Research Open

Nanotechnology and Advanced Material Science
Volume 7 Issue 3

Mini Review

Thermal Properties of Natural and Hybrid Fiber Reinforced Composites

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Received: May 13, 2024; **Accepted:** May 20, 2024; **Published:** May 27, 2024

Abstract

The thermal stability of natural fiber composites is a relevant aspect to be considered since the processing temperature plays a critical role in the manufacturing process of composites. At higher temperatures, the natural fiber components (cellulose, hemicellulose, and lignin) start to degrade and their major properties (mechanical and thermal) change. Different methods are used in the literature to determine the thermal properties of natural fiber composites as well as to help to understand and determine their suitability for a certain applications (e.g., Thermogravimetric analysis (TGA), differential scanning calorimetry (DSC), and differential mechanical thermal analysis (DMA)). Weight loss percentage, the degradation temperature, glass transition temperature (T_g), and viscoelastic properties (storage modulus, loss modulus, and the damping factor) are the most common thermal properties determined by these methods. This paper provides an overview of the recent advances made regarding the thermal properties of natural and hybrid fiber composites in thermoset and thermoplastic polymeric matrices. First, the main factors that affect the thermal properties of natural and hybrid fiber composites (fiber and matrix type, the presence of fillers, fiber content and orientation, the treatment of the fibers, and manufacturing process) are briefly presented. Further, the methods used to determine the thermal properties of natural and hybrid composites are discussed. It is concluded that thermal analysis can provide useful information for the development of new materials and the optimization of the selection process of these materials for new applications. It is crucial to ensure that the natural fibers used in the composites can withstand the heat required during the fabrication process and retain their characteristics in service.

Keywords: *Natural fiber reinforced composite material, Thermal analysis, Thermogravimetric analysis (TGA), Differential scanning calorimetry (DSC), Differential mechanical thermal analysis (DMA)*

Introduction

The application of composites has continuously increased across many industries, in particular in the automotive and aerospace industries where lower weight and high resistance are key factors. The most commonly used fibers that attend these requirements are carbon and glass fibers [1-3]. However, nowadays, the industry is seeking new desirable characteristics of composite materials, such as renewability, eco-friendliness, and low cost. Consequently, there has been great interest in research and innovation in natural fiber composites owing to the advantages of these materials compared to their synthetic fiber counterparts (i.e., lower environmental impact and lower cost), supporting their potential across a wide range of applications in several industrial sectors [4-9]. The natural fiber-reinforced composites (NFRCs) are used mainly in non-structural car body parts, such as door panels, package trays, hat racks, instrument panels, internal engine covers, sun visors, boot liners, oil air filters, and even progressing to more structurally demanding parts, such as seat backs and exterior underfloor paneling [10,11]. Nowadays, most of the automotive makers, such as Audi, Volkswagen, Toyota, Daimler-Benz, Volvo, Ford, etc., use NFRCs to produce components. The continually growing demands for lightweight and fuel-efficient vehicles will further push the growth of NFRCs in the automotive market. There are other exciting market trends going forward in many different industries. For example, tri-dimensional hybrid natural fiber reinforcement preforms have been used recently by sports car manufacturers, such as Porsche and even McLaren in Formula 1 .Other applications of NFRCs include sport equipment, musical instruments, aerospace, construction industry [12-14], and ballistic armour [15,16].

Several types of natural fibers are currently used in industry, such as jute, sisal, oil palm, kenaf, and flax, which are well established in the global market with a well-defined production line. However, new promising natural fibers are being discovered and used on a smaller scale or are still being used only for research. This is the case of the buriti and curauáfibers, for example, that still need some improvements in their production line to be more commercially affordable and reach widespread use [17,18]. They are used as reinforcement fibers in thermoset or thermoplastic polymeric matrix in a variety of applications [19]. Depending upon the matrix type, NFRCs are categorized into completely biodegradable or partially biodegradable composites.The growing importance of natural fiber reinforced composites is reflected by the increasing number of publications (e.g., reviews, patents, book chapters, and books) during the recent years [20-25]. Therefore, it is important to study their thermal and mechanical behaviour in order to utilize their full potential. The thermal stability of natural fiber composites is a relevant aspect to be considered as the processing temperature plays a crucial role in the fabrication process of the composites. At higher temperatures, the natural fiber components (i.e., cellulose, hemicellulose, and lignin), start to degrade and the major properties (mechanical and thermal) of the composite change. Intense research efforts are continuously made and some of the shortcomings of NFRCs were addressed by recent advancements in fiber treatment and modification, exploration of new natural fibers, and hybridization. The fiber modification techniques provide improved fiber–matrix interfacial adhesion, improved fiber roughness, and wettability and depend on the particular fiber/matrix used and the composite application, while the hybridization methods provide flexibility in fiber selection for the material properties according to the end-use application requirements.

Even though there are many recent review articles concerning the use of natural fibers in the production of natural hybrid composites [26-34], one topic that was not covered in any significant detail relates to the thermal characterisation of NFRCs. This paper provides an overview of the recent advances in the thermal properties of natural and hybrid natural fiber composites in thermoset and thermoplastic polymeric matrices. First, the main factors that affect the thermal properties of natural and hybrid fiber composite materials (fiber and matrix type, the presence of additive fillers, fiber content and orientation, the treatment of the fibers, manufacturing process, and type of loading) are briefly presented. Further, the methods used to determine the thermal properties of natural and hybrid composites are discussed. Finally, some conclusions and critical challenges and future perspectives and research activities are summarized.

Influencing Factors

The main factors that affect the thermal properties of natural and hybrid fiber compo-site materials are: fiber and matrix type, the presence of additive fillers, fiber content and orientation, the treatment of the fibers, manufacturing process, and type of loading [35].

Methods Used to Determine the Thermal Properties of Natural and Hybrid Composites

The following methods are used

a) Thermogravimetric Analysis (TGA)

b) Differential Scanning Calorimetry (DSC)

c) Dynamic Mechanical Analysis (DMA)

Conclusions

Thermal analysis can provide useful information for the development of new materials and optimization of the selection process of these materials for new applications. The most common thermal properties studied in the literature are: the percentage of weight loss, the degradation temperature, T_g, and viscoelastic properties (storage modulus, loss modulus, and the damping factor). Different factors affect the thermal properties of natural fiber composites (i.e., fiber and matrix type, the presence of fillers, fiber content, and fiber orientation, the chemical treatment of the fibers, manufacturing process, and type of loading). It is crucial to ensure that the natural fibers used in the composites can withstand the heat required during the fabrication process and retain their characteristics after exposure to heat. Different approaches were used in the literature for the enhancement of thermal properties of natural fiber-based composite materials. For example, using natural fibers with low lignin content leads to a better thermal performance of composites. Another approach involves the removal of lignin through fiber treatment. Finally, the incorporation of synthetic fillers or synthetic fibers in natural fiber reinforced composites increase their thermal stability.

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Citation:

Gokarneshan N, Ritti RH, Kayalvizhi C, Anton SM, Shahanawaz Z, et al. (2024) Thermal Properties of Natural and Hybrid Fiber Reinforced Composites. *Nanotechnol Adv Mater Sci* Volume 7(3): 1-3.