

Lecture 54: Natural fibers reinforced composites-I

Natural Fiber Reinforced Composites - Part 1: Overview

Welcome to the first part of the "Natural Fiber Reinforced Composites" series, exploring the realm of polymer process engineering. Before delving into the details of natural fiber composites, let's briefly revisit the topics covered in our previous lecture.

In our last session, we focused on environmental protection through coatings, covering various aspects such as moisture resistance, water absorption, humidity testing, corrosion protection, wash primers, mechanical safeguarding, and defense against electromagnetic and radio frequency influences. Additionally, we delved into electrostatic discharge, microbial protection, thermal conductivity, and relevant testing procedures.

Now, transitioning to our current segment, we'll introduce the fascinating realm of natural fiber-reinforced composites (NFRCs). This discussion will encompass an exploration of natural fiber types, the structure of NFRCs, their classification, applications, and the prevalent challenges in their utilization.

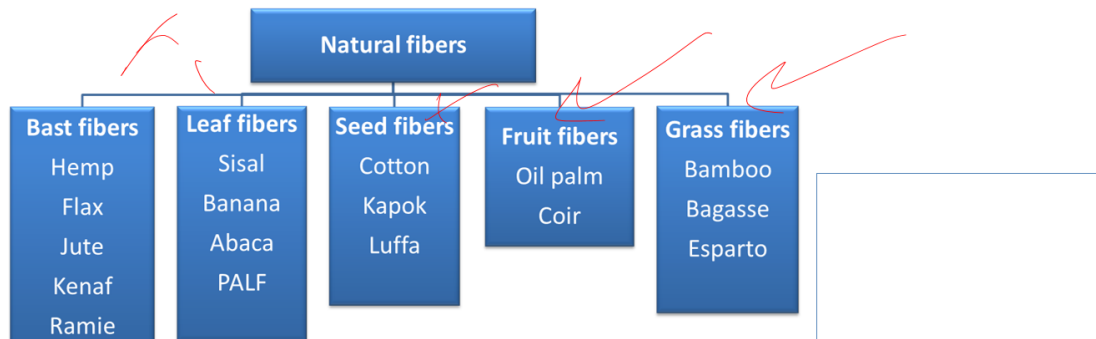
Natural fibers encompass a diverse range of plant, animal, and mineral fibers. Plant fibers, characterized by cellulose as their primary component, include bast fibers like hemp, flax, jute, and kenaf. Animal fibers, predominantly composed of protein, have limited applications in composites. Mineral fibers, once part of the asbestos group, are now avoided due to health concerns.

Our focus will be on the various types of natural fibers suitable for reinforcement, including bast, leaf, seed, fruit, and grass fibers. Examples include hemp, flax, jute, kenaf (bast fibers), sea salt (leaf fiber), cotton (seed fiber), palm, bamboo (fruit fibers), and grass fibers. These fibers hold immense potential for enhancing the properties of composites.

Join us as we navigate through the classification, applications, and challenges of natural fiber-reinforced composites in the upcoming sessions.

Natural fiber types

- The different kind of natural fibers which are used as reinforcement in polymer composites are following:



Bast Fibers

Let's delve into the realm of bast fibers, a widely utilized reinforcement in composite preparation due to their abundant availability compared to other fibers. Extracted from the outer layer of plant systems, bast fibers play a crucial role in various industries.

Flax Fibers:

- Derived from the linseed or flax plant, flax fibers are obtained from the stem. This plant is renowned for providing flax fibers, and linseed oil, extracted from it, finds applications across industries.
- Flax fibers exhibit superior tensile strength compared to glass fibers. They boast high strength, low density, and stiffness.

Hemp Fibers:

- Pulled from the stem of hemp plants, hemp fibers are strong, stiff, and exhibit lower elasticity compared to other natural fibers.
- These fibers possess excellent flexural strength, tensile strength, and fire retardancy, making them a viable alternative to glass fibers in polymer composites.

Leaf Fibers:



- Extracted from plant leaves, leaf fibers fall into the category of hard fibers, characterized by their length and stiffness.
- Cecil fiber, extracted through processes like retting and mechanical extraction, is known for its high tensile strength, corrosion resistance, and resistance to saltwater, acid, and alkali.

Date Palm Fibers:

- Obtained from the leaves of the goth palm, date palm fibers are extracted through processes like retting, mowing, hackling, combing, and spinning.
- These fibers, rich in cellulose, offer high tensile strength, low density, and easy availability.

Bast fibers, with their diverse properties and applications, contribute significantly to the enhancement of composite materials. Stay tuned for further exploration into natural fiber-reinforced composites, including other fiber types and their applications.

Seed, Fruit, and Grass Fibers

Continuing our exploration of natural fiber-reinforced composites, let's delve into seed, fruit, and grass fibers, each with unique properties and applications.

Seed Fibers:

- Seed fibers are extracted from the seeds or seed cases of plants. Cotton fiber, a prominent example, is extensively used in the textile industry and is typically harvested by hand.
- Cotton fiber is known for its exceptional absorbency, constituting 46 percent of the world's fiber production.

Loofah Fibers:

- Loofah fibers do not consist of a single strand but rather form a package of cellulose, resembling a fibrous circulatory system.
- Primarily derived from ripe and dry fruits, loofah fibers exhibit rapid water absorption.

Fruit Fibers:

- Fruit fibers are obtained from the dried fruits of plants. Coir fiber, extracted from the coconut shell, is a notable example.

- Coir fibers are coated with lignin, rendering them more robust than many other natural fibers. They exhibit resistance to saltwater and microbial degradation.

Grass Fibers:

- Grass fibers are extracted from the stems and leaves of plants. Bamboo fiber, sourced from bamboo, is a prime example.
- Bamboo, classified as a grass, provides fibers with unique properties. It is known for its sustainability and versatility.

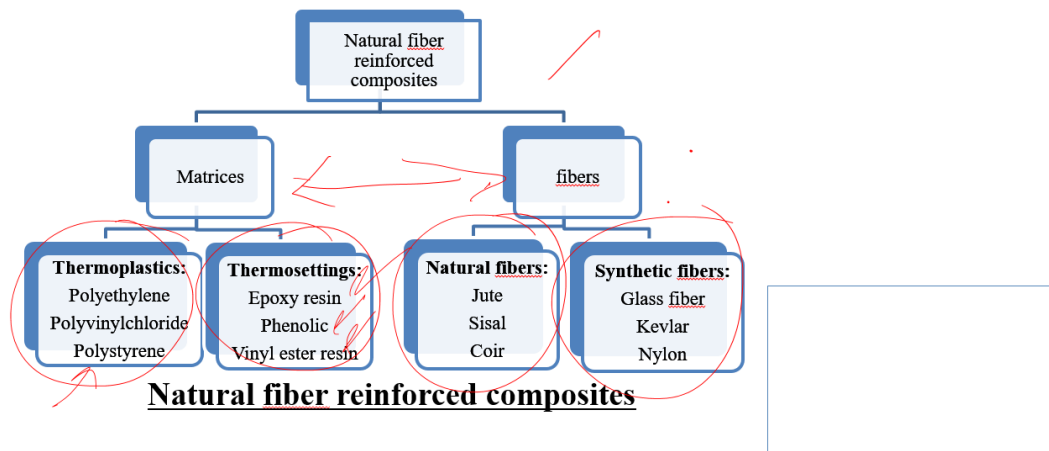
Bamboo fiber, derived from the bamboo plant, stands out as a renewable and versatile cellulosic fiber. Its rapid growth, impressive strength, and carbon dioxide sequestration properties make it a preferred choice for reinforcement in composite materials across various applications.

Key Features of Bamboo Fiber:

1. **High Growth Rate:** Bamboo exhibits a rapid growth rate, making it an abundant and sustainable resource for fiber extraction.
2. **Strength:** Bamboo fiber possesses inherent strength, contributing to the overall mechanical properties of composites.
3. **Carbon Dioxide Sequestration:** Bamboo plants actively absorb carbon dioxide during their growth, offering an eco-friendly aspect to the fiber.

Natural Fiber-Reinforced Composite Materials: Natural fiber-reinforced composites combine fibers like hemp, jute, banana, bamboo, sea salt, or flax with polymer matrices such as polypropylene, polyester, epoxy, and more. These composites provide several advantages compared to traditional materials like steel and aluminum.

NFRCs: Classifications



Advantages of Natural Fiber-Reinforced Composites:

1. **Lower Weight:** These composites are generally lighter than traditional materials, contributing to enhanced fuel efficiency in transportation applications.
2. **Lower Cost:** Natural fibers are often more cost-effective than synthetic counterparts, offering economic benefits.
3. **Better Sustainability:** The use of renewable and plant-based fibers promotes sustainability, aligning with environmentally friendly practices.

Applications: Natural fiber-reinforced composites find applications in various industries, including:

- **Automotive:** Lightweight composites contribute to fuel efficiency.
- **Construction:** Sustainable materials for structural components.
- **Consumer Goods:** Biodegradable and eco-friendly product options.
- **Aerospace:** Lightweight materials for aircraft components.

As the demand for sustainable and eco-friendly materials grows, bamboo fiber-reinforced composites play a pivotal role in meeting these requirements across diverse industries. In the next segment, we'll explore more aspects of natural fiber-reinforced composites.

Methods for Preparing Natural Fiber-Reinforced Composites:

1. **Hand Layup:**

- *Process:* Natural fibers are manually placed in a mold.
- *Application:* Polymer matrix is pulled into the mold, and the composite is cured under specific temperature and pressure conditions.

2. **Compression Molding:**

- *Process:* Natural fibers are impregnated with the polymer matrix.
- *Application:* The resulting product is placed in a mold and compressed under heat and pressure.

3. **Resin Transfer Molding (RTM):**

- *Process:* Natural fibers are placed in a mold.
- *Application:* Polymer matrix is injected under pressure into the mold, and curing occurs at suitable temperature and conditions.

4. **Filament Winding:**

- *Process:* Natural fibers are wrapped around a rotating mandrel.
- *Application:* Polymer matrix is applied to the fibers as they are wound into the mandrel.

These methods offer flexibility in producing natural fiber-reinforced composites with varying characteristics and applications. The choice of method depends on factors such as the desired properties of the composite, production scale, and end-use requirements.

Advantages of Natural Fiber-Reinforced Composites:

- **Sustainability:** Plant-based fibers contribute to environmental sustainability.
- **Weight Reduction:** Composites are generally lighter than traditional materials.
- **Cost-Effectiveness:** Natural fibers can be more economical than synthetic alternatives.
- **Biodegradability:** Some natural fibers enhance the biodegradability of the composite.

Applications:

- **Automotive Industry:** Lightweight components for improved fuel efficiency.

- **Construction:** Sustainable materials for structural elements.
- **Consumer Goods:** Biodegradable and eco-friendly product options.
- **Aerospace:** Lightweight materials for specific applications.

As the demand for sustainable and eco-friendly materials rises, the versatility of natural fiber-reinforced composites makes them a viable solution across various industries. The next segment will delve into specific challenges and considerations associated with these composites.

Pultrusion Method:

- *Process:* Natural fibers are pulled through a dye.
- *Application:* Polymer matrix is applied to the fiber as it passes through the dye, and the resulting component is cured under suitable conditions.

Classification of Natural Fiber-Reinforced Composites:

1. Polymer Matrix Classification:

- **Thermoplastics:** Soften at high temperatures and regain properties after cooling. (e.g., polyethylene, polyvinyl chloride)
- **Thermosets:** Have a high cross-link structure. (e.g., epoxy resin, phenolic, polyester resins)

2. Fiber Classification:

- **Natural Fiber:** Derived from plant or animal sources.
- **Synthetic Fiber:** Man-made fibers such as glass or carbon fibers.

Commonly Used Natural Fibers:

- **Flax, Kenaf, Hemp Fibers:** Widely used for their availability and superior mechanical properties.

Classification Scheme:

- *Matrix Types:* Thermoplastics and Thermosets
- *Fiber Types:* Natural and Synthetic

This classification scheme allows for a systematic categorization of natural fiber-reinforced composites based on both the matrix and fiber types. The choice between

thermoplastics and thermosets, as well as the selection of specific fibers, depends on the desired properties and intended applications of the composite material.

Examples of Fibers:

1. Natural Fibers:

- Jute
- Sea Salt Coir

2. Synthetic Fibers:

- Glass Fiber
- Kevlar
- Nylon

Advantages of Natural Fiber-Reinforced Polymer Composites:

1. **Sustainability:** Natural fibers can substitute synthetic materials, promoting sustainability.
2. **Non-toxic Nature:** Natural fibers are non-toxic, making them safer for certain applications.
3. **Excellent Performance:** Natural fiber composites offer excellent performance in various conditions.
4. **Adaptability:** Natural fibers can adapt to different applications and industries.
5. **Low Processing Cost:** Manufacturing natural fiber composites often incurs lower processing costs.
6. **Non-irritating:** They are non-irritating to the respiratory system and skin.
7. **Corrosion Resistance:** Natural fibers exhibit corrosion resistance.

Energy Consumption Considerations:

- **Synthetic Fiber Production:** Involves higher energy consumption (e.g., glass fibers, nylons).
- **Natural Fiber Production:** Generally involves lower energy consumption.

Eco-friendly and Recycling:

- **Eco-friendly Manufacturing:** Natural fiber-reinforced composites contribute to eco-friendly manufacturing.
- **Recycling Process:** Offers potential for recycling, aligning with eco-friendly practices.

Applications of Natural Fiber-Reinforced Composites:

1. **Electronic Industries**
2. **Aerospace Industries**
3. **Sports Equipment**
4. **Regeneration Equipment**
5. **Boards and Machinery**
6. **Workplace Production**
7. **Automotive Industries**
8. **Structural Components**
9. **Packaging Industries**
10. **Construction Sectors**

The wide range of applications showcases the versatility and potential of natural fiber-reinforced polymer composites across various industries, emphasizing their eco-friendly attributes and performance benefits.

Applications in Electrical, Aviation, and Electronic Industries:

Electrical Industries:

- **Insulators:** Jute-reinforced epoxy composites are used as insulators in electrical equipment due to their high dielectric strength.
- **Cable Spacers:** Kenaf-reinforced composites find applications as cable spacers.

Electronic Industries:

- **Electrical Panels:** Banana fiber-reinforced composites are utilized in electrical panels.

- **Circuit Boards:** Pineapple leaf fiber-reinforced composites are employed for circuit boards.
- **Packaging Material:** Natural fiber-reinforced composites serve as packaging material for electronic components due to their low coefficient of thermal expansion and good thermal stability.
 - Example: Coconut fiber-reinforced composites used as packaging material for electronic components.

Aviation Industry:

- **Aircraft Components:** Natural fiber-reinforced composites are increasingly used in the aviation industry for lightweight and high-strength aircraft components.
- **Examples:**
 - Flax-reinforced epoxy composites used for the internal structure of Airbus A380.
 - Cans of reinforced composites used in the wings of Boeing 787 Dreamliner.
 - Fiber-reinforced composites for aircraft engines.
 - C-sulfide-reinforced composites for aircraft interior panels.

Electronic Devices:

- **Laptop Casing:** Jute fiber-reinforced composites are used for laptop casing.
- **Mobile Phone Casing:** Bamboo fiber-reinforced composites find applications in mobile phone casing.

The applications demonstrate the versatility of natural fiber-reinforced polymer composites in enhancing the performance and sustainability of materials used in electrical, aviation, and electronic industries. These composites offer lightweight, high-strength alternatives with specific advantages in various applications.

Hemp Fibers: China, Canada, and the USA are major producers of hemp fibers, widely utilized in construction industries, textile products, and paper packaging. They find applications in home furnishing, electrical equipment, pipe manufacturing, and insulation materials due to their robust properties.

Jute Fibers: India, Bangladesh, and China are primary producers of jute fibers. These fibers are extensively used in building instrumental panels, roof interior coating, door supports, transport and packaging industries, geotextiles, chipboards, and structural support for agricultural seeding.

Flax Fibers: China, Italy, and Tunisia are major producers of flax fibers. These fibers are employed in diverse applications such as window framework, decking, bicycle frames, snowboarding, green wall panels, and specialized papers, showcasing their versatility.

Coir Fibers: India, Sri Lanka, and Indonesia are leading producers of coir fibers. These fibers find applications in ropes, carpets, brushes, mattresses, geotextiles, horticulture products, building panels, and storage tanks due to their strength and resistance to various elements.

Cotton Fibers: India, China, and the USA are major cotton fiber producers. With applications in the furniture industry, textiles, yarn goods, apparel, home furnishings, and specialty papers, cotton fibers are valued for their absorbency and versatility.

Kenaf Fibers: India, China, and Malaysia are significant producers of kenaf fibers. These fibers are used in packaging materials, mobile phone cases, bags, insulation, clothing, and absorbent materials, showcasing their adaptability.

Sisal Fiber: Brazil, Tanzania, and Kenya are major sisal fiber producers. These fibers play a crucial role in construction industries, used in panels, doors, shutters, rooftops, home furnishing, packaging, and paper and pulp manufacturing.

China, Brazil, and India are major producers of ramie fibers. Their applications span industrial sewing threads, packing materials, fishing nets, filter cloths, household fabrics, furnishing, clothing, paper manufacturing, and textile fabrics, showcasing their versatility.

Electrical Applications: Natural fiber-reinforced composites play a significant role in electrical applications. They are used in electrical insulation components, such as switch gears and panels. Flax or jute fiber-reinforced composites, known for their high dielectric strength, serve as insulating materials. Additionally, these composites find use in electrical connectors and terminals due to their good electrical conductivity, with hemp fiber-reinforced composites being employed in electrical conductors.

Aviation Applications: In the aviation industry, natural fiber-reinforced composites contribute to weight reduction in aircraft interior components. Notably, flax-reinforced composites are utilized in aircraft panels and cabin interiors. Beyond structural elements, these composites are applied to non-structural aircraft components like seat backs,

overhead bins, and laboratory modules. They offer weight savings and enhanced sustainability compared to conventional materials.

These applications underscore the versatility and eco-friendly characteristics of natural fiber-reinforced composites in diverse industrial sectors.

Insulating Materials: Natural fiber-reinforced composites, including flax, hemp, or jute fiber-reinforced composites, serve as insulating materials in electrical applications. These composites exhibit desirable properties such as good electrical insulation, high dielectric strength, and thermal stability. Their applications encompass switch gears, electrical panels, and power distribution systems.

Circuit Boards: Natural fiber-reinforced composites are employed in the manufacturing of circuit boards, serving as printed circuit board substrates. These composites, incorporating fibers like bamboo, sea cells, and can of, offer benefits such as low dielectric constant, excellent thermal stability, and dimensional stability, making them suitable for PCB applications.

Enclosures and Housings: In electronic devices, natural fiber-reinforced composites find use in enclosures and housings. The lightweight characteristics of natural fibers combined with a polymer matrix contribute to both structural integrity and protection. Composites derived from bamboo, kenaf, and coconut fiber can be utilized for casing laptops, mobile phones, and various electronic devices.

Connectors and Terminals: Natural fiber-reinforced composites play a role in connectors and terminals within electrical applications. Fibers like hemp, sea cell, and flax, reinforced with an appropriate polymer matrix, offer a combination of mechanical strength and electrical conductivity. These composites present an eco-friendly alternative to traditional metal connectors.

Electromagnetic Interference: Natural fiber-reinforced composites are also applicable in addressing electromagnetic interference (EMI) and radio frequency interference (RFI) concerns. Their properties make them suitable for mitigating interference issues in electronic systems.

Shielding Applications: Natural fiber-reinforced composites (NFRCs), when enhanced with conductive additives or coatings like carbon nanotubes or metal particles, can effectively exhibit shielding properties. This makes them suitable for applications in electronic devices that require protection against electromagnetic interference (EMI) or radio frequency interference (RFI). The incorporation of such additives showcases the versatility of NFRCs in meeting specific industry needs.

Considerations and Challenges: While NFRCs offer various advantages, including lightweight construction, good electrical insulation, thermal stability, and cost-effectiveness, there are noteworthy challenges associated with their use. One significant challenge is the weak interfacial bonding between natural fibers and the polymer matrix. To address this issue, surface modification of fibers is often necessary to enhance the bonding between the two components.

Durability Concerns: Natural fibers have inherent limitations, as they are not as durable or long-lasting as synthetic fibers. They are more susceptible to environmental conditions such as moisture and temperature variations. These factors can impact the overall performance and lifespan of NFRCs, especially in applications where robustness is crucial.

Mechanical Strength: Another consideration is the mechanical strength of natural fibers, which tends to be lower compared to synthetic fibers. This difference in strength can influence the overall structural integrity and load-bearing capabilities of composites made with natural fibers.

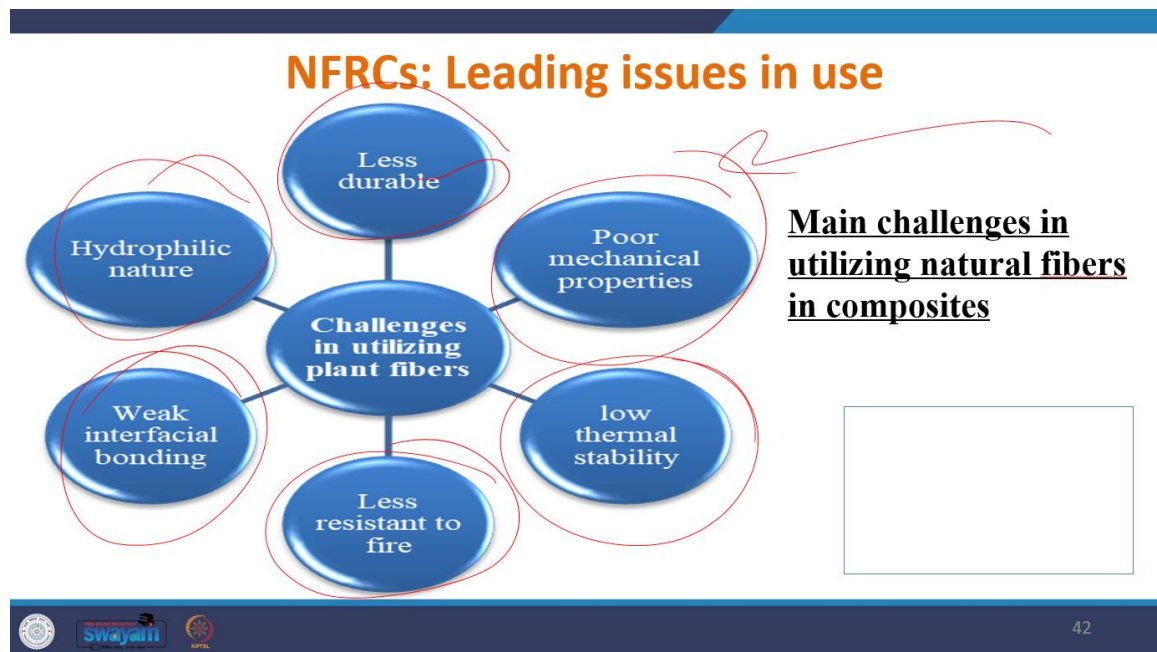
Hydrophilic Nature: Natural fibers are known for their hydrophilic nature, meaning they have an affinity for water. This characteristic can lead to issues in applications where exposure to moisture is a concern. Managing and mitigating the hydrophilic nature of natural fibers is essential to maintaining the desired properties of NFRCs in various environments.

In conclusion, while NFRCs offer numerous advantages, addressing these challenges is crucial to ensuring their successful and reliable application in different industries. Thorough testing, validation, and adaptation of natural fiber-reinforced composites based on specific application requirements are essential steps in overcoming these challenges.

Challenges in Utilizing Natural Fiber:

1. **Low Thermal Stability:** Natural fibers exhibit low thermal stability, making them susceptible to heat-related degradation. This limitation can impact their performance in applications that involve high temperatures.
2. **Limited Fire Resistance:** Natural fibers are generally less resistant to fire compared to synthetic counterparts. Their combustion properties can pose challenges in applications where fire resistance is a critical factor.
3. **Weakness and Mechanical Properties:** Inherent weaknesses in natural fibers contribute to their lower mechanical strength compared to synthetic fibers. This weakness can affect the overall structural integrity of composites.

4. **Weak Interfacial Bonding:** Achieving strong interfacial bonding between natural fibers and the polymer matrix can be challenging. Weak bonding can lead to reduced composite strength and durability.
5. **Hydrophilic Nature:** Natural fibers tend to be hydrophilic, meaning they readily absorb moisture from the environment. This characteristic can result in dimensional changes and affect the material's properties.
6. **Limited Durability:** Natural fibers are generally less durable than synthetic alternatives. Their susceptibility to environmental conditions and biological degradation can impact the longevity of composite materials.
7. **Poor Mechanical Properties:** The mechanical properties of natural fibers may not meet the requirements of certain applications, limiting their suitability in scenarios demanding high mechanical performance.



Natural Degradation:

Biodegradation: Natural fibers undergo biodegradation in the presence of microorganisms, bacteria, or fungi. Enzymatic reactions, particularly with hemicellulose, can weaken the interfacial bonding, leading to a reduction in the strength of the polymer composite.

Biological Conditions: Oxidation and reduction reactions occur as part of the biological degradation process. This can further contribute to the breakdown of natural fibers in environmental conditions.

Water Degradation: Water absorption is a significant concern for natural fiber-reinforced composites. Exposure to moisture from sources like ice, dew, or ocean environments can lead to dimensional changes and affect the material's properties.

Addressing these challenges requires thorough research, innovation, and possibly incorporating protective measures or modifications to enhance the performance of natural fiber-reinforced composites in diverse applications.

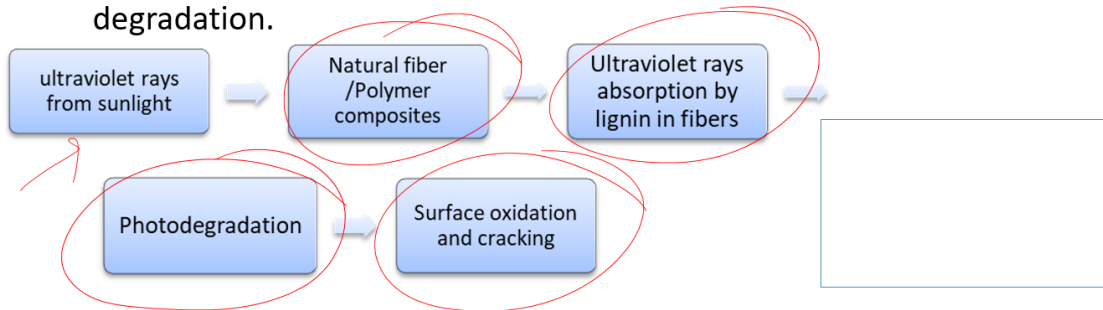
Moisture Absorption and Dimensional Changes: Hemicellulose, a major component of natural fibers, is prone to moisture absorption. This leads to swelling and contraction of fibers, causing cracking and deformation in natural fiber composites. Moisture absorption can weaken the mechanical strength as it interacts with the hydroxyl groups of the fibers.

UV Degradation: Exposure to ultraviolet (UV) radiation from sunlight can result in the degradation of natural fibers in composites. The lignin content in the fibers is particularly susceptible to UV degradation, leading to surface oxidation, in situ cracking, and overall degradation of mechanical properties.

NFRCs: Leading issues in use

UV degradation:

- When natural fiber composites are exposed to the outdoor environment, fiber starts to degrade because of ultraviolet radiation (UV). The lignin present in natural fiber is responsible for UV degradation.



Mechanical Degradation: Environmental factors such as wind, dirt, ice, and other stressors contribute to the mechanical degradation of natural fiber composites. This can lead to stress, fractures, cracks, and abrasion, negatively impacting the overall durability of the material.

Fire Degradation and Limited Fire Resistance: Natural fiber polymer composites often exhibit poor resistance to fire. The pyrolysis process, oxidation, and hydrolysis

contribute to fire degradation. Enhancing fire resistance is crucial to expanding the application of these composites.

Thermal Degradation: The thermal degradation of natural fibers occurs in stages, involving processes such as pyrolysis, oxidation, and hydrolysis. Understanding and managing these thermal degradation stages are essential for maintaining the integrity of the composite material.

Thermal Degradation and Operating Temperatures: The thermal degradation of natural fibers occurs in stages, with the first stage starting around 220 to 280 degrees Celsius and the second stage around 280 to 300 degrees Celsius. Ensuring thermal stability is essential, especially in applications with high operating temperatures, to prevent fire degradation and loss of mechanical properties.

Electrical Conductivity: Natural fibers typically have low or non-conductive properties. In applications requiring electrical conductivity, such as connectors or electromagnetic interference (EMI) shielding, additional measures like incorporating conductive fillers or coatings are necessary to enhance electrical properties.

Compatibility with Polymer Matrix: Ensuring compatibility between the natural fiber and polymer matrix is crucial for achieving proper bonding and optimal mechanical properties. Surface treatments or coupling agents can be employed to enhance interfacial adhesion, improving overall composite performance.

Standardization and Quality Control: The absence of standardized testing methods and quality control protocols for natural fiber-reinforced composites in electrical and electronics applications poses challenges. Establishing industry standards and testing procedures is essential for ensuring consistent and reliable performance.

Variability in Fiber Properties: Natural fibers derived from plants and other sources inherently exhibit variability in properties such as strength, length, diameter, and moisture content. Managing this variability is important for maintaining the uniformity and reliability of natural fiber-reinforced composites.

Variability Impact on Consistency: The inherent variability in properties of natural fibers can impact the consistency and predictability of composite materials. Implementing quality control measures, including meticulous fiber selection and appropriate blending techniques, is crucial to address and manage this variability.

Durability and Longevity: Ensuring the long-term durability and resistance of natural fiber composites to environmental factors such as UV radiation, temperature fluctuations, and chemical exposure is essential. Strategies such as proper protection,

coating, and encapsulation can contribute to enhancing the durability and longevity of composite materials.

In conclusion, the challenges associated with natural fiber-reinforced composites involve a comprehensive consideration of factors ranging from material properties and compatibility to durability and standardization. Adhering to quality control measures and employing protective strategies are key components in addressing these challenges and optimizing the performance of these composites. The broad applications of natural fiber-reinforced composites make them a subject of continuous research and development. If you seek further knowledge on this topic, additional references have been provided for your convenience. Thank you for your attention.