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A Dispersed Phase Reinforcement-Based Composite Classification System

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ABSTRACT:

The composite material is characterized to evaluate its mechanical, thermal, and morphological properties. Mechanical tests assess its strength, stiffness, and toughness through tensile, flexural, and impact tests. Thermal analysis techniques like DSC and TGA study its thermal behaviour and stability. Morphological characterization using SEM examines the dispersion and interfacial bonding of banana fibers, nano SiO2 particles, and the polymer matrix. Results show that incorporating these components significantly enhances the composite's mechanical properties, including tensile strength, flexural strength, and impact resistance. The composite also exhibits improved thermal stability, making it suitable for high-temperature applications. Morphological analysis reveals good fiber-matrix adhesion and uniform nanoparticle dispersion in the polymer matrix.

Keywords: Growing Demand, Sustainable Materials, Natural Fibers, Nanoparticles, SiO2, Chemical Treatments.

1. Introduction

The history of composite materials extends back to ancient civilizations such as the Egyptians, Mesopotamians, and Mongols, and continues to the present day with the development of various modern composite materials for diverse applications. Alongside significant milestones in human progress, such as the discovery of fire, the invention of the wheel, and the production of yarns, the utilization of flexible fabrics made from locally grown fibers like cotton and jute marked a significant advancement over animal skins. The advent of plastics marked a new era in composites, replacing natural resins derived from plants and animals, which had previously served as the primary source of adhesives and binders.

Time Period	Civilizations	Application	Materials
3400 BC	Mesopotamia	Plywood	Glued wood strips
2100 BC	Egypt	Death Masks	Cartonnage and layers of linen
2055 BC	Egypt	Containers	Coarse Fiber
1500 BC	Mesopotamia & Egypt	Construction Materials	Straw Bricks, Pottery, Boats
1500 BC	Egypt	Writing Material	Papyrus Plants
1200 AD	Mongols	Bow	Wood, Horn, Leather, Bamboo, Sinew, etc.

Table 1- History of Composite Materials

The timeline of composite material applications is presented in Table 1, showcasing the evolution of these materials over time. The emergence of modern polymer composites can be traced back to the first half of the 20th century. The backdrop of World War II, with its imposed restrictions on international boundaries and limited availability of materials for military applications, led to a pressing need for lightweight and strong materials, particularly for fighter planes. The demand for nonmetallic materials, such as those used in the housing of electronic radar, further drove the adoption of composites. The first notable application of composites was seen in the British Royal Air Force's use of Glass Fiber Reinforced Plastics (GFRP), specifically Phenolic resin reinforced with GFRP, in the Havilland Mosquito Bomber. This marked a significant milestone in the utilization of laminated composites for military purposes. A composite material is characterized by its composition of two or more materials at a microscopic level, forming distinct chemically dissimilar phases. This heterogeneity is observed at a microscopic scale, while at a macroscopic scale, the composite material appears statistically homogeneous. It is important to note the distinction between composites and alloys or metals with impurities. In alloys, it is not possible to visually identify the individual constituents within the material cross-section. However, in composites, both the components and the interfaces between them can be physically discerned. As per the ASTM D3878 standard, a composite is defined as a single substance composed of two or more materials that are insoluble and collectively form an engineering material.

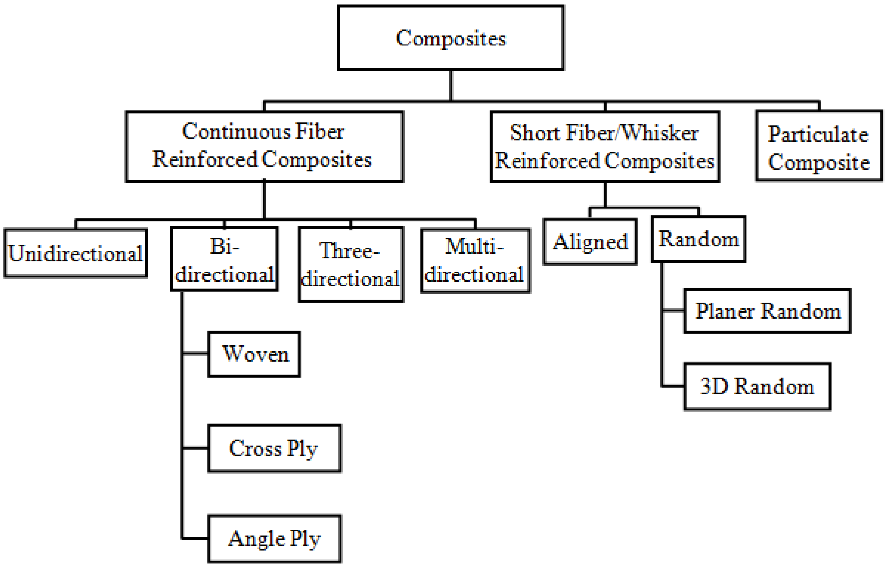

Figure 1- Composite Classification based on Dispersed Phase Reinforcement

Reinforcement Natural Fibers

Reinforcement in composite materials refers to the dispersed phase that is embedded within the continuous phase. These reinforcements can take various forms such as fibers, fabric particles, or whiskers. Fibers, including woven sheets or flakes, are characterized by a long axis and are preferred due to their strength and stiffness. Particles, on the other hand, lack preferred orientation and shape, making them suitable for cost reduction purposes. Whiskers, although having a preferred shape, are small in both diameter and length compared to fibers. Within the matrix, these reinforcements are randomly arranged, contributing to the macroscopic isotropic behavior of the composite material.

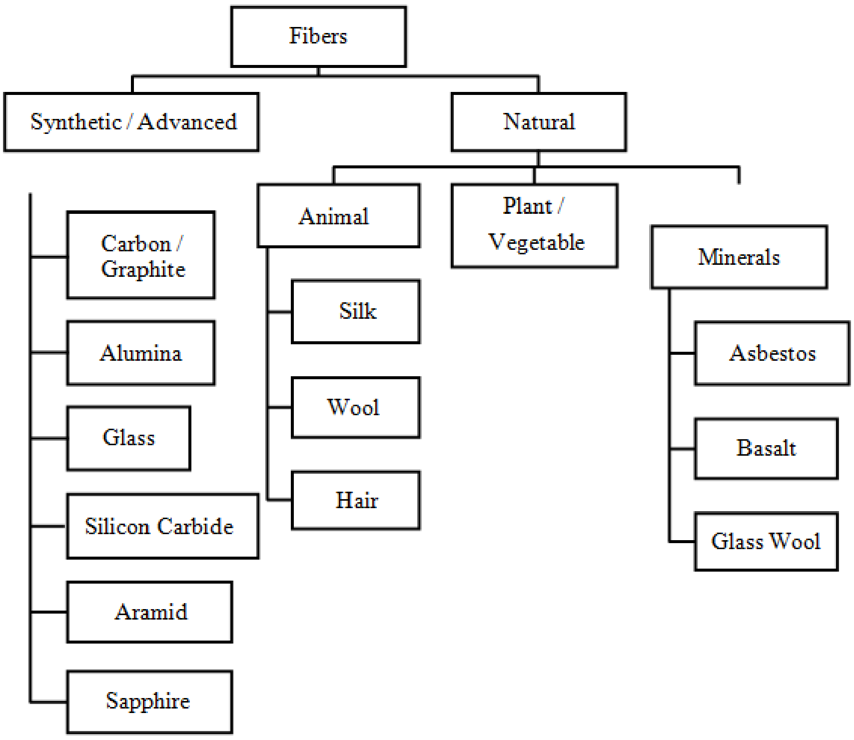

Figure 2- Classification of Dispersed Phase Reinforcement

Fibers play a crucial role as the primary constituents in fiber reinforced composite materials. They occupy the largest volume fraction within the composite and bear the majority of the load applied to the structure. The selection of the fiber type, fiber volume fraction, fiber length, and fiber orientation is of utmost importance as they directly impact key characteristics such as density, tensile strength, compressive strength, flexural strength, modulus, fatigue strength, electrical conductivity, thermal conductivity, and cost. Therefore, careful consideration and optimization of these parameters are essential for achieving desired material properties and overall performance of the composite.

Matrix Biopolymers

The most predominant ingredient of a composite called as a matrix that can be made by polymer, metal, or can be made out of ceramic. Here, the investigation is carried out with polymer matrix keeping in focus. The polymer can be classified into two major types, one is plastic and others are elastomers. Detailed classification of engineering polymer is shown in Figure 3. The matrix plays a major role in the satisfying performance of the composite structure. The matrix material holds the fiber together and deforms and distributes the stress to the reinforcement under an applied load. It also provides rigidity and shape to the structure. The matrix isolates the fibers and keeps the fibers at desired positions so that individual fibers can acts separately which stops or slows the propagation of a crack and mechanical abrasion between them does not occur. The matrix provides a better surface finish quality and aids in the production of net shape part. It also protects the fibers from the environmental effects. The matrix materials improve such properties as transverse strength and impact resistance. Thermo-set materials are having qualities such as a well-bonded three-dimensional molecular structure after curing and decay instead of melting on hardening. They can be retained in a partially cured condition over extended periods and it also takes longer curing time. Due to this reason, thermosets like epoxy and phenolic polyamide are most preferable for advanced chopped fiber reinforced composites applications.

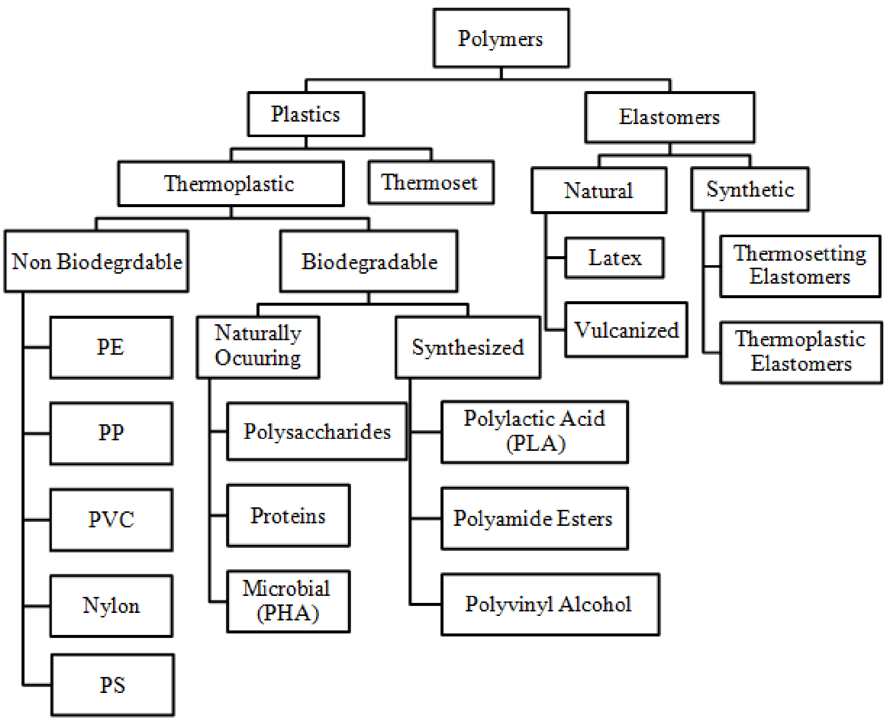

Figure 3- Classification of Engineering Polymers

Thermoset resins are having low viscosity so composite processing is much easier. Processing of thermoset requires low pressure and temperature but takes long curing time. It has very good strength and modulus but have low tensile elongations. Repair and recycling of thermoset polymer based composites are very difficult. Some of the widely used thermosets are polyester, epoxy, polyimide, Phenol-Formaldehyde (PF), etc. Thermoplastics have one or two-dimensional molecular structure which tends to at an elevated temperature and shows the inflated melting point. Nowadays the experiments have been done to improve the base properties of the matrix and get the utmost advantages from them.

Manufacturing of Polymer Composites

The selection of the fabrication process for composites is decided based on the type of matrix used and material structure. The summary of fabrication processes for any kind of composite material is shown in Figure 4. A metal matrix composite (MMC) is a material that contains a minimum of two constituents, one being metal and another may be other material (like ceramic and organic compound), metal, or alloy. In MMC, Alumina, Silicon Carbide, Titanium Nitride, Zirconium areused as reinforcement which can be in the form of particles, whiskers, long fibers, or sheets laminates and Steel, Magnesium, Titanium, Copper, Aluminum can be used as matrix material. The MMC can be produced by various methods and the selection is based on the desired quantity and distribution of both the phases and its applications. Ceramic matrix composites (CMC) are materials in which one or more distinct ceramic phases are intentionally added to another, to enhance the property that is not possessed by the monolithic ceramic materials. In CMC, a given ceramic matrix is reinforced with either discontinuous reinforcement such as particles, whiskers / chopped fibers, or continuous fibers. The basic reinforcement which is including in the ceramic matrices is carbon, glasses, oxides, etc.

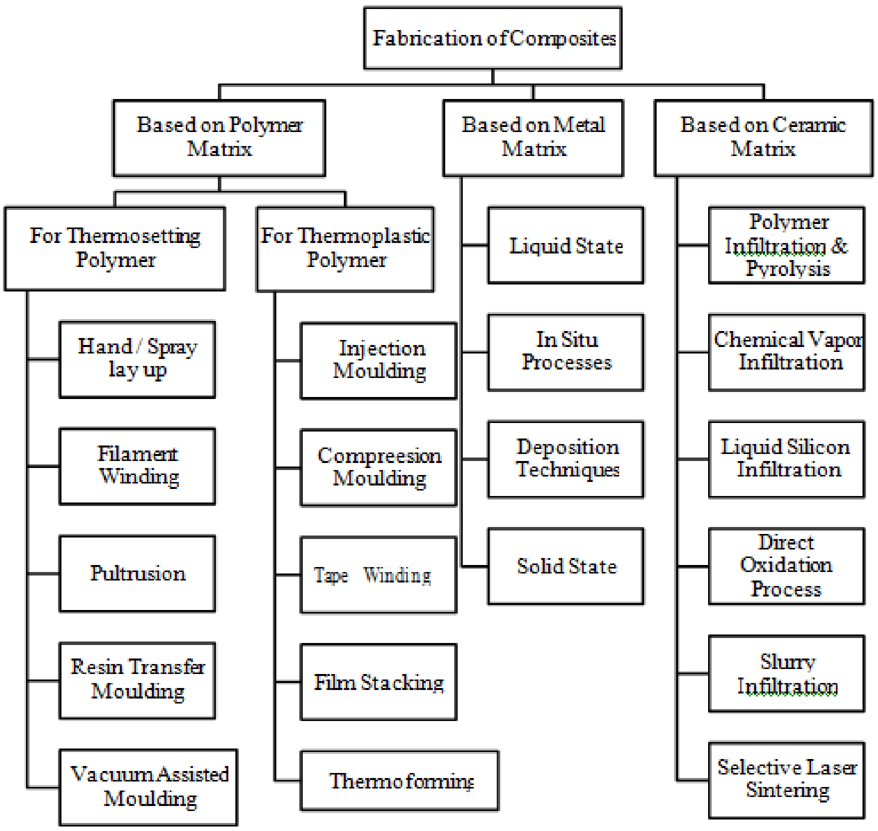

Figure 4- Different Fabrication Processes of Composites

The polymer matrix composites (PMC) can be categorized according to the type of matrix used like thermoset matrix and thermoplastic matrix which uses synthetic or natural fiber as reinforcement. With a focus on the polymer matrix composites, all the fabrication process for thermosetting and thermoplastics composites are briefly explained in the following subsections.

1. **Thermoset Composites**- Thermoset composites are fabricated either using wet forming processes or processes which used premixes or prepregs. In wet forming processes, liquidus resin is used while forming the final product. The resin gets cured in the product which may be aided by the application of external heat and pressure. In other processes, which use premix/prepregs forms those are pre- fabricated material like bulk molding compounds and sheet molding compounds that are in semi-cured form are used to provide the shape to the final product .
2. **Thermoplastic Composites**- Thermoplastic matrix composites may either have long continuous fibers or short fibers. The fabrication process for both the types of composites is considerably different. The raw material for short fiber reinforced thermoplastic composites comes in pellets. These pellets have short fibers embedded in the matrix material. Process parameters of short fiber reinforced thermoplastics like thermal conductivity, tool wear, rheological and shrinkage properties are considerably diverse than plain thermoplastics.

Optimization of Natural Fiber Reinforced Composites

Optimization of various mechanical and thermal properties, fabrication parameters, process parameters, design parameters can be evaluated by different optimization processes each having their characteristics, advantages, and limitations. The imperialist Competitive Algorithm (ICA) is an evolutionary algorithm used to model the mechanical properties and presents a cultural evolutionary process to solve the various optimization problems. Few others of these are explained in the following section. The main objective of this investigation is to evaluate the best possible combination of processparameters like fiber length and wt% to enhance the mechanical properties using the Taguchi method and utility concept. As it is a multi-objective optimization problem utility concept has been used along with the Taguchi method. These two theories can be used to evaluate the optimal combination of the process parameters and results obtained have been validated by confirmation tests. In this study, control factors such as aspect ratio, volume fraction, and orientation of fibers were the variables for determining the optimum tensile strengths. Applying Taguchi robust design technique for the greater the better, the highest signal to noiseratio for the quality mechanical properties being investigated was obtained by Minitab 16 software. Thermoplastic starch and clay reinforced nanocomposite were produced by the solution casting method and the influences of four factors (starch source, clay cation, glycerol content, and mixing mode) on the morphology and mechanical properties of nanocomposite were mathematically evaluated using Taguchi experimental method. The tensile strength and modulus of the nanocomposite films were best improved with 6 wt% of citric acid-activated montmorillonite (CMMT) loading.

R. Kumar et al. have investigated and processed epoxy-based wood dust reinforced composite with varying the content of filler and speed. Experiments were conducted based on two design parameters like speed and filler content. Optimization of load and mechanical test parameters were done through the Taguchi method and concluded by ANOVA. This analysisis used to get the most significant factor like speed is for tensile and filler content for flexural properties. V. Prasad et al. have analyzed the characterization of general-purpose resin and cashew nut shell resin based banana and jute fiber reinforced hybrid composites. The hybrid polymer matrix composite with different variations of CNSL and general-purpose resin matrix is obtained whose tensile properties are calculated at various combinations and the best results are obtained using the ANOVA technique. This hybrid composite can replace many synthetic resin composites considering its recyclability and cost concerns.

3. Conclusion

The Alkaline treatment has two effects on fibers: (1) Increases surface roughness resulting in better mechanical interlocking (2) Increases the amount of cellulose exposed on the fiber surface which increases the number of possible reactions sites. It has been observed form the SEM analysis that cemented materials like wax, pectin, lignin, hemicelluloses are removed from the multicellular fiber wall and individual cells became more prominent which lead to the improvement of the composite mechanical properties. In this experimental study, banana fiber and banana-coir fiber reinforced and corn starch based hybrid green composites have been developed by the injection moulding process. Composite made by injection moulding gives good interferential bonding between reinforcement and matrix.

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