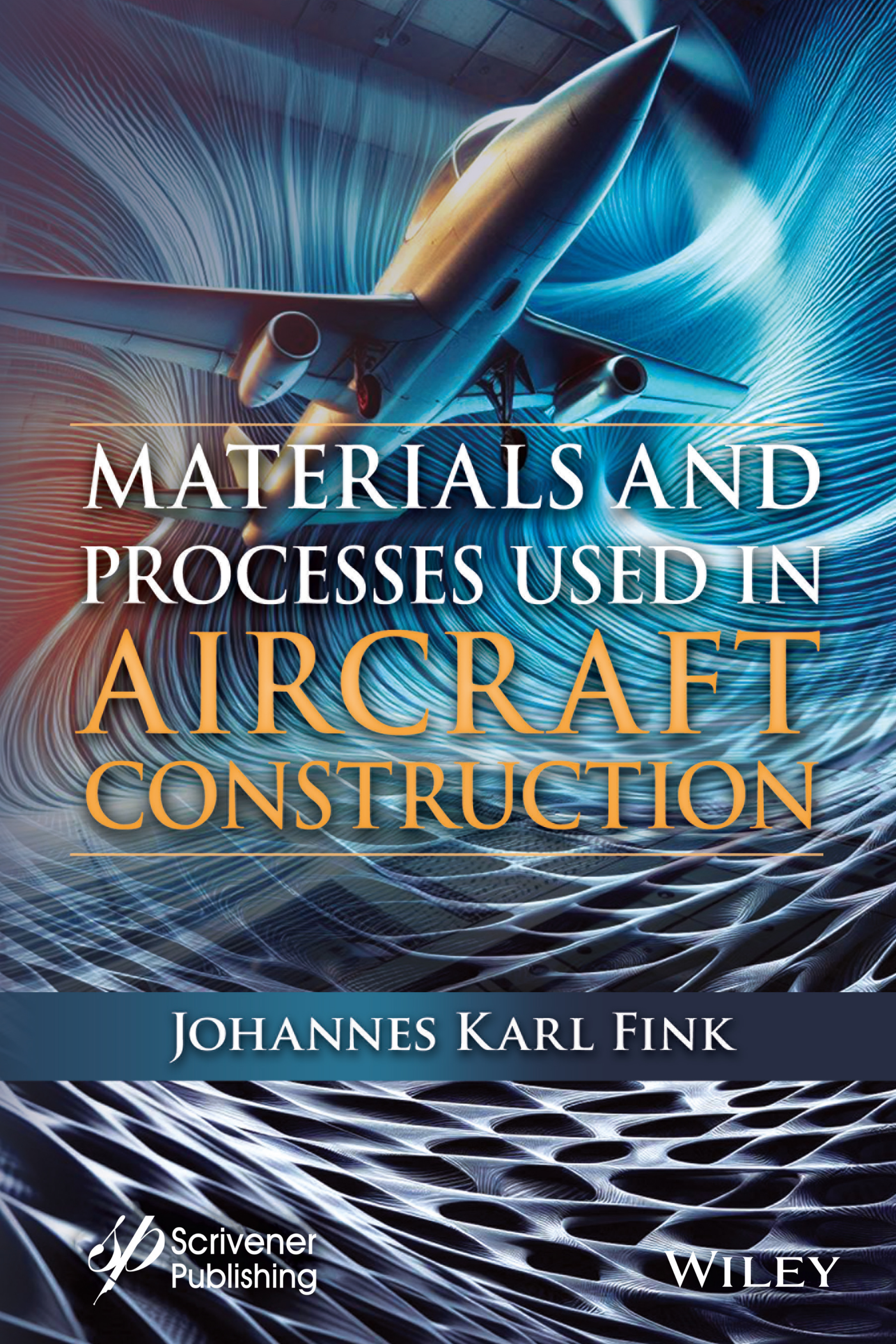

MATERIALS AND PROCESSES USED IN AIRCRAFT CONSTRUCTION

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Preface

This book focuses on issues involving the use of plastics in the aerospace industry. A detailed discussion of their various applications is included along with the innovations presented in the literature over the past decade.

Several important issues are discussed in the book, such as the health of aircrews and passengers during flying. In this case, examples are given of the effects of degraded engine oil and hydraulic fluid fumes of fume events. Here, continuous monitoring can significantly increase the operational safety.

Another important issue is the benefit of information acquired in real time, which would increase understanding of the fracture mechanics of composites, improving confidence in their use and broadening their applications. Moreover, since the cost of inspecting aircraft is approximately one-third of the cost of acquiring and operating composite structures, in order to compete in the increasingly demanding area of aircraft structures, the cost-effective techniques that need to be developed are discussed.

A wide range of topics are included herein. The book begins with a brief presentation of the evolution of aircraft design. Then, Chapter 2 presents the aircraft design standards that need to be followed, and Chapter 3 discusses the simulation of aircraft models. Basic materials used in aircraft construction are presented in Chapter 4, and special materials used in constructing aircraft are discussed in Chapter 5. Polymers used in the aerospace industry are given in Chapter 6 and aircraft systems are discussed in Chapter 7. Wing, helicopter and balloon design are presented in chapters 8 through 10, respectively. Issues concerning the monitoring and management of health are discussed in Chapter 11, and laminated materials used in the aerospace industry in Chapter 12. Finally, Chapter 13 deals with lightweight materials for aircraft applications.

This book will serve the needs of both those with only a passing knowledge of the field and specialists who need to increase their knowledge of a particular area.

How to Use This Book

Utmost care has been taken to present reliable data. Because of the vast variety of material presented here, it is recommended that the reader study the original literature for more complete information.

The reader should be aware that mostly US patents have been cited where available, but not the corresponding equivalent patents in other countries. For this reason, the author cannot assume responsibility for the completeness, validity or consequences of the use of the material presented herein. Every attempt has been made to identify trademarks; however, there were some that the author was unable to locate.

Index

There are three indices: an index of acronyms, an index of chemicals, and a general index.

In the index of chemicals, compounds that occur extensively, e.g., "acetone", are not included at every occurrence, but rather when they appear in an important context.

Acknowledgements

I am indebted to our university librarians, Dr. Christian Hasenhüttl, Friedrich Scheer, Christian Slamenik, and Elisabeth Groß for their support in literature acquisition. Also, many thanks to Boryana Rashkova for her helpful support.

I also want to express my gratitude to all the scientists who have carefully published their results concerning the topics dealt with herein. This book could not have been otherwise compiled.

Last, but not least, I want to thank the publisher, Martin Scrivener, for his abiding interest and help in the preparation of the text. In addition, my thanks go to Jean Markovic, who made the final copyedit with utmost care.

Johannes Fink

1

Evolution of Aircraft Design

The interdependency of aircraft technological systems, the global reach of the aviation transport industry, and the uncertainty surrounding potential atmospheric effects have made defining the relationship between aviation and environmental impact an arduous task, as shown in an existing monograph (1). As shown in an existing monograph (2), air travel continues to experience the fastest growth of all modes of transport, and although the energy intensity of the aviation transport system continues to decline, fuel use and total emissions have steadily risen.

This trend, which represents a conflict between growth and environmental impact, has motivated the aircraft manufacturing and airline industries, the scientific community, and governmental bodies to consider what pace of emissions reduction is acceptable. This chapter analyzes the historical influence of aircraft performance on cost to examine the potential pace of future efficiency improvements and emissions reduction. Technological and operational influences on aircraft energy intensity are quantified and correlated with direct operating cost and aircraft price using analytical and statistical models built upon historical data for US airlines. The energy intensity reduction potential and economic characteristics of future aircraft are also projected, through extrapolations of historical trends in aircraft technology and operations (1).

If the strong growth in air travel continues, world air traffic volume may increase five-fold to as much as twenty-fold by 2050 compared to the 1990 level and account for roughly two-thirds of global passenger miles traveled (IPCC, 1999; Schafer and Victor, 1997).

Global modeling estimates directed by the Intergovernmental Panel on Climate Change (IPCC) show that aircraft were responsible for about 3.5% of the total accumulated anthropogenic radiative forcing of the atmosphere in 1992, and their radiative forcing may increase to 5.0% of the total anthropogenic forcing with an uncertainty range of 2.7% to 12.2% by 2050 (IPCC, 1999). Given the strong growth in air travel and increasing concerns associated with the effects of aviation emissions on the global atmosphere, the aviation industry is likely to face a significant environmental challenge in the near future (Aylesworth, 1996). Current estimates show that global air traffic volume is growing so fast that total aviation fuel consumption and subsequent aviation emissions impacts on climate change will continue to grow despite future (1).

1.1 Unmanned Air Systems

Unmanned air systems trace their modern origins back to the development of aerial torpedoes almost 95 years ago (3). Efforts continued through the Korean War, during which time the military services experimented with missions, sensors, and munitions in attempts to provide strike and reconnaissance services to battlefield commanders. In the 1950s, both the Navy and Air Force bifurcated their efforts to concentrate on cruise missile and unmanned aerial vehicle (UAV) development via separate means.

There are three classes of UAVs:

1. Pilotless target aircraft that are used for training purposes (such as target drones);
2. Nonlethal aircraft designed to gather intelligence, surveillance, and reconnaissance (ISR) data; and
3. Unmanned combat air vehicles (UCAVs) that are designed to provide lethal ISR services.

UAVs have been around much longer than most people realize. During World War I, both the Navy and the Army experimented with aerial torpedoes and flying bombs (3). Some of the most brilliant minds of the day were called on to develop systems to be used against U-boat bases and to break the stalemate caused by nearly four years of trench warfare. Efforts consisted of combining wood and fabric airframes with either gyroscope or propeller revolution counters to carry weapons of almost 200 pounds of explosives a distance of approximately 40 miles. Hostilities ceased before either could be fielded (4). These World War I UAVs highlighted two operational problems: crews had difficulty launching and recovering the UAVs, and they had difficulty stabilizing them during flight. The aircraft engineering principles have been detailed in a monograph (5).

During the Interwar period, radio and improved aircraft engineering allowed UAV developers to enhance their technologies, but most efforts failed. Despite failures, limited development continued, and after UAVs successfully performed as target drones in naval exercises, efforts were renewed in radio-controlled weapons delivery platforms. World War II saw the continued use of target drones for anti-air gunnery practice. Additionally, radio-controlled drones were used by both the Allied and Axis powers as weapons delivery platforms and radio-controlled flying bombs and gliding bombs.

With the start of the Cold War, UAVs began to be used as ISR systems, with limited success as weapons delivery platforms. Development continued conflict throughour the Vietnam War, but interest soon waned once hostilities ceased. The 1991 Gulf War renewed the interest in UAVs, and by the time the Balkans Conflict began, military intelligence personnel were regularly incorporating UAV ISR information into their analyses. Currently, UAVs effectively provide users with real-time ISR information. Additionally, if the ISR information can be quickly understood and locations georegistered, UCAVs can be used to strike time-sensitive targets with air-to-surface weapons. Like many weapon systems, UAVs thrive when the need is apparent; when there is no need, they fall into disfavor.

Numerous obstacles have hindered the development of UAVs. Oftentimes, technologies simply were not mature enough for the UAVs to become operational. Other times, lack of service cooperation led to failure. For example, the U.S. Army Air Corps funded Project Aphrodite (using B-17s as flying bombs) in World War II, while the Navy's World War II Project Anvil was very similar but used PB4Ys (the Navy's designation for the B-24). If the services had coordinated efforts, perhaps the overall effort would have been successful. Additionally, competing weapon systems made it difficult for UAVs to get funding. And of course, it was sometimes difficult to sell pilotless aircraft to senior service leaders, who were often pilots. Many obstacles still stand in the way of continued UAV development. These include mostly nontechnical issues, such as lack of service enthusiasm, overall cost-effectiveness, and competition with other weapon systems (e.g., manned aircraft, missiles, or space-based assets).

When the US entered World War I, the world's first unmanned aerial torpedo, known as the Kettering Bug, was developed. In 1911, just 8 years after the advent of manned flight, Elmer Sperry, inventor of the gyroscope, became intrigued with the application of radio control to aircraft. Sperry succeeded in obtaining Navy financial support and assistance and, between 31 August and 4 October 1913, oversaw 58 flight tests conducted by Lieutenant P. N. L. Bellinger at Hammondsport, New York, in which the application of the gyroscope to stabilize flight proved successful (6).

In 1915, Sperry and Dr. Peter Cooper Hewitt became members of the Aeronautical Committee of the Naval Consulting Board, established by Secretary of the Navy Josephus Daniels on 7 October 1915 and led by Thomas A. Edison to advise Daniels on scientific and technical matters (7–9).

1.2 Morphing Aircraft

The term morphing aircraft describes a broad range of air vehicles and vehicle components that adapt to planned and unplanned multipoint mission requirements (10). The adaptation or morphing requires changing system features such as including vehicle states, such as vehicle shape, during in-flight operation.

The term morphing can be applied to almost any activity in which in-flight vehicle features are changed. As such, morphing has become a buzzword loosely applied to a wide variety of activities, some of which are disconnected from air vehicle morphing development.

This has led to three myths (10):

1. morphing shape change is too expensive,

2. morphing aircraft must weigh more than non-morphing aircraft, and
3. morphing requires exotic materials and complex systems.

A study attempted to dispel these myths by reviewing early morphing aircraft history to identify inventions and innovations that led to both successes and failures.

Also discussed were some recent government-sponsored activities in the United States. In particular, morphing systems development sponsored by the Defense Advanced Research Projects Agency viewed from the author:s perspective as a former Defense Advanced Research Projects Agency Program Manager. The review concludes with identification of possible avenues for future morphing aircraft evolution and morphing device development (10).

1.3 Special Materials

1.3.1 Glare

Glare (derived from GLAss REinforced laminate) is a fiber metal laminate composed of several very thin layers of metal (usually aluminum) interspersed with layers of S-2 glass fiber pre-impregnated, bonded together with a matrix such as epoxy. The unidirectional pre-impregnated layers may be aligned in different directions to suit predicted stress conditions (11).

The history of the development of a new aircraft material, Glare, has been documented (12, 13). Glare is a fiber metal laminate composed of several thin layers of aluminum. Thus, early metal aircraft have been shown to be prone to persistent corrosion.

1.3.2 Thermal Coatings

In a study, thin thermal barrier coatings (TBCs) for protecting aircraft turbine section air foils were examined (14).

The study focused on those advances that led first to TBC use for component life extension and more recently as an integral part of airfoil design. The designs are also detailed in a monograph (15).

Development has been driven by laboratory rig and furnace testing, corroborated by engine testing and engine field experience.

The technology has also been supported by performance modeling to demonstrate benefits and life modeling for mission analysis. Factors that have led to the selection of current state-of-the-art plasma-sprayed and physical vapor-deposited zirconia-yttria/MCrAlX TBCs are emphasized, as are observations fundamentally related to their behavior. Also, some directions in research into TBCs and the progress at NASA were noted (14).

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2

Standards

The Standard Aircraft Handbook for Mechanics and Technicians is now available (1).

2.1 ASTM Standards

At ASTM International, a standards organization that develops and publishes voluntary consensus technical international standards, when the term "Aircraft and Helicopter" is searched for on the internet, only 24 results are found.

2.2 ASTM Aircraft Standards

Some ASTM Aircraft Standards are collected in Table 2.1.

2.2.1 Standard Terminology for Aircraft

The terminology standard for Aircraft contains a listing of terms, abbreviations, acronyms, and symbols related to aircraft covered by ASTM Committees F37 and F44 airworthiness design standards (2).

2.2.2 Standard Specification for Aircraft Powerplant Installation

A detailed explanation of a powerplant is presented in a monograph (3). This specification provides minimum requirements for the installation and integration of powerplant system units and is

Table 2.1 List of ASTM Aircraft Standards.

Number	Name	Reference
F3060-20	Standard Terminology for Aircraft	(2)
F3062/F3062M-20	Standard Specification for Aircraft Powerplant Installation	(4)
F3235-22	Standard Specification for Aircraft Storage Batteries	(5)
F3341/F3341M-23	Standard Terminology for Unmanned Aircraft Systems	(6)
F2109-01	Standard Test Method to Determine Color Change and Staining Caused by Aircraft Maintenance Chemicals upon Aircraft Cabin Interior Hard Surfaces	(7)
F3245-19	Standard Guide for Aircraft Electronics Technician Personnel Certification	(8)
F3234/F3234M-21	Standard Specification for Exterior Lighting in Small Aircraft	(9)
F3065/F3065M-21a	Standard Specification for Aircraft Propeller System Installation	(10)
F3227/F3227M-22	Standard Specification for Environmental Systems in Aircraft	(11)
F3409-19e1	Standard Practice for Simplified Aircraft Loads Determination	(12)
ASTM D 2240	Standard Test Method for Rubber Property–Durometer Hardness	(13)
ASTM D 412	Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers–Tension	(14)
ASTM D 624	Standard Test Method for Tear Strength of Conventional Vulcanized Rubber and Thermoplastic Elastomers	(14)
ASTM D 297	Standard Test Methods for Rubber Products–Chemical Analysis	(15)

applicable to small airplanes as defined in the F44 terminology standard (4).

The specification contains: An air induction system for each engine and auxiliary power unit (APU) and their accessories, powerplant exhaust system, forced air induction and bleed air systems, oil system, liquid cooling, turbojet and turbofan reversing systems, and powerplant accessories and components. Also specified are tank tests for pressure, vibration, and tank sloshing.

So, this specification covers minimum requirements for the installation and integration of powerplant system units. It is applicable to small aeroplanes as defined in the F44 terminology standard.

2.2.3 Standard Specification for Aircraft Storage Batteries

This specification establishes the requirements for the electrical storage battery aspects of airworthiness and design for small aircraft.

It prescribes the Aircraft Type Code (ATC) compliance matrix (4) based on airworthiness level, number of engines, type of engine(s), stall speed, cruise speed, meteorological conditions, altitude, and maneuvers.

An ATC is defined by taking into account both the technical considerations regarding the design of the aircraft and the airworthiness level established based upon risk-based criteria. The installation requirements defined by this specification cover nickel cadmium batteries. For each nickel cadmium battery installation capable of being used to start an engine or APU, there must be provisions to prevent any hazardous effect on structure or essential systems that may be caused by the maximum amount of heat the battery can generate during a short circuit of the battery or of its individual cells.

The specification covers electrical storage battery aspects of airworthiness and design for airplanes. The material was developed through open consensus of international experts in general aviation. This information was created by focusing on Normal Category aeroplanes. The content may be more broadly applicable; it is the responsibility of the applicant to substantiate broader applicability as a specific means of compliance. The topics covered within this document are electrical storage batteries, nickel cadmium batteries, and rechargeable lithium batteries.

The standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.

2.2.4 *Standard Terminology for Unmanned Aircraft Systems*

This terminology standard covers definitions of terms and concepts related to unmanned aircraft systems (UASs) (6).

2.2.5 *Practice for Simplified Aircraft Loads Determination*

This practice provides an acceptable, and simplified, means of determining certain design loads criteria and conditions for fixed wing aircraft (12). In particular, the practice provides overall aircraft flight loads and flight conditions

2.2.6 *Search and Rescue Operations Standards*

The ASTM search and rescue operations standards cover the personnel, equipment, and procedures relevant in the performance of search and rescue (SAR) operations. These procedures involve the use of available personnel and facilities in locating and providing immediate aid to persons, other living beings, or property that are in actual or imminent distress. These operations are most commonly carried out in urban and suburban locations, combat sites, areas of large bodies of water, and rugged terrains such as mountains, deserts, and forests. These standards help guide SAR organizations and emergency response teams in conforming to the proper methods of conducting these emergency aid procedures.

2.2.7 *Rubber Property–Durometer Hardness*

The ASTM D 2240 test method is based on the penetration of a specific type of indentor when forced into the material under specified conditions (13). The indentation hardness is inversely related to the penetration and is dependent on the elastic modulus and viscoelastic behavior of the material.

Table 2.2 List of ASTM standards.

Number	Year	Name
F1956-20	2020	Standard Specification for Rescue Carabiners
F2491-20	2020	Standard Guide for Determining Safety Factors for Technical Rescue Systems and Equipment
F2684/F2684M-07	2022	Standard Test Method for Portable High Anchor Devices
F1764-97	2024	Standard Guide for Selection of Hardline Communication Systems for Confined-Space Rescue
F2822-10	20204	Standard Specification for Fixed Anchorages Installed on Structures Used for Rope Rescue Training
F2266-24e1	2024	Standard Specification for Masses Used in Testing Rescue Systems and Components
F1772-24	2024	Standard Specification for Harnesses for Rescue and Sport Activities Management and Operations
F1583-95	2019	Standard Practice for Communications Procedures-Phonetics
F1422-08	2020	Standard Guide for Using the Incident Command System Framework in Managing Search and Rescue Operations

Table 2.2 (cont) List of ASTM standards.

Number	Year	Name
F2047-00	2019	Standard Practice for Workers Compensation Coverage of Emergency Services Volunteers
F1591-95	2019	Standard Practice for Visual Signals Between Persons on the Ground and in Aircraft During Ground Emergencies
F2752-19	2019	Standard Guide for Training for Basic Rope Rescuer Endorsement
F1730-96	2020	Standard Guide for Throwing a Water Rescue Throwbag
F1729-96	2020	Standard Practice for Single Person Cold Water Survival/Rescue Technique: HELP Position
F1728-96	2020	Standard Practice for Multiple Persons Cold Water Survival/Rescue Technique: Huddle Position
F1422-08	2020	Standard Guide for Using the Incident Command System Framework in Managing Search and Rescue Operations

The geometry of the indentor and the applied force influence the measurements such that no simple relationship exists between the measurements obtained with one type of durometer and those obtained with another type of durometer or other instruments used for measuring hardness. This test method is an empirical test intended primarily for control purposes. No simple relationship exists between indentation hardness determined by this test method and any fundamental property of the material tested (13).

2.2.8 Vulcanized Rubber and Thermoplastic Elastomers

All materials and products covered by the test method ASTM D 412 must withstand tensile forces for adequate performance in certain applications. These test methods allow for the measurement of such tensile properties. However, tensile properties alone may not directly relate to the total end use performance of the product because of the wide range of potential performance requirements in actual use (14).

The tensile properties depend both on the material and the conditions of test, i.e., extension rate, temperature, humidity, specimen geometry, pretest conditioning. Therefore, materials should be compared only when tested under the same conditions.

The temperature and the rate of extension may have substantial effects on tensile properties and therefore should be controlled. These effects will vary depending on the type of material being tested.

Tensile set represents residual deformation which is partly permanent and partly recoverable after stretching and retraction. For this reason, the periods of extension and recovery (and other conditions of test) must be controlled to obtain comparable results.

2.2.9 Tear Strength

The test method ASTM D 624 describes procedures for measuring a property of conventional vulcanized rubber and thermoplastic elastomers called tear strength (14).

Vulcanized rubber and thermoplastic elastomers often fail in service due to the generation and propagation of a special type of rupture called a tear (14).

The tear strength may be influenced to a large degree by stress-induced anisotropy (mechanical fibering), stress distribution, strain rate, and test piece size. The results obtained in a tear strength test can only be regarded as a measure under the conditions of that particular test and may not have any direct relation to service performance. The significance of tear testing must be determined on an individual application or product performance basis.

2.2.10 Chemical Analysis of Rubber Products

The ASTM D 297 test methods cover the qualitative and quantitative analyses of the composition of natural and synthetic crude rubbers (15). These methods are divided into general and specific test methods.

General test methods shall be performed to determine the amount and type of some or all of the major constituents of a rubber product, and shall include determination of rubber polymer content by the indirect method, determination of density, and extract, sulfur, fillers, and ash analyses. Specific test methods, on the other hand, shall be performed to determine specific rubber polymers present in a rubber product such as crude, unvulcanized, reclaimed, and vulcanized rubbers (15).

2.3 Examples of Usage

2.3.1 Tensile Properties of Polymer Matrices

The test method ASTM D3039/D3039M-08 is designed to produce tensile property data for material specifications, research and development, quality assurance, and structural design and analysis (16). Factors that influence the tensile response and should therefore be reported include the following: material, methods of material preparation and lay-up, specimen stacking sequence, specimen preparation, specimen conditioning, environment of testing, specimen alignment and gripping, speed of testing, time at temperature, void content, and volume percent reinforcement. Properties, in the test direction, which may be obtained from this test method include the following (16):