Potential Natural Fiber-Reinforced Composite for Biomedical Application

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Abstract. Natural fibers have been used extensively as a composite reinforcement in response to various weaknesses of synthetic fibers. They are used as composite reinforcement and their use has been widely developed for biomedical applications because they are biocompatible, non-toxic properties, environmental benefits, and good mechanical performance. As a material from renewable sources, they have been successfully produced into biocomposites which manufacture involves a lot of polymers, and ceramics as matrices. In terms of biomedical applications, they have been widely used in drug delivery, tissue engineering, and orthopedics. The purpose of this review article is to provide a comprehensive review of the potential of natural fibers as composite reinforcement in biomedical applications, such as tissue regeneration, and organ implants that experience trauma or degeneration. Recent research advances on the production of natural fiber reinforced scaffolds for soft tissue reconstruction are also addressed in this paper.

Keywords: Biomedical application, natural fiber, biocomposite

1. Introduction

Natural fibers are a very potential resource used as material in various applications such as automotive, light construction, cosmetics, medicine and for fine chemicals [1]. Their advantages are compared with synthetic fibers, namely low cost, low weight, mechanical properties are relatively good, abundant, and are renewable resources [2, 3]. In the medical field, they are widely used because they have high strength to their weight ratio, high fracture toughness, non-corrosive properties, and can be renewable [3].

Natural fibers have been used extensively in biomedical applications such as drug delivery, tissue engineering, and orthopedics [4]. Based on the nature of its resources, natural fibers can be classified into two types, namely renewable and non-renewable. They can be sourced from animals or plants [5]. In the biocomposite production process, they are like kenaf, industrial hemp, hemp, hemp, hemp, and sisal generally combined with biopolymers [6, 7]. This biocomposite has been widely applied in the field of biomedicine because it is very flexible, a good amplifier phase distribution in the composite, and various mechanical and biological advantages [8, 9].

In a variety of applications, "fiber-reinforced matrix composites" are specifically noted for their excellent properties and the superiority of natural fibers over synthetic fibers in terms of their
relatively low weight, abundance, low prices, good tensile modulus and flexible modulus, easy processing, and renewable resources [10].

2. Natural Fiber Reinforced Composites for Biomedical Application

2.1. Natural Fiber Reinforced Composites and Its Characteristics

In composites with fiber reinforcement, reinforcing materials such as palm oil, flax, bananas, sisal, coconut and kenaf are placed in a polymer that acts as a composite matrix [8]. Based on its nature, the matrix of polymers can be divided into two groups, namely thermoplastic and thermostet type polymers. Thermoplastic material has a one- or two-dimensional molecular structure, as a result thermoplastic turn soft or melt if subjected to high heat and return to their original properties if heat is removed from the polymer. As with thermoset polymers, it is a highly crosslinked polymer that is able to soften when given heat, or combines heat and pressure, and also the use of light irradiation. Thermostet properties are strongly influenced by molecular structure. Its high flexibility allows this type of polymer to be set properly to have desirable properties such as its modulus and strength [5, 11]. Thermoplastics which are widely used as matrices include high-density polyethylene [12], and polypropylene [13]. Whereas the composite matrix of thermostetting type which is widely used comes from the type of epoxy resin, polyester, and phenolic [14, 8]. The natural characteristics of composite polymer fibers are influenced by several factors such as the hydrophilic nature and the composition of natural fibers that act as fillers/reinforcement [10, 15-18]. The arrangement of fiber composition in the matrix is strongly influenced by the purpose of using composite. The consequences arising from the increase in fiber content in the host matrix are an increase in composite tensile properties [6]. In addition to composite composition, composite manufacturing process parameters are the main determinants of properties. Therefore, the desired composite properties must be determined when selecting the manufacturing process parameters [19].

The mechanical performance of natural fibers as reinforcement in polymeric matrix composites has been studied by many researchers [20-24]. They [11, 19, 25] have focused their studies on improving the compatibility of fibers and polymers by modifying fiber surfaces in composite manufacturing processes. Also, comparative studies have been carried out on different natural fibers and their performance in various applications [26]. For example, the properties of jute-polymer composites have been studied in depth in terms of composite stability with respect to temperature and light, fiber surface modification, and crystallinity in relation to its application [26]. The nature of pure hemp-reinforced fiber composites of biodegradable polymers has been developed and investigated by Mohanty et al. [27] They have reported that impact strength, tensile strength, and flexural strength increased by 50%, 30%, and 90% respectively by the presence of hemp fibers in composite matrix when compared to pure biopoly.

2.2. Main consideration in selection biomass material

Natural fiber is abundant and provides many advantages such as low density, good mechanical properties and renewable [28]. Another advantage is that they are recyclable and biodegradable. Thus, this natural fiber does not damage the environment. Composites based on natural fiber-reinforced polymers have less mechanical properties than stiff metals. This property is closer to the mechanical properties of bones, therefore natural fiber-reinforced polymeric composites can be a good alternative for bone implant materials [28].

Thmmana Gouda et al. [29] have reported that composites promote the prevention of stress shielding and also stimulate bone remodeling. They can be developed by coating them with bone graft materials such as calcium phosphate and hydroxyapatite. This material can be formed into a plate so that it can be used to implant reconstruction of fractured bones so as to help fixation inside and external fixation. This composite also has the potential to replace metal bone plate material for bone fracture fixation which is generally made of stainless steel and titanium alloy. A fundamental consideration is that this
metal material causes several problems such as metal mismatch, corrosion, magnetic effects, anode-cathode reactions, and delay in fracture healing.

**Table 1. Mechanical properties of biomaterials [30]**

| Materials      | Elongation at break (%) | Young’s modulus (GPa) | Tensile Strength (MPa) | Yield strength (MPa) |
|----------------|--------------------------|-----------------------|------------------------|----------------------|
| CoCr Alloy     | 10                       | 225                   | 735                    | 525                  |
| SS316          | 18                       | 120                   | 900                    | 830                  |
| Al₂O₃          | 0                        | 350                   | 1000-10,000            | 0                    |
| Stainless steel| 55                       | 210                   | 600                    | 240                  |
| Ti6Al4V        | 0-8                      | 15-30                 | 70-150                 | 30-70                |
| HDPE           | 20                       | Viscoelastic          | 7-1                    | -                    |
| PMMA           | 200-400                  | 0.6-1.8               | 23-40                  | -                    |
| Cortical Bone  | 0.5                      | 3.0                   | 35-50                  | -                    |

The main considerations in the selection of biomaterials can be grouped into two categories [31, 30,32], namely (i) based on material properties, and (ii) based on functional requirements in the application. The properties of materials that are taken into consideration are chemical, physical and mechanical properties. Chemical properties include chemical composition, and surface bonding of materials. Physical properties include volumetric mass density, topological of surfaces, and surface roughness. Meanwhile, mechanical properties include tensile strength, compressive strength, flexural strength, Young's modulus, shear modulus, flexural modulus, and surface hardness. While the functional requirements in the application can be based also in categorized into mechanical, physical and chemical requirements. Mechanical properties considered in this requirement include fracture strength, impact strength, fatigue strength, stiffness, creep resistance, wear resistance, and adhesion strength. Form and geometry, thermal expansion coefficient, electrical conductivity, aesthetic and color, index of refraction, opacity and translucency are physical properties that are functional considerations for the selection of biomaterials. In addition, functional requirements for biomaterials are also based on the chemical properties of materials which include biocompatibility, bioactive, toxicity, biodegradability, and biostability.

**Table 2. Various types of natural fibers that are potential for biomaterial applications [30]**

| Materials kinds | Elongation at break (%) | Tensile strength (MPa) | Young’s modulus (GPa) |
|-----------------|-------------------------|------------------------|-----------------------|
| Natural fibers: |                         |                        |                       |
| Banana          | 3                       | 529 - 914              | 27 – 32               |
| Kenaf           | 3.5                     | 295 - 1191             | 2.86                  |
| Flax Flax       | 1.3 - 10                | 300 - 1500             | 24 – 80               |
| Sisal           | 2 - 25                  | 80 - 840               | 9 – 38                |
| Ramie           | 1.2 - 8                 | 348 - 938              | 44 – 128              |
| Pineapple       | 2.4                     | 170 - 1627             | 60 – 82               |
| Hemp            | 1.6 - 6                 | 310 - 900              | 30 – 70               |
| Oil palm        | 7 – 14.3                | 130 - 248              | 3.58                  |
| Cotton          | 3 – 8                   | 264 - 800              | 5 – 12.6              |
| Spider silk     | 17 - 18                 | 875 - 972              | 11 – 13               |

*Human tissues:*

| Elastic cartilage | 30 | 3 | - |
2.3. Natural fiber-reinforced scaffolds

Soft tissue surgeons often have difficulty reconstructing damaged soft tissue. Soft tissue techniques have been developed as new strategies to respond to these difficulties. In the last decade, soft tissue engineering has grown rapidly in response to various problems including the provision of appropriate scaffold implant materials. For this purpose, various natural materials including gelatin and collagen have been used as biomaterials for soft tissue engineering [33-35]. Although many of them did not qualify because of the restriction of their mechanical properties [36]. Good mechanical properties are needed because they have a direct effect in improving the ability of cell proliferation and adhesion [37-40]. Collagen fibers in a three-dimensional structure are the main proponents of the majority of soft tissues in the human body. Therefore, the use of fiber as a scaffold reinforced has many advantages for regeneration and remodeling such as the ease of adaptation to the mechanical environment of soft tissue [35].

The design of nanofiber reinforced nanofiber scaffolds using electrospun silk fibroin was carried out by Yang et al. [41]. In its development, silk-based materials have also been made for the design of reinforced scaffolding [42]. To support this function, nanofibrous silk fibers are functioned as reinforcement in vessel prostheses. This study is similar to that carried out by many researchers [43,44] where the scaffold was applied clinically for soft tissue regeneration of the skin. Research into the use of silk fibroin has undergone a development, silk fibroin is used as a reinforcement for collagen-based membrane to improve the mechanical properties of corneal implants [45].
Figure 1. SEM analysis of cell adhesion (a, b) Human dermal fibroblasts cell line and (c, d) Human Keratinocytes cell line [37]

3. Conclusion
Natural fibers with precise ratio control in composite matrices are very potential for making composites for biomedical applications. Reinforced biomaterial composites are usually made from polymeric based systems reinforced with natural materials, including natural fibers. This natural fiber plays an important role. For example, collagen fibers embedded in the hydrogel matrix are able to mimic microstructure and soft tissue. In addition, natural fiber reinforced composites are also able to enhance biomechanics, biocompatibility, bioactivity, integration and degradation of composites in soft tissue reconstruction.

4. References
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