



# Toughening Mechanisms in Composite Materials

Edited by  
Qinghua Qin and  
Jianqiao Ye

Woodhead Publishing Series in Composites  
Science and Engineering: Number 55

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*Qinghua Qin and Jianqiao Ye*



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Woodhead Publishing is an imprint of Elsevier



Woodhead Publishing is an imprint of Elsevier  
80 High Street, Sawston, Cambridge, CB22 3HJ, UK  
225 Wyman Street, Waltham, MA 02451, USA  
Langford Lane, Kidlington, OX5 1GB, UK

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### British Library Cataloguing in Publication Data

A catalogue record for this book is available from the British Library.

**Library of Congress Control Number:** 2015931787

ISBN 978-1-78242-279-2 (print)

ISBN 978-1-78242-291-4 (online)

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# Introduction to the composite and its toughening mechanisms

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## 1.1 Basic concepts

The word “composite” usually signifies that two or more separate materials are combined on a macroscopic scale to form a structural unit for various engineering applications. Each of the material components may have distinct thermal, mechanical, electrical, magnetic, optical, and chemical properties. It is noted that a composite composed of an assemblage of these different materials gives us a useful new material whose performance characteristics are superior to those of the constituent materials acting independently (Ye, 2003; Qin and Yang, 2008). One or more of the material components is usually discontinuous, stiffer, and stronger and known as the reinforcement; the less stiff and weaker material is continuous and called the matrix. Sometimes, because of chemical interactions or other processing effects, an additional distinct phase, called an interphase, exists between the reinforcement and the matrix (Damiel and Ishai, 2006). Composite materials have some advantages when compared to their components or metal parts. Some material properties that can be improved by forming a composite material are (Jones, 1999):

- Strength
- Stiffness
- Wear resistance
- Weight
- Fatigue life
- Extreme temperature response
- Thermal insulation or conduction
- Electrical insulation or conduction
- Acoustical insulation or conduction
- Response to nuclear, X-ray, or magnetic radiation
- Chemical response or inertness to an environment (corrosion resistance)
- Electromagnetic and radar insulation or conduction
- Crack (fracture) resistance and arrest
- Cost
- Fabrication
- Temperature-dependent behavior
- Attractiveness.

Further, composite materials have the following advantages: (1) composites can have unique properties (e.g., specific strength and modulus) that are significantly better



than their metal, polymer, and ceramic counterparts; (2) composites offer a greater flexibility in designing and manufacturing a specific engineering structure; (3) composites can be fabricated to a final product from raw materials; and (4) composites can be tailored to have given properties required by the end users.

### **1.1.1 Matrix materials**

Polymers, metals, and ceramics are all used as matrix materials in composites. They are the constituents that are continuously distributed in a composite. Examples of matrix materials are (1) polymers: epoxies, polyesters, phenolics, silicone, polyimide, nylon, polyethylene, polystyrene, and polycarbonate. The first five belong to the category of thermoset plastic, which is the material that can be melted and shaped only once (if it is heated a second time, it tends to crack or disintegrate); whereas the last four are categorized as thermoplastic, which is, in contrast, a material that can be melted and shaped over and over again; (2) metals: steel, iron, aluminum, zinc, carbon, copper, nickel, silver, titanium, and magnesium; and (3) ceramics: alumina, silicon carbide, aluminum nitride, silicon nitride, zirconia, and mullite. The functions of the matrix are to transmit forces between fibers, hold fibers in proper orientations, protect fibers from the environment, and stop cracks from spreading between fibers. To effectively realize those functions, a desired matrix material should have good ductility, high toughness and interlaminar shear strength, stable temperature properties, and high moisture/environmental resistance. In addition, a strong interface bond between the fiber and matrix materials is desirable, so the matrix must be capable of developing a mechanical or chemical bond with the fiber (Gibson, 2012).

### **1.1.2 Reinforcement materials**

Reinforcement materials usually add rigidity and greatly impede crack propagation. In particular, they enforce the mechanical properties of the matrix and, in most cases, are harder, stronger, and stiffer than the matrix. The reinforcement can be divided into four basic categories: fibers, particulates, fillers, and flakes.

Flakes are in flat platelet form and have a primarily two-dimensional geometry with strength and stiffness in two directions. They can form an effective composite material when suspended in a glass or plastic. Ordinarily, flakes are packed parallel to one another with a resulting higher density than fiber-packing concepts. Typical flake materials are mica, aluminum, and silver. Mica flakes embedded in a glassy matrix provide composites that can be machined easily and are used in electrical applications. Aluminum flakes are commonly used in paints and other coatings in which they orient themselves parallel to the surface of the coating. Silver flakes are used where good conductivity is required.

Fillers are particles or powders added to material to change and improve the physical and mechanical properties of composites. They are also used to lower the consumption of a more expensive binder material. In particular, fillers are used to modify or enhance properties such as thermal conductivity, electrical resistivity, friction, wear resistance, and flame resistance. Typical fillers are calcium carbonate,