strength was still below 100 MPa. The FDM production of CF-ABS composites with various fibre contents and fibre lengths was explored by Ning et al. According to the findings, the specimen with 150 mCF had a greater tensile strength and elastic modulus than the specimen with 100 mCF. The tensile mechanical characteristics increase initially, then decline, then increase as the fibre content rises.



Figure 1.14. 3D printed vehicles [79].

Therefore, by modifying fibre length, content, and orientation, SFRT composites' mechanical characteristics may be enhanced. However, it's challenging to fill short fibres to a weight fraction greater than 40% owing to nozzle blockage and filament toughness loss. The low fibre content of SFRT composites restricts their mechanical capabilities.

3D printed SFRT composites are unsuitable for use in load-bearing constructions because to their poor characteristics and cost-performance ratio. To create CFRT composites, the researchers attempt to incorporate continuous fibres into thermoplastic materials. Currently,

single nozzle and double nozzle FDM printing techniques are available for CFRT materials. Inside the extrusion head, the thermoplastic filaments and fibre bundle are combined [80]. One nozzle of a double-nozzle FDM printer, like the MarkForged MarkOne, extrudes thermoplastic matrix, while the other extrudes continuous fibre [81]. Researchers investigated the effects of penetration depth, extruded breadth, printing temperatures, and velocity on the tensile mechanical behavior of consistently 3D-printed CF-PLA composites[82]. They came to the conclusion that the transmission of external loads to the carbon fibres via the fiber-matrix contact is the mechanism that strengthens the tensile mechanical characteristics.

The specifics of matrix breaking and fiber-matrix bonding, however, cannot be seen from their images. In order to assess the impact of the process parameter, [83] investigated the flexural strength and modulus of the continuous CF-PLA and examined the fracture surfaces. In order to explain the relationships between process and performance, they developed the formation mechanism of many interfaces. The impact of fibre orientation, however, was not studied. Continuous GF-PLA was subjected to 3D printing process parameter adjustment by [84], with the fibre content increasing to up to 45 weight percent. However, compared to ordinary laminates, the tensile strength is much lower. Numerous research have attempted to create CFRTs based on polyamide (PA) in an effort to enhance the qualities of FDM printing composites.

In order to investigate the qualities of continuous Kevlar fibre (KF)-PA dumbbell specimens performed tensile testing [85]. Contrary to the rectangular examples of laminates, these dumbbell specimens are made of concentric ring fibres on the outside and PA in the centre. In actuality, the shape of the specimen has a significant impact on the outcomes of the experiment. Furthermore, 3D printed continuous fibre composites vary from traditional composites

in several ways. However, there isn't a standard for experimental 3D printed composites. In the tensile investigations, for instance, several rectangle, dumbbell, and bowtie samples with varying fibre infill patterns were employed, and the experimental outcomes were quite diverse. Additionally, studies on the bending features [86] and delamination traits [87] of CFRTs have been conducted. Impact damage is a crucial topic for conventional composites research. In order to better understand how 3D printed CFRTs perform, several attempts have been done in this direction. [88] investigated the impact resistance of additive manufactured fibre reinforced composite samples with notches for the impacts of build direction, fibre type, and fibre volume percent.

The construction direction is one of them and a brand-new study area distinct from traditional laminates. According to the findings, on-edgebuilt specimens had greater impact strength than flat-built ones. The specimens, nevertheless, are unidirectional. Furthermore, a comparison of specimens with and without notches was not done. Using onyx and glass fibre filaments, [89] created un-notched specimens and assessed the impact of infill density and infill pattern on the amount of energy absorbed. However, because of the various material system and printing techniques, their results can't be compared to [88].

1.1.1.7 Methods for Synthesis of Nanoparticles and Nanocomposites

The Scotch tape method is not transferable to industrial production of graphene, but it was a stepping-stone. Several different production processes have emerged since graphene was first isolated. Two different strategies can be applied:

Bottom Up: Graphene produced from gases by Chemical Vapour Deposition (CVD)

Top Down: Graphene produced from graphite by exfoliation (chemical, mechanical, oxidative)

Hand lay-up technique

Hand lay-up technique is the oldest method of woven composite manufacturing. The samples are prepared by respecting some steps. First of all, the mold surface is treated by release anti-adhesive agent to avoid the sticking of polymer to the surface. Then, a thin plastic sheet is applied at the top and bottom of the mold plate to get a smooth surface of the product. The layers of woven reinforcement are cut to required shapes and placed on the surface of the mold. Thus, as previously mentioned, the resin mixed with other ingredients and infused onto the surface of reinforcement already positioned in the mold using brush to uniformly spread it. And then the other mats are placed on the preceding polymer layer and pressured using a roller to remove any trapped air bubbles and the excess of polymer as well. The mold is then closed and pressure is released to obtain a single mat. After curing at room temperature, the mold is opened and the woven composite is removed from the mold surface. The schematic of hand lay-up is shown in Figure 1.15.

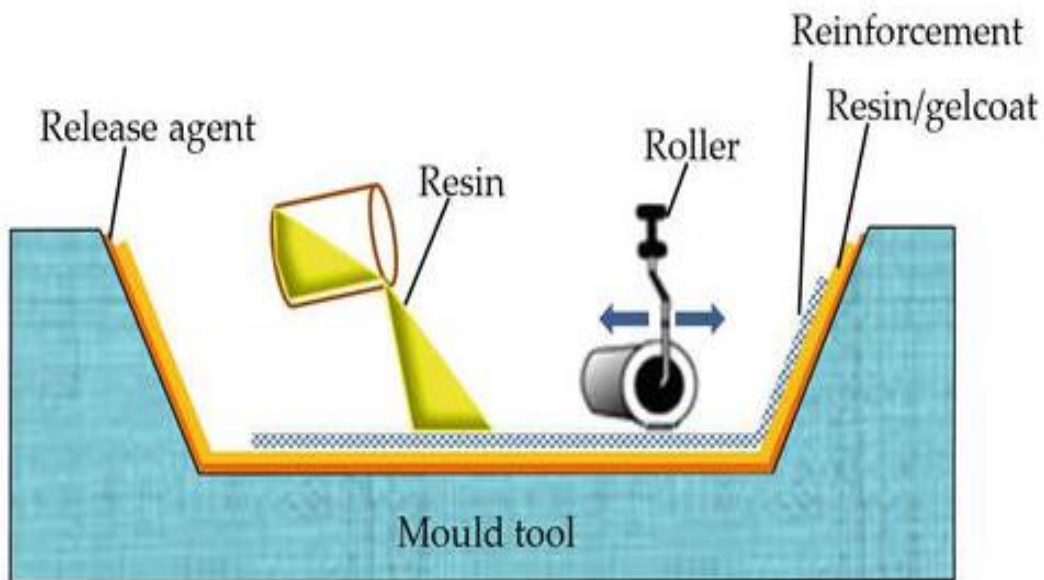


Figure 1.15. Hand lay-up method [90].

Autoclave processing

The autoclave processing or vacuum bagging is typically the method of choice to produce the woven reinforced plastic composite components for various high performance applications. The generic production scenario of the woven composites involves a few main steps. First, the layers of woven reinforcement are laid-up and placed in an open mold after the pretreatment of tools' surfaces by chromic acid or phosphoric acid aiming to improve the bond between the adhesive system and the used aluminum alloy. Then the material is covered with a release film, bleeder/ breather fabric, and sealant tape, and a vacuum bag. After curing with a continuous vacuum to extract entrapped gasses from laminate, the mold is opened and the woven composite is removed from the mold surface (Figure 1.16).

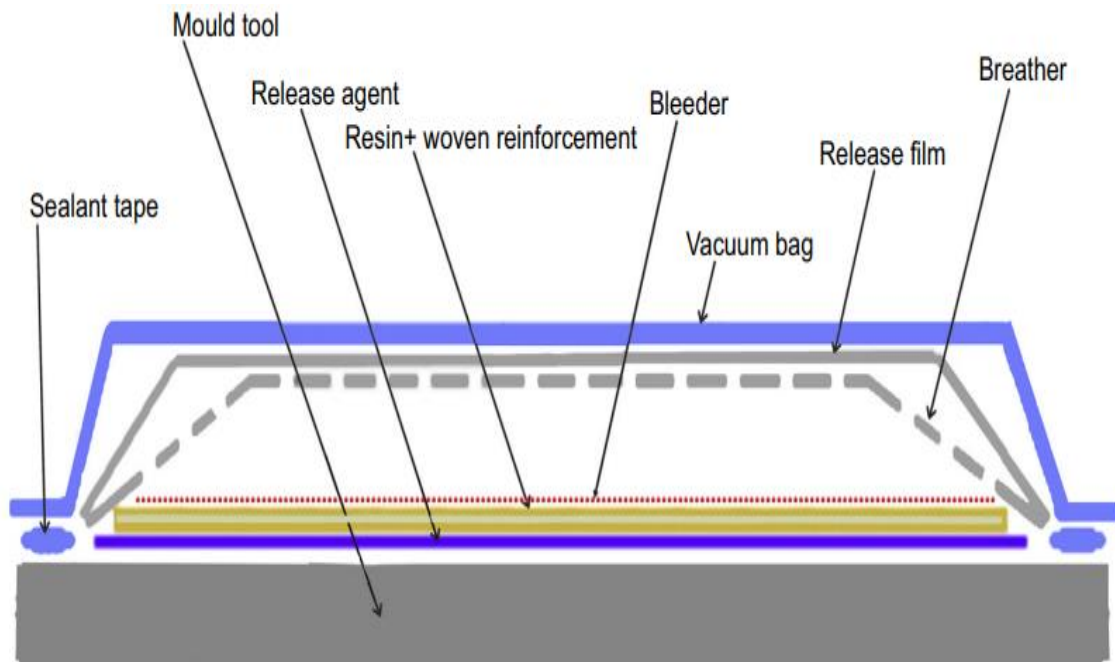


Figure 1.16. Autoclave process [91].

Pressing techniques

The press molding is a quite simple process that resembles vacuum bag molding but the vacuum is replaced by pressure. The desired shaping of woven composite is achieved by hand lay-up, spray lay-up, or prepregs, with two halves of a die mounted on a press being immediately relocated and lightly clamped together. Initially, an anti-adherent flexible sheet is applied onto the mold and then the mold is closed and autoclaved under pressure at steam atmosphere (Figure 1.17).

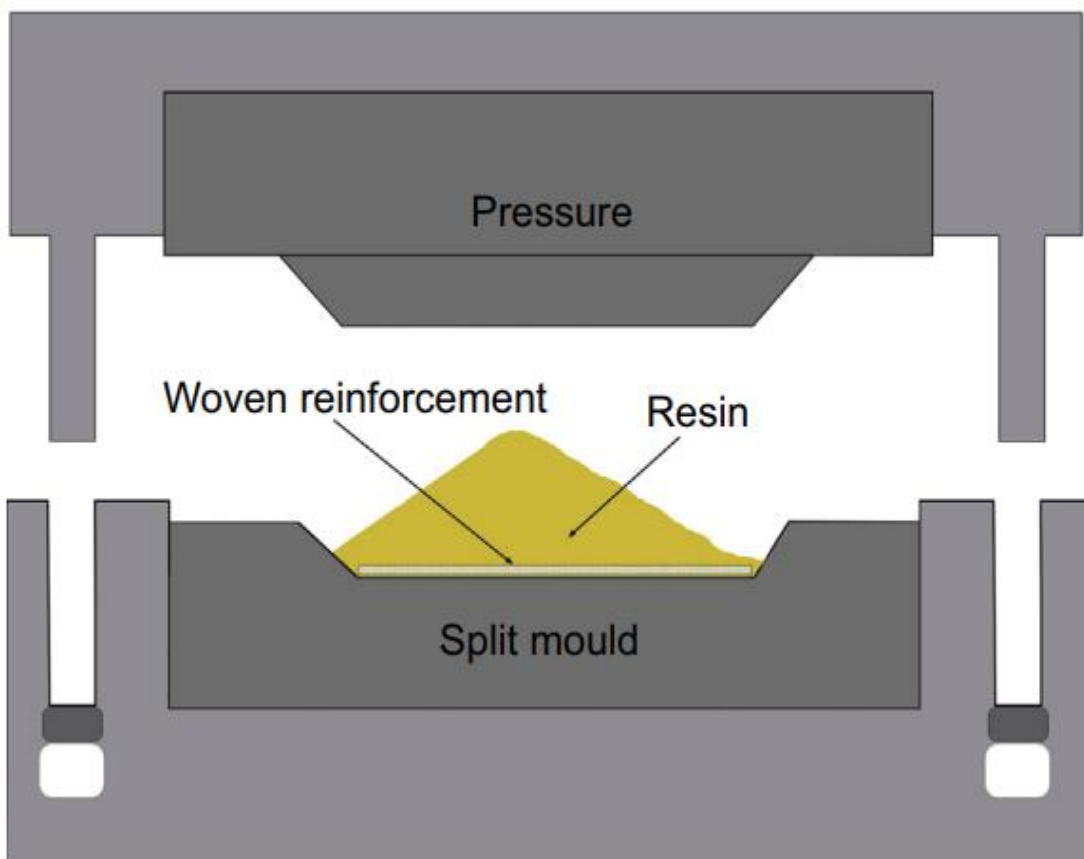


Figure 1.17. Pressing process [91].

1.1.2 Machinability of composites

In industrial machining processes, an end mill is a particular kind of milling cutter, or cutting instrument. In terms of manufacture, application, and configuration, it is distinct from a drill bit. Unlike drill bits, which are limited to cut in one direction (axial), the majority of milling bits can cut in both directions. Not all mills have the ability to cut axially; those that do are known as end mills [68].

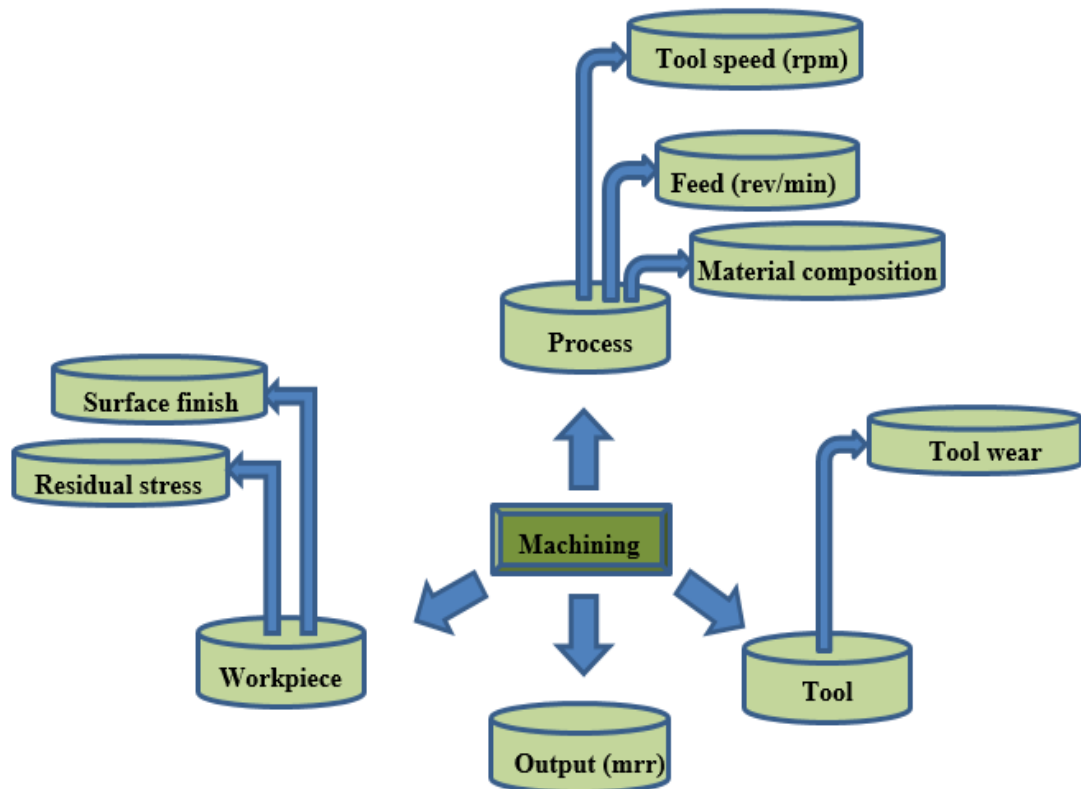


Figure 1.18. Main factors to consider when working with hard turning.

Tool shape and material both affect cutting performance and longevity in every application using cutting tools. This also applies to machining composite materials. But with composites, the tool material also influences performance [92]. The key elements to consider for a better knowledge of hard turning are presented in Figure 1.18. Unless the edge material can survive the abrasion well enough to keep its geometry and maintain its sharpness, composites can

cause the tool to wear so quickly that the geometry can change quickly as well. Composites can often be milled and drilled using significantly lighter equipment. To keep the part's thin, stiff walls from wobbling and fraying, high-end cutting tools and custom-built work holders will likely be needed. The Fiber Orientation is one element that affects the cutting behaviour or "machinability" of composite materials. The stacking of the layers to create a ply is referred to as the fiber orientation [93].

The most prevalent plies include stacking patterns of 0-90 degrees, 0-45 degrees, and 0-45 degrees, 90 degrees, and 135 degrees. The most challenging layers to cut are at 45 and 135 degrees, hence manufacturers of cutting tools have created a number of geometries to properly process those kinds of CFRP [94].

1.1.2.1 Modeling and Optimisation Techniques used for machining

In modelling approach, a model with mathematical equations is created based on the relationship between input and response parameters to obtain the best cutting condition. In the optimization process, the cutting condition is obtained by formulating an objective function with or without a mathematical model [95].

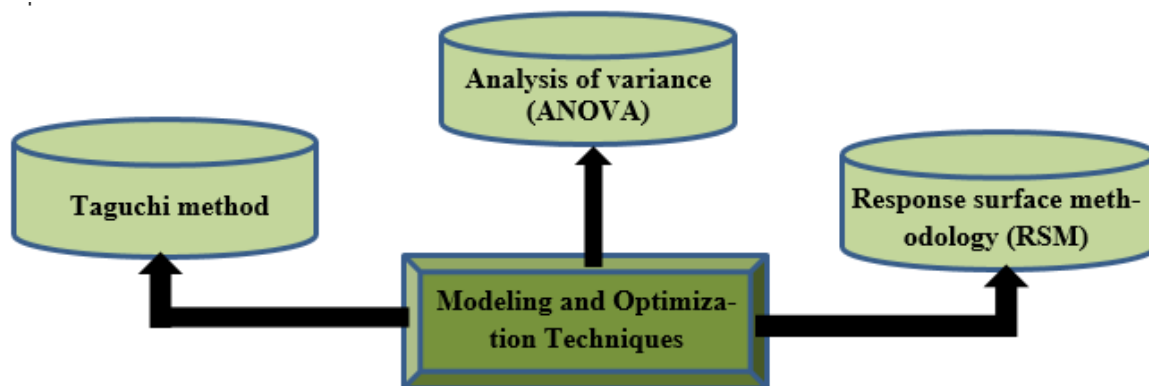


Figure 1.19. Modeling and optimisation techniques used by various researches.

A lot of academics have been interested in the modelling and optimisation of drilling and milling procedures because of their major impact on the final product's cost. Furthermore, more trials must be conducted as the number of machining parameters rises [96]. Hard turning requires a high level of specificity, which means a different model is needed for each application, piece of raw material, and cutting condition, as is the case with most machining operations. In hard turning, modelling and optimization methods are shown in Figure 1.19.

1.1.2.2 Taguchi method

An effective analysis method for simulating and examining the impact of output performance control elements is experimental design. It is challenging to apply traditional experimental design, particularly when there are several tests and a growing number of processing factors. The choice of control elements is the phase design of the experiment's most crucial component [97]. The Taguchi technique, developed by Dr. Genichi Taguchi, is therefore given as an experimental strategy that facilitates the optimization of the experiment numbers by utilising orthogonal matrices and reducing the influence of control variables.

By conducting these experiments and data analyses, the Taguchi approach offers a plan of experiments to collect data in a controlled manner in order to learn more about the behaviour of the specified process. Additionally, it is a group of approaches that take into account the natural variability in materials and the manufacturing process when designing deer. The Taguchi design nearly closely resembles the design of the experiment (DOE) [98], but it offers the most effective fractional factorial design technology due to its balanced experimental (orthogonal) combination. This method has been used in production processes to resolve the most perplexing issues, particularly to track the extent of the control elements effect.

According to Taguchi's definition, a product's quality is measured by the amount of product that is lost after being given to a business up until the point where it is delivered to the client. Losses resulting from functional variation are those brought on by the product's functional attributes deviating from the target value that was intended. Additionally, uncontrollable elements like noise cause a product's functional attributes to fall short of their intended levels [99]. The causes of noise can be divided into three categories: product degradation, manufacturing flaws, and external causes (such as temperature and human error).

Making ensuring a product can be resistant against all potential noise causes is the major goal of quality engineering. As a result, the Taguchi technique may guarantee product quality while reducing cycle time or product experience, improving benefits while decreasing costs, and finding crucial elements quickly. Three stages system design, design requirements, and tolerance make up the Taguchi design method [95]. The design parameters, which are considered to be the most important stage, may be used to identify the variables that impact the industrial process's quality attributes. The appropriate orthogonal matrix (OA) must be chosen in line with process variables as the first stage in creating the Taguchi values.

As a result, the tests were conducted in accordance with previously discovered OA, and the experimental data were then examined to determine the ideal condition. Once the ideal circumstances have been established, confirmation tests are run using the determined ideal values for each parameter. The major goal is to manufacture resilient goods for all noise factors through quality engineering [100]. Taguchi created a standard orthogonal array to incorporate as many components as feasible in the control factor selection technique in order to detect non-significant variables on the first occurrence. As a way to quantify the selection of quality criteria, Taguchi employed the signal-to-noise ratio (S/N).

This demonstrates how engineering systems can act in a way that allows the three types of production factors to be manipulated:

Controlling variables, (variables that have an impact on the S/N ratio's measurement of process variability)

Signal variables (variables that have no impact on the S/N ratio or process mean).

Factors (i.e., variables unrelated to the S/N ratio or process mean).

1.1.2.3 Taguchi analysis

The performance of the tool was improved by the researchers by modifying a number of manufacturing parameters [101]. When turning Titanium and Aluminium with treated and unprotected cemented carbide tools during dry circumstances, high cutting speeds, and increased surface roughness, the Taguchi optimization approach was used to optimise the process parameter. To find the optimal arrangement, an L_{27} factorial design with four components power, feeds, cutting depth, and tools grades—and three levels for each parameter was employed. Using ANOVA, it was discovered that the cutting speed and tool quality were key determinants of surface smoothness. [102]

A multilayered tungsten carbide cutter has been used to convert steel whereas preserving a constant feed rate and keeping the cutting depth assessed using RSM. Utilizing a face-centered CCD, analyse the impact of three variables on surface condition and tangential force, including tool rotational speed, feeds, and SCEA. The allocation of performance metrics is influenced by a wide range of factors. Tangential force is influenced by the SCEA2, the feed and SCEA interconnection, the tool rotational speed, and several other factors, whilst the SCEA2 as well as the combination of feed and SCEA contribute to surface roughness. [103] used the Taguchi approach to enhance the NEMA 1130 milling setting for glass fibre reinforce

ed plastic. The purpose of this study would be to optimise milling parameters for various performance characteristics using the Grey Relational Analysis and Taguchi approach. The milling experiments were conducted on a vertical milling machine.

L₁₈ was used in the experiments (OA). The milling method, tool rotational speed, feeds, and cutting depth have been selected as the four process parameter for this experimentation. In order to investigate the impacts of tool rotational speed, feeds, cutting depth and related two-way relationships, investigators [104] build a regression models for surface quality. Three cut depth levels, four cutting speed levels, and seven feed rate levels were chosen as the operating parameters. According to the findings, the cutting feed became the most crucial factor while the interactions between the cutting feed and cutting tool rotational speed were most relevant when they involved the depth of cut.

During semi-finishing and finishing conditions of high speed cutting [105], best cutting parameters in the final milling operation are used when utilising a TiN-coated P10 carbide insert tool to manufacture hardened steel AISI H13. Utilizing the Taguchi technique for design of experiments, it is examined how various milling parameters, including tool rotational speed, feed rate, and cutting depth, influence the process (DOE). The study discovered that the Taguchi strategy required the lowest trials to solve the given problem when compared to a full factorial design [106]. Investigations were done into how different machining parameters affected the the austenitic stainless steel is dry turned. For this experiment, a heavy-duty lathe machine from HMT has been used. Three process parameters, comprising tool rotational speed, feeds, and cutting depth, together with three crucial machining parameters such as MRR, thrust force, and surface quality, were assessed using the L₂₇ orthogonal array (R_a).

1.1.2.4 ANOVA analysis

Analysis of variance (ANOVA) [107] has been used to evaluate the sufficiency and importance of specific parameters. The parameter is deemed statistically significant at a 95% confidence level if the p-value is less than 0.05, which explains that the individual parameter has a significant impact on the response variables. To determine the statistical significance of machining parameters on material removal rate, ANOVA has been commonly utilised in machining investigations (mrr). Statistical analysis was done with ANOVA using MINITAB. Cutting speeds range from 0.15 to 0.25 mm/rev, feed rates from 150 to 200 m/min, and cut depths between 0.8 and 1 mm.

Cutting tool vibration and flank wear have been seen as variables since they are uncontrolled continuous predictions. Understanding how cutting circumstances, tool flank wear, and machine tool vibrations affect surface quality is the main goal of this research effort. Cutting tool vibration is really intriguing. After process parameter, flanks wear, and cutting tool vibrations were taken into account independently along the cutting depth (V_x), tool rotational speed (V_y), and feeds (V_z) directions, ANOVA tables for R_a and R_t were generated [108]. These ANOVA tables are shown in Tables 1, 2, 3, 4, 5, and 6, and inferences based on the F ratios and tabulated p-values have been made.

1.1.2.5 Response surface methodology (RSM)

To design tests and maximise the impact of process factors, a group of statistical and mathematical techniques known as response surface methodology is utilised. This approach is based on the design of experimentation. RSM minimises the number of trials while acknowledging how the removal process is impacted by the process parameters [109].

Response surface methodology is one method to ascertain the link between various inputs and responses (RSM). The significance of these factors on the answers is likewise determined using RSM. The processes may be developed, enhanced, and optimised with the help of RSM, which offers a broad perspective of the system response inside the design space [110]. The RSM was used to research the impacts of cutting speed, feed rate, and material composition on drilling and milling (slot cutting operation).

1.1.3 Finite Element Analysis (FEA)

Wear is a complicated process that depends on numerous elements. It is challenging to explain every piece of knowledge discovered through experimentation due to the combination of these components. Finite element analysis (FEA) recently offered a useful technique for forecasting polymer performance during wear processes [111]. To determine the worn volume and profile of the worn surface, a series of FEAs were performed utilising wear parameters from polymer tribo-systems. The approach to simulating wear will be to:

1. Identifying the important variables that have a significant impact on the rates of material removal is the core technique for simulating wear.
2. Determine adequate wear rates employing specimen-level tests.
3. Continually run finite element analyses to progressively eliminate materials from the simulation.

The accuracy with which FEA can handle variations in applied pressure and the progressive changes in surface geometry brought on by material loss make it a powerful tool for predicting wear. The difficulty with this approach is formulating equations that roughly represent the relationships that need to be looked at. In FEA, a complicated network of nodes points that together form a grid is used. This mesh has been coded to incorporate the material and

structural properties that affect how well the structure will react to various loading scenarios.

1.1.3.1 FEM based analysis and water absorption profile

The application of polymer composite in mechanical, electrical, medical and many more applications is undeniable [112]. Investigating the properties of composite with the help of an experiment is difficult and costlier. So, with the help of various analytical models and methods developed by various researchers the properties can be calculated. The well-known models that have been propounded are Voigt also called the rule of mixture [113] and Reuss also called inverse rule of mixture [114] and these models are used for the calculation of properties of unidirectional composite. The Halpin-Tsai [115] model tends to correct longitudinal shear modulus and the transversal Young's modulus.

The Chamis micromechanical [116] model is the most used and trusted model which gives a formulation for all five independent elastic properties. Nielsen Elastic [117] Model is obtained by simply introducing maximum packing fraction ϕ_{\max} and its value depends on model geometry. The Micromechanical model [118] is applying eight models to calculate the elastic property of composite and compared with experimental results and FEA. There are lots of options to enhance the property of composite like by varying fiber orientation, varying volume fraction and thickness of composite [119]. RVE or unit cell is being considered as a statistical sample used for the calculation of properties.

The desired thickness of composite material is obtained by an infinite number of these unit cells. RVE will finally give the stress and corresponding strain real value of material and gives a better idea about the elastic property. The method used to show the mechanical behavior of material along with circular inclusion [120]. They found that property is varying

with the orientation of inclusion and shape of inclusion. Moreover, they got by increasing interphase thickness leads to an improvement in the modulus. In this article (a) The Effective Elastic Moduli of polymer composite is being investigated using FEM methodology. Here the main aim is to relate the value of FEA with the value of the analytical solution to find the best property of composite. There is a good comparison between FEA and Analytical results found. Finally, it seems to be almost all methods showing good agreement up to 50% and thereafter deviation is going to increase.

Further, it can be concluded that Nielsen elastic method showing large and maximum deviation after 50%. The results show that the analytical model gives the effects of varying the diameter and volume fraction of fiber on longitudinal Modulus, but there is a slight variation in transverse modulus of elasticity, modulus of rigidity and Poisson's ratio. Water absorption profile of Natural fibers like bamboo fiber, jute fiber, shows poor wettability characteristics, and poor adhesion between matrix and untreated fiber results in debonding with the lapse of time [121]. The water absorption by the thermosetting polymer composite leads to degradation in property and so it will affect its performance.

The mechanism including swelling of fiber results in a decrement in property [122]. Swelling in natural composite results in a decrement in tensile property, flexural property value and another mechanical parameter [123]. Moisture diffusion in polymer composites is governed by 3 mechanisms. Firstly there is a dispersion of water inside the polymer next due to capillary action there will be a gap and flaw between fiber and matrix. Lastly, there is a microcrack inside the matrix due to swell fiber, especially happening for natural composite [124]. (b) Samples of GFRP composites have been successfully produced Hand Lay-up method. The material is used to investigate its behavior under different aqueous environments such as

Distilled water, acidic water, and seawater respectively. This test is done on room temperature and elevated temperature during the different time intervals. Water absorption tests were performed by immersing composite specimens into three different aqueous environments, namely: an acidic solution (pH-3), seawater (pH-8), and distilled water (pH-7) which were at room temperature and elevated temperature. From the results found it was observed that the pattern of water absorption resembles non-Fickian. The maximum moisture content value (Mm) and the highest diffusion coefficient (D) value have been recorded.

1.1.3.2 Vibrational Study using FEM

Composite material consists of one or more discontinuous phases as fiber and the matrix which is continuous phase. The fiber act as a strengthening and stiffening agent since 3400 BC by the Mesopotamians who mixed wood veneer plus wood grain to make plywood. Ref. [125] uses CNTs as fiber. The density of CNTs is half of the aluminium density and having strength 20 times greater than steel alloys, elastic modulus is greater than 1TPa, 0.2TPa for steel 0.07TPa for aluminium, current carrying capacity is 1000 times greater than that of the copper and transfer heat double by the pure diamond [126]. As this technology provides the good property like high value of strength and stiffness so CNTs is being considered as an ideal fiber by various researchers throughout the world.

To implement such unique combination of size and properties, implementing CNTs as a reinforcement along with different matrices. CNTs have been a hot topic for study all over the world. Various challenges regarding large particle size, stress concentration are substantially reduced because of smallest size but larger surface area, no other filler give such a high value of stiffness and strength [127]. So, in order to have better insight of CNTs various analytical

models have been developed and extensive work on various matrices with CNTs as a reinforcement is being performed. Nano technology mainly powered by the miraculous properties of CNTs, can convert technology by huge amount than the evolution of the silicon revolution [128]. The analysis of geometric properties is a complicated experimental task because of very small dimensions of nanotubes. The different micrographs like SEM [129] and TEM [130] images have shown significant waviness in nanotube reinforced polymer composite as shown in Figure 6.1. Carbon Nano Tubes are modern form of carbon allotrope having hexagonal network and tubular structure. Carbon Nano Tubes are known as a single walled CNTs, double walled CNTs or multi walled CNTs. The diameter varies in the range of 0.4-40nm and maximum possible aspect ratio as 132,000,000:1.

Because of its exceptional properties nano tubes have considerable capability so it can be used in advanced composites as nanofibers. The novel evolution in nano-technology plus nano fabrication gives inspiration for characterization and development of CNTs-based composites. Generally two approach namely molecular dynamics (MD) and continuum mechanics (CM) are applied to identify the properties of CNTs based composites. MD simulation provide better insight of local contact of nano tube with matrix plus interfacial properties [131]. Using continuum mechanics approach one assumes that the material is continuous and there is no space in between and no void. Because of large number of equation formation it is difficult for large scale model.

Innumerable studies [132] affirm that the effective modulus of Carbon nano tubes is reduced by its curvature in comparison with straight CNTs. [133] have presented the CNTs waviness on elastic modulus and found that the values are very sensitive to waviness later there is decrement with the increase in waviness. [134] found that because of poor bonding waviness

increases the stiffness value. Because of their intrinsic properties [135] carbon nano-tubes (CNTs) are among the most attractive material for reinforcement of FRC. Several researchers have found that with the addition of few weight percentage of single walled CNTs or multi-walled CNTs either one the properties can be severely improved [136]. [137] succeeded a 27% increment in the modulus of elasticity of multi-walled CNTs reinforced composites. In recent times, [138] conclude that with the addition of 3wt% of MWCNTs there is an enhancement in the youngs modulus and tensile strength of composite up to 55.2% and 43.1%, respectively.

Although various works are there related with the vibrational behavior of nano tubes [139], but very less attention on CNTs waviness effect on the vibrational properties of CNTs reinforced nanocomposite are there. However, the macro mechanical models of vibrational behavior of curved beams have presented where it is found that there is a effect of curvature on modal frequencies are there [140]. The vibrational parameters of straight CNTs reinforced composites were studied using Eshelby-mori-tanaka method [141]. They focus on the influence of volume fraction and the alignment of CNTs on the modal properties.

1.2 Research gaps

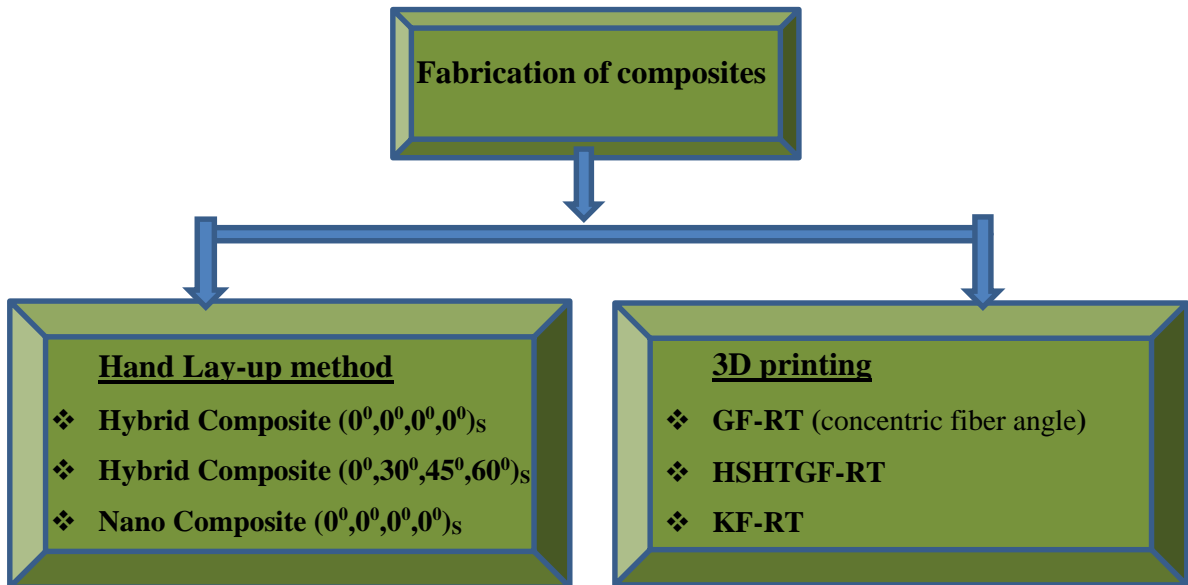
This chapter of the thesis describes the detailed knowledge extracted from the literature review as reported regarding the development of futuristic composites and studies on its machinability. The present understanding of physical properties, mechanical properties, the dry sliding friction and wear behaviour and machinability have been reviewed but there is lack of studies involving:

- ❖ Multi-functional Hybrid Composite (glass fiber + Jute fiber) and graphene-based hybrid composite.
- ❖ Based on the literature survey, very limited investigation has been done and published on the machining of graphene-based composite.
- ❖ Studies lacking in Finite Element Analysis of nano material based polymer composite.
- ❖ Studies lacking in natural fiber composite such as bamboo fiber, coconut fiber, Jute fiber etc.
- ❖ Fractographic characterization and its correlation to interfacial, quasi static and low velocity impact analyses are observed to be in the literature.

Based on the above research gap the various aims and objective has been drawn which is listed in the next section.

1.3 Aims and objectives

The present research work discusses the physical properties, mechanical properties, thermal properties and machining performance of plain composite and nanocomposite and identifies critical microstructural parameters that influence their different properties. The composites are fabricated by the Hand layup method and 3D printing method. 3D printed composites consist of onyx as a matrix material and the different reinforcements are glass fiber, carbon fiber, high strength high temperature glass fiber and aramid (Kevlar) fiber. Onyx is a mixture of nylon (thermoplastic polymer) and chopped carbon fiber. By using the Hand lay-up method two types of hybrid composites were fabricated and those are pristine composites and nanocomposites based on two-dimensional nanomaterial (Graphene). The reinforcements are glass fiber, Jute fiber, epoxy (Thermosetting polymer) is used as a matrix material and graphene is used as a filler material.



NOTE: (1) GF-RT: Glass fiber reinforced thermoplastic
(2) HSHTGF-RT: High strength high temperature glass fiber reinforced thermoplastic
(3) KF-RT: Kevlar fiber reinforced thermoplastic

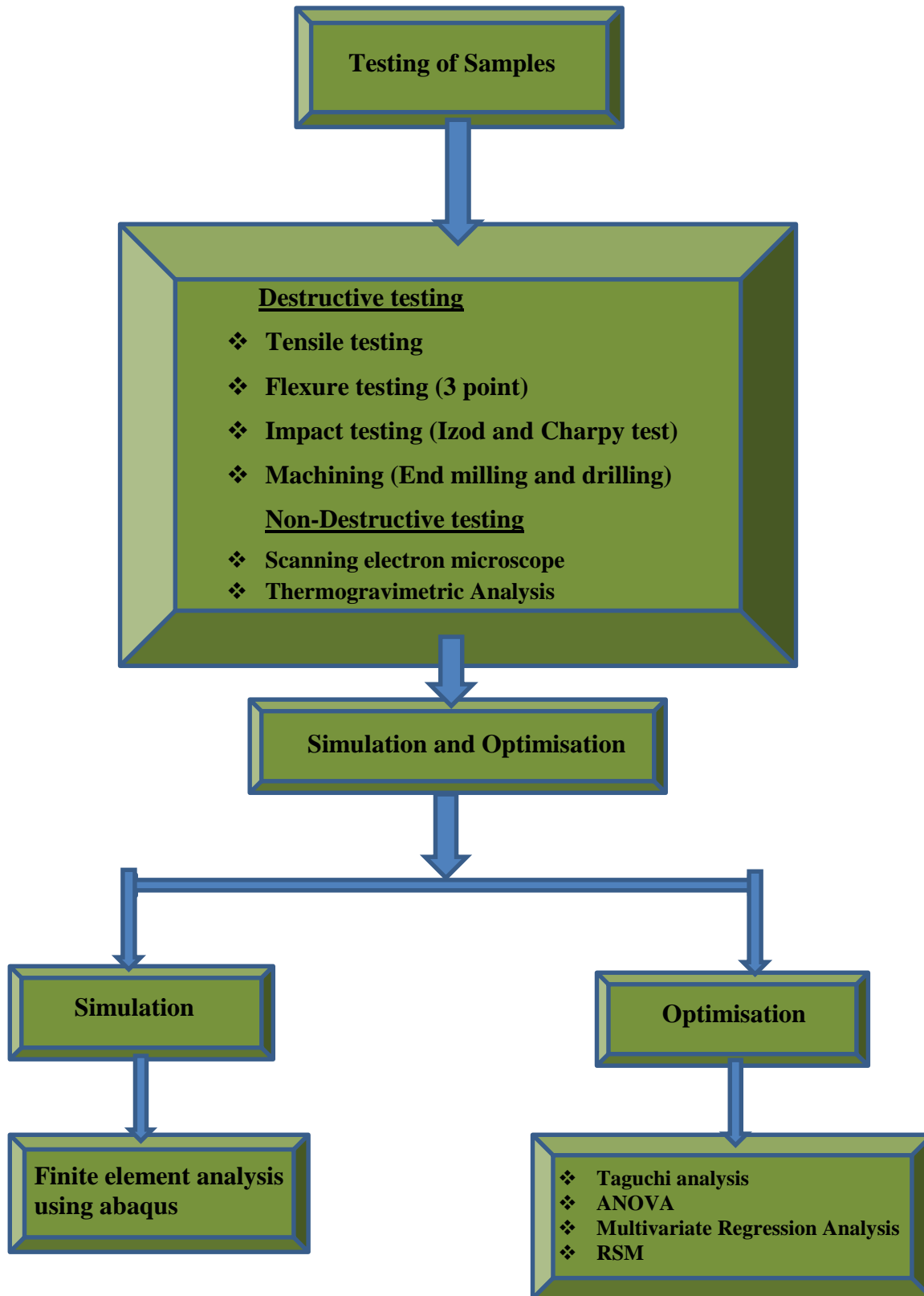


Figure 1.20. Flow chart showing the aims and objectives

1.4 Organisation of thesis

This thesis has been divided into eleven chapters. **The first chapter** is intended to introduce the plain composites and nano composites and then present the Research gaps, aims and objectives of work alongwith the critical literature review on the physical properties, mechanical properties, thermal properties and machining performance of different composites. With respect to different fabrication method such as Hand layup method, 3D printed fabricated composites etc.

Chapter 2; Represents the physical properties, mechanical properties, thermal properties and machining performance of plain composites and nanocomposites. The composites are fabricated by using Hand layup Technique.

Chapter 3; Represents the physical properties, mechanical properties, thermal properties and machining performance of 3D printed composites.

Chapter 4; Represents the tribological behaviour of composites under dry sliding environment.

Chapter 5; Represents the analysis of mechanical properties of GFRP Composite using FEM and analytically and generation of water absorption profile experimentally.

Chapter 6; Represents the vibrational Study of Wavy-CNT Reinforced Composites using FEM.

Chapter 7; Represents the conclusion and future work.