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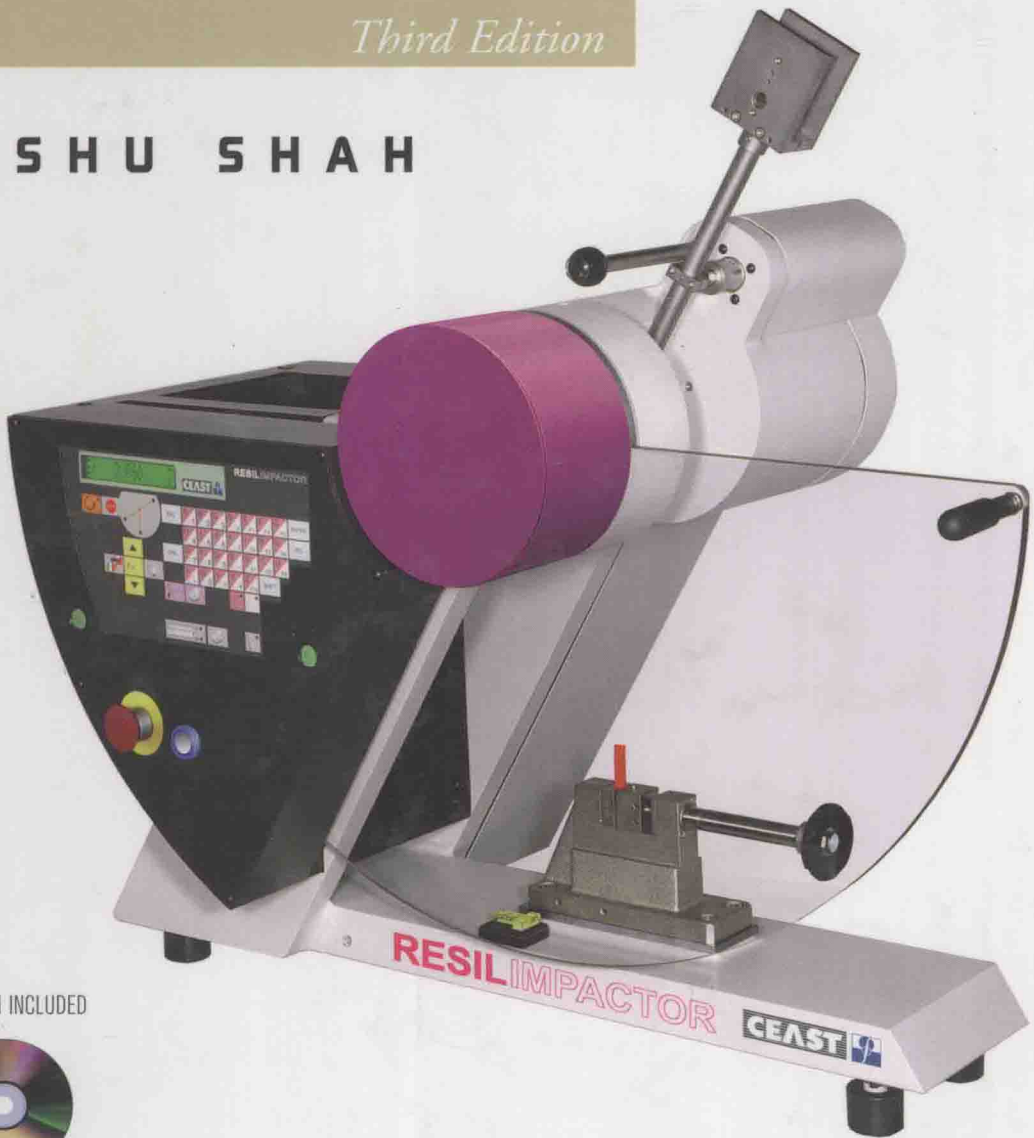
HANDBOOK OF PLASTICS TESTING AND FAILURE ANALYSIS

Third Edition

VISHU SHAH



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HANDBOOK OF PLASTICS TESTING AND FAILURE ANALYSIS

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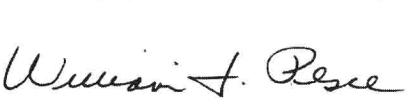

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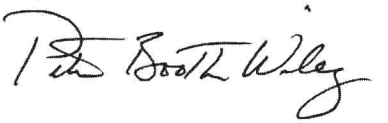

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FOREWORD

The Society of Plastics Engineers is pleased to sponsor and endorse the third edition of *Handbook of Plastics Testing and Failure Analysis* by Vishu Shah. This volume offers a varied compilation of the most common tests used in the plastics industry. The text is an excellent source and reference guide for engineers, chemists and students in plastics testing technology. The author's writing style and knowledge of the subject matter have resulted in an enjoyable presentation allowing the reader to gain meaningful insights into testing and corresponding procedures.

SPE, through its Technical Volumes Committee, has long sponsored books on various aspects of plastics. Its involvement has ranged from identification of needed volumes and recruitment of authors to peer review and approval and publication of new books.

Technical competence pervades all SPE activities, not only in the publication of books, but also in other areas such as sponsorship of technical conferences and educational programs. In addition, the Society publishes periodicals including *Plastics Engineering, Polymer Engineering and Science, The Journal of Injection Molding Technology, Journal of Vinyl & Additive Technology*, and *Polymer Composites*, as well as conference proceedings and other publications, all of which are subject to rigorous techincal review procedures.

The resource of some 36,000 practicing plastics engineers, scientists, and technologists has made SPE the largest organization of its type worldwide. Further information is available from the Society of Plastics Engineers, 14 Fairfield Drive, Brookfield, Connecticut 06804.

PREFACE TO THE 3rd EDITION

During the period that elapsed between the second edition and the date of writing of this third edition, the author shifted his career from a full-time molder to a full-time Consultant/Expert witness/Educator. The opportunity existed for analyzing numerous plastic-part-related premature failures. Failure analysis and testing go together. In order to analyze the failure, it is often necessary to conduct tests. In this third edition, therefore, the decision was made to expand the current chapter on failure analysis substantially and alter the title of the book to *Handbook of Testing and Failure Analysis* to reflect the change appropriately.

Existing books and literature on the subject of failure analysis are too complex, too detailed, sometimes difficult to understand, and more suitable to the persons well-versed in polymer chemistry and physics. This book attempts to simplify a rather difficult subject of failure analysis by focusing on four major types of failures and key reasons behind failure of plastic parts. A step-by-step procedure starting from very basic and simple visual analysis to highly advanced analytical tests is presented. A simple flow chart is included to help with the investigation. To assist with the understanding of the subject matter, several actual case studies are included. This simple approach to analyzing failures is not intended primarily for a specialist but for those who wish to acquire basic knowledge and understanding of the failure mechanism. The author's aim is not to replace excellent books that are in existence on this subject but to supplement and pave the road for more detailed and sophisticated failure analysis techniques in existence today.

All other chapters in the book have been updated with the latest information, diagrams, and photographs of the test equipment. The Appendix section has been updated. Appendix I, which listed the properties of the most common plastics, elastomers, and rubbers in the early edition, has been replaced with information about four major electronic databases for plastic materials. In order to increase the versatility of the book, numerous color photographs depicting photoelastic analysis and color theory along with various animations have been added on to the compact disk that is included with the book. More importantly, a virtual tour of a prominent Plastics Testing Laboratory is included to give the reader an

opportunity to visit the laboratory from his or her desk and learn and understand how the tests are conducted and data are collected.

The author wishes to express thanks to all the users of previous editions for their constructive comments and helpful suggestions for changes and improvements for the next edition and to those who helped with this revision. In particular, he wishes to thank Jim Beauregard and Jim Galipeau of Plastics Testing Laboratory for their invaluable contribution, agreeing to the novel concept of virtual laboratory tour and making it possible. The author also wishes to thank Gerard Nelson of Ceast USA, GE Plastics, Kishor Mehta of Plascon Associates, Bayer Corporation, Dr. Alex Redner of Strainoptics, Inc., Paul Gramann of The Madison Group, Jim Rancourt of Polymer Solutions, and Steve Ferry of Micobac Laboratories. Many thanks to Steve Tuszynski of Algoryx for his contribution and to all other companies for providing numerous illustrations and diagrams. The book by Myer Ezrin, *Plastics Failure Guide, Causes and Prevention*, has been an important and valuable source of theoretical and practical information, and the author highly recommends his book for more detailed and in-depth discussion of the subject.

Once again, I would like to thank my family for their encouragement and constant support.

VISHU SHAH

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Brea, CA

PREFACE TO THE SECOND EDITION

Since the publication of the first edition, little has changed as far as the basic concepts and methods of plastics testing. What has changed is the manner in which the data is collected and analyzed. Since the advent of computers and digital instruments, data collection and subsequent analysis and interpretation have become much simpler and faster.

This revised edition attempts to update the book in line with the latest developments in the field of testing, data acquisition, and analysis. The photographs depicting the commercially available testing equipment have been replaced with newer versions. A new chapter covering uniform global testing standards has been added. This chapter also includes current information about computerized material selection, which allows the user to compare various test data and material ranking based on the test data with utmost speed and ease. the entire section on impact properties has been rewritten to include an expanded discussion of instrumented impact testing. The chapters on electrical weathering properties and material characteristics have been revised. Owing to significant changes and developments in flammability testing this chapter has also been updated. The chapter on failure analysis is expanded significantly to further satisfy the need of someone trying to determine a failure mechanism. The discussion on SQC/SPC in the chapter on quality control has been expanded along with the current trend toward "supplier certification." The chapter on nondestructive testing has also been rewritten to include many other NDT techniques and the latest developments. The Appendix has been expanded to include plastics education degree programs and organizations. The list of test equipment suppliers has been updated and now includes appropriate web site addresses. The specification section includes ISO test method designations and ASTM/DOD cross references.

The author wishes to thank all those who helped to make this second edition possible for their constructive and candid comments, support, and guidance. In particular he wishes to thank professor Steven Driscoll (University of Massachusetts Lowell) and Professor Robert Speirs (Ferris State University) for their suggestions and guidance. Special thanks to R. Bruce Cassel of Perkin-Elmer and Kurt Scott of Atlas Electric Devices Company

for reviewing and improving the manuscript and to Steve Caldarola of SGS–U.S. Testing who assisted in updating the chapter on flammability. I wish to thank Peter Grady of Ceast U.S.A., John Dechristofaro of Dynisco–Kayeness, Brookfield Engineering, G.E. Plastics, Society of Plastics Industry, Instron Corporation, Underwriters Laboratories, Strain Optics, D.A.T.A. Publishing, Newport Scientific and many others for providing technical assistance and photographs for reproduction. Many thanks to James Galipeau and Mr. James Beauregard of Plastics Testing Laboratories for providing material on advances in plastics testing and for reviewing the entire manuscript.

Last, but not least, I thank my wife Charlene, my son Neerav, and my daughter Beejal for their understanding and patience during many evenings and weekends when I was wrapped up in the preparation of this revised edition.

VISHU SHAH

Performance Engineered Products, Inc.
Pomona, California

PREFACE TO THE FIRST EDITION

The desire to compile this book was initiated mainly because of the virtual non-existence of a comprehensive work on testing of plastic materials. The majority of the literature concerning the testing of plastics is scattered in the form of sales and technical brochures, private organizations' internal test procedures, or a very brief and oversimplified explanation of the test procedures in plastics literature. The main objective of the present book is to provide a general purpose practical text on the subject with the main emphasis on the significance of the test or *why* and not so much on *how* without being extremely technical.

Over the years ASTM (American Society for Testing and Materials) has done an excellent job in providing the industry with standard testing procedures. However, the test procedures discussed in ASTM books lack the theoretical aspects of testing. The full emphasis is not on *significance* of testing but on *procedures* of testing. The ASTM books are also deficient in showing the diagrams and photographs of actual, commercial testing equipment. In this book I have tried to bridge the gap between the oversimplified and less explained tests described in ASTM books and the highly technical and less practical books in existence today.

This handbook is not intended primarily for specialists and experts in the area of plastics testing but for the neophyte desiring to acquire a basic knowledge of the testing of plastics. It is for this reason that detailed discussions and excessive technical jargon have been avoided. The text is aimed at anyone involved in manufacturing, testing, studying, or developing plastics. It is my intention to appeal to a broad segment of people involved in the plastic industry.

In Chapter 1 the basic concepts of testing are discussed along with the purpose of specifications and standards. Also discussed is the basic specification format and classification system. The subsequent chapters deal with the testing of five basic properties: mechanical, thermal, electrical, weathering, and optical properties of plastics. The chapter on mechanical properties discusses in detail the basic stress–strain behavior of the plastic materials so that a clear understanding of testing procedures is obtained. Chapter 7 on

material characterization is intended to present a general overview of the latest in characterization techniques in existence today. A brief explanation of the polymer combustion process along with various testing procedures are discussed in Chapter 8. An attempt is made to briefly explain the importance of conditioning procedures. A table summarizing the most common conditioning procedures should be valuable. Several tests that are difficult to incorporate into a specific category were placed in the chapter on miscellaneous tests. End-product testing, an area generally neglected by the majority of processors of plastic products, is discussed along with some useful suggestions on common end-product tests.

Chapter 13 on identification analysis should be important to everyone involved in plastics and particularly useful to plastic converters and reprocessors. The flowchart summarizes the entire identification technique. Since there are so many different tests in existence on the testing of foam plastics, only a brief explanation of each test is given. The chapter on failure analysis is a compilation of methods commonly used by material suppliers. A step-by-step procedure for analyzing product failure should prove valuable to anyone ivolved in failure analysis. Quality control, although not part of the testing, is included in order to explain quality control as it relates to plastics. The section on visual standard, mold control, and workmanship standard is a good example. In this increasing world of product liability, the chapter on product liability and testing should be of value to everyone.

In order to increase the versatility of this book and meet the goal of providing a ready reference on the subject of testing, a large appendix section is given. One will find very useful data: names and addresses of equipment manufacturers, a glossary, names and addresses of trade publications, information on independent testing laboratories, and a guide to plastics specifications. Many useful charts and tables are included in the appendix. Throughout the book, wherever possible, numerous diagrams, sketches, and actual photographs of equipment are given.

A handbook of this magnitude must make inevitable compromises. Depending on the need of the individual user, there is bound to be a varying degree of excess and shortage. In spite of every effort made to minimize mistakes and other short-comings in this book, some may still exist. For the sake of future refinement and improvements, all constructive comments will be welcomed and greatly appreciated.

VISHU H. SHAH

Pomona, California
October 1983

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BASIC CONCEPTS AND ADVANCEMENT IN TESTING TECHNOLOGY

1.1. BASIC CONCEPTS

Not too long ago, the concept of testing was merely an afterthought of the procurement process. But now, with the advent of science and technology, the concept of testing is an integral part of research and development, product design, and manufacturing. The question that is often asked is "why test?" The answer is simple. Times have changed. The manner in which we do things today is different. The emphasis is on automation, high production, and cost reduction. There is a growing demand for intricately shaped, high-tolerance parts. Consumer awareness, a subject totally ignored by the manufactures once upon a time, is now a major area of concern. Along with these requirements, our priorities have also changed. When designing a machine or a product, the first priority in most cases is safety and health. Manufacturers and suppliers are now required to meet a variety of standards and specifications. Obviously, relying merely on past experience and quality of workmanship is simply not enough. The following are some of the major reasons for testing:

1. To prove design concepts
2. To provide a basis for reliability
3. Safety
4. Protection against product liability suits
5. Quality control
6. To meet standards and specifications

Handbook of Plastics Testing and Failure Analysis, Third Edition, by Vishu Shah

7. To verify the manufacturing process
8. To evaluate competitors' products
9. To establish a history for new materials

In the last two decades, just about every manufacturer has turned to plastics to achieve cost reduction, automation, and high yield. The lack of history along with the explosive growth and diversity of polymeric materials has forced the plastics industry into placing extra emphasis on testing and on developing a wide variety of testing procedures. Through the painstaking efforts of various standards organizations, material suppliers, and mainly the numerous committees of the American Society for Testing and Materials (ASTM), over 10,000 different test methods have been developed.

The need to develop standard test methods specifically designed for plastic materials originated for two main reasons. Initially, the properties of plastic materials were determined by duplicating the test methods developed for testing metals and other similar materials. The Izod impact test, for example, was derived from the manual for testing metals. Because of the drastically different nature of plastic materials, the test methods often had to be modified. As a result, a large number of nonstandard tests were written by various parties. As many as eight to ten distinct and separate test methods were written to determine the same property. Such practice created total chaos among developers of the raw materials, suppliers, design engineers, and ultimate end-users. It became increasingly difficult to keep up with various test methods or to comprehend the real meaning of reported test values. The standardization of test methods acceptable to everyone solved the problem of communication between developers, designers, and end-users, allowing them to speak a common language when comparing the test data and results.

In spite of the standardization of various test methods, we still face the problem of comprehension and interpretation of test data by an average person in the plastics industry. This is due to the complex nature of the test procedures and the number of tests and testing organizations. The key in overcoming this problem is to develop a thorough understanding of what the various tests mean and the significance of the result to the application being considered (1). Unfortunately, the plastics industry has placed more emphasis on *how* and not enough on *why*, which obviously is more important from the standpoint of comprehension of the test results and understanding the true meaning of the values. The lack of understanding of the real meaning of heat deflection temperature, which is often interpreted as the temperature at which a plastic material will sustain static or dynamic load for a long period, is one such classic example of misinterpretation. In the chapters to follow, we concentrate on the significance, interpretation, and limitations of physical property data and test procedures. Finally, a word of caution: it is extremely important to understand that the majority of physical property tests are subject to rather large errors. As a general rule, the error of testing should be considered ±5 percent. Some tests are more precise than others. Such testing errors occur from three major areas: (1) the basic test itself, (2) the operators conducting the tests, and (3) variations in the test specimens. While evaluating the test data and making decisions based on test data, one must

consider the error factor to make certain that a valid difference in the test data exists (2).

1.2. SPECIFICATION AND STANDARDS

A specification is a detailed description of requirements, dimensions, materials, and so on. A standard is something established for use as a rule or a basis of comparison in measuring or judging capacity, quantity, content, extent, value, and quality.

A specification for a plastic material involves defining particular requirements in terms of density, tensile strength, thermal conductivity, and other related properties. The specification also relates standard test methods to be used to determine such properties. Thus, standard methods of test and evaluation commonly provide the bases of measurement required in the specification for needed or desired properties (3).

As discussed earlier, the ultimate purpose of a standard is to develop a common language, so that there can be no confusion or communication problems among developers, designers, fabricators, end-users, and other concerned parties. The benefits of standards are innumerable. Standardization has provided the industry with such benefits as improved efficiency, mass production, superior quality goods through uniformity, and new challenges. Standardization has opened the door to international trade, technical exchanges, and establishment of common markets. One can only imagine the confusion the industry would suffer without the specific definition of fundamental units of distance, mass, and time and without the standards of weights and measures fixed by the government (4).

Standards originate from a variety of sources. The majority of standards originate from industry. The industry standards are generally established by voluntary organizations that make every effort to see that the standards are freely adopted and represent a general agreement. Some of the most common voluntary standards organizations are the American Society for Testing and Materials, the National Sanitation Foundation, the Underwriters Laboratories, the National Electrical Manufacturers Association, and the Society of Automotive Engineers. Quite often, the industry standards do not provide adequate information or are not suitable for certain applications, in which case private companies are forced to develop their own standards. These company standards are generally adapted from modified industry standards.

The federal government is yet another major source of standardization activities. The standards and specifications related to plastics are developed by the U.S. Department of Defense and the General Services Administration under the common heading of Military Standards and Federal Standards, respectively.

After the World War II, there was a tremendous increase in international trade. The International Standards Organization (ISO) was established for the sole purpose of international standardization. ISO consists of the national standards bodies of over 90 countries from around the world. The standardization work of ISO is conducted by technical committees established by agreement of five or more