Multiple scale study of hydrothermal degradation in the interfacial regions of flax fiber/bio-based polyurethane composites

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Abstract

Bio-composites have become more popular in a variety of applications in recent years. Bio-composites have been subjected to a lot of research in order to enhance their performance. The optimization of interfacial characteristics is one of the most essential aspects. Natural fibres' inherent hydrophilic characteristics not only create matrix incompatibility, but also render the interfacial areas extremely vulnerable to weathering impacts. Long-term deterioration of the interfacial areas, which is one of the least known components of bio-composites, may be caused by changes in ambient temperature and humidity. The goal of this research is to learn more about hydrothermal degradation and how it affects the interfacial characteristics of flax fiber/bio-based polyurethane composites. Experiments were carried out on two different scales. Single yarn fragmentation experiments were used to focus on the fiber/matrix interactions in a reliable fashion. To examine the effects of deterioration at the size of composites, corresponding unidirectional tensile tests were conducted. The deterioration caused by hydrothermal impacts was shown to decrease interfacial adhesion between flax fibres and matrix. The results from the two scales are highly correlated. Indicators from single yarn fragmentation tests, including as fragmentation development, fragmentation length distributions, and fracture forms, can accurately represent degradation in the interfacial areas. Water absorption and desorption both induce deterioration of fiber/matrix interactions, which is surprising

Nature succeeds in producing hybrid materials with extraordinary mechanical properties, such as high strength toughness, suited to the unique demands of biological systems, by mixing biopolymers and minerals into hierarchical nanoscaled structures. Complex biological structures that exhibit self-assembly processes and indicate a significant role for nanostructuration and nano-objects fascinate and motivate researchers in the creation of new engineering materials in this regard. Bio-inspired materials have already been studied in a variety of engineered materials that imitate natural systems including nacre, tooth, bone, and wood. In practise, it appears that these designs, through nanostructuration and the creation of a "hierarchical architecture," change stress transmission processes inside the material and increase its strength and fracture toughness. The deployment of structures displaying specificorganizations at different lengthscales, from the macro- to the nanoscale, and providing interestingproperties to the whole material may be described as the hierarchical architecture of a system. This idea has been used to composite materials in the form of hierarchical fibres created by the deposition of nano-objects on fibre surfaces. Carbon fibre whiskerization with carbon nanotubes (CNTs), for example, has been developed for the production of carbon fibre reinforced composites. Due to greater mechanical interlocking and reduced local stress concentrations at the fibre/matrix interface, the produced nanostructured composites showed improved mechanical characteristics, resulting in higher strength and toughness. Karger-Kocsis et al. (2015) also mentioned the possibility of using such hierarchical composites for sensing applications, such as in-situ stress, strain, and damage sensing for structural health monitoring. Furthermore, contemporary environmental concerns drive the development of eco-friendly and high-performance composite materials, either hybrid (synthetic/bio-based) or entirely bio-based (reinforced with natural fibres and/or bio-based nano-objects). In this regard, the development of hierarchical fibres in the interphase zone of (bio)composites is still in its early stages, but it could be a promising strategy for addressing the current and future challenges posed by the use of fully bio-based natural fibre reinforced biocomposites in industrial applications.

The current state of the art for using hierarchical fibres to improve fibre/matrix interface adhesion and toughening of (bio)composite materials is discussed in this study. To comprehend the function of nano-objects in naturally occurring hierarchical structures, many biological systems will be presented first. Then, current studies on hierarchical fibre reinforced composites will be discussed and divided into three main categories: (i) fully synthetic hierarchical composites, (ii) hybrid hierarchical composites either reinforced with bio-based nanoparticle modified synthetic fibres, or with synthetic or mineral nanoparticle modified natural fibres, and (iii) hierarchical biocomposites reinforced with bio-based nanoparticle modified natural fibres, the matrix being oil-based or bio-based.

In biological systems such as bones, nacre, and wood, nano-objects play a critical role in hierarchical structures, according to his review. By altering load transmission within the microstructure and failure processes in interfacial areas, these nanoscaled-hierarchical structures dramatically enhance the tensile strength and toughness of biological systems. The bio-inspired idea of hierarchical fibres modified by nano-objects has been proposed to improve the fibre/matrix interphase in man-made composite materials based on these discoveries. Coating synthetic and natural fibres with nano-objects (CNTs, graphene, ZnO nanowires, nano-TiO2, nanoclay, BC, CNC, CNF) results in increased roughness and specific surface area. Furthermore, nano-objects at the interface allow for a smoother transition between the fibres and the matrix in terms of microstructure and mechanical characteristics of the interphase, resulting in improved load transmission inside the compositeHierarchically nanostructured fibres also reduce fibre debonding by ensuring greater mechanical interaction with the matrix. Finally, nano-objects can prevent fracture propagation, which preferentially occurs at interfaces and follows a zig-zag patternAs a result, the addition of hierarchical fibres to composite materials significantly alters their mechanical properties. The interfacial shear strength (IFSS) between the fibres and the polymer matrix is improved, which contributes to the composites' improved mechanical performance, particularly their strength and toughness.

Biography

Yunlong Jia is a doctoral candidate in Hamburg University of Technology with his research topic 'durability of flax fiber reinforced bio-composites for structural applications'. He graduated with M.Sc. in mechanical engineering in 2012 and published four articles during his graduate program. After graduation, he was finically supported by the China Scholarship Council to conduct his research in the Institute of Polymer Composites

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