Composite Structures 92 (2010) 2793–2810

Contents lists available at ScienceDirect

Composite Structures

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

Review

A review of recent research on mechanics of multifunctional composite materials and structures

Ronald F. Gibson

Department of Mechanical Engineering, University of Nevada, Reno, MS-312, Reno, NV 89557, United States

ARTICLE INFO

Article history:
Available online 8 May 2010

Keywords:
Multifunctional
Material
Structure
Composite
Nanocomposite
Polymer

ABSTRACT

In response to the marked increase in research activity and publications in multifunctional materials and structures in the last few years, this article is an attempt to identify the topics that are most relevant to multifunctional composite materials and structures and review representative journal publications that are related to those topics. Articles covering developments in both multiple structural functions and integrated structural and non-structural functions since 2000 are emphasized. Structural functions include mechanical properties like strength, stiffness, fracture toughness, and damping, while non-structural functions include electrical and/or thermal conductivity, sensing and actuation, energy harvesting/storage, self-healing capability, electromagnetic interference (EMI) shielding, recyclability and biodegradability. Many of these recent developments are associated with polymeric composite materials and corresponding advances in nanomaterials and nanostructures, as are many of the articles reviewed. The article concludes with a discussion of recent applications of multifunctional materials and structures, such as morphing aircraft wings, structurally integrated electronic components, biomedical nanoparticles for dispensing drugs and diagnostics, and optically transparent impact absorbing structures. Several suggestions regarding future research needs are also presented.

Contents

1. Introduction

The number of publications dealing with various aspects of the mechanics of multifunctional materials and structures has increased markedly in recent years. Fig. 1 shows how the number of English language refereed journal articles in multifunctional materials and structures has steadily increased since 2000, based on data collected from the Engineering Village© web-based information service. Along with the increase in the number of publications in this area comes a need for a comprehensive review article,

E-mail address: ronaldgibson@unr.edu

0263-8223/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.compstruct.2010.05.003

Nomenclature

A	surface area of spherical particle
C_D	drag coefficient
C_L	lift coefficient
E_B	nominal stored battery energy
E_i	incident electric field
E_t	transmitted electric field
H_i	incident magnetic field
H_t	transmitted electric field
k_s	piezoelectric coupling coefficient for sensing
k_a	piezoelectric coupling coefficient for actuation
k_c	electrical conductivity of composite
k_f	electrical or thermal conductivity of filler
k_m	electrical or thermal conductivity of matrix
$K_{Ic_{healed}}$	Mode I fracture toughness for healed specimen
$K_{Ic_{virgin}}$	Mode I fracture toughness for virgin specimen
$P_{c_{healed}}$	critical fracture load for healed Mode I fracture specimen
$P_{c_{virgin}}$	critical fracture load for virgin Mode I fracture specimen
S	wing planform area
SE	EMI shielding effectiveness
t_E	flight endurance time
U_e	electrical (dielectric) energy density
V	volume of spherical particle
W_B	battery subsystem weight
W_{PL}	payload subsystem weight
W_{PR}	propulsion subsystem weight
W_S	structure subsystem weight
W_m	mechanical (strain) energy density
α	conductivity exponent
η	crack healing efficiency
η_B	efficiency factor for battery
η_P	propeller efficiency
ρ	air density
φ	concentration of carbon nanotubes
φ_c	critical concentration of carbon nanotubes, or percolation threshold

and the objective of this paper is to address this need. The emphasis of the publications surveyed will be on the mechanics aspects, although the multidisciplinary nature of the topic will lead to the inclusion of some publications on relevant disciplines such as materials science, thermodynamics, and electronics. In addition, the vast majority of the surveyed articles deal with polymer composites, and by definition, a multifunctional material must be a composite. Due to the large number of articles involved, and the lack of electronic access to many conference proceedings, the emphasis of this review is on the more accessible refereed journal articles. It was not practical to cover all of these articles, and since some articles had already been covered by previous related review articles, an attempt was made to select representative articles in each of the relevant categories. According to Fig. 1, most of the relevant articles have been published since 2000, so that is the focus of this review.

The increased interest in multifunctional materials and structures is driven by the need for the development of new materials and structures that simultaneously perform (a) multiple structural functions, (b) combined non-structural and structural functions, or (c) both. One example of a multifunctional structure of type (a) would be a composite structure that has high strength, high stiffness, high fracture toughness and high damping. An example of type (b) would be a load-bearing structure that has the capability of providing its own noise and vibration control, self-repair, thermal insulation, and energy harvesting/storage, whereas an example of type (c) would be a structure combining the functions of both type (a) and type (b). Most of the recent developments in multifunctional materials and structures tend to be of type (b).

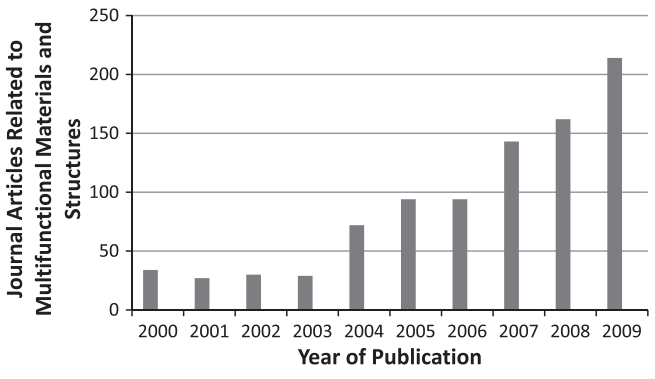

Fig. 1. Recent English language refereed journal publications related to multifunctional materials and structures. Data collected from Engineering Village© web-based information service.

Multifunctional materials are necessarily composite materials, and the strong growth in the use of composites has been greatly influenced by multifunctional design requirements. The traditional approach to the development of structures is to address the load-carrying function and other functional requirements separately, resulting in a suboptimal load-bearing structure with add-on attachments which perform the non-structural functions with the penalty of added weight. Recently, however, there has been increased interest in the development of load-bearing materials and structures which have integral non-load-bearing functions, guided by recent discoveries about how multifunctional biological systems work.

Due to the interdisciplinary nature of multifunctional materials and structures, and the need to avoid duplication in the current review, it is appropriate to cite several relevant previous review articles. For example, Baur and Silverman [1] reviewed the challenges and opportunities in multifunctional nanocomposite aerospace structures, while Ye et al. [2] reviewed developments in the application of artificial intelligence to functionalize composite airframes. By definition, a multifunctional material must be a composite, and it is becoming increasingly apparent that nanostructured composites can produce and/or enhance multifunctionality in ways that conventional composites could not. For example, Thostenson et al. [3] and Chou et al. [4] reviewed recent advances related to the science and technology of carbon nanotubes and their composites; Breuer and Sundararaj [5] reviewed recent studies on polymer/carbon nanotube composites; Li et al. [6] surveyed the recent advances related to the use of carbon nanotubes and their composites as sensors and actuators, while Gibson et al. [7] reviewed recent publications dealing with vibrations of carbon nanotubes and their composites, and Sun et al. [8] reviewed articles dealing with various types of energy absorption in nanocomposites. With the addition of very small amounts of carbon nanotubes, non-conducting polymers and polymer composites can be transformed to conducting materials, thus enhancing their multifunctionality. Accordingly, Bauhofer and Kovacs [9] have re-