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# Review on Properties of Natural Fiber Reinforced Polymer Composites: Effect of Gamma Radiation and Nanoparticles

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**ABSTRACT:**
Materials comprised of a polymer matrix with natural fibre reinforcement are known as natural fiber reinforcement polymer composites (NFRCs). Scientists have recently become quite interested in these composite materials because they provide improved properties over conventional synthetic fiber reinforced polymer composites at a lower cost and with environmental advantages. However, several factors, including gamma radiation exposure and the addition of nanoparticles, can impact the properties of NFRCs. This review will focus on the effects of gamma radiation and nanoparticles on the mechanical, thermal, and water-resistance properties of NFRCs. In order to help in the creation of new and improved NFRCs for diverse applications, this review seeks to provide a comprehensive understanding of the properties of NFRCs and the effects of gamma radiation and nanoparticles by facilitating better bonding between fiber and matrix to enhance the overall performance of the composite materials.
**Key Words:** natural fiber, polymer matrix, properties of composite, gamma radiation, nanoparticles

## 1 INTRODUCTION

In general, composite materials can be described as a heterogeneous mixture of at least two distinct materials at the microscale, featuring novel properties distinct from those of its constituents, and typically having a nearly homogeneous structure at the macroscale. The possibility of tailoring a composite material's qualities to meet the needs of the desired application is the most distinctive aspect that results from the opportunity to combine this mixture of properties (Erden & Ho, 2017). In addition, many sectors are currently searching for novel properties of composite materials, such as renewability, little environmental effect and affordability. The advantages of natural fiber reinforced composite materials over traditional materials and synthetic fiber-reinforced composites have led to an increase in research and innovation in these fields (Neto et al., 2022). Besides, natural fibers are inexpensive, have a low density, and have many unique characteristics. Unlike other reinforcing fibers, these are flexible, nontoxic, nonabrasive and biodegradable. Additionally, they are easily accessible and their unique characteristics are similar to those of other fibers employed as reinforcements (Aravindh et al., 2022). The mechanical properties of composites are greatly influenced by the fiber structure. The cellulose fibers found in natural plant materials are made of a matrix of amorphous lignin and some helically wrapped cellulose microfibrils. Lignin aids in keeping water inside fibers and giving stems strength to withstand wind and gravity, it serves as defence against biological attack. A compatibilizer between cellulose and lignin, hemicellulose is a component of natural fibers. Figure 1 depicts the structure of natural fiber (M. K. Gupta & Srivastava, 2016).

Physical, chemical, morphological characteristics, fiber orientation, crystal structure and cross-sectional area of natural fibers affect their mechanical qualities. Furthermore, the essential components, which contribute the fibers strength and stiffness are the cellulose chains, high molecular weight, intermolecular and intramolecular hydrogen bonding, fibrillar structure and crystalline structure in natural fibers (Nguyen et al., 1981). The effect of resin inside fiber lumen was investigated and resulted in the single fibers having a central hollow lumen which takes up a significant proportion of the cross-sectional area. The fraction of cross- sectional area taken up by the lumen has been found 27.2%, 6.8% and 34.0% for sisal, flax and jute respectively (Li et al., 2015).

Again, a polymer composite, a class of highly effective and versatile material, is produced by combining at least two distinct phases of materials, typically a matrix polymer and a reinforcing fiber. Because the mix of polymer and

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natural fibers produce special mechanical and thermal qualities that are impossible for a reinforcement material to attain. The fiber serves as the primary loadbearing component in polymer composites because its strength and stiffness are substantially higher than those of the matrix material. Conversely, the matrix acts as a load distributor by evenly distributing the imparted force to the fiber. To generate an effective load transfer the matrix must therefore securely hold the fiber, which in turn raises the mechanical properties of the polymer composites (R. Rahman & Putra, 2018). Besides, natural fiber reinforced polymer composites have certain drawbacks despite of their benefits, such as low impact strength and high moisture absorption characteristics. The addition of supplementary reinforcements like nanoparticle fillers to the matrix and other treatments, such as gamma irradiating natural fiber composites, are typically used to get around these constraints which increases the mechanical properties of the materials (Younes et al., 2019). The physio mechanical properties of natural fiber reinforcement polymer composites can also be developed using gamma radiation. This approach has some benefits, including reduced time requirements, uninterrupted operation, environmental friendliness, and design flexibility. Strong ionizing radiation called gamma radiation can change a material's internal structure and make it less hydrophilic, which promotes better crosslinking between the natural fiber and matrix (Motaleb et al., 2020). According to research, adding nanoparticles improves a number of polymer composite features, including their superior toughness and mechanical strength, good electrical and thermal properties, exceptional flame retardancy, and a stronger barrier to moisture and gases (Singh et al., 2021). As a result of their greater environmental friendliness, natural fiber reinforced composites and nanocomposites are more frequently used in the building and construction (partition boards, ceiling panelling), transportation (automobiles, railway coaches, aerospace packaging, consumer products, etc.), and other industries (Hosseini, 2017).

In Asia, there is a plentiful supply of many kinds of natural fibers, including bagasse, bamboo, banana, coir, jute, kenaf, hemp, sisal, and ramie. Natural fiber composites have significantly advanced over the past 10 years and are currently the most promising material for a variety of applications as well as less costly than others synthetic composite. Natural fibers have demonstrated their effectiveness as an alternative for synthetic fiber in the transportation industry, notably in automobiles, railways, and the building, packaging, consumer goods and construction industries for ceiling panels, partition boards, etc. (Mahir et al., 2019). The usage of natural fibers affects a wide range of businesses, including those in the building, sporting, pharmaceutical, aerospace, and automobile sectors. However, there have also been significant challenges with the development of these composites. The previous three decades have seen an excessive amount of research articles aimed at enhancing the properties of natural fiber composites, indicating a promising future for these materials in the manufacturing sector (Kannan & Thangaraju, 2021).

In this review, we have provided a complete summary of the various properties of natural fiber reinforced polymer composites. This is attributable to the study of lignocellulose fiber-reinforced composites, which demonstrated its effectiveness and development. The impact of gamma radiation and nanoparticles on the mechanical, thermal, and water-resistance characteristics of NFRCs will be looked at in this paper. In-depth knowledge of the characteristics of NFRCs and how ionized particles and nanoparticles can affect them is the main goal of this review. This will serve as guidance for the creation of fresh, enhanced NFRCs for numerous applications.

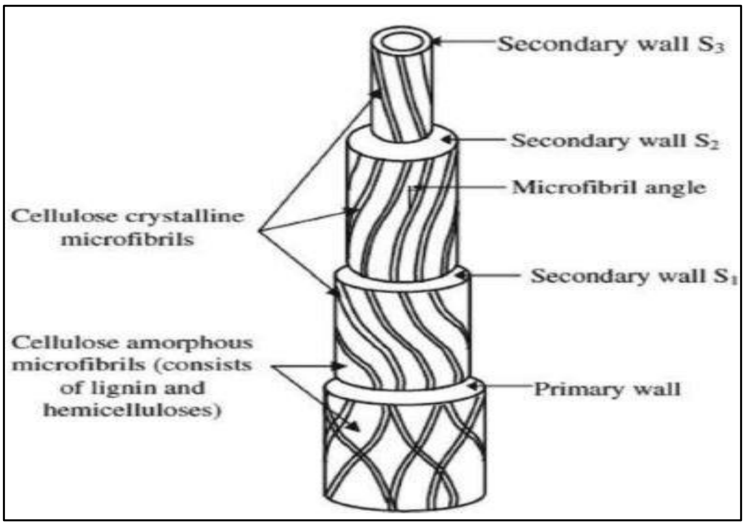


**Figure 1:** Structure of natural fiber (Gupta & Srivastava, 2016).

## 2 LITERATURE REVIEW

Natural fiber reinforced polymer composites (NFRCs) are materials that consist of a polymer matrix reinforced with natural fibers. These composites have been used in various applications for thousands of years and have gained popularity in recent years with the discovery of new types of natural fibers with improved properties. For example, NFRCs are widely used in the automotive industry as a lightweight and sustainable alternative to traditional materials such as steel and aluminum. They are also used in the construction industry for applications such as roofing, siding, and flooring due to their high strength, stiffness, and durability. In the packaging industry, NFRCs are used to produce biodegradable and compostable packaging materials, which are more environmentally friendly than traditional petroleum-based packaging materials (Syduzzaman et al., 2020). Based on their intended usage, the natural fibers can be utilized to repair composite patches. Instead of replacing the damaged components with new ones, the fiber composites were utilized to fix the existing ones, cutting down on both costs and turnaround time. By fixing the cracks, the repaired component with bonded composites had a longer lifespan. Aerospace applications saw good performance from the Kenaf fiber repair on damaged carbon fiber panels (Muda & Mustapha, 2018). Both sugar palm fiber and kenaf fiber were used to generate a hybrid composite material with a 10% lower environmental impact than the anti-roll bar used in the car sector. Due to its low energy consumption and low carbon footprint, sugar cane and palm fiber composites are excellent for anti-roll bar applications in automobiles (Mastura et al., 2017).

The most prevalent residue on earth is agricultural waste, which deposition causes environmental contamination, that not only offers significant health hazards but also provides a difficult ecological challenge. The inappropriate disposal of agricultural wastes, such as open-air burning, land filling, drifting through river currents, or heavy rains, results in air pollution as well as contamination of rivers, groundwater, and soil. Traditional agricultural residue storage on farms and building rooftops can lead to fire risks and encourage the growth and spread of illnesses and insects. Massive organic waste disposal results in the production of greenhouse gases, which affect the climate. Nevertheless, the creation of polymer composites has successfully utilized these wastes (Suresh et al., 2020). Furthermore, the next generation of composite products will be made from sustainable and renewable materials because of their recyclability, renewability, cost effectiveness, and satisfactory mechanical performance, which has caused increased environmental concerns and global warming to shift global efforts in this direction. In order to reduce greenhouse gas emissions and carbon footprints, a bio composite has been created using natural fibers, which are ecofriendly materials used as reinforcement. However, natural fiber has several drawbacks that need to be addressed, such as poor compatibility between the reinforcing fiber matrices, excessive moisture absorption, swelling, poor chemical and fire resistance and high dispersion of mechanical characteristics (Islam et al., 2022). One of the key factors that has contributed to the advancement of NFRCs is the development of improved processing techniques. For example, the use of high-pressure impregnation and hot press molding has led to the production of composites with more uniform fiber distributions and better fiber-matrix adhesion. In addition, the use of advanced polymer processing techniques, such as melt blending, has allowed for the production of composites with improved mechanical properties (Gholampour & Ozbakkaloglu, 2020).

In addition, researchers have developed new methods for processing jute fibers, which have led to improved mechanical properties and reduced moisture uptake. Similarly, the use of bamboo fibers has become increasingly popular due to their high tensile strength and stiffness, as well as their availability and low cost (Sanivada et al., 2020). The results of the experimental and numerical investigation of the jute-bamboo natural fiber-based polymer composites were tested for their mechanical properties as an application of skateboards and safety helmets, and the findings showed that by incorporating the ideal amount of jute and bamboo fibers, the mechanical properties of the composite can be increased. The composite sample had greater tensile, flexural, and impact strengths, measuring 49.89 MPa, 45.43 MPa, and 132 J/m2 respectively (Zannat et al., 2019). The orientation of the fiber considerably impacts the mechanical properties, such as the tensile, flexural, and impact strength of the manufactured composites, according to the study on the mechanical characteristics of woven jute and coir-based polymer composites. Hybrid jute and coir fiber composite with jute fiber orientation of 45°/45° and coir fiber 0°/90° showed a maximum tensile strength of 62 MPa, Flexural strength of 89.12 MPa, and impact strength of 190.65 J/ $m^2$ (Rafiquzzaman et al., 2017). Researchers experienced fraction ratio of 7:3, hybrid bio-composites of sisal and coir fibers with polylactide reinforced and evaluated their mechanical properties, and it was discovered that by using alkali treatment on the sisal and coir fiber produced a strong interfacial bonding which led to superior mechanical properties (Barkoula et al., 2008). Extrusion was used to create 7.5 wt% fly ash and banana fiber-reinforced high-density polyethylene composites, which were then tested for their thermal, mechanical, and dynamic mechanical characteristics as well as fly ash particles greatly improved the tensile strength, flexural modulus, and hardness of the material (Satapathy & Kothapalli, 2018).

On the other hand, properties of such novel composite mainly depend on adhesion between fiber and matrixes. As a result, inadequate adhesion, increased moisture absorption, and swelling cause the matrix and fiber to split. Therefore, numerous techniques such as alkaline, silane, acetylation, permanganate, peroxide, benzoylation, acrylonitrile grafting, maleic anhydride grafted, acrylation and isocyanate have been tried till date to modify both fiber surfaces to enhance their adhesion and reduce their water absorption (Aravindh et al., 2022). When compared to pure polypropylene composites reinforced with sugar cane bagasse fiber , researchers found that the pretreatment with sulfuric acid raised the tensile modulus for composites with 10 wt% of fiber content by as much as 66% (Mulinari et al., 2018).

Additionally, exploration of new natural fibers, especially, natural fibers with higher strength and modulus, such as curaua or nano-scaled cellulosic fibers, offer a promising potential for expanding the application of these composites. Fiber's treatment and addition of fillers are also solutions to reduce moisture absorption of these composites (Neto et al., 2022). By using graphite nanoparticles, the thermal and fatigue properties have been significantly improved. The water contact angle measurements showed that the hydrophilic values increased from 54.4 to 74.5, which can be express at 36.94% with the inclusion of graphite particles. The woven bamboo fiber hybrid composites' tensile strength, flexural strength, and impact characteristics reached 32.78%, 27.37%, and 172.4%, respectively (Pulikkalparambil et al., 2023). Another analysis revealed that the silica nanoparticles contribute the most towards wear performance with a contribution ratio of 32.61% and a combination of 2 wt% of silica nanoparticles, 10 N normal load, 1.5 m/s sliding speed and 500 m sliding distance resulted in higher wear resistance (Singh et al., 2021). Further, sucrose-treated jute reinforcement composite with 40 wt% were exposed gamma radiation of 5.0 KGy gamma dose showed 10%, 16% and 25% higher tensile strength, impact strength and water uptake properties compared to untreated composite. The water uptake property of the sucrose-treated composites was comparatively high (Sahadat Hossain et al., 2020). Overall, recent advancements in NFRCs have led to the development of new types of natural fibers, improved processing techniques, and the use of NFRCs in various applications. The use of NFRCs has grown in popularity due to their excellent mechanical properties, low cost, and sustainability, and they are expected to play an increasingly important role in a variety of industries in the future. With continued research and development, the potential for NFRCs to provide sustainable and cost-effective solutions to various challenges will likely continue to increase.

## 3 NATURAL FIBER REINFORCED COMPOSITES: HISTORICAL BACKGROUND:

Composite materials have been utilized for many different purposes throughout history for thousands of years. The earliest recorded use of natural fibers for reinforcement in polymer composites can be traced back to ancient civilizations. For example, the ancient Egyptians used straw and flax fibers to reinforce mud bricks, while the Greeks and Romans used hemp fibers to reinforce concrete. In the Middle Ages, natural fibers were also used to reinforce wattle and daub construction, which was a common method of building walls in Europe and Asia (Baley et al., 2021). Before the development of plastics, fiber composites were used to bind materials together using natural resins or matrixes. Synthetic polymers including vinyl, polystyrene, phenolic, and polyester were developed in the early 1900s. However, due to their poor strength, plastics were unable to be used in many applications, including load-transferring components for cars, planes, sporting goods, wind turbine blades and more. As a result, reinforcements were devised to improve their qualities. The first fiber reinforced composite was created in 1935, but World War II saw a significant advancement in fiber composite technology due to the need for lightweight materials. Following the second world war, several resins and synthetic fibers were found in the 1970s, dramatically altering the way that traditional materials were used (Vigneshwaran et al., 2020).

The modern use of natural fibers in polymer composites began in the mid-19th century when Henry Ford introduced the concept of using agricultural waste as a reinforcement material in plastic composites. In 1941, he built a car made of plastic reinforced with hemp fibers, which was significantly lighter than traditional steel-bodied cars. This was the first recorded use of natural fibers in the automotive industry and marked the beginning of the use of natural fibers in polymer composites on a large scale (Shahzad, 2012). In the 1950s and 1960s, research into the use of natural fibers as reinforcement materials in polymer composites began to gain momentum. Scientists discovered that natural fibers had excellent mechanical properties, including high tensile strength, stiffness, and toughness, making them ideal for reinforcement. Furthermore, natural fibers were renewable and biodegradable, making them more environmentally friendly than synthetic fibers (Press & Press, 2015). During the 1970s and 1980s, advances in polymer processing techniques led to the development of new types of NFRCs. The development of the melt-blending method, which involved melting the polymer matrix and blending it with the natural fibers, made it possible to produce NFRCs with improved mechanical properties. This method also made it possible to produce composites with more uniform fiber distributions and better fiber-matrix adhesion (Robeson, 2014).

In recent years, NFRCs have gained widespread popularity in a variety of applications, including automotive, construction, and packaging. This is due to their excellent mechanical properties, low cost, and sustainability. The use of natural fibers as reinforcement materials has also helped to reduce the reliance on finite resources, such as petroleum, and has contributed to the development of a more sustainable future (Faruk et al., 2013). The historical background of natural fiber reinforced polymer composites dates back thousands of years, with the earliest recorded use of natural fibers for reinforcement in polymer composites in ancient civilizations. Over the centuries, the use of natural fibers in polymer composites has evolved and expanded, and today they are widely used in a variety of applications. With continued advancements in polymer processing techniques and a growing demand for sustainable materials, the future of NFRCs looks bright.

## 4 PROPERTIES OF NATURAL FIBER REINFORCED COMPOSITES:

A form of composite material known as Fiber Reinforcement Polymer (FRP) composites is created by adding fibers to a polymer matrix. They are commonly utilized because of a special combination of features including high strength-to-weight ratio, stiffness, corrosion resistance, fatigue resistance, electrical and thermal insulation, design flexibility and dimensional stability. In general, FRP composites provide a distinctive combination of qualities that make them suitable for usage in a variety of applications, including building, bridges, pipelines, boats, and wind energy. FRP composites are a flexible material that may be used in a variety of sectors since they can also be customized to fulfill certain needs.

### 4.1 Mechanical Properties

The mechanical properties of natural fiber reinforcement polymer composites depend on various factors such as the type of natural fiber used, fiber orientation, fiber content, and the matrix polymer. The main factors affecting mechanical performance of natural fiber reinforcement composites are: fiber selection (including type, harvest time, extraction method, aspect ratio, treatment and fiber content), matrix selection, interfacial strength, fiber dispersion, fiber orientation and porosity. However, the fibers with higher cellulose contents, such as sisal and flax present higher tensile strength and flexural modulus values as 410 and 330 MPa and 27 and 22 GPa, respectively (Pickering et al., 2016). The properties of natural fibers vary considerably depending on chemical composition and structure, which relate to fiber type as well as growing conditions, harvesting time, extraction method, treatment and storage procedures. Strength has been seen to reduce by 15% over 5 days after optimum harvest time and manually extracted flax fibers have been found to have strength 20% higher than those extracted mechanically (Pickering et al., 2007) . Similarly, fiber strength increases to a maximum with increasing moisture content and decreases as temperature increases; fiber Young's modulus decreases with moisture content. The longitudinal Young's modulus for jute has been estimated to be 7 times that for the transverse Young's modulus (Madsen & Lilholt, 2003).

The fiber orientation of kenaf- reinforced polymer composites, in addition to the $CaCO_3$ filler content, has a significant impact on their tensile performance. With a 50% increase in the amount of $CaCO_3$ filler, the tensile strength of the kenaf fiber composites improved up to 152 MPa while the flexural strength rise up to 180 MPa with 30% filler loading, respectively (Fairuz et al., 2016). Again, the strength and stiffness of the composite are often perceived to improve with higher fiber content since it is generally believed that the fibers are stronger and stiffer than the matrix. This depends on having adequate fiber/matrix interfacial strength, which can decline with increasingly high fiber content in strongly hydrophobic matrices like polypropylene (PP) unless coupling agents or other interfacial engineering techniques are employed. In spite of this, tensile strength, flexural strength and impact strength typically rises from 43 MPa, 78 MPa and 3.68 kj/m2, respectively with fiber concentration, but more smoothly than when the interface is not optimized (*Copyright Statement : The Improvement of Interfacial Bonding , Weathering and Recycling of Wood Fibre Reinforced Polypropylene Composites*, 1994). Figure: 2, Figure: 3, Figure: 4 illustrated the tensile strength, impact strength and flexural strength of different natural fiber reinforcement composite with various matrix respectively.

Chemical treatments are often employed and have been shown to reduce the water absorption of the fibre and enhance the tensile strength of jute, rami, and sisal fibre by 148%, 83%, and 114%, respectively. Through mechanical interlocking or chemical bonding at the interface, these approaches improve the adherence of the fibre to the matrix (de Araujo Alves Lima et al., 2020). A statistical experimental approach was used to create polypropylene sawdust composites with different compatibilizer (maleic anhydride grafted PP) ratios. The investigation reveals that the sawdust concentration influenced the flexural modulus, tensile strength, and percentage elongation at break characteristics. The stiffness of the composite rose as sawdust concentration increased. The compatibilizer resulted in a modest increase in tensile strength up to 23.4 MPa and a decrease in 4.36% elongation at break, indicating enhanced adhesion at the polypropylene sawdust interface (Yang et al., 2010).

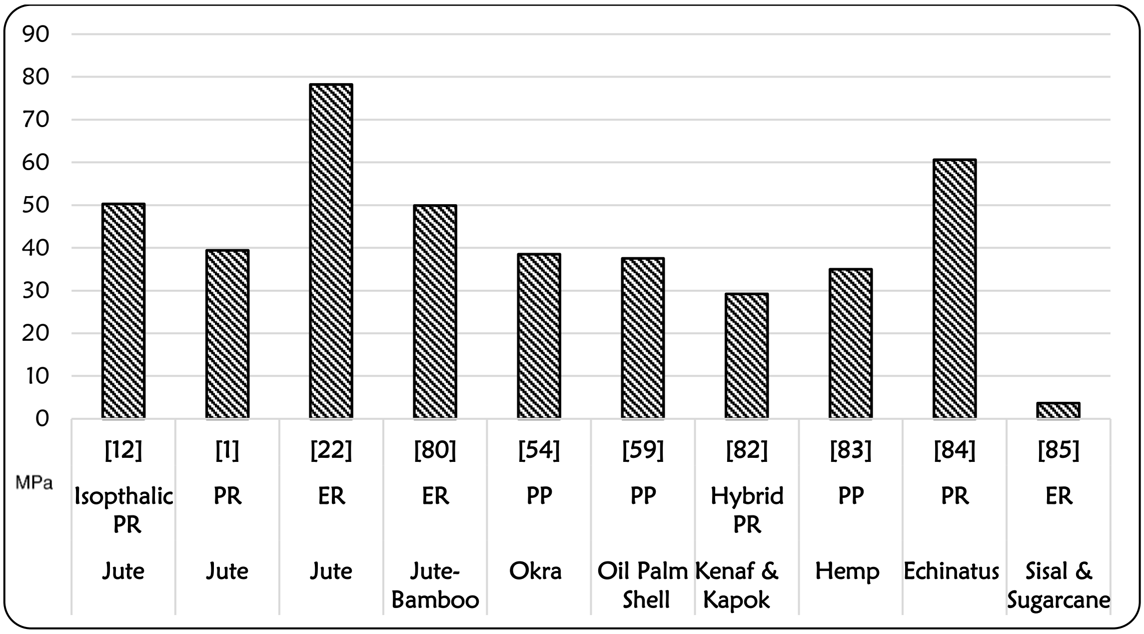


**Figure 2:** Tensile strength of different natural fiber reinforcement composite with various matrix.

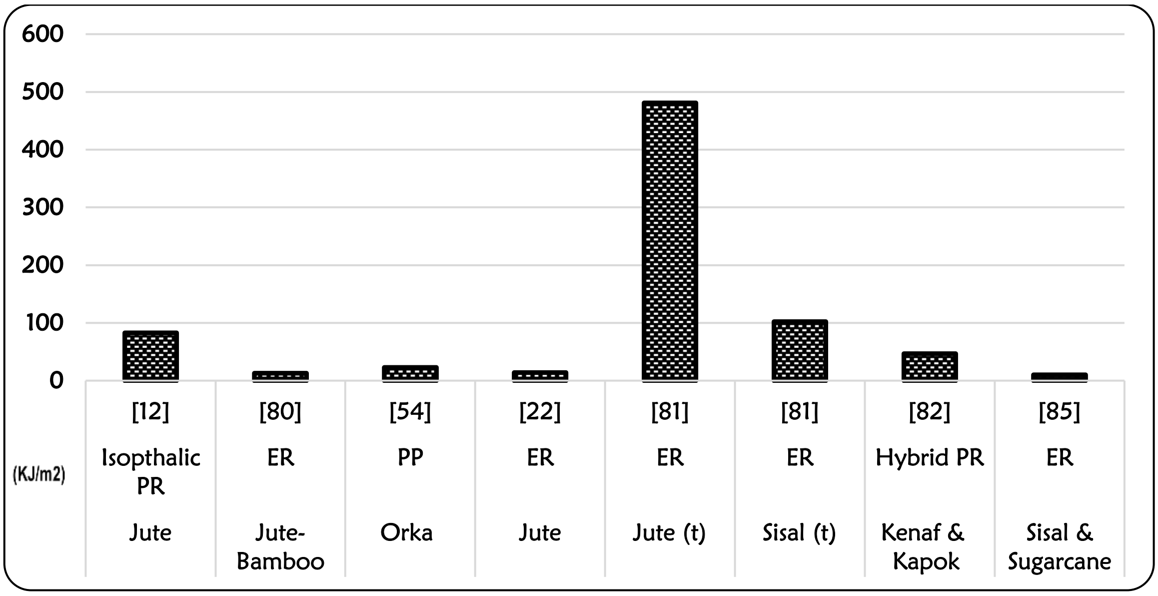


**Figure 3:** Impact strength of different natural fiber reinforcement composite with various matrix.

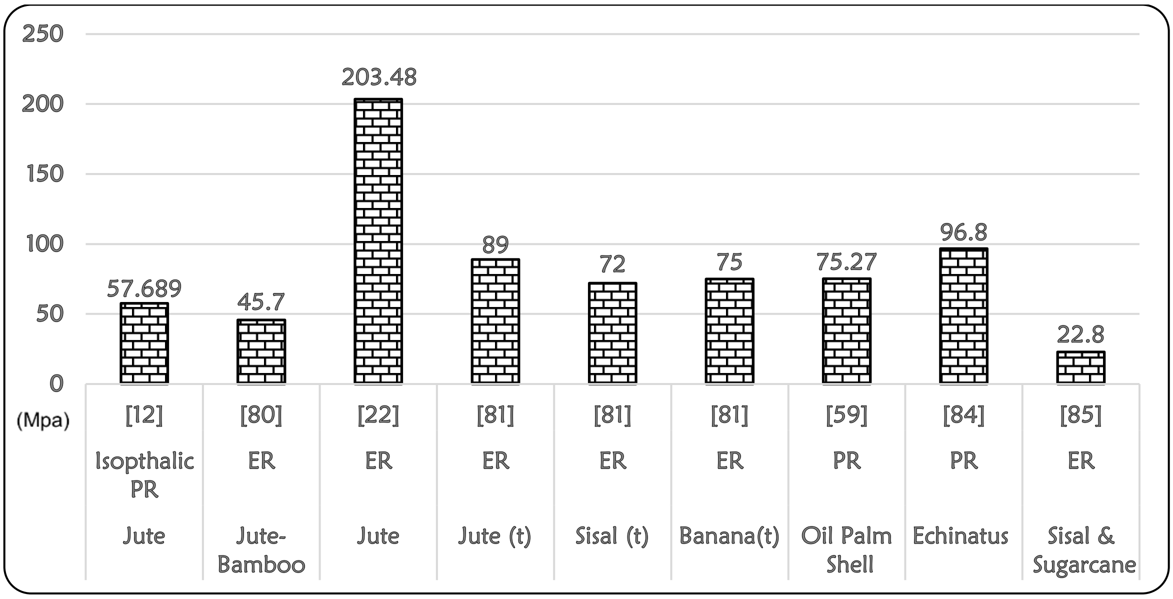


**Figure 4:** Flexural strength of different natural fiber reinforcement composite with various matrix.

Flexural properties, which include flexural strength, flexural modulus, flexural load, and deflection at break, are one of the key parameters in composite materials and are primarily used to evaluate the material's potential for structural applications. The hybrid composite's stacking order is very important for its flexural qualities (Abu Shaid Sujon et al., 2020). According to research on the flexural characteristics of natural fiber composites, flexural strength is correlated with fiber content and length. For example, chopped snake grass fiber isophthalic polyester composites can achieve their maximum flexural strength and modulus at 25% for 120mm and 150mm long fibers (Sathishkumar et al., 2012). Some authors found that the stacking sequence has an insignificant effect on the impact strength, while the fiber orientation in the hybrid composite has a noticeable effect on the impact strength. The mechanical properties of fiber reinforced composites are mainly affected by fiber content and orientation (Ramesh et al., 2016). Increased fiber length generally increases fiber load bearing efficiency due to increased area for stress transfer, however, if fibers are too long they may get tangled during mixing resulting in poor fiber dispersion which can reduce the overall reinforcement efficiency (Sreekumar et al., 2007).

Overall, the mechanical properties of natural fiber reinforced polymer composites are highly dependent on the specific combination of fibers and matrix polymer used, as well as the fiber orientation, fiber content and fiber matrix interfacial bonding. The aim is to produce composites that have improved mechanical properties compared to the matrix polymer alone, while also maintaining their lightweight, biodegradability and sustainability.

### 4.2 Thermal Properties

The kind of natural fiber utilized, the matrix polymer, the chemical treatments, and the processing technique all affect the thermal characteristics of natural fiber reinforcement polymer composites. Natural fiber reinforced polymer composites' most crucial thermal characteristics include thermal conductivity, thermal expansion, thermal stability and flame retardancy. In order to improve the thermal properties and mechanical properties, chemical treatments of fiber reinforcement composites provide better results than the physical treatments. Generally, the concentration of the chemical used and exposure time influence the properties significantly. Combination of treatments with two different chemicals presented better thermal properties than the individual treatments in some cases (Barkoula et al., 2008). The silane-treated abaca fiber has higher thermal conductivity of 0.43 W/(m·K) rather than alkaline treated fiber (Liu et al., 2014). At 10% of NaOH content, banana treated fiber significantly increased thermal conductivity of 0.178 W/(m·K) (Annie Paul et al., 2008). For improvement of thermal stability, attempts have been made to coat the fibers or to graft the fibers with monomers. Grafting is possible since the lignin can react with the monomers. The study revels that the grafting of acrylonitrile on jute improved the thermal stability as evidenced by the increase in the degradation temperature from $170^0$ to $280^0$ C (Mohanty et al., 1989). Due to its advantages in terms of the environment and economy, polymer composites reinforced with natural fiber acquired as industrial waste are of special interest. Alkali-treated sugarcane bagasse fibers, a by-product of the manufacturing of sugar and ethanol, were added to a polypropylene matrix at a rate of 25% weight to increase adhesion to the composite matrix. For both types of composites those with untreated fibers and those with alkali-treated fibers thermal evaluations showed that the alkali treatment increases the compatibility between the bagasse fiber and the polypropylene matrix, resulting in better thermal resistance by heat flow of -1.20 W/g (Gomes de Paula et al., 2014). The jute fiber-based composites showed higher mechanical properties than that of jute-based fabrics. The polypropylene-based composites showed better mechanical properties than that of linear low-density polyethylene. At $-18^0$ C mechanical properties were highest and lowest at $50^0$ C (Niloy Rahaman et al., 2019). However, at temperatures between 30° and 200° C, it has been discovered that adding jute fiber up to 30 wt.% to an epoxy matrix improves the composite's mechanical, thermal, and water-absorbing qualities (M. Gupta & Srivastava, 2017).

### 4.3 Chemical Properties

The chemical properties of natural fiber reinforcement polymer composites rely on a number of variables, including the type of natural fiber used, fiber surface condition, the matrix polymer, the processing method and the loading conditions. Some of the most important chemical properties of natural fiber reinforced polymer composites include chemical resistance, water absorption, biodegradability and UV stability. In addition, interfacial bonding between fiber and matrix plays a vital role in determining the chemical and mechanical properties of composites. Since stress is transferred between matrix and fibers across the interface, good interfacial bonding is required to achieve optimum reinforcement, although, it is possible to have an interface that is too strong, unable to crack propagation which can reduce toughness and strength (Bader et al., 1993). However, for plant-based fiber composites there is usually limited interaction between the hydrophilic fibers and matrices which are commonly hydrophobic leading to poor interfacial bonding lowering mechanical performance as well as low moisture resistance affecting long term properties. For bonding to occur, fiber and matrix must be brought into intimate contact; wettability can be regarded as an essential precursor to bonding. Insufficient fiber wetting results in interfacial defects which can act as stress concentrators (Chen et al., 2006). It has been reported that hemp fiber reinforced PP composites with a fiber volume fraction of 0.7 absorbed almost 53m% water and had not reached saturation after 19 days, whereas only 7m% water uptake was observed in composites with a fiber volume fraction of 0.3 and saturation had been achieved in the same time period (Shahzad, 2012). Surface treatment of natural fibers is usually performed to enhance the properties of natural fibers, before using them to manufacture a composite material. Fiber surface modification can improve the interfacial bonding, roughness, wettability and decrease the moisture absorption of the fiber (Barkoula et al., 2008).

## 5 EFFECT OF GAMMA RADIATION ON THE NFRPC PROPERTIES:

The effect of gamma radiation on the properties of natural fiber reinforcement polymer composites can be both positive and negative which is depending on the type of natural fiber, matrix polymer and intensity of radiation. The hydrophilic characteristic of natural fiber is the primary issue with natural fiber reinforced composites. Using various compounds, many researchers are working to reduce this issue, but there is still research being done on a full cure. Different techniques are being used by scientists to enhance the mechanical properties. The two techniques that are most frequently employed to increase mechanical qualities are chemical treatment and gamma radiation (Güven et al., 2016). Gamma radiation was used to study the tensile characteristics of composites with jute fiber reinforcement. The radiation was utilized to sterilize experimental biodegradable medicinal polyurethanes with varied hydrophilic to hydrophobic segment ratios based on hydrophilic poly (ethylene oxide) and hydrophobic poly (e-caprolactone) diol. To varying degrees, irradiated polymers deteriorated; this was linked to a loss of mechanical properties hydrophobic polycaprolactone-based polyurethanes' surface roughness was hardly impacted by gamma radiation, which also slightly increased contact angle. Gamma radiation caused the surface roughness and contact angle of the hydrophilic polymers based on polycaprolactone diol and polyethylene oxide to rise by 36-76% and 20-45%, respectively. The thermal properties of the irradiated materials also clearly changed (Gorna & Gogolewski, 2003).

The dose of radiation plays a critical role in the effect of gamma radiation on the mechanical properties of natural fiber reinforcement polymer composites. High dose of gamma radiation can cause degradation of the polymer matrix, leading to a decrease in its tensile strength, stiffness and impact resistance whereas low doses of radiation can have a positive effect on the properties. By exposing to the gamma radiation, the chemical structure of the matrix polymer changes in its chemical properties such as water absorption and biodegradability. which can have a positive or negative effect on the strength-to-weight ratio. Gamma radiation can induce crosslinking between polymer chains, resulting in the formation of additional chemical bonds. Besides, this can increase the stiffness and mechanical properties of the composite. Radiation can also cause the formation of new chemical species in the polymer matrix, which can improve its mechanical, thermal and microstructure properties (Motaleb et al., 2019).

To improve the mechanical properties of the composites, gamma radiation which is a form of high intensity ionizing radiation was also used. The mechanical properties of silk fiber reinforced polypropylene matrix composites are improved by the use of gamma rays up to 16.33%, 13.1%, 41%, 13%, and 20.6% for TS, BS, TM, BM and IS, respectively (Shubhra & Alam, 2011). Gamma radiation is known to impose energy in solid cellulose by compton scattering and the rapid localization of energy among molecules that generate macro-cellulosic radicals. This is thoughtful in that it varies the physical, chemical, and biological properties of cellulosic fibers (Valadez-Gonzalez et al., 1999). The fiber reinforced composite can be exposed to various gamma radiation doses; however, 5.0 kGy gamma dosage produced the best results. Depending on the reinforcing and matrix materials, the tensile strength of the natural fiber reinforced composites increased from 5% to 62% under 5.0 kGy gamma dosage (Shahriar Kabir et al., 2018). The jute-based natural rubber composites were exposed to gamma rays to increase the compatibility between the fiber and matrix. Radiation exposure ranged from 50 to 1000 krad overall. The irradiation (250 krad) composites greatly improved in terms of tensile characteristics. Increases in tensile modulus and tensile strength of up to 47% and 147%, respectively (Mushfequr Rahman et al., 2012). There is also a significant impact of gamma irradiation on dielectric properties of composites by producing active site up to 300 units at 62$^{0}$C and certain radiation dose. But in case of higher irradiation doses, mechanical properties reduce dramatically from 63 MPa, 73 MPa and 2.93 kj/m2 for TS, BS and IS, respectively (Haydaruzzaman et al., 2009).

The physio-mechanical characteristics of okra fiber-polypropylene composites were shown to be improved by 26% in TS, 11% in TM, 28% in BS, 23% in BM, and 10% increase in IS when compared to a non-irradiated sample. This suggests that gamma irradiation may be a possible source of improvement of mechanical properties (A. N. M. M. Rahman et al., 2018). Composites that were exposed to gamma rays (Co-60) at different doses to improve the compatibility between pineapple leaf fiber and low-density polyethylene matrix produced the greatest results. After 7.5 kGy dose gamma irradiation, the tensile characteristics of the composites were found to have greatly improved, up to 38.49 MPa in TS, 98.94 MPa in BS and 36.12% increase of IS. indicating that a higher dose inhibits cross-linking and increases amorphous regions in the composite (H. Rahman et al., 2019). The mechanical properties of jute yarn reinforced polypropylene composites that had been treated with 3% aqueous starch solution were further improved when they were subjected to gamma radiation (Co-60) at a dose of 500 krad. At room temperature (25$^{0}$C), water absorption of the composites was evaluated, and it was discovered that starch-treated samples had better water uptake characteristics than the control sample. The improved composites maintained their 75% tensile strength and 93% tensile modulus after 500 hours of mimicking weathering tests (Khan, Khan, Haydaruzzaman, Ghoshal, et al., 2009). Low-density polyethylene-based composites reinforced with disaccharide-treated jute fibers were created for the best outcome; their tensile strength, tensile modulus, and elongation at break values were 26, 940 MPa and 18%, respectively. The sucrose-treated composites displayed significantly worse mechanical characteristics to the untreated composites when exposed to gamma radiation (2.5, 5.0, and 7.5 KGy). Both composites performed best at a gamma dose of 5.0 KGy. The composites treated with sugar had a rather high water absorption capacity (Sahadat Hossain et al., 2020).

Gamma radiation's impact on the surface composition and mechanical characteristics of woven cotton, flax, and silk fabrics was researched. Moderate levels of radiation (up to 15 kGy), which are adequate to effectively disinfect textiles, were discovered to induce only negligible effects in the fiber properties examined. However, it was discovered that doses upped to 100 kGy significantly degrade the tested materials and cause a 26-33% loss in tensile strength. Cotton and linen fabric specimens do not differ from silk fabric in their susceptibility to fungal biodegradation after receiving a dosage of 100 kGy (Machnowski et al., 2013). Compression molding was used to create composites with jute fabric reinforcement made of polyethylene and polypropylene mixed matrices with 50 wt% fiber to test their mechanical and electrical characteristics. It was determined that the hybrid matrices-based jute fabric reinforced composites that had a combination of 80% polypropylene and 20% polyethylene worked best. On polypropylene, polyethylene, and jute materials, gamma radiation (250–1000 krad) was administered before composites were created. In comparison to the non-irradiated composites, it was discovered that the irradiated composites (500 krad) had dramatically improved mechanical characteristics (Zamam et al., 2009). Hessian cloth (jute fiber) reinforced polypropylene (PP) composites with 50% fiber content and 500 krad/h gamma-irradiated composites and PP sheets demonstrated that improved mechanical characteristics. The PP sheets' enhanced tensile strength, tensile modulus, bending strength, and bending modulus, as well as the composites' improved 16%, 45%, 12%, and 38%, respectively. Measurements of the composites' water absorption at 258$^{0}$C revealed that treated samples had less favourable water uptake characteristics. The treated composite was discovered to have a greater dielectric constant than the untreated one. The transition temperatures for untreated and irradiation composites, respectively, were discovered to be 808$^0$C and 758$^0$C (Khan, Khan, Haydaruzzaman, Hossain, et al., 2009).

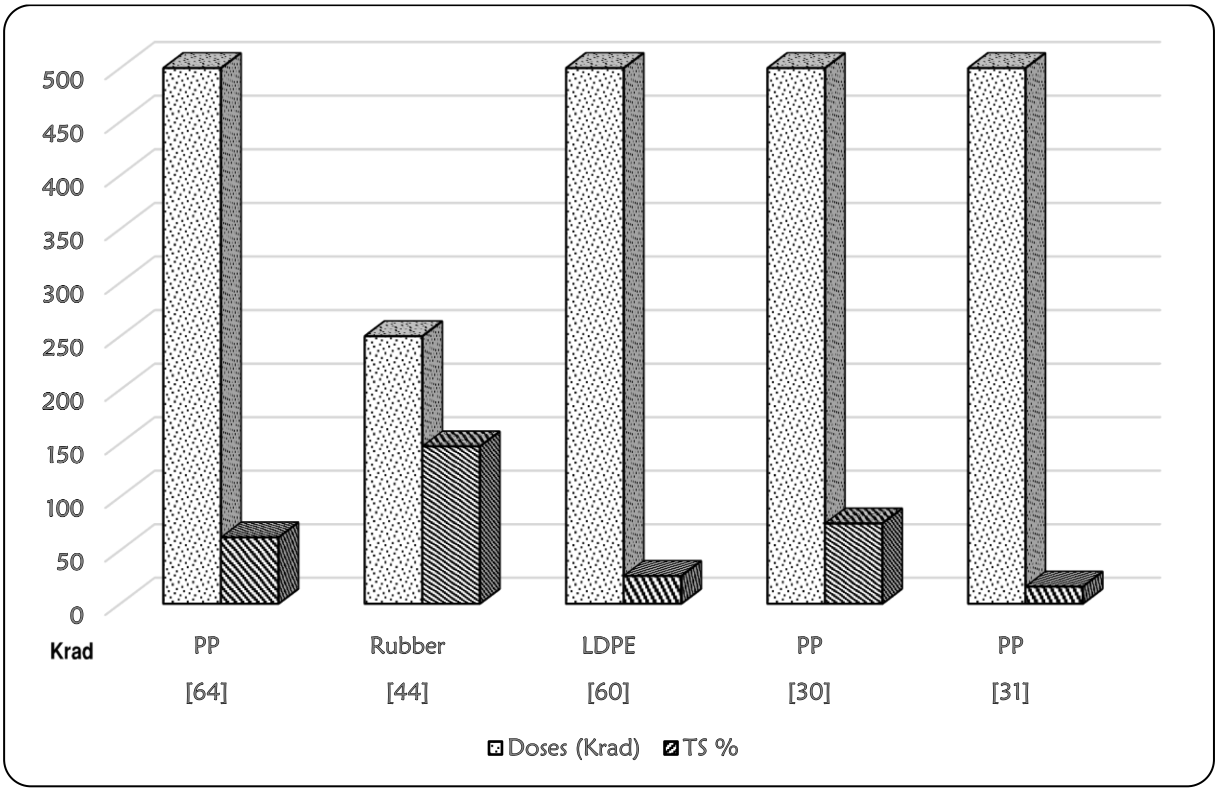


**Figure 5:** Effect of various doses of gamma radiation on jute fiber reinforcement composite with different matrix.

Overall, the effects of gamma radiation on various properties of natural fiber reinforced polymer composites are complex and significantly depend on the radiation intensity. The most common effect of gamma radiation is an increase in tensile strength due to crosslinking of the matrix material. This can be beneficial for a variety of applications, such as in aerospace and automobile components, as increased tensile strength can result in increased durability and performance. However, it can also lead to embrittlement of the composite, as the gamma radiation can cause further cure of the matrix material, resulting in decreased ductility and toughness. In addition to increasing tensile strength, gamma radiation can also cause an increase in the glass transition temperature of the matrix material, which may result in a decrease in the composite's stiffness. This decrease in the composite's stiffness can adversely affect its fatigue resistance, as well as its impact toughness. In general, gamma radiation can be beneficial for improving the water resistance properties of natural fiber reinforced polymer composites, but it is important to consider the effects of radiation on the other properties of the composite before using it as a strengthening agent. Figure: 7 reveals the effect of various doses of gamma radiation on jute fiber reinforcement composite with different matrix.

## 6 EFFECT OF NANOPARTICLE ADDITION ON THE NFRPC PROPERTIES:

Nanoparticles have been found to have a significant effect on the chemical properties of natural fiber reinforced polymer composites. The performance and quality of materials, including their thermal, mechanical, water absorption, flame retardancy and electrical properties can be significantly improved by this sophisticated method, which involves adding a little amount of material to a variety of polymers and other materials. Nanoparticles are particles that are less than 100 nanometers in diameter, and they can be used to strengthen and improve the properties of a composite material. Nano fillers are solid-state additions that can improve a variety of original materials' qualities without affecting the density of the material.

Natural fiber reinforced polymer composites are composites made of natural fibers, such as wood, hemp, or flax, which are combined with a polymer matrix to create a strong, lightweight material. Nanoparticles can be added to a composite material to increase its strength, stiffness, and toughness. In addition, nanoparticles can improve the surface finish of the composite, which can improve its aesthetic appeal. Nanoparticles can increase the surface area of the material, resulting in better adhesion between the fibers and the polymer matrix. The increased surface area also allows for better chemical interactions between the fibers and the matrix, resulting in increased tensile strength and improved resistance to chemical attack. Nanoparticles can also improve the fire resistance of natural fiber reinforced polymer composites. Many nanoparticles are able to absorb heat, which can make the composite material more resistant to fire.

Additionally, some nanoparticles can act as catalysts, causing the polymer resin to break down at lower temperatures than it would without the presence of the nanoparticles. This can reduce the fire hazard of the composite material. Furthermore, the nanoparticles can also act as a filler, which can reduce the porosity of the composite and thus improve its tensile properties. Nanoparticles have been also found to have a significant effect on the thermal properties of natural fiber reinforced polymer (NFRP) composites. The addition of nanoparticles to the composite matrix can improve the thermal conductivity, thermal stability, and thermal shock resistance of the composite. Nanoparticles can also reduce the thermal expansion coefficient of the composite, which can lead to improved dimensional stability.

Nanoparticles have been found to have a significant impact on the chemical properties of natural fiber reinforced polymer composites. Nanoparticles can interact with the chemical structure of the fibers, creating a stronger bond between the fibers and the polymer matrix, resulting in improved strength and toughness. Nanoparticles also have the ability to act as a barrier between the fibers and the polymer, helping to reduce the risk of corrosion and degradation of the fibers. Additionally, nanoparticles can be used to modify the surface of the fibers, reducing their surface energy and improving the adhesion between the fibers and the polymer. Ultimately, the use of nanoparticles in natural fiber reinforced polymer composites can result in improved mechanical and chemical properties, making them more suitable for applications in various industries.

The effects of nanoparticles on the interactions between fiber and epoxy resin were studied, and the results demonstrated that silica nanoparticles created by sol-gel really enhanced the interfacial interactions effectively, enhancing the composite's mechanical and thermal properties. When fiber-epoxy composites fractured, nanoparticles provided improved energy dissipation and more effective stress transfer. The interfacial shear strength and transverse fiber bundle tensile strength of the CF/20 wt% nano silica-EP system was higher than those of the CF/EP system by around 38% and 59%, respectively. The interlaminar shear strength of unidirectional laminar was also increased by up to 13% for the CF/10 wt% nano silica-EP system (Tian et al., 2017). The impregnation of styrene-acrylonitrile co-polymer into Simul wood in the presence of nano-SiO2 and nano clay modified with tri-methoxy silyl propyl methacrylate resulted in the creation of wood polymer nano composites, and the results demonstrated that the addition of SiO2 decreased the water-uptake capacity of treated wood polymer nano composite samples. The least amount of water was absorbed by the wood polymer nano composite with a SiO2/nanoclay ratio of 0.5:0 (Devi & Maji, 2012).

The impact of coir fiber and titanium carbide (TiC) nanoparticles on the physio-mechanical, and thermal properties of basalt fiber reinforced bio-synthetic epoxy hybrid composites was examined for use in the design of automobile and aircraft constructions. According to the investigation the coir fiber and TiC nanoparticles significantly improved the mechanical and thermal properties of the material, resulting in the greatest load transfer between the fillers and matrix components. The thermal stability investigation of the newly created epoxy hybrid composites shows that they are more resistant to temperature changes than the pure polymer sample. The synthetic epoxy reinforced with basalt fiber and coir micro-particles had the maximum impact strength, measuring 27.67 kJ/ $m^2$, as a result of greater interfacial adhesion between the matrix and fillers (Arshad et al., 2021). The synergy between exfoliated graphite nanoplatelets (xGnP) and kenaf fibers were investigated for the poly (lactic acid) based composites by Han et al. (2012). Nano bio-composites were made by melt-mixing followed by injection molding using xGnP-coated kenaf fibers which were prepared by sonication. This study indicated that with increasing XGnP content, flexural strength fluctuated slightly and flexural modulus increased 25–30% (Han et al., 2012).

The effects of purified graphene and commercial graphene on morphology, thermal, mechanical, and combustibility properties of palm empty fruit bunch fiber reinforced epoxy composite were investigated. The evaluation of empty fruit bunch epoxy nanocomposites revealed that the mechanical properties improved with low graphene loading (0.01 wt.%). Specimens containing empty fruit bunch fibers and graphene fillers appeared more thermally stable and produced lower gross heat of combustion compared to neat epoxy. At the same filler loading, commercial graphene seems to be slightly more compatible with the resin matrix and ease of dispersion compared to the purified graphene (Tshai et al., 2016). Scientists evaluated the effects of nano-$SiO_2$ on physical and mechanical properties of fiber reinforcement composites. In the specimen preparation, three levels of nano-SiO2 (0, 2, and 5 wt.%) and 40 wt.% of bagasse fibers were used. The results showed that as nano-SiO2 content increases, tensile strength increases up to load of 38.82 MPa for bagasse-filled composite reinforced with 5 wt.% nano-$SiO_2$ and the tensile modulus of pure high-density polyethylene was experienced 221.84% increase, when bagasse fibers and 5 wt.% nano-SiO2 were added. They also reported same increasing trend of flexural strength and modulus of rupture, and water absorption by increasing $SiO_2$ content up to 5 wt.% (Hosseini et al., 2017). The grafted flax fiber yarn with nanosized TiO2 for the fabrication of epoxy-based composites was investigated and found that their tensile and bonding properties of the single fibers. The incorporation of TiO2 nanoparticles (2.34 wt%) grafted flax fibers into the epoxy matrix improved the tensile Nanotechnologies for fiber-reinforced composites strength and the interfacial shear strength (IFSS) by 23.1% and 40.5%, respectively (Wang et al., 2015). The surface modification of flax fibers with ZrO2 by sol-gel processed and investigated the wetting performance and surface characterization of modified fibers. Their study demonstrated that the flax fibers modified with ZrO2 significantly reduced the water uptake capacity of the composite (Boulos et al., 2017).

The impact of oil palm shell nanoparticle at 3 wt% showed the best physical, mechanical, morphological, and thermal properties of hybrid kenaf-coconut fiber reinforcement polyester composite (Rosamah et al., 2017). When the number of nanoparticles (silica and clay) in the matrix was increased, the mechanical properties of rice straw polypropylene composites were assessed. The findings revealed that the impact strengths significantly decreased, but tensile and flexural modulus and elongation were only relatively improved. With an increase in nanoclay up to 2 wt%, the flexural and tensile modulus further enhanced. Nanoclay-filled composites made of rice straw and polypropylene often have better mechanical characteristics than nanosilica-filled composites (Ashori, 2013). Some research examined how nanoclay affected the mechanical properties of epoxy and polyester resin and found that the nanoclay content had a significant impact on the tensile and hardness properties of the nanocomposites. In comparison to composites with higher nanoclay contents, those with 5 wt% nanoclay in polymer resin produced better results (Shettar et al., 2017).

The effect of dispersing titanium dioxide ($TiO_2$) nanoparticle with flax fiber reinforced epoxy composite revealed that, the matrix reformation utilizing nano $TiO_2$ raised the tensile strength value of composites to 12.31%, increasing the $TiO_2$ concentration in composites from 4% to 6%. The young's modulus values followed a similar pattern, with the greatest values found at 6% TiO2 content in the composite, which implies an increase in value of 23.17 percent above 4% TiO2 content in composite (Prasad et al., 2018). Nano clay has demonstrated its potential in sisal fiber reinforced composites to reduce water absorption, which is highly desirable. Nano $SIO_2$ has also demonstrated its value in improving the mechanical properties of these composites (Devnani & Sinha, 2019). To assess its functioning mechanical qualities, several mechanical tests were conducted. Experiments have shown that natural fiber nano-composites are ideal for non-structural uses such as decorative objects, fishing rods, cushioning pads, interior paneling, food trays, and lamp shades (Kumar Singh et al., 2021).

## 7 CONCLUSIONS

This review article provides a comprehensive overview of the properties of NFRPC's and the effects of gamma radiation and nanoparticles on these properties. the properties of natural fiber reinforced polymer composites natural fiber reinforced polymer composites can be influenced by various factors, including exposure to gamma radiation and the addition of nanoparticles. Numerous research' findings suggest that adding nanoparticles and being exposed to gamma radiation can significantly affect the mechanical characteristics of natural fiber reinforced polymer composites. However, depending on the matrix and reinforcing elements, NFRPC's often degrade after exposure to relatively large doses of radiation, as opposed to low levels. Additionally, by increasing the surface area of the composite material, nanoparticles can improve fire resistance, reduce thermal expansion coefficient, and improve water absorption capabilities. This results in improved adhesion between the fibers and the polymer resin. Overall, this review highlights the need for continued research into the properties of natural fiber reinforced polymer composites and the effects of gamma radiation and nanoparticles on these properties. Such research will help to guide the development of new and improved natural fiber reinforced polymer composites for a variety of applications, including construction, packaging, and the automotive industry. The potential of natural fiber reinforced polymer composites as a sustainable and cost-effective alternative to traditional materials makes it an area of significant interest and importance.

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