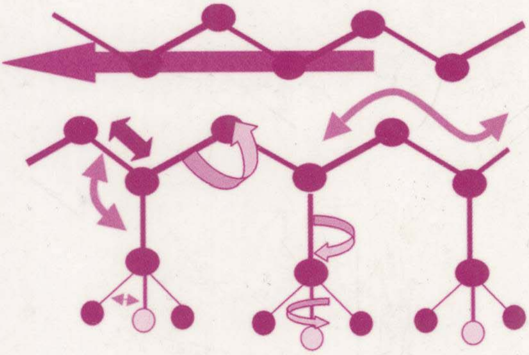
HANDBOOK OF PLASTICS ANALYSIS



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PLASTICS ENGINEERING

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Preface

Plastics are one of the enabling technologies of the 20th century. They are among the most complex engineering materials being used in the world today, with amazing properties that have revolutionized the way in which products are manufactured. They are used in almost every walk of life, ranging from the mundane to high-end applications in which no other material could serve as a replacement. In each of these applications, it has been crucially important to understand their behavior through various parts of their product life, from manufacture to utilization and eventually their reclaim or disposal. The tools and techniques used to develop this understanding are referred to as plastics analysis.

Plastics analysis can be broadly grouped into two main categories. *Physical analysis* refers to the evaluation of the physical behavior of the material. Properties such as strength, thermal behavior, and flow properties fall into this category, as do failure and morphological characteristics. *Chemical analysis* seeks to evaluate the compositional characteristics of the polymer. The combination of these two broad approaches has been used successfully to correlate the behavior of plastics to their composition.

A wide variety of modern tools are available to the plastics analyst. As the range of available tools continue to expand, it is necessary for the analyst to keep abreast of all these technologies so as to be able to apply the most appropriate technique to the solution of a particular problem. This handbook seeks to highlight the most prominent tools in use by providing information on these diverse techniques and their application, and provides guidelines on the analysis and interpretation of results. It also provides a ready source of detailed references to readers interested in a more complete understanding of the subject matter.

In order to maintain a practical focus, the book concentrates on an approach that is more phenomenological than theoretical. While not going into detailed derivations, the book sets forth the basic governing equations where necessary to provide a good theoretical understanding of the techniques. Through the use of case studies and illustrations, the reader will be aided in the understanding of possible outcomes of each analysis technique.

A number of plastics analysis techniques are currently standardized to national and international norms. The book lists these norms in the form of reference tables and provides brief descriptions where necessary.

The chapters contain:

Introduction of the technique and a brief scientific basis; governing equations if applicable
Illustrations of test instruments along with schematics to aid in the understanding of the techniques
Detailed descriptions, including measurement method(s), highlighting differences in technique(s), if relevant, including merits and deficiencies of the technique
Images of typical outcomes of the analysis
A listing of applicable national and international standards
Applications with typical case studies and corresponding results; these are intended to aid in the analysis and interpretation of results from the analysis
Discussions
Conclusion, including information on the latest advances in the field (noncommercial) so as to provide an indication of future potential of the technology
References and additional reading

The handbook will serve as a concise reference to practitioners in the industry, providing technical information about plastics analysis and descriptions of the technology used to perform the measurements. It is aimed at laboratory personnel who need to have a working knowledge of plastics analysis techniques and would like to keep abreast of the latest developments in the field. These will include laboratory managers, supervisors, and engineers.

The book will also serve as a basic reference to research engineers and scientists who may be looking for techniques to solve problems or investigate behavioral phenomena.

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1

General Introduction to Plastics Analysis

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INTRODUCTION

Plastics have undoubtedly been the wonder materials of the last century. They have fundamentally revolutionized the manner in which we conceptualize and implement new products. They are ubiquitous in today's environment, appearing in ways that range from mundane to high-tech, from indispensable to completely wasteful. The manner in which these materials have been used has shaped our impressions of plastics as necessary evils as well as miracle materials.

A lot of the negative impressions have come from the fact that the world was not prepared for materials of this complexity. In many ways, our inability to understand plastics affected the manner in which we used or misused them. Before the arrival of plastics, most materials were relatively simple, or if complex, natural. In both cases, either by the application of existing science or by long historical knowledge of their use, it was possible to use these materials in an effective manner. In the case of plastics, the converse occurred. The arrival of plastics heralded the onset of one of the most comprehensive periods of discovery in material science. The very nature of plastics has demanded significant advances in our ability to understand polymers, analyze their composition, and characterize this behavior. These technologies, collectively termed plastics analysis techniques, have come a long way in helping us design novel materials for a better tomorrow.

Our impression of plastics as miracle materials has also stemmed from an incomplete understanding of their complexity. Plastics analysis has allowed us to apply the rigorous application of scientific technique to deepen our knowledge of their behavior, replacing our previous wonder with a deep-rooted scientific understanding that permits us to truly appreciate the capabilities of these materials. Indeed, it is this knowledge that will shape our use of these truly amazing materials in the new millennium.

The introduction of plastics requires us to apply a wide range of techniques to understand their behavior. Plastics exhibit complex molecular characteristics. From our understanding of molecular structure, we are now able to attempt to correlate behavior to structure. This ability, however, is still, far from an exact science. The complex manner in which polymer molecules interact still prevents us from developing strong structure–property relationship theories. Indeed, the disconnection between our understanding of molecular-level behavior and macro-level characteristics is one of the sharpest dividing lines between classical material science and polymer science. In the case of metals, it has been relatively easy to apply our atomic-level understanding of the material and its microstructure to its behavior. In sharp contrast, polymer molecules vary widely in molecular weight. The manner in which polymer molecules interact with each other depends to a great extent on the pendant groups that are attached to the chain. Most frustrating of all, even though we are able to understand these aspects, this still does not permit us to apply our knowledge to understand macro-level behavior. This has forced the simultaneous development of both chemical analysis and physical analysis to grapple with the problem.

Chemical analysis techniques permit us to analyze molecular composition and molecular weight to allow us to characterize plastics precisely. Physical methods allow us to look at the behavior of plastics in response to a variety of influences such as temperature, pressure, and time. This understanding helps us to say how the plastics will behave in their lifetime. Plastics analysis may include identification and chemical composition, thermal properties, mechanical properties, physical properties, electrical properties, and optical properties, among others. Chemical analysis may include material identification and characterization by techniques including FTIR, NMR, GC, GC/MS, HPLC, and GPC. Thermal analysis does provide information such as melting point, glass transition, flash point, heat deflection temperature, melt flow rate, and Vicat softening point. Mechanical properties, on the other hand, provide critical information such as tensile properties, flexural strength, impact strength, hardness, compressive strength, modulus, and fatigue. Recent advances in microscopy also permit us to peek into molecular structure. The atomic force microscope, for example, has truly revolutionized our ability to probe molecular behavior, promising us a startling new understanding of plastics.

The past few years have been characterized by a large growth in development of new polymers and composite materials. Modern research and developments of high-technology materials have also driven the development of new analytical equipment and analytical technologies. As materials become more and more sophisticated and complex, so also must become the analytical techniques required for materials testing and materials characterization.

Innovative, accurate, easy-to-use, performance, and reliability are the requirements that describe instrumentation needed in modern laboratories involved in materials research or materials manufacturing facilities. Instrumentation of this type is needed in order to deliver outstanding performance to downstream customers. Modern instruments, hardware, and software products are designed to support such requirements.

This book covers some of the most significant techniques used in modern analytical technology to characterize plastic and composite materials. A short general introduction to some of them is provided here to the topics covered in more detail in later chapters. A general introduction is also given to other techniques that are not covered in extensive detail in this book but that are of significant use in characterization of certain critical properties of plastic materials.

Much of plastics testing is done by methodology developed and validated in-house by analytical scientists to meet specific needs. There are also a large number of official testing methods developed by agencies such as the American Society for Testing Materials (ASTM). A reference list of ASTM methods used for analysis of plastic and plastic-related materials is included as an appendix at the end of this book.

There are many applications of plastics analysis. It is useful to examine these applications using a life-cycle viewpoint. In each area, one is then able to see the importance of these vital techniques to the understanding and proper application of plastic materials in our lives and the environment.

PLASTICS AND PRODUCT DESIGN

Historically, product developers have had a great deal of difficulty working with plastics. They simply did not behave in the conventional manner. None of the conventional rules of behavior applied either in the manner in which the product was made or in the manner in which it behaved once it was produced. There were serious contradictions to conventional design philosophies—for example, the concept that making it thicker did not necessarily make it stronger, or that once it was made, it did not necessarily want to stay that way. Factors such as stress relaxation and residual stresses played havoc with first-generation plastic products, giving plastics the bad reputation that years of continuous improvement have not been able to erase. A lot of improvement can be attributed to our current understanding of physical behavior.

Plastics exhibit large nonlinear stress–strain behavior. Large recoverable deformation is, in fact, one of the defining characteristics of a plastic. This characteristic has been used unfairly to portray plastics as weak materials because they lack the stiffness and strength of metals. In fact, it means that a plastic part can undergo a large amount of recoverable deformation before it breaks. This characteristic has been exploited, for example, in the replacement of the metal automotive bumper with TPO. The stress–strain relationship of a plastic shows a continuously decreasing stiffness with larger strain. This is because, in contrast to metals, plastics do not undergo complete instantaneous recovery upon unloading. When the plastic is unloaded, the response is viscoelastic, with partial instantaneous "elastic" response and a component of "viscous" time-based recovery. The introduction of the dimension of time is therefore a serious complicating factor, presenting essentially a fourth dimension to be considered in design. Viscoelasticity, creep, and stress relaxation are some of the measures used to characterize this behavior.

PLASTICS AND MANUFACTURING

In conjunction with the injection molding process, plastics have revolutionized the manufacturing process over the past 20 years. Major economies in assembly were achieved by molding in features and incorporating subcomponents into a single part. For a very long time, however, injection molding was perceived to be a "black art" because of the extreme difficulty of making good parts. It took significant research in areas of polymer rheology, thermal properties, and mechanical behavior to develop the scientific understanding that guides modern injection molding. Other plastics processing methods have also benefited from these advances. Characterizations of viscoelastic behavior and extensional rheology guide modern blow molding and thermoforming, transforming this industry into a producer of high-quality engineering products.

PLASTICS AND THE ENVIRONMENT

Just as steel rusts and wood rots, plastics degrade in the environment. This is in stark contrast to the picture of the 1960s, which presented plastic as both