Summary

The purpose of this volume has been to discuss physical testing required for the successful assessment of a material or article in relation to the function it is to fulfill, that is, to establish suitability for a given application. Unique philosophy and methodology have been shown to be required for this, compared to the other reasons for testing such as quality assurance, obtaining standard reference or typical value data, or research to obtain a fundamental understanding of polymer structure. The philosophy of physical testing presented by Evans has been echoed in various forms throughout the remainder of this book. The words "relevancy of the test" are stated or implied in every paper.

Physical testing was defined, in phenomenological terms, as the measurement of the output response of a polymer system under given boundary conditions and in a given surrounding environment when it is subjected to external input physical excitations. It is shown that the influence of the time-form of the excitation functions, the boundary conditions and the surrounding environment on the nature of the output response must be considered in any test method selection. Unfortunately, many testing technologists have tended to overlook this in favor of assuming that physical properties of polymers can be represented as unchanging values that describe material behavior. Because of this, it is estimated that 70 percent of physical testing data is either useless or ignored.

Test methods employed in physical testing have been divided into three classes. Fundamental tests yield data concerning basic physical properties independent of the boundary conditions. Component tests yield data from a finished part to allow the prediction of article behavior under service conditions. Hybrid tests yield data from special specimen geometries or machines with results dependent on the boundary conditions. Practical tests, while dependent on boundary conditions, are modeled so that the boundary conditions of the test are identical with those to which the component would be exposed. Adoption of a sound philosophy of engineering measurement has been repeatedly emphasized requiring fundamental, component or practical tests relevant to end-use performance to be used whenever possible in place of typical value measurements.

As the first example where typical value data cannot be used to judge end-use performance concerned prediction of the bursting strength of polyethylene pipe containing flaws or scratches. For such cases, a fracture mechanics approach is adopted. Fracture toughness testing of plastics is in its infancy, especially in regard to the acceptance of standard procedures for its determination. However, it has been shown to be a critical aspect of many physical testing programs where correlation with end-use performance is expected. The fracture toughness of a material is a fundamental property analogous to strength or modulus. However, determination of this property requires that the sample fail by brittle fracture. Fuller, et al, examined the validity of the fracture mechanics adopted from metals technology. Single edge notched specimens cut directly from pipes were tested in three point bending. Three modes of failure were observed under varying conditions ranging from ductile to brittle. The authors show that the validity question is critical, since simple calculation of the fracture toughness is shown to give erroneous, nonconservative values if the fracture is not sufficiently brittle due to specimen size, test conditions, or precrack introduction procedure. By careful selection of conditions and fractographic analysis, it is shown that it is possible to apply fracture mechanics to high density polyethylene. The agreement between the predicted and experimental pipe burst data for HDPE pipe with longitudinal external cracks indicated that standard procedures used for metals may serve as a guideline when the test parameters are adjusted to obtain the correct output response, brittle fracture for example. Data presented show that predictions of performance assuming only that the crack reduces wall thickness predict gross overestimates of burst strength. However, because of the ductile nature of polymers, the general validity of fracture toughness equations to particular applications should be closely examined. Nevertheless, this paper illustrates that fracture mechanics techniques can be employed that correlate with actual end-use performance. Several ASTM task groups are presently concerned with the general application of fracture mechanics to polymeric materials.

A second example where relevant physical evaluations were required concerned measurements of the long term behavior of plastics under either sustained dynamic or static loads.

Two excellent examples of meaningful fatigue testing were discussed by Loveless. These examples also clearly demonstrate the rationale to be followed when evaluating a material for a known application. Fatigue can be considered as a fundamental test. However, it is necessary that the shape and size of the input excitation have the same form encountered in the end-use application. In the first application, flexural fatigue tests, adopted from ASTM Test for Flexural Fatigue of Plastics by Constant-Amplitude of Force (D-671), using tensile-compressive load input were able to predict the secondary bonding characteristics of resins employed in the fabrication of boats. Those tests simulated the input excitations encountered by the boat in choppy waters. Such tests were adopted after several other ASTM standards for short term properties including flexural, tensile and lap shear strengths gave inconclusive, often meaningless results.

The other example concerned static tensile fatigue encountered in the steel core of aluminum conductor, steel-reinforced cable used in electrical power transmission. Since such cables are expected to have a normal life expectancy of 35 to 40 years, the long term tensile strength of the load carrying core is the fundamental property that should be measured. Since the short term tensile strength of glass reinforced polyester rod is 82 percent of steel, it is suggested that a designer might be tempted to substitute a slightly larger glass reinforced rod for a steel rod to save weight. However, when the long term strengths were predicted from accelerated tests, the glass reinforced rod had 50 percent of the strength of steel. Also, it is shown that the lower stiffness glass reinforced core prevents it from becoming the principle load-bearing component as is the case for steel. This analysis prevented misapplication of a plastic that could have proved disastrous resulting in a disservice to both the end-user and the plastics industry.

Recently developed impact testing equipment is discussed in the next paper which has permitted a shift from the classical hybrid types of impact testing such as Izod, Charpy, and Gardner to practical or component types of tests that can directly predict performance. Classical tests are based on either the measurement of total absorbed energy or by "go no-go" evaluations. The boundary conditions of these types of tests have been stated as having little relation to those imposed in-service, a fact often ignored by the test technologist. With instrumented impact testers, it is shown that a complete record of the load applied to the specimen during the entire impact event is provided, in addition to the conventional single value of the total absorbed energy. Impact performance can be evaluated in terms of all characteristics of the fracture process. Thus, loads for fracture initiation can be measured as well as total failure. Also, the boundary conditions can be selected to correlate with the end-use application.

Ireland presents several examples of full penetration types of data which correlate with end-use performance and discusses load initiation and total energy required for rupture. Automotive flex fans, protective head gear, chain saw housings, etc. were some examples of tests with an instrumented apparatus. Another unique feature of instrumented impact tests has been shown to be the ability to conduct low blow types of tests, where the impacter does not completely penetrate the specimen, that is, it delivers just enough energy to cause incipient damage. Such measurements of the extent of damage are necessary for example to assess the damage caused by a tool dropped on an epoxy/graphite wing section of an airplane. Incipient damage can be detected from the change in slope of the initial elastic loading.

The use of instrumented drop impact testing for the general evaluation of a material and the establishment of bounds for acceptable performance is discussed by Rieke. The mode and velocity of impact is stated to simulate actual blows that a material such as PVC siding would be expected to experience in service. The types of failure mechanisms and the ductile-brittle transition for six formulations of PVC showed wide differences even though the room temperature data indicated that most materials would perform equally well. The importance of including an environmental aging study were also emphasized. The relative behavior instead of the absolute values as a function of temperature permitted the ranking of materials and the selection of the most suitable candidate. The critical recognition in this paper is that when general evaluation of materials is being made using other than fundamental tests, only relative rankings of materials can be made because the absolute values change as the specimen geometry are changed. The presentation of these data in a graphical form also make them very useful for the designer to determine the bounds for ductile behavior.

Instrumented impact tests were also shown to be able to easily assess the effect of fabrication as shown by the different behavior of two injection molded refrigerator trays. This illustrates the need to fabricate the test piece in the same manner that the material will be fabricated in end-use. The effect of thickness on impact strength is another parameter that is shown to be easily assessed and the data capable of being used in a design for end-use. Linear relationships between thickness and energy to failure were not observed even though many standard methods still recommend normalizing impact data. Thus, meaningful impact tests should be conducted using test specimens having the same thickness as the intended part designed for end-use.

Both the discussions by Ireland and Rieke illustrate that instrumented impact measurements can provide more information for the same amount of effort and material than can be obtained by the more classical methods being utilized. The interest in instrumented impact testing is increasing and ASTM is considering the development of standard methods.

The next two papers discuss various surface tests and the special techniques that are recommended for their correlation with end-use performance. Surface testing is particularly difficult because by definition such tests are dependent on the boundary conditions, or mating surfaces, and are thus either hybrid or practical. This has been clearly indicated by Carroll in searching for the most appropriate abrasion tests to evaluate photographic film. Falling carborundum particles and horsehair brushes did not produce abrasion patterns that correlated with end-use performance. This is not surprising since both tests were hybrid. When a spherical stylus scratch test was used, which produces an abrasion by the same type of high unit pressure over a small area common to film sliding or feeding through various camera and developing mechanisms, excellent correlation with actual performance was found.

The same rationale applies to explain why a point contact friction test was more sensitive to assessing the effects of film lubrication than the standard ASTM Test for Static and Kinetic Coefficients of Friction of Plastic Film and Sheeting (D-1894-78) flat sled. The test also allowed the role of lubricity in changing scratch resistance to be quickly determined.

Once the relevancy of a surface test for an end-use application has been demonstrated, the actual test apparatus might be very simple. This has been illustrated by the paper clip friction tester which was designed to detect film lubricants. A close relationship exists between the projection life of photographic films and their level of lubrication as quantified by this test.

Predictions of wear performance has been shown to be another area where laboratory tests are generally hybrid in nature and considerable insight is required to establish that the boundary conditions of the test are related to end-use. Eiss uses the concept of an output response to an input excitation to study wear. This system approach requires that the interaction of the material, geometric, structural, physical, chemical, and thermal components be considered.

The wear mechanisms identified involve deformation wear which includes abrasive and fatigue wear, interfacial wear which includes adhesive wear and material transfer, and chemical wear which includes material loss by melting or degradation. While the mechanisms of wear have been identified, there are no models that the designers can use to predict wear rates. They must rely on measurements made in wear tests.

Unfortunately, as Eiss notes, most wear tests are designed with an eye on accelerated tests at a minimum cost. They usually provide no information on the wear rate which will be experienced when the material is used in end-use. The standard ASTM Test for Resistance of Plastic Materials to Abrasion (D1242-75) for example, should only be expected to correlate with performance when abrasive wear dominates. The pressure-velocity (PV) limit should correlate when chemical wear dominates. The establishment of generally applicable wear tests is doubtful. Rather, the designer should analyze each situation and develop practical tests which match the boundary conditions with those of end-use. However, in trying to develop new test methods, the author recognizes that a great deal of information may be generated for the designer that will produce better correlations between test results and end-use performance.

The paper by Pang and Isaacs discusses the designers impressions of ASTM testing procedures for establishing suitability for an end-use application. Attention is called to the large amount of nonessential data for product design that is presented in product sheets. As found throughout this volume, the need for fundamental properties as a function of temperature, time under loading and under other environmental influences is emphasized. The problems encountered in the development of a plastic iron and drip coffeemaker are used as two examples to illustrate that there is a definite need for making available to the end-user more descriptive and meaningful physical performance data. Many of these problems can be related to the failure of the supplier to provide fundamental properties of the material over a wide range of conditions. For example, had a fundamental thermal mechanical profile obtained by a technique such as dynamic mechanical analysis been presented instead of a single misleading hybrid heat distortion temperature, the high temperature performance of a polypropylene material would have been obvious. The authors note that better presentations of physical properties would have aided the selection of materials.

In the last paper, O'Toole discusses the need for a coherent plastic design and strength of materials technology comparable in effectiveness with that of metals. Because of the viscoelastic behavior of plastics, however, characterization of their performance requires techniques different from that used for metals. To overcome the special problems encountered with plastics, O'Toole recommends the generation of plastics design practices and performance test procedures based on the pooling of available knowledge of plastics behavior using both the disciplines available in ASTM D–20 as well as those that would need to be recruited, that is, the designers themselves. To accomplish this a sweeping reorganization of Committee D–20 is proposed. The proposed reorganization, however, is more extensive than required to start development of design and performance criteria. This paper does, however, present an excellent summary of the kind of philosophy that ASTM Committee D–20 must adopt if it is to meet the challenge of the future. Fundamental, practical, and component test methods needed for design and performance must be clearly distinguished from purchase specification tests.

Unfortunately, some topics presented at the symposium are not included in this volume. One of the most important areas is mechanical spectrometry. A simple thermal mechanical profile of the energy stored, (modulus) and energy dissipated (Tan δ) by a plastic perhaps yields more insight and fundamental information about such viscoelastic materials than any other single measurement. The reader is urged to consult other texts to find demonstrations of the contributions of dynamic mechanical measurements to end-use applications.

Another area that is not discussed in this volume concerns the use of portable microprocessors to collect field data, strain and acceleration values for example, on an actual component in service so that the magnitude and shape of input excitations given to the laboratory specimens can be adjusted to be relevant with the end-use conditions.

The problems of testing for meaningful predictions of end-use performance have been summarized, the current state of the art reviewed, and various approaches suggested for improving our rate of progress. One proposition on which there is general consensus is that there is a great deal of work to do that is challenging both technically and logistically.

What then are the priorities for improved physical testing techniques which better correlate with end-use performance in the future? On the basis of the papers included in this volume, it appears that a rationale and methodology for meaningful testing can be established. However, such future development will require closer liaison between the testing experimentalist and the designer. More than any other factor, the inherent interdisciplinary nature of plastics usage has frustrated the development and promulgation of a complete and coherent performance testing program.

As O'Toole has stated, ASTM Committee D–20 is in an excellent position to act as a coordinating focus in any efforts to develop relevant testing procedures. An initial step has been taken with the formation of Section D–20.10.24 on "Design and Performance Criteria." The goal of this D–20 section is to provide guidelines for the selection of procedures and physical properties applicable to the reliable design and performance of plastics. Hopefully designers and test engineers will use this common forum to express and exchange ideas leading to the development of new standards. Further progress in these areas should be reported regularly in future publications of this sort.

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