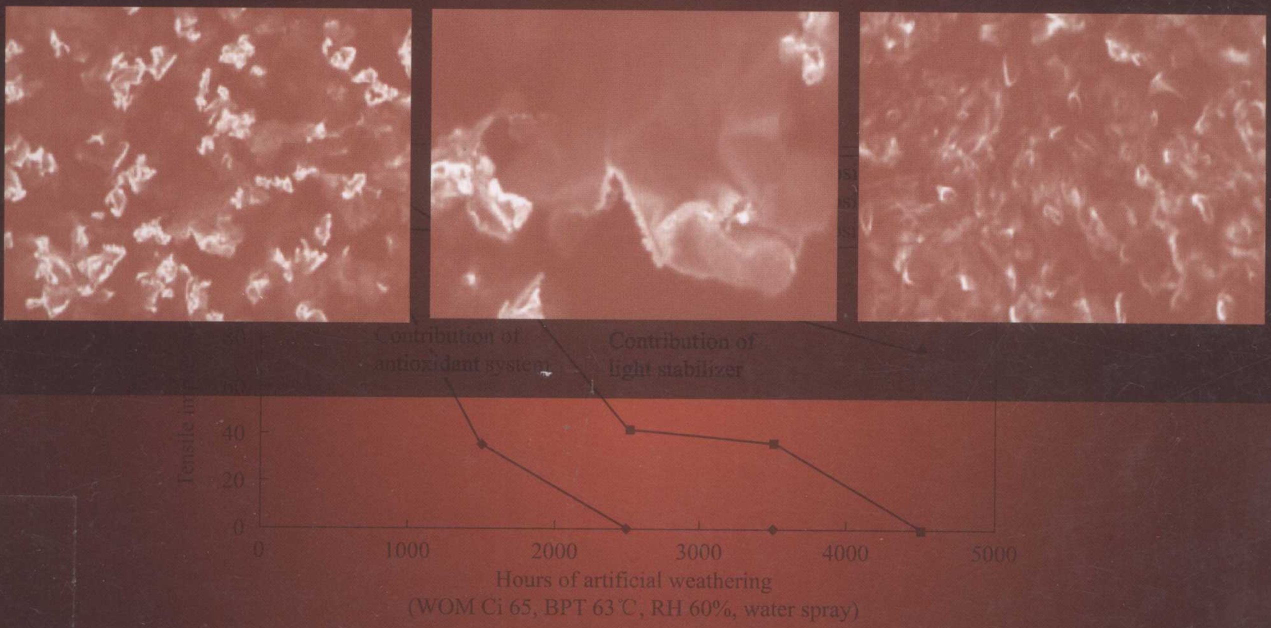
“十二五”普通高等教育本科规划教材

复合材料与工程专业英语

郝凌云　主编　　陈晓玉　叶原丰　副主编



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·北京·

《复合材料与工程专业英语》旨在指导该专业学生阅读相关专业的英语书刊和文献，进一步提高学生阅读英语科技资料的能力，并能以英语为工具获取复合材料与工程专业所需要的信息。本书共分 8 章，共 23 个单元，每个单元有一篇精读课文和两篇泛读课文，配有相应的练习题、注释和词汇表。其中第 1 章为复合材料概论，主要介绍复合材料的概念、分类及应用；第 2 章和第 3 章分别介绍基体材料和加强材料，第 4 章介绍界面的分类、力学特征和检测方法。第 5～8 章分别介绍高分子基复合材料、金属基复合材料、陶瓷基复合材料、纳米复合材料的概念、制造技术和应用。

本书可作为普通高等院校复合材料与工程专业本科生教材外，也可作为相关材料专业的研究生、教师及企业技术人员在学习教学与研发过程中参考。

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前言

专业英语是从语言学习到信息交流的发展，也是大学英语教学中一个不可缺少的重要的组成部分,担负着促使学生学会在专业领域中用英语去进行有实际意义的交流。高质量的专业英语教材是完成专业英语教学的基础。

当今社会与外语联系越来越紧密,同时也对复合材料与工程专业的学生掌握英语的程度有了更高的要求。《复合材料与工程专业英语》是根据大学英语教学大纲（理工科本科用）的专业阅读部分的要求编写的。编写的主要目的是扩充学生的复合材料与工程专业的词汇量，提高学生阅读和翻译英语文献和资料的能力，深化学生对本专业关键技术的认识，了解本学科目前的进展与动向，从而契合该专业的工程化教育及学生的国际化培养。

本教材收集了陶瓷基体、聚合物基体、金属基体等复合材料的制备、界面控制、材料性能及应用等复合材料与工程专业领域的最新英语文献，共有八章内容，每章包括精读和泛读两部分，均设有词汇表、注释和练习项目，读者可在掌握复合材料与工程专业英语的翻译及写作技巧的同时进一步学习专业的有关知识。

本教材由郝凌云主编。其中第1章由郝凌云、冯志强编写；第2章由叶原丰编写；第3章由林青编写；第4章由陈晓玉、李俊琳编写，第5章由陈晓宇编写；第6章和第8章由张小娟编写；第7章由韦鹏飞编写；教材后的阅读理解和词汇表由陈晓玉统一编撰、汇总。

由于编者水平有限，对本书中不当之处，敬请广大读者批评指正。

郝凌云

2014年1月

Contents

Chapter 8 Nanocomposite ········ 260

Appendixes ········ 309

Glossary ········ 314

Chapter 1

Introduction to composite materials

Unit 1 Introduction and conception

Intensive Reading

Natural and Man-made Composites

A composite is a material that is formed by combining two or more materials to achieve some superior properties. Almost all the materials which we see around us are composites. Some of them like woods, bones, stones, etc. are natural composites, as they are either grown in nature or developed by natural processes. Wood is a fibrous material consisting of thread-like hollow elongated organic cellulose that normally constitutes about 60%-70% of wood of which approximately 30%-40% is crystalline, insoluble in water, and the rest is amorphous and soluble in water. Cellulose fibres are flexible but possess high strength. The more closely packed cellulose provides higher density and higher strength. The walls of these hollow elongated cells are the primary load-bearing components of trees and plants. When the trees and plants are live, the load acting on a particular portion (e.g., a branch) directly influences the growth of cellulose in the cell walls located there and thereby reinforces that part of the branch, which experiences more forces. This self-strengthening mechanism is something unique that can also be observed in the case of live bones. Bones contain short and soft collagen fibres i.e., inorganic calcium carbonate fibres dispersed in a mineral matrix called apatite. The fibres usually grow and get oriented in the direction of load. Human and animal skeletons are the basic structural frameworks that support various types of static and dynamic loads. Tooth is a special type of bone consisting of a flexible core and the hard enamel surface. The compressive strength of tooth varies through the thickness. The outer enamel is the strongest with ultimate compressive strength as high as 700MPa. Tooth seems to have piezoelectric properties i.e., reinforcing cells are formed with the application of pressure. The most remarkable features of woods and bones are that the low density, strong and stiff fibres are embedded in a low density matrix resulting in a strong, stiff and lightweight composite (Tab. 1.1). It is therefore no wonder that early development of aero-planes should make use of woods as one of the primary structural materials, and about two hundred million years ago, huge flying amphibians, pteranodons and pterosaurs, with wing spans of 8-15 m, could soar from the mountains like the present-day hang-gliders. Woods and bones in many respect, may be considered to be predecessors to modern man-made composites.

Tab. 1.1 Typical mechanical properties of natural fibres and natural composites

Materials	Density /(kg/m^3)	Tensile modulus /GPa	Tensile strength /MPa
Fibres			
Cotton	1540	1.1	400
Flax	1550	1	780
Jute	850	35	600
Coir	1150	4	200
Pineapple leaf	1440	65	1200
Sisal	810	46	700
Banana	1350	15	650
Asbestos	3200	186	5860
Composites			
Bone	1870	28	140
Ivory	1850	17.5	220
Balsa	130	3.5	24
Spruce	470	11	90
Birch	650	16.5	137
Oak	690	13	90
Bamboo	900	20.6	193

Early men used rocks, woods and bones effectively in their struggle for existence against natural and various kinds of other forces. The primitive people utilized these materials to make weapons, tools and many utility-articles and also to build shelters. In the early stages they mainly utilized these materials in their original form. They gradually learnt to use them in a more efficient way by cutting and shaping them to more useful forms. Later on they utilized several other materials such as vegetable fibres, shells, clays as well as horns, teeth, skins and sinews of animals.

Woods, stones and clays formed the primary structural materials for building shelters. Natural fibres like straws from grass plants and fibrous leaves were used as roofing materials. Stone axes, daggers, spears with wooden handles, wooden bows, fishing nets woven with vegetable fibers, jewelleries and decorative articles made out of horns, bones, teeth, semiprecious stones, minerals, etc. were but a few examples that illustrate how mankind, in early days, made use of those materials. The limitations experienced in using these materials led to search for better materials to obtain a more efficient material with better properties. This, in turn, laid the foundation for development of man-made composite materials.

The most striking example of an early man-made composite is the straw-reinforced clay which molded the civilization since prehistoric times. Egyptians, several hundred years B.C., were known to reinforce the clay like deposits of the Nile Valley with grass plant fibres to make sun baked mud bricks that were used in making temple walls, tombs and houses. The watch towers of the far western Great Wall of China were supposed to have been built with straw-reinforced bricks during the Han Dynasty (about 200 years B.C.). The natural fibre reinforced clay, even today continues to be one of the primary housing materials in the rural sectors of many third world countries.

The other classic examples are the laminated wood furniture used by early Egyptians (1500 B.C.), in which high quality wood veneers are bonded to the surfaces of cheaper woods. The origin of paper which made use of plant fibres can be traced back to China (108 A.D.). The bows used by the warriors under the

Mongolian Chief Djingiz Chan (1200 A.D.) were believed to be made with the adhesive bonded laminated composite consisting of buffalo or antilope horns, wood, silk and ox-neck tendons. These laminated composite bows could deliver arrows with an effective shoot in range of about 740 m.

Potteries and hydraulic cement mortars are some of the earliest examples of ceramic composites. The cloissone ware of ancient China is also a striking example of wire reinforced ceramics. Fine metallic wires were first shaped into attractive designs which were then covered with colored clays and baked. In subsequent years, fine metallic wires of various types were cast with different metal and ceramic matrices and were utilized in diverse applications. Several other matrix materials such as natural gums and resins, rubbers, bitumen, shellac, etc. were also popular. Naturally occurring fibres such as those from plants (cotton, flax, hemp, etc.), animals (wool, fur and silk) and minerals (asbestos) were in much demand. The high value textiles woven with fine gold and silver threads received the patronage from the royalty and the rich all over the world. The intricate, artful gold thread embroidery reached its zenith during the Mughal period in the Indian subcontinent. The glass fibres were manufactured more than 2000 years ago in Rome and Mesopotamia and were abundantly used in decoration of flower vases and glass wares in those days.

The twentieth century has noticed the birth and proliferation of a whole gamut of new materials that have further consolidated the foundation of modern composites. Numerous synthetic resins, metallic alloys and ceramic matrices with superior physical, thermal and mechanical properties have been developed. Fibres of very small diameter (<10 nm) have been drawn from almost all materials. They are much stronger and stiffer than the same material in bulk form. The strength and stiffness properties have been found to increase dramatically, when whiskers (i.e., single crystal fibers) are grown from some of these materials. Fig. 1.1 illustrates the specific tensile strength and the specific tensile modulus properties are obtained by dividing the strength (MPa) and modulus (GPa) by either the density (kg/m^3) or the specific gravity of the material. Because of the superior mechanical properties of fibers, the use of fibers as reinforcements started gaining momentum during the twentieth century. The aerospace industries took the lead in using fiber reinforced laminated plastics to replace several metallic parts. The fibres like glass, carbon, boron and Kevlar, and plastics such as phenolics, epoxies and polyesters caught the imagination of composite designers. One major advantage of using fibre reinforced plastics (FRP) instead of metals is that they invariably lead to a weight efficient design in view of their higher specific modulus and strength properties.

Composites, due to their heterogeneous composition, provide unlimited possibilities of deriving any characteristic material behavior. This unique flexibility in design tailoring plus other attributes like ease of manufacturing, especially molding to any shape with polymer composites, repairability, corrosion resistance, durability, adaptability, cost effectiveness, etc. have attracted the attention of many users in several engineering and other disciplines. Every industry is now vying with each other to make the best use of composites. One can now notice the application of composites in many disciplines starting from sports goods to space vehicles. This worldwide interest during the last four decades has led to the prolific advancement in the field of composite materials and structures. Several high performance polymers have now been developed. Substantial progress has been made in the development of stronger and stiffer fibres, metal and ceramic matrix composites, manufacturing and machining processes, quality control and nondestructive evaluation techniques, test methods as well as design and analysis methodology. The modern man-made composites have now firmly established as the future material and are destined to dominate the material scenario right through the twenty-first century.

[Copy from: “COMPOSITE MATERIALS AND STRUCTURES”, Chapter 1 Introduction to composite materials, P. K. Singa Published by: Composite Centre of Excellence, AR & DB, Department of Aerospace Engineering, I.I.T. Kharagpur]

New words and expressions

amorphous	*a.* 无组织的，模糊的；无固定形状的，非结晶的
load-bearing	支撑结构
elongated cell	细长细胞
collagen fibre	胶原纤维
apatite	*n.* 磷灰石
enamel surface	釉质表面
piezoelectric propert	压电性能
amphibian	*n.* 两栖动物，水旱两生植物; 水陆两用车，水陆两用飞行器 *a.* 两栖（类）的，水陆两用的；具有双重性的
pteranodon	*n.* 无齿翼龙
pterosaur	*n.* 翼龙
hang-glider	滑翔机
flax	*n.* 亚麻
jute	*n.* 黄麻
coir	*n.* 椰子壳的纤维;棕
sisal	*n.* 剑麻
balsa	*n.* 西印度白塞木
spruce	*n.* 云杉
birch	*n.* 桦木
veneer	*n.* 表层饰板
bow	*n.* 弓
pottery	*n.* 陶器
hydraulic cement mortar	液压水泥砂浆
cloissone ware	景泰蓝制品
bitumen	*n.* 沥青
shellac	*n.* 虫胶
gold thread embroidery	金线刺绣
phenolics	*n.* 酚醛塑料
epoxy	*n.* 环氧树脂
polyester	*n.* 聚酯，涤纶
heterogeneous	*a.* 多种多样的；不均匀的，异质的

Notes

1) When the trees and plants are live, the load acting on a particular portion (e.g., a branch) directly influences the growth of cellulose in the cell walls located there and thereby reinforces that part of the branch, which experiences more forces. 存活树木或植物的纤维素在其特殊部位（如枝干）的附着支撑作用会直接影响到该部位细胞壁上纤维素的生长，故使枝干等部位表现出更耐受强力的特征。

2) The most remarkable features of woods and bones are that the low density, strong and stiff fibres are embedded in a low density matrix resulting in a strong, stiff and lightweight composite. 木材和骨头具有密度低、强度高和柔韧好的显著特点，因为纤维沉积在低密度的介质中会形成高强度、高韧性和轻质地的复合材料。

3) Substantial progress has been made in the development of stronger and stiffer fibres, metal and ceramic matrix composites, manufacturing and machining processes, quality control and nondestructive evaluation techniques, test methods as well as design and analysis methodology. 寻找更强、更韧纤维、金属和陶瓷基复合材料，优化复合材料制造及加工工艺、探究质量控制和无损伤检测技术以及对其设计和评估等复合材料领域的各方面研究都在持续进展。

Exercises

1. Question for discussion

The modern man-made composites have now firmly established as the future material and are destined to dominate the material scenario right through the twenty-first century. What are the main reasons about this trend?

2. Translate the following into Chinese

1) It is therefore no wonder that early development of aero-planes should make use of woods as one of the primary structural materials, and about two hundred million years ago, huge flying amphibians, pterendons and pterosaurs, with wing spans of 8-15 m, could soar from the mountains like the present-day hang-gliders.

2) Stone axes, daggers, spears with wooden handles, wooden bows, fishing nets woven with vegetable fibers, jewelleries and decorative articles made out of horns, bones, teeth, semiprecious stones, minerals, etc. were but a few examples that illustrate how mankind, in early days, made use of those materials.

3. Translate the following into English

1) 纤维素中空细长细胞是树和其他植物结构的基本支撑组分。

2) 向复合材料中增加晶须（即单晶纤维）后发现材料的强度和韧性显著增加了。

3) 航空业率先使用纤维增强基层状塑料材质代替其部分金属部件。

4. Reading comprehension

1) Which material is the man-made material?

A. pottery B. wood C. horn D. stone

2) What is the major advantage of using fibre reinforced plastics (FRP) instead of metals?

A. Low density B. higher specific modulus

C. strength properties D. weight efficient design

Reading material

1-1 Introduction to Composite Materials Design (book review)

By Ever J. Barbero

As the new millennium approaches, composite materials are increasingly being used in engineering structures, particularly for civil infrastructure applications. The widespread applications of composite materials demand the development of user friendly engineering approaches to design of structures made of composite materials. Unlike in most traditional composites books, which emphasize the mechanics and material behaviors, the author of *Introduction to Composite Materials Design* aims to present a design analysis approach to composite materials and structures, by a balanced combination of fundamentals and with charts, simplified design equations, and a computer-aided design software.

One of the most advantageous features of a composite material is its flexibility in design, allowing the designer to "tailor" both structural shape (e.g., geometric parameters) and material architecture (e.g., fiber orientations and volume fractions) to achieve the best structural performance. To exploit this advantage, the author adopts a systematic approach to design of composite materials and structures, from material constituents to micro-, macro-, component, and system-level. The contents of the book are mainly divided into three parts: first, material and manufacturing (Chapters 1-3); second, design of composites in micro/macromechanics levels (Chapters 4-7); and third, design of composite structural components (Chapters 8-10).

In Part Ⅰ, basic concepts on composites design (Chapter 1), material selections (Chapter 2), and manufacturing processes (Chapter 3) are discussed. The author first highlights composites design philosophy and emphasizes the advantages and disadvantages of various materials and processing methods from the designer's point of view. Then, different types of fibers and matrices are described, and their typical properties tabulated. Also, various fiber forms and their common terminology are briefly described. A concise and clear explanation of creep, temperature, moisture, corrosion resistance, and flammability of polymers is also given. Finally, the basic characteristics of most common manufacturing processes (e.g., resin transfer molding, pultrusion, filament winding, etc.) are presented, but in the context of structural design rather than of material science and process engineering. The study of Part Ⅰ provide the readers with a sound background on material constituents, their properties, and manufacturing processes.

Part Ⅱ of the book is concerned with the design of composites at the micro- and macro-level. Once the designer selects the constituent materials (fiber and matrix) for the composite product to be designed, all of the required properties can be obtained from micromechanics formulations. In Chapter 4, the complexity of micromechanics models is described in qualitative terms, and the author directly introduces the most relevant micromechanics formulas for stiffness and strength predictions of unidirectional composites and continuous (or chopped) strand mats (CSM). The computation of fiber volume fraction (V_f) for typical plies consisting of unidirectional layers, composite mats, and CSM are also given in details. In the following chapter, the constitutive equations for a ply (layer or lamina) in material and global coordinate systems are presented and, consistent with classical formulations, the explicit expressions for ply transformed reduced stiffnesses and compliances are given as functions of fiber orientation. In the next two chapters the constitutive equations and various failure criteria for a laminate are presented. In addition to the traditional classical lamination theory, a relatively advanced lamination theory is introduced in Chapter 6 by including out of- plane shear-deformation effects. To facilitate the design process of a laminate by structural engineers, the concept of *carpet plots* is adopted, and the designers can directly obtain apparent moduli and strengths for a number of common laminate configurations. The use of *carpet plots* simplifies the design procedure and is a powerful tool for practicing designers dealing with the design of laminated panels.

Part Ⅲ presents the analysis and design of structural components, including beams, plates, stiffened panels, and shells made of composite materials. Preliminary design procedures for composite structural beams with respect to deflection, strength, and buckling are presented first, followed by a mechanics of materials formulation of thin-walled composite beams under bending and torsion loads; the explicit equations for beam axial, bending, and torsional stiffness coefficients are expressed in terms of wall (laminate) stiffnesses. Also, based on Barbera's extensive research, design equations for thin walled columns are given, accounting for Euler buckling, local buckling, material failure, and mode interaction. The next chapters provide preliminary design methods for composite panels and shells. In Chapter 9, design equations for plate bending and plate local buckling with various loading and boundary conditions are given, including corresponding *carpet plots* to facilitate the design effort. Also included is the design of stiffened panels consisting of flat or curved laminates attached to orthogonal grids and subject to bending and in-plane loads. Based on membrane theory for shells, the design procedures for curved structures (e.g., pressure vessels and pipes) are summarized in the final chapter.

Accompanying the book, the user's manual and guidelines for the computer program CADEC—*Computer Aided Design Environment for Composites*—is provided by the author. The program is available through the Internet as a windows application with an intuitive and web-browser-like graphical user interface. All of the formulas introduced in the book for micromechanics, ply mechanics, macromechanics, failure analysis, and thin-walled beam theory are integrated into CADEC. This program can aid designers and students with the solution of complicated problems related to composite materials and structures, and overcome tedious hand computations and matrix algebra operations. Also, in every chapter, the author includes sufficient design examples and exercises, and references at the end of each chapter are available for readers who want to further explore specific topics.

In conclusion, the book provides a wealth of valuable and practical information on design aspects of composite materials and structures. The systematic approach used in the book can enable designers to ''tailor'' composite materials to specific structural demands. The approach used follows a natural sequence, from selection of constituent materials and fiber architectures to final concurrent design of lay-up and geometry of structural components to satisfy specific structural performance requirements. The computer software CADEC can assist the designer at every stage of design and also help students understand the concepts better. The book can serve as a text book for senior undergraduate curriculum in composite materials design, and/or as a textbook for an introductory composite course for graduate students. Presently, we are using this book and the program CADEC to teach a new undergraduate course on composites for civil infrastructure; students in this class have no previous background on composites and limited expertise on mechanics. The book presents a refreshing new approach to composites design and is an absolutely valuable reference for structural designers, manufacturers, researchers, and state and federal officials leading research efforts on advanced materials.

[Selected from: “Book Review: Introduction to Composite Materials Design.”Journal of Composites for Construction，1999, 3(3), 151-152.]

New words and expressions

civil infrastructure	民用基础设施
terminology *n.*	术语
material creep	材料蠕变
flammability of polymer	聚合物阻燃性能
manufacturing process	制造工艺
pultrusion *n.*	拉挤成型
filament winding process	长丝卷绕工艺（缠绕成型法）
micromechanics model	细观力学模型
stiffness *n.*	刚度
strength *n.*	强度
continuous strand mat(CSM)	连续原丝毡
chopped strand mat(CSM)	短切毡
ply (layer or lamina)	（毛线、绳等的）股；层；厚；（夹板的）层片
compliance *n.*	柔度
constitutive equation	本构方程
failure criteria	破坏(岩体、土体时应力)准则、失效判据
apparent modulus	表观模量

Notes

1) resin transfer molding 树脂转移成型

2) out of plane shear deformation effect 非平面内剪切变形的影响

3) torsional stiffness coefficient 扭转刚度系数

4) tedious hand computation 繁琐的手工计算

5) matrix algebra operation 矩阵代数运算

6) To facilitate the design process of a laminate by structural engineers, the concept of *carpet plots* is adopted, and the designers can directly obtain apparent moduli and strengths for a number of common laminate configurations. 结构工程师采用*地毯图*概念，简便薄层设计过程，使设计者能够从具有相同构象的多层结构直接获取材料的表观模量和强度。

Reading comprehension

1. What are not described in the book *Introduction to Composite Materials Design*?

A. The balanced combination of fundamentals and with charts

B. The simplified design equations

C. The mechanics and material behaviors

D. The computer-aided design softwares

2. Which part of the book is the computation of fiber volume fraction (V_f) for typical plies consisting of unidirectional layers, composite mats, and CSM being discussed in?

A. Part Ⅰ B. Part Ⅱ C. Part Ⅲ D. Part Ⅳ

3. What aren't included by the analysis and design of structural components?

A. constituent B. beams, plates

C. stiffened panels D. shells made of composite materials.

4. CADEC——Computer Aided Design Environment for Composites program can aid designers with the solution of complicated problems related to______.

A. selection of constituent materials

B. tedious hand computations

C. matrix algebra operations

D. composite materials and structures

1-2 Basic Concepts

Structural materials can be divided into four basic categories: metals, polymers, ceramics, and composites. Composites, which consist of two or more separate materials combined in a structural unit, are typically made from various combinations of the other three materials. In the early days of modern man-made composite materials, the constituents were typically macroscopic. As composites technology advanced over the last few decades, the constituent materials, particularly the reinforcement materials, steadily decreased in size. Most recently, there has been considerable interest in "nanocomposites" having nanometer-sized reinforcements, such as carbon nanotubes.

The relative importance of the four basic materials in a historical context has been presented by Ashby, as shown schematically in Fig. 1.1 that clearly shows the steadily increasing importance of polymers, composites, and ceramics and the decreasing role of metals. Composites are generally used because they have desirable properties that cannot be achieved by any of the constituent materials acting alone. The most common example is the fibrous composite consisting of reinforcing fibers embedded in a binder or matrix material. Particle or flake reinforcements are also used, but they are generally not so effective as fibers. Although it is difficult to say with certainty when or where humans first learned about fibrous composites, nature provides us with numerous examples. Wood consists mainly of fibrous cellulose in a matrix of lignin, whereas most mammalian bone is made up of layered and oriented collagen fibrils in a protein-calcium phosphate matrix. The book of Exodus in the Old Testament recorded what surely must be one of the first examples of man-made fibrous composites, the straw-reinforced clay bricks used by the Israelites. The early natives of South and Central America apparently used plant fibers in their pottery. These early uses of fibrous reinforcement, however, were probably based on the desire to keep the clay from cracking during drying rather than on structural reinforcement. Much later, humans developed structural composites such as steel-reinforced concrete, polymers reinforced with fibers such as glass and graphite, and many other materials.

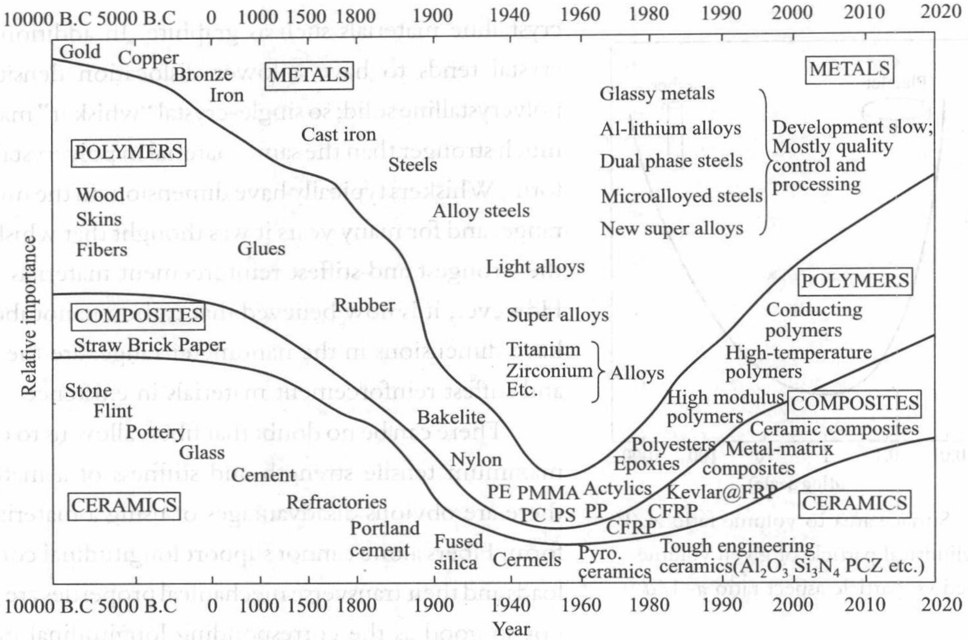


Fig. 1.1 The relative importance of metals, polymers, composites, and ceramics as a function of time. The diagram is schematic and describes neither tonnage nor value. The time scale is nonlinear (Form Ashby, M.F. 1987. Philosophical Transactions of the Royal Society of London, A322,393-407.With permission)

Fibrous reinforcement is so effective because many materials are much stronger and stiffer in fiber form than in bulk form. It is believed that this phenomenon was first demonstrated scientifically in 1920 by Griffith, who measured the tensile strengths of glass rods and fibers of different diameters. Griffith found that as the rods and fibers got thinner, they got stronger (see Fig.1.2 form ref. [3], as shown in ref [4],), apparently because the smaller the diameter, the smaller the likelihood that failure-inducing surface cracks would be generated during fabrication and hangling. By extrapolating these results, Griffith found that for very small diameters, the fiber strength approached the theoretical cohesive strength between adjacent layers of atoms, whereas for large diameters, the fiber strength dropped to near the strength of bulk glass theoretical cohesive strength.

Results similar to those published by Griffith have been reported for a wide of other materials. The reasons for the differences between fiber and bulk behavior, however, are not necessary the same for the other materials. For example polymeric fibers are stronger and stiffer than bulk polymers because of the highly aligned and extended polymer chains in the fibers and the randomly oriented polymer chains in the bulk polymer. A similar effect occurs in

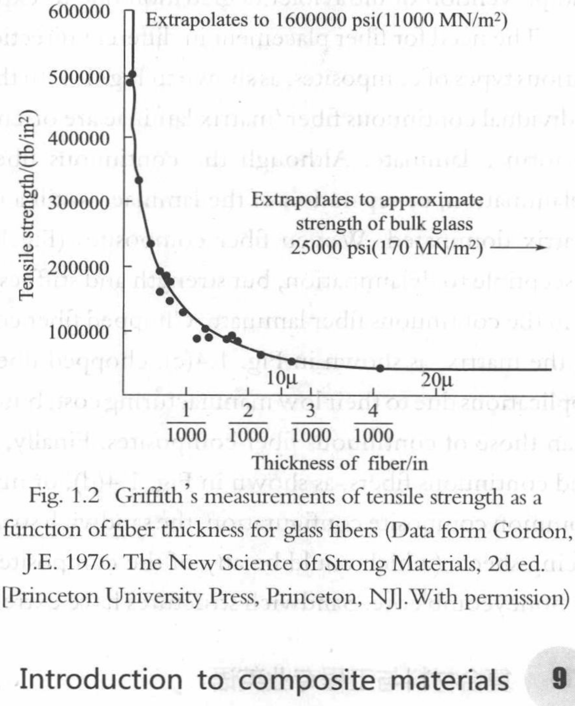


Fig. 1.2 Griffith's measurements of tensile strength as a function of fiber thickness for glass fibers (Data form Gordon, J.E. 1976. The New Science of Strong Materials, 2d ed. [Princeton University Press, Princeton, NJ].With permission)

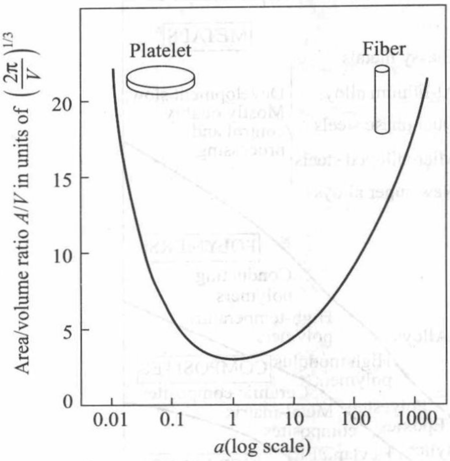
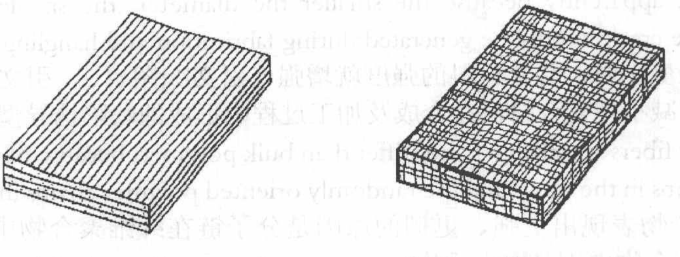


Fig. 1.3 Surface area-to-volume ratio A/V of a cylindrical particle of given volume plotted vs. particle aspect ratio $a=1/d$

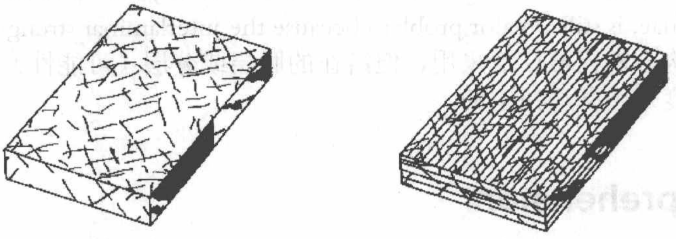
crystalline materials such as graphite. In addition, a single crystal tends to have a lower dislocation density than a polycrystalline solid; so single-crystal "whisker" materials are much stronger than the same material in polycrystalline bulk form. Whiskers typically have dimensions in the micrometer range, and for many years it was thought that whiskers were the strongest and stiffest reinforcement materials available. However, it is now believed that carbon nanotubes, which have dimensions in the nanometer range, are the strongest and stiffest reinforcement materials in existence.

There can be no doubt that fibers allow us to obtain the maximum tensile strength and stiffness of a material, but there are obvious disadvantages of using a material in fiber form. Fibers alone cannot support longitudinal compressive loads and their transverse mechanical properties are generally not so good as the corresponding longitudinal properties. Thus, fibers are generally useless as structural materials unless they are held together in s structural unit with a binder or matrix material and unless some transverse reinforcement is provided. Fortunately, the geometrical configuration of fibers also turns out to be very efficient from the point of view of interaction with the binder or matrix. As shown in Fig. 1.3 from ref [7], the ratio of surface area to volume for a cylindrical particle is greatest when the particle is in either platelet or fiber form. Thus, the fiber/matrix interfacial area available for stress transfer per unit volume of fiber increases with increasing fibers length-to-diameter ratio. The matrix also serves to protect the fibers from external damage and environmental attack. Transverse reinforcement is generally provided by orienting fibers at various angels according to the stress field in the component of interest. Filler particles are also commonly used in composites for a variety of reasons such as weight reduction, cost reduction, flame and smoke suppression, and prevention of ultraviolet degradation due to exposure to sunlight.

The need for fiber placement in different directions according to the particular application has led to various types of composites, as shown in Fig. 1.4. In the continuous fiber composite laminate (Fig.1.4[a]), individual continuous fiber/matrix laminae are oriented in the required directions and bonded together to form a laminate. Although the continuous fiber laminate is used extensively, the potential for delamination, or separation of the laminae, is still a major problem because the interlaminar strength is matrix dominated. Woven fiber composites (Fig.1.4 [b]) do not have distinct laminae and are not susceptible to delamination, but strength and stiffness are sacrificed because the fibers are not so straight as in the continuous fiber laminate. Chopped fiber composites may have short fibers randomly dispersed in the matrix, as shown in Fig. 1.4(c), chopped fiber composites are used extensively in high-volume applications due to their low manufacturing cost, but their mechanical properties are considerably poorer than those of continuous fiber composites. Finally, hybrid composites may consist of mixed chopped and continuous fibers, as shown in Fig. 1.4(d), or mixed fiber types such as glass and graphite. Another common composite configuration, the sandwich structure (Fig.1.5), consists of high-strength composite facing sheets (which could be any of the composites shown in Fig.1.4) bonded to a lightweight foam or honeycomb core. Sandwich structures have extremely high flexural stiffness-to-weight ratios and are widely used in aerospace structures. The design flexibility offered by these and other composite configurations is obviously quite attractive to designers, and the potential exists to design not only the structure but also the structural material itself.



(a) Continuous fiber composite (b) Woven fiber composite



(c) Chopped fiber composite (d) Hybrid composite

Fig. 1.4 Types of fiber-reinforced composites

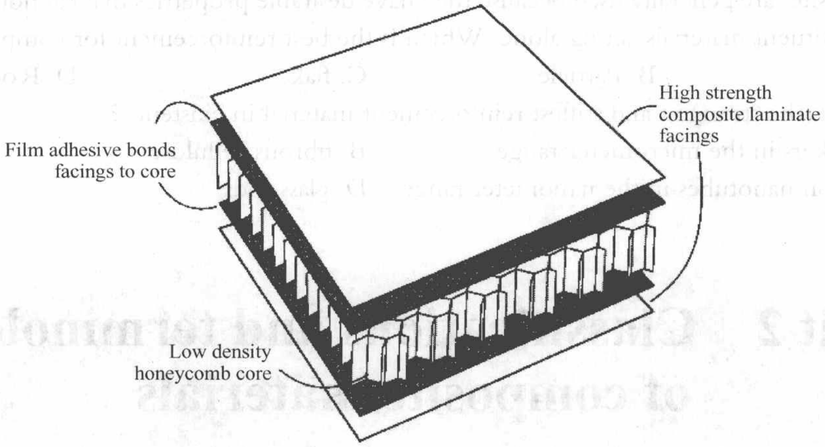


Fig. 1.5 Composite sandwich structure

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New words and expressions

lignin *n.*	木质素	longitudinal compressive load	纵向压载
mammalian bone	哺乳动物骨质	transverse mechanical property	横向力学性能
failure-inducing surface crack	缺陷诱导的表面裂纹	flexural stiffness-to-weight ratio	弯曲刚度与重量比
theoretical cohesive strength	理论结合强度		