Materials Science and Engineering R 113 (2017) 1–29

Contents lists available at ScienceDirect

Materials Science and Engineering R

journal homepage: www.elsevier.com/locate/mser

Processing-structure-property relationships of continuous carbon fiber polymer-matrix composites

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ARTICLE INFO

Article history:
Received 1 September 2016
Accepted 16 January 2017
Available online 1 February 2017

Keywords:
Carbon fiber
Polymer-matrix composite
Processing
Structure
Properties
Applications

ABSTRACT

This paper reviews the processing-structure-property relationships of continuous carbon fiber polymer-matrix composites, which are important for lightweight structures. Such relationships constitute the guiding principles in materials design, development and tailoring. Although much research has been performed for decades on the mechanical behavior of continuous fiber composites, the functional behavior (electrical, electromagnetic, dielectric, thermal, thermoelectric, vibration damping, etc.) of these materials are quite new, with research activities that are rapidly growing in recent years due to the importance of multifunctional structural materials and smart structures. In addition, the combined use of continuous fibers and nanofillers such as nanofibers and nanotubes is a relatively new direction that has provided hierarchical or multi-scale composites with attractive properties. The properties addressed in this review relate to the mechanical (static, dynamic, fatigue, wear), viscoelastic, thermal expansion, thermal conductivity, electrical, piezoresistive, dielectric, electromagnetic, thermoelectric and environmental durability behavior, as well as the effects of temperature, humidity, strain and damage. The structure/processing parameters relate to the fiber arrangement, interlaminar interface, curing pressure, fiber type, fiber treatments, fiber volume fraction, fillers, interlayers, coatings, through-thickness rods, polymer matrix and the fastening-relevant interface between contacting unbonded composites. In addition, this paper reviews the rapidly broadening applications of this class of materials.

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http://dx.doi.org/10.1016/j.mser.2017.01.002
0927-796X/

1. Introduction

Processing governs the structure of a material. The structure in term governs the properties of the material. The processing-structure-property relationships constitute the guiding principles in materials design, development and tailoring, and represent the core of materials science and engineering. This core in the context of metallurgy has long been established. However, this core in the context of non-metallic materials has not been addressed adequately.

Composite materials refer to artificial combinations of materials, such that a certain material is the matrix and certain other material is the filler (whether continuous or discontinuous). The processing-structure-property relationships of composite materials have not been addressed adequately, particularly in relation to properties other than the mechanical properties.

Due to their combination of low density, high strength and high elastic modulus, continuous carbon fibers are dominant among reinforcements used for high-performance lightweight composite materials, particularly polymer-matrix composites. The dominance of polymer-matrix composites among composites with various matrices (polymer, carbon, ceramic, metal, cement, etc.) stems from the relative ease (low cost) of fabrication and the relatively good bonding ability of polymers. Applications include aircraft, satellites, automobile, sporting goods, wind turbines, structural repair, etc.

Much investigation has been performed over decades on the mechanical behavior of continuous fiber polymer-matrix composites and mechanics-based theories for explaining the mechanical behavior are well established. However, the functional behavior (electrical, electromagnetic, dielectric, thermal, thermoelectric, vibration damping, etc.) of these materials are relatively new, with research activities that are rapidly growing in recent years due to