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Introduction

Fiber-reinforced polymers (FRPs), which combine a fiber as the reinforcing material and a polymer as the matrix, are used as structural materials in many industrial fields. Carbon-fiber-reinforced polymers (CFRPs), which offer excellent properties such as high strength, high rigidity, and light weight have been used as structural materials since the 1980s for applications such as main structural members of aircraft, ships, automobiles, and other devices that must maintain high reliability during long operating periods. Research on the durability evaluation methods for FRP, especially for CFRP, has been pursued actively. Particularly, the accelerated testing methodology (ATM) should be established for long-term prediction of the useful life of CFRP and its structures, as shown in Figure 1.1. For ATM, data collection is conducted using accelerated testing. From the obtained data, design for durability becomes possible, that is, highly reliable CFRP structures can be developed.

Figure 1.2 shows the role of the resin matrix during molding and operation of CFRPs. The mechanical behavior of the resin matrix changes drastically from liquid to solid by curing, but that of carbon fibers remains perfectly stable during the molding process. The behaviors of physical aging, chemical aging, and viscoelasticity, all of which influence CFRPs' durability, are generated in the resin matrix and the interface during the operating processes. Carbon fibers are perfectly stable during operation, as shown in Figure 1.2. The most important characteristic is the viscoelasticity of the matrix resin because physical aging is preventable by pre-aging treatments. Chemical aging can also be prevented by the stabilization of molecular structures using various methods. However, viscoelasticity cannot be prevented to the desired degree as long as the polymer resin exists as the matrix. Therefore, the durability of CFRP and its structures is related mainly to the viscoelasticity of the matrix resin.

This book presents a discussion on the ATMs used for the design of durable CFRPs and structures from the viewpoint of the role of the resin matrix's viscoelasticity. Therefore, this book is necessary reading for development engineers who produce and apply CFRP as an advanced FRP to main structural members of aircraft, ships, automobiles, and other devices that must maintain high reliability during long periods of operation.

Durability of Fiber-Reinforced Polymers, First Edition. Yasushi Miyano and Masayuki Nakada.

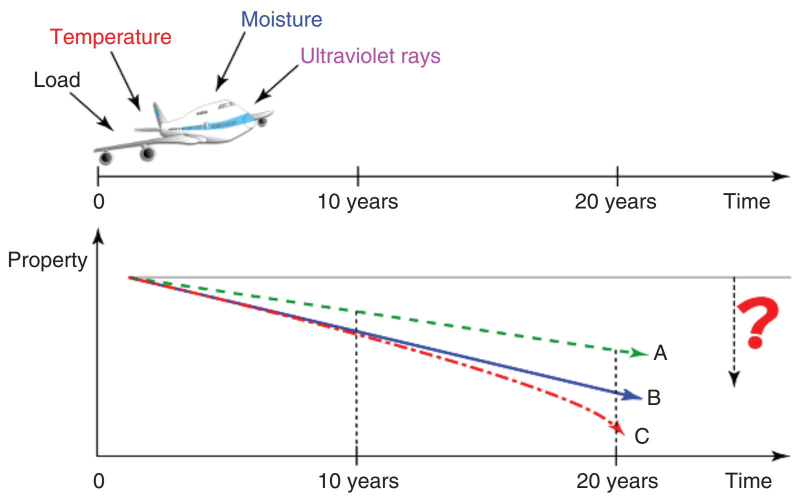

Figure 1.1 Necessity for accelerated testing.

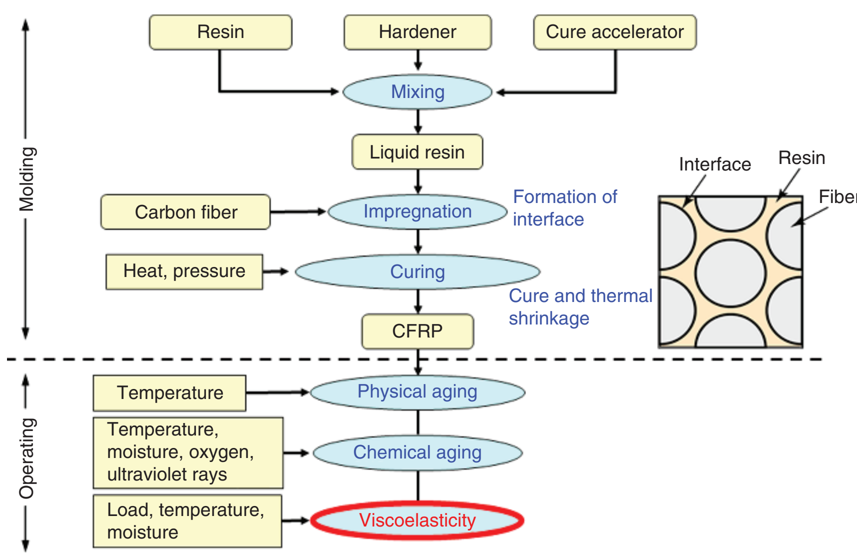

Figure 1.2 Role of matrix resin on CFRP.

Chapter 2 presents concepts of viscoelastic behavior and the time–temperature superposition principle (TTSP), which is the most important condition of an ATM. They are explained using mechanical models including the spring and dashpot models. Furthermore, the master curves of static, creep, and fatigue strengths, in addition to the viscoelastic behavior, are explained based on TTSP, by which these properties can be described as functions of time for a wide range of arbitrary reference temperatures.

In Chapter 3, from the data measured through creep tests and dynamic mechanical analysis (DMA) tests, the master curves of viscoelastic coefficients of the epoxy resin as an actual polymer resin are obtained. Furthermore, a simplified method of determining the long-term viscoelastic behavior is introduced.

In Chapter 4, the roles of the mixture for ascertaining the mechanical and thermal properties of carbon fiber and matrix resin from a unidirectional CFRP are assessed and presented for an actual CFRP.

In Chapter 5, the static and fatigue strengths for various load directions of unidirectional CFRP are measured at various strain rates and temperatures. The master curves of these strengths are constructed based on TTSP for the matrix resin. It is clarified experimentally that the same TTSP for the matrix resin holds for these strengths.

The formulations of static and fatigue strengths under various load directions of a unidirectional CFRP are introduced in Chapters 6 and 7, respectively. The master curves of these strengths are constructed using the measured data and the characteristics of strength degradation caused by increasing the time and temperature.

In Chapter 8, the statistical formulation of the creep failure time of unidirectional CFRP is presented. The creep failure time is predicted by substituting the statistical static strengths of unidirectional CFRP and the matrix resin viscoelasticity into this formulation, and is compared with the experimental data measured by creep tests.

Four applications of ATM are introduced in Chapters 9–12 as follows. In Chapter 9, the master curves of static strengths under various load directions of a unidirectional CFRP are obtained under water absorption condition as application 1. In addition, the influence of water absorption on these strengths is discussed. In Chapter 10, the master curves of static and fatigue flexural strengths of various woven FRP laminates under water absorption conditions are obtained as application 2. The influence of water absorption on the flexural strengths of FRP laminates combined with fibers and matrix resins of various kinds is discussed. In Chapter 11, life prediction of CFRP bolted joints is performed based on ATM as application 3. In Chapter 12, the micromechanics of failure (MMF)/ATM method is introduced as the life prediction method of CFRP structures. The life prediction of quasi-isotropic CFRP laminates with a central hole under static and fatigue compression loads is performed based on the MMF/ATM method as application 4.

Additionally, the following two topics are presented as the appendices titled “Effect of Physical Aging on the Creep Deformation of an Epoxy Resin” and “Reliable Test Method for Tensile Strength in Longitudinal Direction of Unidirectional CFRP.”