

COMPOSITE AS BIOMATERIALS: VERSATILE APPLICATIONS

Abstract

Composites, as biomaterials, refer to engineered materials specifically designed for medical and healthcare applications. These composite materials are composed of two or more distinct components, each with its own unique properties, combined to create a new material with desirable characteristics for biomedical use. The components of these composites work synergistically to achieve superior mechanical, biological, or functional properties compared to the individual components alone. Composites are chosen based on their biocompatibility, mechanical strength, degradation behavior (if applicable), and their ability to interact favorably with the human body. The combination of different materials allows for tailoring of specific properties, making these composites highly versatile and suitable for a wide range of medical applications. Composite biomaterials have significantly advanced medical technology and have been instrumental in various medical applications, including implants, prosthetics, drug delivery, tissue regeneration, and diagnostic tools. Their ability to mimic or enhance the properties of natural tissues makes them essential for improving patient outcomes and overall healthcare. As research and development continue, composite biomaterials are expected to play an increasingly vital role in addressing complex medical challenges and improving the quality of life for patients worldwide.

Keywords: Biocomposites, Matrix, Reinforcement, Orthopedics, Cancer, Drug delivery systems.

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I. INTRODUCTION

Composites are a significant class of materials made by combining two or more distinct materials with significantly different physical or chemical properties. The resulting material exhibits enhanced properties that often exceed those of its individual components. Composites are widely used in various industries due to their unique combination of strength, durability and versatility. A composite is a substance formed by combining two or more distinct elements, each of which retains its distinct properties within the resulting element. Composites are engineered to harness the strengths of different materials, creating a synergistic combination that offers enhanced properties or functionalities that cannot be achieved by any of the individual components alone.

The word “composite” means combination on a microscopic scale, of two or more material; they are different for many factors like morphology, physical properties and combination. The term “composite” is generally reserved for those materials in which individual phases are separated on a scale larger than the atomic and whose properties, such as elastic modulus, vary significantly compared to a homogeneous material. Composites are widely used in various industries, such as aerospace, automotive, construction, sports equipment and electronics. They allow engineers to optimize materials for specific applications, addressing a wide range of requirements. The choice of matrix, reinforcement, their proportions and the manufacturing process all affect the final properties of the composite material.

The design of composite biomaterials involves careful consideration of matrix and reinforcement materials, their interactions, mechanical properties, biocompatibility and bioactivity. Composite biomaterials refer to a special class of materials that combine multiple components with the goal of creating materials that can be effectively used in medical and healthcare applications. These materials are designed to integrate the advantages of different materials to achieve properties that meet the specific needs of biological systems while ensuring biocompatibility and functionality. Composite biomaterials represent a remarkable convergence of science, engineering, and medicine, which has immense potential to transform the healthcare and medical technology landscape. By intelligently combining different materials at different scales, composite biomaterials provide tailored solutions that bridge the gap between human biology and technological innovation. These materials are not just a scientific achievement; they are a testament to human ingenuity and relentless pursuit to improve life. The ability to combine individual components to create materials with enhanced mechanical, biological and functional properties has revolutionized fields such as tissue engineering, regenerative medicine, medical devices and drug delivery systems. Composite biomaterials are versatile architects of healing and advancement. They can stimulate tissue regeneration, provide mechanical support to damaged structures, deliver therapeutic agents with precision, and seamlessly integrate with the human body. In the form of bone scaffolds that direct the growth of new tissue or nanoparticles that navigate complex physiological pathways, composite biomaterials embody the harmony between innovation and biology.

However, the journey to composite biomaterials is not without its challenges. Balancing biocompatibility, mechanical integrity, degradation rate and bioactivity requires careful orchestration. Collaboration among materials scientists, biomedical engineers,

clinicians, and regulatory experts is essential to navigating this complex terrain. As we stand at the forefront of medical innovation, composite biomaterials open the door to unknown possibilities. Their evolution is ongoing, fueled by the search for ingredients that blend seamlessly with the human body, enhancing well-being and quality of life. The intersection of biology and the physical sciences has ushered in a new era of healing, where the boundaries of medical capabilities continue to expand.

Table 1: Mechanical Property of Hard Tissues

Hard Tissue	Modulus (GPa)	Tensile Strength (MPa)
Cortical bone(longitudinal direction)	17.7	133
Cortical bone (Transverse direction)	12.8	52
Cancellous bone	0.4	7.4
Enamel	84.3	10
Dentine	11.0	39.3

Table 2: Mechanical Properties of Soft Tissues

Soft Tissue	Modulus (GPa)	Tensile strength (MPa)
Articular Cartilage	10.5	27.5
Fibrocartilage	159.1	10.4
Ligament	303.1	29.5
Tendon	401.5	46.5
Skin	0.1-0.2	7.6
Arterial Tissue (longitudinal direction)	10.5	0.1
Arterial Tissue (transverse direction)	159.1	1.1

As an example, modern composites like metals or plastics reinforced with glass fibers or CFs find extensive applications in the automobile and aircraft industries. These composites exhibit favorable mechanical properties while maintaining a lighter weight compared to traditional metals or plastics. Their strength and stiffness can be adjusted by altering the ratio of reinforcement to matrix. Given their distinctive characteristics, composite materials offer notable advantages in various biomedical applications. The human body is a complex system characterized by diverse compositions, structures, and functions. Tissues can generally be categorized into hard tissues (such as bone and teeth) and soft tissues (like skin, cartilage, and blood vessels), each possessing distinct mechanical properties (refer to Table 1 and Table 2). Consequently, metallic and ceramic biomaterials with relatively high stiffness are frequently employed for repairing or replacing hard tissues, while polymers are commonly used for repairing soft tissues. It's worth noting that bone is a natural nanocomposite material, comprising a combination of a resilient yet brittle substance and collagen, a natural polymer. This composite nature contributes to bone's strength and resilience, allowing it to endure significant stresses, carry substantial loads (up to five times the body weight for the hip joint during walking, and over ten times the body weight during jumping), and withstand numerous cycles of motion (around 10^6 motion cycles for a finger and hip joint in a year). Given the high stiffness of metals and ceramics, as well as the brittleness of ceramics, it becomes exceedingly challenging to create bone replacement materials that are mechanically compatible with natural bone using a single type of metallic or ceramic material, if at all

possible. The mechanical mismatch between the implanted material and the natural bone leads to unsatisfactory result such as loosening of implants since bone is remodeled because of high stress caused by the implantation of prosthesis with very high stiffness. According to Wolff's Law, biological tissues such as bone adapt to the mechanical load they experience by remodeling their structure to optimize strength and minimize stress. In composites, the principle of load sharing dictates how mechanical loads are distributed among components with different mechanical properties. The stiff components carry a large portion of the load, while the matrix facilitates stress transfer between components. These principles collectively emphasize the dynamic response of biological tissues and the importance of load distribution in achieving optimal performance and durability in composite materials, particularly in fields such as healthcare and engineering.

Ultra-high molecular weight polyethylene (UHMWPE) is a carbon fiber reinforced composite material that combines the exceptional mechanical properties of UHMWPE with the high strength and stiffness of carbon fiber. This compound provides improved impact resistance, wear performance, and load carrying capacity. In dentistry and prosthesis, UHMWPE-carbon fiber composites can be employed to manufacture lightweight and durable dental prosthetics, and orthodontic devices, which benefit from the improved mechanical properties of the composite while maintaining biocompatibility. These composites have the potential to provide long-lasting solutions to restore dental function and esthetics, especially in cases where the materials have high mechanical demands.

Composites possess distinct properties and typically exhibit greater strength than any of the individual materials comprising them. Professionals in this field have harnessed this advantage and employed it to address challenging issues that require tissue in-growth. These include:

- Deposited Al₂O₃;
- Carbon/ PTFE;
- Al₂O₃/ PTFE;
- PLA-coated Carbon fibers

II. CLASSIFICATIONS OF COMPOSITE

Composites are materials composed of two or more distinct materials with different physical and chemical properties, which are combined to form a new material with improved or unique properties. They are generally classified based on various criteria, such as the nature of the constituent elements, their phase distribution and their intended application. Composites are classified into based on Matrix material: Ceramic matrix composites, Polymer matrix composites, Metal-matrix composites. Alternatively composites are classified based on matrix reinforcement: Fiber reinforcement composites, Particle composite, and Structural composites.

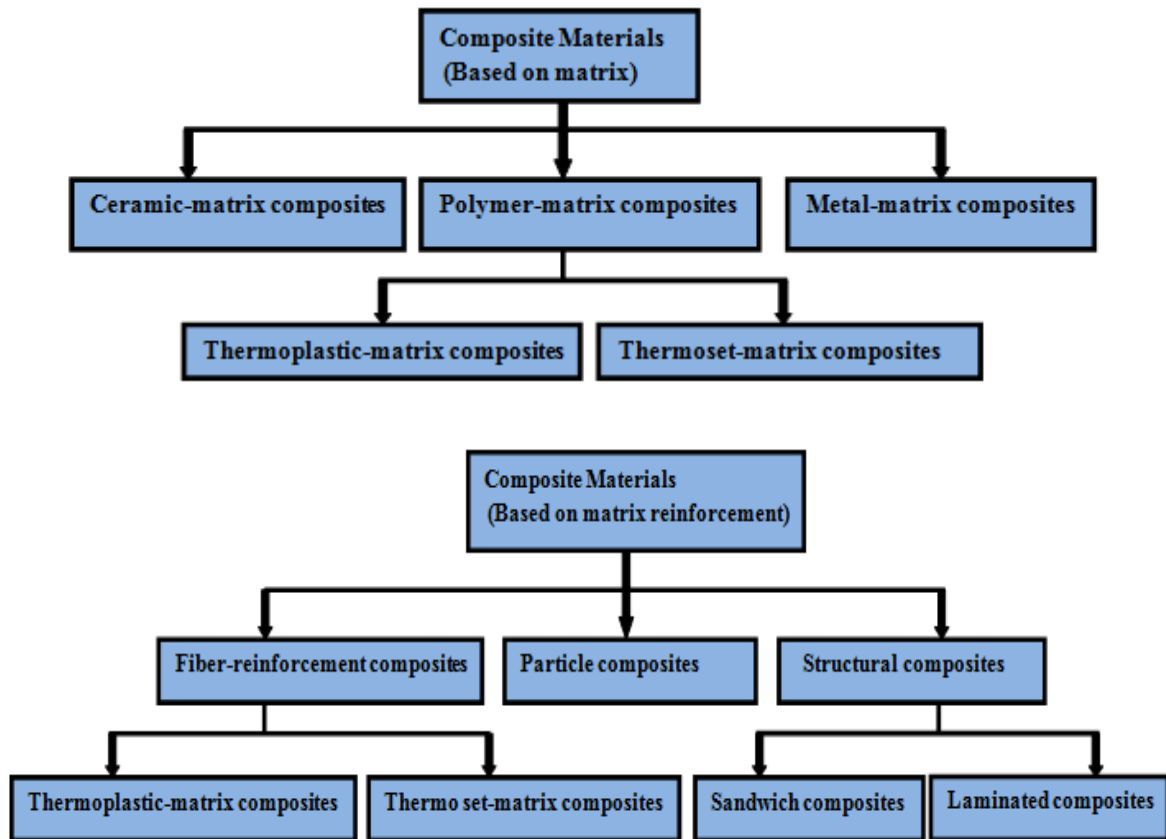


Figure 1: Classifications of Composites

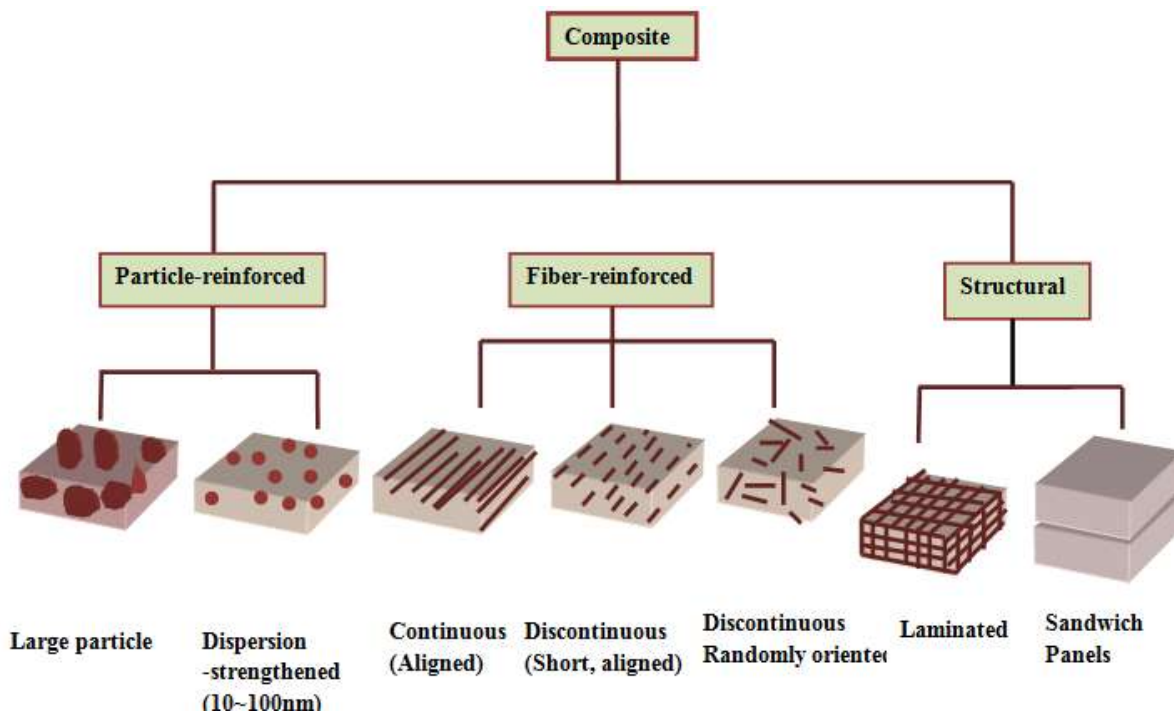


Figure 2: Composite classification according to the geometry of the reinforcement (the second, minor phase)

Based on Matrix materials

1. Ceramic Matrix Composites

- **Bioactive Glass-Ceramics:** These composites combine glass and ceramic phases to create materials that bond to bone and promote tissue regeneration. They are used in bone grafting and dental applications.
- **Ceramic –Polymer Composites:** These composites combine ceramics with polymers to improve mechanical properties while maintaining some flexibility. They can be used in load-bearing implants and dental restorations.

2. Polymer-Matrix Composites

- **Fiber-Reinforced Composites:** These composites combine a polymer matrix with reinforcing fibers (eg, carbon, glass, or aramid fibers). FRPs can be used for bone fixation plates, dental implants and orthopedic implants due to their mechanical properties and biocompatibility.

3. Metal- Matrix Composites

- **Titanium -Based composites:** These composites use titanium as the matrix material and may include ceramic reinforcements. They are used for orthopedic and dental implants due to their biocompatibility and strength.

Biomedical composites can be categorized into three main types: bioinert composites, bioactive composites, and biodegradable composites. Bioinert composites typically consist of two or more chemically distinct bioinert materials. On the other hand, bioactive composites incorporate materials, whether in the form of the matrix or reinforcement, that stimulate specific biological responses for cell functions, exemplified by A-W glass ceramics and other bioactive bioceramics. In the context of biodegradable composites, constitutive materials such as biodegradable polymers (e.g., PLA, PLGA, PCL) and bioceramics (e.g., TCP) that can fully break down within the human body with minimal or no adverse effects are used, resulting in these composites being suitable for the development of next-generation implants.

III. MATRIX, REINFORCEMENT, AND INTERFACE

1. **Polymers:** Polymers are widely used as biomaterials in various medical and biological applications due to their versatility, tunable properties and biocompatibility. Biomaterials are substances that interact with biological systems for therapeutic or diagnostic purposes. Polymers used as biomaterials can be developed for mimicking natural tissue, drug delivery, tissue regeneration, and so on.

Many polymers are engineered to be biocompatible, meaning they can interact with living tissue without causing harmful reactions. This property is crucial for reducing inflammation, rejection and other adverse reactions.

Polymers can be tailored to a wide range of mechanical, chemical and biological properties. This flexibility allows them to match the requirements of various applications, from rigid bone implants to flexible drug delivery systems.

Examples of commonly used polymers as biomaterials include polyethylene glycol (PEG), poly (lactic-co-glycolic acid) (PLGA), polyurethane, polycaprolactone (PCL), and many others. The choice of polymer depends on the specific application requirements, including mechanical properties, degradation rate, and interaction with the surrounding biological environment.

- 2. Metals:** Metals are a class of materials that have been widely used as biomaterials in various medical and biological applications due to their unique combination of mechanical properties, biocompatibility, and corrosion resistance. These properties make metals suitable for implants, devices and tools in biomedical engineering.

Many metals, such as titanium and stainless steel, exhibit excellent biocompatibility, meaning they are well tolerated by the body without causing adverse reactions such as inflammation or rejection. Metals have desirable mechanical properties including high strength, toughness and durability. These properties are essential for load-bearing applications such as orthopedic implants (eg, hip and knee replacements) and dental implants.

The metallic systems most frequently used in the body are:

- Iron-base alloys of the 316L stainless steel
- Titanium and titanium-base alloys, such as
 - Ti-6% Al-4%V, and commercially pure $\geq 98.9\%$
 - Ti-Ni (55% Ni and 45% Ti)
- Cobalt base alloys of four types
 - Cr (27-30%), Mo (5-7%), Ni (2-5%)
 - Cr (19-21%), Ni (9-11%), W (14-16%)
 - Cr (18-22%), Fe (4-6%), Ni (15-25%), W (3-4%)
 - Cr (19-20%), Mo (9-10%), Ni (33-37%)

Among the frequently employed metals for implants are 316L stainless steel, Ti-6% Al-4%V, and Cobalt-based alloys categorized as " π " and " θ ". Researchers are also exploring additional metal systems, including Cobalt-based alloys referred to as " ρ " and " χ ", as well as Niobium and shape memory alloys. Of these, the alloy (Ti 45% -55%Ni) is currently the focus of the most extensive research efforts.

Some metals are used as passive substitutes for hard tissue replacement such as:

- Orthopedic Implants;
- Bone fixation devices;
- Cardiovascular stents;
- Neurological implants;

3. Ceramics: Ceramics are inorganic, nonmetallic, and solid materials. Due the high stiffness and mechanical strength (Table 3) of bulk bioceramics such as (Al_2O_3), make them good candidates for load-bearing medical devices in orthopedics and dentistry. Ceramics are a class of inorganic materials that possess a wide range of properties that make them suitable for a variety of applications, including the biomedical and healthcare fields. When used in the context of biomaterials, ceramics refer to materials designed to interact with living tissues and organisms for medical or therapeutic purposes. Ceramic biomaterials are used in various medical devices, implants and treatments due to their biocompatibility, mechanical properties and other unique properties.

Some Common Applications of Ceramics include

- Dental implants,
- Joint replacements,
- Bioactive scaffolds,
- Wound healing,
- A variety of tissues in growth related applications in
 - Orthopedics
 - Dentistry, and
 - Heart valves.

Ceramics, in certain instances, face limitations due to their typically subpar mechanical attributes, including: (a) tension resistance; (b) brittleness; (c) load-bearing capacity. When it comes to applications like implant devices subject to substantial tensile forces, meticulous design and manufacturing are imperative to ensure the safe utilization of ceramics.

Table 3: Mechanical Property of Ceramics

Ceramics	Modulus (GPa)	Tensile Strength (MPa)
Alumina	380	300
Zirconia	220	820
Bioglass	35	42
HA	95	50

IV. REINFORCEMENTS

1. Particles: Particle reinforcement in the field of biomedical materials involves incorporating solid particles into a matrix material to create composites with improved properties for various medical and healthcare applications. These particle-enhanced biomaterials can offer enhanced mechanical strength, bioactivity, biocompatibility, and other properties that make them suitable for use in medical devices, implants, drug delivery systems, and tissue engineering.

Some common applications of particle reinforcement in the biomedical field

- **Tissue Engineering:** Particle-reinforced scaffolds are used in tissue engineering to provide mechanical support for cell growth and tissue regeneration. Porous scaffolds containing particles such as hydroxyapatite or bio-glass can promote bone tissue regeneration.
- **Diagnostics Devices:** Particle-reinforced materials can be used in diagnostic devices such as biosensors or microfluidic devices to increase sensitivity, stability, and functionality.
- **Implant Coating:** Particulate reinforced coatings can be applied to the surface of medical implants to improve their biocompatibility, wear resistance, and corrosion resistance.

The selection of particle type, size and concentration depends on the intended application and the specific requirements of the biomedical device or treatment. Biocompatibility, toxicity, degradation, and interactions with biological systems must be carefully considered to ensure the safety and efficacy of particle-powered biomaterials.

2. Whiskers and Chopped Fibers: Whiskers and chopped fibers are types of reinforcements used in composite materials to improve their mechanical properties. They are usually incorporated into a matrix material to produce composites with improved strength, stiffness and other desired properties. Both whisker and chopped fibers offer unique advantages based on their form and application.

- **Whiskers:** Whiskers are single-crystal fibers with a very high aspect ratio (length-to-diameter ratio). They are extremely strong and hard due to their crystallographic structure. Whiskers are often made from materials such as silicon carbide (SiC) or aluminum oxide (Al₂O₃).
 - **Aspect Ratio:** The high aspect ratio of whisker contributes to their exceptional mechanical properties. This shape allows for efficient load transfer and reinforcement within the matrix.
 - **Applications:** Whiskers are used in high-performance composites, especially in applications where exceptional mechanical properties are required. They are commonly used in aerospace and advanced engineering fields.
- **Chopped Fibers:** Chopped fibers are short fibers usually a few millimeters in length. They are often randomly oriented within the matrix. Chopped fibers can be made from a variety of materials, including glass, carbon, aramid (Kevlar), and natural fibers.
 - **Dispersion:** Chopped fibers are easier to diffuse into the matrix than long continuous fibers. They can be uniformly distributed to improve mechanical properties.

- **Reinforcement:** Although chopped fibers have a lower aspect ratio than whisker or continuous fibers, they still offer superior strength, stiffness, and impact resistance to composites.
- **Applications:** Chopped fiber-reinforced composites find applications in a wide range of industries, including automotive, consumer goods, construction, and marine equipment. They are often used when improved properties are required without the complexity of continuous fiber reinforcement.

Both whisker and chopped fibers offer benefits based on their specific properties and application. Whiskers excel in providing exceptional mechanical properties in high-performance applications, while chopped fibers offer improved properties and ease of processing in a wide range of industries. The choice between the two depends on the final product requirements and the manufacturing process.

Whiskers and chopped fibers can also be used as reinforcements in biomaterials, creating composite materials that provide enhanced properties for a variety of biomedical and healthcare applications. These reinforcements can improve the mechanical strength, durability, and functionality of biomaterials used in medical devices, implants, tissue engineering scaffolds, and more.

3. **Long Fibers:** Continuous fiber reinforced composites (i.e., long fiber as reinforcement) are also used in the biomedical field. Long fibers are generally either polymer or ceramic fibers and include aramid fibers, UHMWPE fiber, cellulose fibers, CFs, glass fibers, and Ca-P fibers. CFs is made from a variety of precursor fibers (polymer, mesophase pitch, etc.)

V. INTERFACE

Bonding Mechanism: The interaction between the reinforcement and the matrix significantly influences the properties of the resulting composite, which are determined by various bonding processes, ranging from strong to weak. Typically, a robust interface yields high composite strength but may result in reduced toughness. Conversely, a weaker interface can yield composites with lower strength and, at times, susceptibility to cracks. Figure 3 illustrates the interfacial bonding, which can be either physical or chemical.

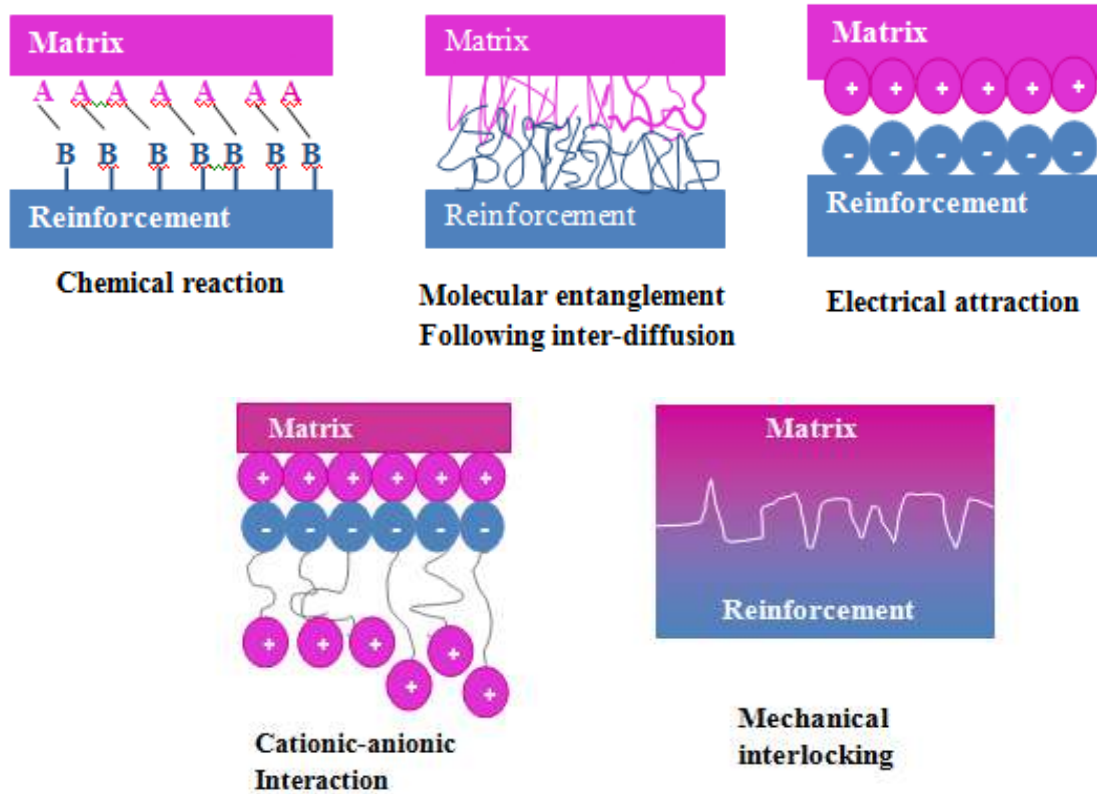


Figure 3: Schematic diagrams showing interfacial bonding between the reinforcement and matrix in composites

VI. INTERFACIAL BOND STRENGTH

The interfacial bond strength of composite materials refers to the bond strength between the different components or phases of the composite. Composites are generally made by combining two or more materials with distinct properties to create a new material with improved mechanical, thermal or electrical properties.

In a composite material, you have two main components:

1. **Matrix:** The matrix is the continuous phase that surrounds and binds the other component(s) together. It can be polymer, metal, ceramic, or other types of materials.
2. **Reinforcement:** The reinforcement, which is integrated into the matrix, serves to enhance strength, stiffness, or other advantageous characteristics and takes various forms, such as fibers, particles, or flakes.

The interfacial bond strength is critical to the overall performance of the composite because it affects how well the matrix and reinforcement transfer stress between each other. If the bond between the matrix and reinforcement is weak, it can lead to poor load transfer, reduced mechanical properties, and premature failure of the composite.

Experiments and theoretical analysis are conducted to explore the interfacial bond strength of different fibrous composites, with the goal of examining the shear stress responsible for the detachment of reinforcement from the matrix and the associated debonding process. Frequently, single-fiber pull-out or single-fiber push-out tests are employed to ascertain the critical interfacial shear stress required for debonding, as illustrated in (Figure 4), serving as a means to quantify the interfacial bond strength.

VII. DESIGN OF COMPOSITES

Major Influencing Factors for Composite Properties: Properties (Physical, structural, mechanical, biological, etc.) of composites are affected by many factors. Major influencing factors for biomedical composites include

1. Matrix Elements

- The choice of matrix material affects properties such as biocompatibility, degradation rate and overall mechanical behavior.
- The matrix should match the intended application and provide a suitable environment for the reinforcement materials.

2. Reinforcement material

- The type, size, shape and orientation of reinforcement materials significantly affect properties such as strength, stiffness and conductivity.
- Reinforcements can be fibers, nanoparticles, particles or other structures, each contributing distinct properties.

3. Volume fraction of reinforcement

- The ratio of reinforcement relative to the matrix affects the mechanical properties. Higher volume fractions generally result in increased strength and stiffness.

4. Interfacial bonding

- The quality of the bond between the matrix and the reinforcement materials affects the load transfer between phases and the overall composite strength.

5. Particle size and distribution

- For particle-reinforced composites, particle size, distribution, and arrangement affect mechanical, thermal, and electrical properties.

6. Orientation of Reinforcement

- The alignment or arrangement of reinforcement materials within the matrix can lead to anisotropic properties, where the material behaves differently in different directions.

7. Particle-Matrix Interactions

- Interactions between matrix and reinforcement at the atomic and molecular level can affect properties such as electrical conductivity, heat transport and chemical reactivity.

8. Composite Geometry and Design

- Shape, geometry and dimensions of composites effect properties such as mechanical behavior, load distribution and thermal response.

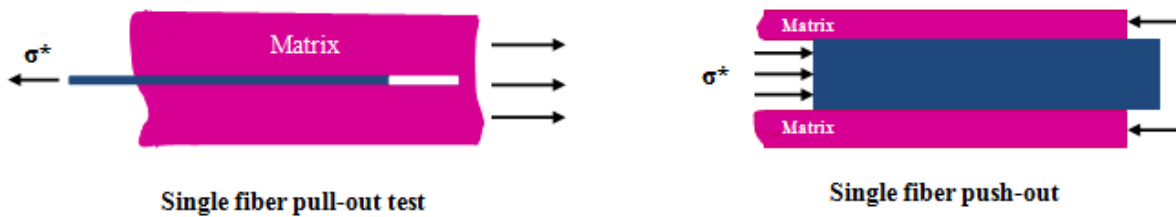


Figure 4: Schematic diagrams showing mechanical tests for determining interfacial bond strength.

VIII. BIOMEDICAL APPLICATIONS OF COMPOSITES MATERIALS

- 1. Composites in Dentistry:** Almost every person faces dental problems in his/her life. Various biomaterials are used for various dental treatments ranging from cavity filling to tooth replacement. Biocomposites have found various applications in dentistry due to their advantageous properties. Biocomposites are used as dental filling materials to restore the form and function of damaged or decayed teeth. These materials provide good mechanical strength and durability, making them suitable for withstanding the forces of chewing. Biocomposites can be used as implant materials due to their biocompatibility, which reduces the risk of rejection or adverse reactions from the body. They also have a bone-like structure, which encourages osseointegration, the process of the implant fusing with the surrounding bone. Biocomposite-based dental adhesives are used to bond restorative materials to tooth structures. The adhesive properties of these materials ensure a strong and durable bond, reducing the risk of restoration failure.
- 2. Composites in Orthopedics:** Biocomposites in orthopedics are designed to promote tissue integration, reduce inflammation, and enhance the healing process, making them ideal for various medical devices and implants used in orthopedic treatments. Biocomposites have been explored for cartilage repair and tissue engineering applications. They can be used as scaffolds to support the growth of new cartilage cells and aid in the regeneration of damaged cartilage. In the field of tissue engineering, biocomposites are being investigated to create joint scaffolds that can help repair or regenerate damaged joint tissues, such as articular cartilage and menisci. Biocomposites can be used in orthopedic applications that involve soft tissue repair, such as tendon and ligament repairs. These materials can provide support and promote healing while gradually breaking down and being replaced by natural tissue. Biocomposites are used in

the manufacturing of various orthopedic implants, such as plates, screws, and rods, which are implanted in the body for bone fixation and stabilization.

- 3. Composites in Tissue Engineering:** Composites play an important role in tissue engineering, a multidisciplinary field that aims to create functional biological tissues and organs using combinations of cells, biomaterials and bioactive molecules. Tissue engineering composites are designed to mimic the complex structure and properties of native tissues, ultimately promoting cell adhesion, growth and differentiation to regenerate or replace damaged or diseased tissues. Tissue engineering scaffolds are three-dimensional structures that provide a template for cell attachment and tissue regeneration. Composites are often used as scaffolding materials due to their versatility and ability to combine different properties. Biocompatible polymers, ceramics, and natural materials such as collagen or fibrin are commonly combined to form composite scaffolds. These composites match the mechanical properties of specific tissues, providing mechanical support during tissue formation. Biodegradable composites are used in tissue engineering to create temporary scaffolds that degrade over time as new tissue forms. These composites often consist of a combination of synthetic polymers and natural materials, which allows them to provide structural support in the early stages of tissue regeneration while gradually making room for newly formed tissue. Nanocomposites, which consist of nanoscale materials, are used in tissue engineering to improve properties such as mechanical strength, surface roughness, and bioactivity. Incorporating nanoparticles into composite matrices can improve cell adhesion, proliferation and tissue integration.
- 4. Composites in Drug Delivery:** Composites in drug delivery refer to the use of composite materials to improve controlled release and targeted delivery of pharmaceutical agents to specific sites in the body. These compounded drug delivery systems are designed to enhance the therapeutic efficacy of drugs, reduce side effects, and increase patient compliance. Composites used in drug delivery are usually composed of different materials, such as polymers, ceramics, metals or nanoparticles, that work together to achieve specific drug delivery objectives. Here are some common types and applications of composites in drug delivery:

 - **Polymeric Composites:** polymeric composites are widely used in drug delivery systems due to their biocompatibility, tunable properties and ease of fabrication. These composites can be designed to encapsulate drugs within a polymer matrix, allowing controlled release over time. In addition, functionalization of polymer matrices with specific ligands or targeting moieties can enable targeted drug delivery to specific tissues or cells.
 - **Nanocomposites:** Nanocomposites, which consist of nanoparticles dispersed within a polymer matrix, are used to improve drug delivery efficiency. Nanoparticles can enhance drug stability, protect drugs from degradation, and provide sustained release profiles. Examples of nanoparticles used in drug delivery include liposomes, micelles, and solid lipid nanoparticles (SLNs).
- 5. Composites in Medical Imaging:** Composites play a significant role in medical imaging, contributing to improved image quality, diagnostic accuracy, and patient safety. Medical imaging composites are designed to enhance the performance of imaging modalities, such

as X-ray, computed tomography (CT), magnetic resonance imaging (MRI), ultrasound, and nuclear medicine. These composites often consist of a combination of different materials, coatings, or contrast agents to optimize image acquisition and visualization. Here are some common applications of composites in medical imaging

- **Contrast Agents:** Composites are used as contrast agents in various imaging modalities to improve the visualization of specific tissues or structures. For example, in CT and X-ray imaging, iodinated composites are used as contrast agents to enhance the visibility of blood vessels, organs, and tumors.
 - **MRI Contrast Agents:** In MRI, composites containing paramagnetic or superparamagnetic materials, such as gadolinium or iron oxide nanoparticles, are used as contrast agents. These composites alter the relaxation times of nearby protons, resulting in enhanced image contrast and better tissue characterization.
 - **Ultrasound Contrast Agents:** Ultrasound imaging benefits from the use of microbubble-based composites as contrast agents. These microbubbles resonate in response to ultrasound waves, producing strong echoes that improve the imaging of blood flow and perfusion in organs.
 - **Radiopaque Coatings:** Composites can be used as radiopaque coatings for medical devices, such as catheters or guidewires, to aid their visualization during X-ray procedures. These coatings enable accurate device positioning and placement within the body.
6. **Composites in Cancer Treatments:** Composites are being explored and developed for various applications in cancer treatments. These composite materials leverage the unique properties of their components to enhance the effectiveness of cancer therapies and improve patient outcomes. Some key areas where composites are making an impact in cancer treatments include:
- **Drug Delivery Systems:** Composite materials can serve as carriers for chemotherapy drugs or other therapeutic agents. These drug-delivery systems offer controlled and targeted release of medications, allowing for more efficient drug delivery to cancerous cells while minimizing side effects on healthy tissues. By precisely delivering drugs to the tumor site, composite drug carriers can increase the therapeutic efficacy and reduce systemic toxicity.
 - **Radiotherapy Enhancements:** Composites can be employed as radiation-sensitizing agents to enhance the effects of radiotherapy. By incorporating radiation-sensitizing nanoparticles or high-Z materials into a polymer matrix, the composite can increase the radiation absorption within the tumor, leading to improved tumor cell kill rates during radiotherapy.
 - **Imaging and Diagnostic Tools:** Composite materials with imaging agents, such as fluorescent dyes or nanoparticles, can be used in various imaging modalities (e.g., MRI, CT, and PET). These imaging composites aid in early cancer detection, precise tumor localization, and treatment monitoring. Additionally, composites may be

developed for image-guided interventions, allowing for more accurate and targeted biopsies or surgical procedures.

- **Photothermal and Photodynamic Therapies:** Composites can be designed for photothermal therapy (PTT) or photodynamic therapy (PDT), where specific components in the composite generate heat or reactive oxygen species upon exposure to light. These treatments can selectively destroy cancer cells, making them potential options for localized tumor ablation.

IX. CONCLUSION

Composites have various applications as biomaterials in the field of medicine and healthcare due to their versatility, tunable properties, and biocompatibility. These composite biomaterials are designed to interact with biological systems, promote tissue regeneration, and improve patient outcomes. The unique properties of composites, such as mechanical strength, biodegradability, and tailored drug release, make them valuable biomaterials for a wide range of medical applications. As research in materials science and biomedical engineering continues to advance, composite biomaterials are expected to play an increasingly vital role in developing innovative medical solutions and improving patient care. In the coming years, composite biomaterials will continue to illuminate new avenues for medical advancement, inspiring novel solutions that enable us to heal, recover and thrive. Their story is one of cooperation, perseverance and the relentless pursuit of a healthy future for all.

REFERENCES

- [1] Min Wang, Qigong Zhao. "Biomedical Composites", Elsevier BV, 2018.
- [2] www.uotechnology.edu.iq.
- [3] Nguyen Hoc Thang, Truong Bach Chien, Dang Xuan Cuong. "Polymer-Based Hydro gels.
- [4] Handbook of Bioceramics and Biocomposites, 2016.
- [5] Wong, S.C. "Effect of specimen thickness on fracture toughness and adhesive properties of hydroxyapatite-filled polycaprolactone", Composites Part A, 200804.
- [6] Xiaotong Peng, Jing Zhang, Zbigniew H. Stachurski, Mark M. Banaszak Holl, Pu Xiao. "Visible-Light-Sensitive Triazine-Coated Silica Nanoparticles: A Dual Role Approach to Polymer Nanocomposite Materials with Enhanced Properties" , ACS Applied Materials & Interfaces, 2021.
- [7] Sodagudi Francis Xavier. "Thermoplastic Polymer Composites" , Wiley, 2022
- [8] Xiang Gao, Jinlin Song, Ping Ji, Xiaohong Zhang, Xiaoman Li, Xiao Xu, Mengke Wang, Siqi Zhang, Yi Deng, Feng Deng, Shicheng Wei. "Polydopamine-Templated Hydroxyapatite Reinforced Polycaprolactone Composite Nanofibers with Enhanced Cytocompatibility and Osteogenesis for Bone Tissue Engineering", ACS Applied Materials & Interfaces, 2016.
- [9] Brahatheeswaran Dhandayuthapani, Yasuhiko Yoshida, Toru Maekawa, D. Sakthi Kumar. "Polymeric Scaffolds in Tissue Engineering Application: A Review" , International Journal of Polymer Science, 2011
- [10] Mónica C. Garcia. "Drug delivery systems based on nonimmunogenic biopolymers", Elsevier BV, 2018.
- [11] Springer Briefs in Materials, 2015.
- [12] Vasif Hasirci, Nesrin Hasirci. "Fundamentals of Biomaterials" , Springer Science and Business Media LLC, 2018
- [13] www.researchgate.net.
- [14] www.slideshare.net.
- [15] archive.org.
- [16] eprints.usm.my.
- [17] www.mdpi.com.
- [18] www.ncbi.nlm.nih.gov
- [19] www.sciencedirect.com

- [20] baadalsg.inflibnet.ac.in
- [21] pdfs.semanticscholar.org
- [22] dokumen.pub
- [23] qmisg.com
- [24] corpus.ulaval.ca
- [25] d-scholarship.pitt.edu
- [26] epdf.pub
- [27] ir.lib.uwo.ca
- [28] Derek W, Jones, Amin S, Rizkalla, "Characterization of Experimental Composite Biomaterials "Biomedical Materials Research (Applied Biomaterials), vol. 33,pp.89-100, 1996.
- [29] Pilliar, R.M.Vowels, R. Williams, D.F, "The effect of environmental aging on the fracture toughness of dental composites" J. Dent. Res. Vol. 66(3), pp.722-726, 1987.
- [30] Kawaguchi, M. Fukushima, T. Horibe, T. Effect of monomer structure on the mechanical properties of light-cured composite resins, Dent. Mater, J.8(1): 40-45, 1989.
- [31] Bonfield, W. New trends in implant materials, Pizzoferrato, A. Marchetti, P.G, Ravaglioli, A. Lee, A.J.C., eds, Advances in Biomaterials, vol.7, Biomaterials and Clinical Applications. Amsterdam: Elsevier; 1987:275-280.
- [32] Bastioli,C. Romano, G. Migliaresi, C. Water sorption and mechanical properties of dental composites. Biomaterials 11(3): 219-223, 1990.
- [33] Soderholm, K.J, Roberts, M.J. influence of water exposure on the tensile strength of composites, J. Dent. Res. 69(12), 1812-1816, 1990.
- [34] S. Ramkrishna, J. Mayer, E.Wintermantel, Kam. W. Leong, "Biomedical applications of polymer-composite materials", Composites science and technology, vol.61, pp. 1189-1224, 2001.
- [35] S. Blazewicz, J. Chlopek, A. Litak, C. Wajiler, E. Staszko, "Experimental study of mechanical properties of composite carbon screws", Biomaterials, vol. 18, pp 437-439, 1997.
- [36] S. Ramkrishna, Z.M. huang, "Biocomposites", Comprehensive structural Integrity, vol.9, pp. 215-296, 2003.[https://doi.org/10.1016/S0266-3538\(00\)00241-4](https://doi.org/10.1016/S0266-3538(00)00241-4).
- [37] W.Bonfield,"Composites for bone replacement", Journal of Biomedical Engineering, vol.10, pp.522-526, 1988.[https://doi.org/10.1016/0141-5452\(88\)90110-0](https://doi.org/10.1016/0141-5452(88)90110-0).
- [38] S. Zafar, N. Verma, M.K. Singh, H. Pathak, " Advances in the processing of composites biomaterials for bone grafting and other biomedical applications", Encyclopedia of materials: plastics and polymers, vol.4, pp.614-634, 2022.
- [39] J. Huang, S.M. Best, " Chapter 1- Ceramic biomaterials for tissue engineering", Tissue engineering using ceramics and polymers(Third edition), pp-3-40, 2022.<https://doi.org/10.1016/B978-0-12-820508-2.00007-6>.
- [40] S. Ajmal, F. A. Hashmi, I. Imran, "Recent progress in development and applications of biomaterials", Materials Today: Proceedings, vol.62, part1, pp. 385-391, 2022.<https://doi.org/10.1016/j.matpr.2022.04.233>.
- [41] S. Punj, J. Singha, K. Singha, "Ceramic biomaterials: properties, state of the art and future prospective", Ceramics International, vol.47, pp.28059-28074, 2021.
- [42] M. Sokolsky-Papkov, K. Agashi, A. Olaye, K.Shakshoff, A. J. Dombo, "Polymer carries for drug delivery in tissue engineering", advanced drug delivery reviews, vol.59, pp.187-206, 2007.<https://doi.org/10.1016/j.addr.2007.04.001>.
- [43] N.I. Syazana, M.Yusoff, M.U. Wahit, W.H.Tham, Tuck-Whye Wong, X.Y.Lee, F.H. Jamaludin, " Chapter21-Biodegradable polymer blends and composites for biomedical applications", Biodegradable Polymers, Blends And Composites, pp.573-590, 2022.<https://doi.org/10.1016/B978-0-12-823791-5.00016-8>.
- [44] S. Gopinath, Nayarassery N.Adarsh, P. Radhakrishnan Nair,S.Mathew, "Recent trends in thermo-responsive elastomeric shape memory polymer nanocomposites" Polymer composites, 2023. <https://doi.org/10.1002/pc.27464>.
- [45] R. Kannan, G.Wei, Peter X. Ma, " Chapter-2 Synthetic polymeric biomaterials for tissue engineering", Tissue engineering using ceramics (Third Edition), pp.41-74, 2022. <https://doi.org/10.1016/B978-0-12-820508-2.00023-4>.
- [46] S.V. Gohil, S.Suhail, J.Rose, T.vella, L.S.Nair, "Chapter 8- Polymers and composites for orthopedic applications, Materials for bone disorders, pp.349-403, 2017. <https://doi.org/10.1016/B978-012-802792-9.00008-2>.

- [47] Andre D.R. Silva, Thiago.D. Stocco, Alessandro E. C. Granato, Samarah V. Harb, S. Afewerki, Nicole, J. Webstar, F. R. Marciano, A. O. Ilobo. "Chapter 2- Recent advances in nanostructured polymer composites for biomedical applications", pp. 21-52, 2019. <https://doi.org/10.1016/B978-0-12-816771-7.00002-8>.
- [48] O. Adekomaya, T. Majozi, Chapter 23- Industrial and biomedical applications of fiber reinforced composites", *Fiber reinforced Composites*, pp.753-783, 2021, <https://doi.org/10.1016/B978-0-12-821090-1.00004-1>.
- [49] M. Wang, Q. Zhao, "Biomedical Composites", *Encyclopedia of Biomedical Engineering*, <https://doi.org/10.1016/B978-0-12-801238-3.99868-4>.
- [50] S.B.Park, E.Lih, K.S. Park, Y.K. Joung, D.K.Han, "Biopolymer –based functional composites for medical applications", *Progress in polymer science*, vol.68, pp.77-105, 2016, <https://doi.org/10.1016/j.progpolymsci.2016.12.003>.
- [51] Moustafa M. Zagho, Essraa A. Hussein, Ahmed A. Elzatahry, "Recent overviews in functional polymer composites for biomedical applications", *polymers* 2018, 10,738, doi: 10.3390/polym10070739.
- [52] E. Salernitano, C. Migliaresi, "Composites materials for biomedical applications", *Journal of Applied Biomaterials and biomechanics* 2003, 1:3-18.
- [53] Min Wang, "Developing bioactive composite materials for tissue replacement", *Biomaterials*, vol.24, pp.2133-2151, 2003, [https://doi.org/10.1016/S0142-9612\(03\)00037-1](https://doi.org/10.1016/S0142-9612(03)00037-1).
- [54] Jitha S. Jayan, S. Appukuttan, R. Wilson, K. Jospheh, G. George, K. Oksman, "Chapter-1 An introduction to fiber reinforced composites materials", *Fiber Reinforced Composites*, 2021, pp.1-24, <https://doi.org/10.1016/B978-0-12-821090-1.00025-9>.
- [55] S.Kumar, A. Manna, R.Dang, "A review on application of natural Fiber- Reinforced Composites(NFRCS)", *Materials Today: Proceedings*, vol.50, pp.1632-1636, <https://doi.org/10.1016/j.matpr.2021.09.131>.
- [56] R. Ahmed Raus, W.Mohd Fazil Wan Nawawi, R.R. Nasaruddin, "Alginate and alginate composites for biomedical applications", *Asian Journal of Pharmaceutical Sciences*, vol.16, pp.280-306, 2021, <https://doi.org/10.1016/j.ajps.2020.10.001>.
- [57] M. Oprea, S. L. Voicu, "Recent advances in composites based on cellulose derivatives for biomedical applications", *Carbohydrate Polymers*, vol.247, 2020, 116683, <https://doi.org/10.1016/j.carbpol.2020.116683>.
- [58] G. Kaur, V. Kumar, F. Baino, John C. Mauro, G. Pickrell, L. Evan, O. Bretcanu, "Mechanical properties of bioactive glasses, ceramics, glass-ceramics and composites: State-of the-art-reviews and future challenges", *Materials Science and Engineering:C*, vol.104, 2019, 109895, <https://doi.org/10.1016/j.msec.2019.109895>.
- [59] M. Nagalakshmaiah, S. Afrin, R.P. Malladi, S. Elkoun, M. Robert, M. A. Ansari, Z. Karim, "Chapter 9- Biocomposites: present trends and challenges for the future", *Green Composites for Automotive Applications*, 2019, pp.197-215, <https://doi.org/10.1016/B978-0-08-102177-4.00009-4>.
- [60] Robert S Pomeroy, "Chapter 9- Biodegradable biocomposites", *Rethinking Polyester Polyurethanes*, 2023, 215-228, <https://doi.org/10.1016/B978-0-323-99982-3.00006-7>.
- [61] A. Kumar Das, Md. Nazrul Islam, R. Kumar Ghosh, R. Maryana, "Cellulose-based bionanocomposites in energy storage applications-A review" *Heliyon*, vol.9, 2023, e13028, <https://doi.org/10.1016/j.heliyon.2023. e13028>.
- [62] M. Jacob John, S. Thomas, "Biofiber and biocomposites", *Carbohydrate polymers*, vol. 71, pp.343-364, <https://doi.org/10.1016/j.carbpol.2007.05.040>.
- [63] A. K. Mohanty, M. Mishra, G. Hinrichsen, "Biofibers, biodegradable polymers and biocomposites: An overview" *Macromolecules Materials and Engineering*, vol. 267-277, pp.1-24, 2000, [https://doi.org/10.1002/\(SICI\) 14392054\(20000301\) 276](https://doi.org/10.1002/(SICI) 14392054(20000301) 276).
- [64] B Aaliya, K. V. Sunooj, M. Lackner, "Biopolymer Composites: a review", *International Journal of Biobased plastics*, vol.3, pp. 40-84, 2021, <https://doi.org/10.1080/24759651.2021.18881214>.
- [65] Panday, Jitendra Kumar, A. Pratheep, Mishra, Manjusri, Mohanty, Amar K, Drzal, Lawrence T, Palsingh, Raj, "Recent advances in biodegradable nanocomposites", *Journal of Nanoscience and Nanotechnology*, vol.5, pp.497-526(30), 2005, <https://doi.org/10.1166/jnn.2005.111>.
- [66] Kestur G, Satyanarayana, Gregorio G.C. Arizaga, Fernando Wypych, "Biodegradable composites based on lignocellulosic fibers- An overview", *Progress in Polymer Science*, vol.34, pp.982-1021, 2009, <https://doi.org/10.1016/j.progpolymsci.2008.12.002>.
- [67] T. Biswal, S. Kumar Badjena, D. Pradhan, "Synthesis of polymer composite materials and their biomedical applications", *Materials Today: Proceedings*, vol.30. pp. 305-315, 2020, <https://doi.org/10.1016/j.matpr.2020.01.567>.

- [68] Ana B. da Silva, Kessily B. Rufato, Ariel C. De Oliveira, Paulo R. Souza, Elisangela P. da Silva, Edvani C. Munzi, Bruno H. Vilsinski, Alessandro F. Martins, "Composites materials based on chitosan/gold nanoparticles: From synthesis to biomedical applications", *International journal of Biological Macromolecules*, vol.161, pp. 977-998, 2020, <https://doi.org/10.1016/j.biomac.2020.06.113>.
- [69] Dr. A. G, D. Ronca, L. Ambrosio, et.al, " Technical features and criteria in designing fiber-reinforced composite materials: From the aerospace and aeronautical field to biomedical applications", *Journal of Applied Biomaterials & Functional Materials*, vol.9, 2011, <https://doi.org/10.5301/JABB.2011.8569>.
- [70] B. Ates, S. Koytepe, S. Balcioglu, A. Ulu, C. Gurses, " 12- Biomedical applications of hybrid polymer composites materials", *Hybrid Polymer Composite materials*, 2017, pp. 343-408, <https://doi.org/10.1016/B978-0-08-100785-3.00012-7>.
- [71] Jin Liang Wang, " Application of composite materials on sports equipments" , *Applied Mechanics and Materials*, vol.155, pp.903-906,2012.
- [72] M. Hasan, J. Zhao, Z. Jiang, "Micromanufacturing of composite materials: a review", *International Journal of Extreme Manufacturing*, vol.1, 2019, DOI 10.1088/2631-7990/ab0f74.
- [73] J. Fleischer, R. Teti, G. Lanza, P. Mativenga, Hans-Christian Mohring, A. Caggiano, *CIRP Annals*, vol.67, pp.603-626, 2018, <https://doi.org/10.1016/j.cirp.2018.05.005>.
- [74] M. W. Hyer, S. R. White, " Stress analysis of fiber-reinforced composite materials, DEStech Publications, INC, 2019.
- [75] J. Degrieck, W. V. Paepegem, "Fatigue damage modeling of fibre-reinforced composite materials:Review,Appl.Mech.Rev.,vol.54(4),pp.279-300,2001, <https://doi.org/10.1115/1.1381395>.
- [76] P. Tormala, Biodegradable self-reinforced composite materials; manufacturing structure and mechanical properties", *Clinical Materials*, vol.10. pp.29-34, 1992, [https://doi.org/10.1016/0267-6605\(92\)90081-4](https://doi.org/10.1016/0267-6605(92)90081-4).
- [77] Yong X. Gan, D. Solmon, M. Reinbolt, "Friction stir processing of particle reinforced composite materials",*Materials*, vol.3(1), pp.329-350, <https://doi.org/10.3390/ma3010329>.
- [78] Hyoung Seop Kim, "On the rule of mixture for the hardness of particle reinforced composites", *Materials Science and Engineering*, vol.289, pp. 30-33, 2000, [https://doi.org/10.1016/S0921-5093\(00\)00909-6](https://doi.org/10.1016/S0921-5093(00)00909-6).