Overview

The last two decades have witnessed an explosion in the use of polymeric materials and their composites for structural applications. This has resulted in more demanding acceptance criteria with respect to all mechanical and chemical properties of these materials. In addition to the usual static properties obtained at very low testing speeds, it has become essential to know how polymeric systems behave under dynamic loading conditions, such as high-speed impact. Examples of such applications for these versatile materials are now commonplace: bumper backup beams, leaf springs, oil pan assemblies, car body panels, equipment container cases, gasoline tanks, helicopter blades, radiator shrouds, and other applications. In each instance the success of the material in the application requires knowledge of its mechanical and chemical property profile and, in particular, characterization of its impact performance. This Special Technical Publication has been published as a result of the 1985 symposium on Instrumented Impact Testing of Plastics and Composite Materials, held in Houston, Texas, in an effort to communicate state-of-the-art technology to those actively engaged in these studies. The symposium was the outgrowth of work within ASTM Subcommittee D20.10.02 on Impact and High-Speed Properties, a subcommittee of ASTM Committee D-20 on Plastics.

It is well known to those involved in impact testing that there frequently appear to be more variables than constants available to the engineer. The engineer is required to make the right choices to characterize the material properly for its ultimate use. It is generally true that an impact event can be thought of as the contact of a high-speed projectile [velocity $\geq$203 m (8000 in.)/min] of some specified geometry with a supported test specimen. During this impact event the specimen absorbs and transmits energy that can be expressed in simplest terms as the integral of the force-displacement curve. The shape of the curve provides information on the initiation, yielding, and propagation of energy during the event. The choices for the actual test configuration can be extremely diverse: the specimen may be notched or unnotched, may be supported as a cantilever or flexural beam, and may be a flat plaque, a rectangular bar, or the fabricated component. The striker (or tup) may be driven or free-falling, and the test data may be instrumented or noninstrumented. Consideration of the inertial effects of equipment may or may not be required. The engineer may be more interested in characterizing the impact fatique life of the material, using low-blow impacts at energies less than that required for failure. Whether the material becomes work-toughened or fails catastrophically after a particular number of impacts can then be determined. This can then provide insight into the useful life of a material under certain expected conditions.

In order to define the proper test configuration for a material and application, the stress states and likely conditions need to be identified. What constitutes failure, the mode of failure, and its likely cause need to be established. This provides the guidance necessary to determine what combination of tests is required and what environmental conditions need to be considered. In the development of materials for new applications, instrumentation of the impact event is essential so that changes in the mechanism of failure can be quantified. Instrumentation provides data on the effective dynamic modulus of the material under the conditions of test, its strain and elongation capacities, and its energy storage capability. If no instrumentation is applied, a single number is obtained, which confounds these property values and does not provide the engineer with information for modifying the material and measuring exactly how that modification has affected the impact trace or force-displacement curve. In addition, instrumentation allows the engineer to define conditions of failure that do not require destruction of the component. For instance, a performance standard for a high-speed gear assembly could limit the strain to less than 0.5% at a ram energy of 11.3 N · m (100 in. · lb), although the part may actually yield or break only at a much higher energy level.

The collection of 19 papers published in this volume has been grouped into five major categories. Some papers could be placed in more than one category, and here an arbitrary selection has been made. These categories are methodology, impact testing for end-use applications, impact characterization of selected materials, partial impact testing and fatigue response of plastics, and fracture toughness.

Methodology for Impact Testing

The papers in the section on methodology are written with varying levels of technical depth, which provides those relatively new to the technology with specific guidelines for preparing the system for data collection, as well as evaluation of the data collected. In at least one paper the information is generic in nature and is independent of the specific type of data system, test geometry, and material tested. The differences between drop-weight machines and servohydraulic systems are also discussed. In this section the methodology for selecting impact tests applicable for automotive composites and interpreting their data is presented in detail. The approach that has been taken would be suitable for any application and consists of four basic steps: establishing the functional requirements for an application (a composite fender, for example), listing the stress states that could occur for the range of impact conditions for each functional requirement, determining the controlling variables for each stress state, and listing the failure limits for each functional requirement. It is often the case that several impact configurations and test conditions are required to test a material for a given end use. Also included in this section is an analysis of the stability and reproducibility of a driven ram impact tester and recommendations on improving the reliability of the data. The issue of changing velocity of the impact ram and its implications on the test data collected have been addressed. Digital filtering has also been reviewed in this section, with guidance provided as to its valid use and its misuse, which leads to anomalous data and incorrect analysis.

Impact Testing for End-Use Applications

The section on impact testing for end-use applications is, by its title, of a more applied nature and demonstrates the techniques used for various end uses. Those specifically reviewed in this section are impact measurements on low-pressure thermoplastic foam, material impact characteristics in the use of cushioning systems, a detailed survey of ten test methods for characterizing materials for automotive components, and impact testing for a variety of products such as tires, reinforced thermosetting pipe, boat hulls, and baseball helmets. In this section the effects of strain rate and temperature on the relative brittleness/ductility of materials is discussed, as well as the influence of the thickness and cross-sectional uniformity of the material. In the case of the survey of ten impact tests, conclusions regarding the relative discrimination powers of the tests, in comparison with each other, and their correlation or lack of correlation with each other are presented. The paper on cushioning systems presents a technique for quantifying the damping capacity of materials by the use of instrumentation of the impact event, which can discriminate between recoverable, elastic deformation and permanent, nonrecoverable deformation.

Impact Characterization of Selected Materials

The third section, on impact characterization of selected materials, covers more of the fundamental, research-oriented characterization of materials. As described in the paper on polyether sulfone, an effort was made to effect material failure by machining a central hole 1 mm in diameter in the flat plates, which were subsequently impacted by a falling dart. This work was done since the material would not fail under no-notch conditions. This preliminary work pointed to a brittle-ductile transition that was influenced by the presence of the machined hole, but only within a defined thickness range. Another interesting study was reported on the influence of test rate and temperature on the fracture behavior of rubber-modified acrylonitrile-butadiene-styrene (ABS) and polyvinyl chloride (PVC), with particular emphasis on the location of the brittle-ductile transition. The crazing mechanism due to the presence of the rubber modifiers was demonstrated to be responsible for the toughening capacity of these materials. Varying levels of rubber modifier were also considered.

The remaining papers address high-performance composites reinforced with aramid and graphite fibers. In the paper on new composite materials for aerospace applications, the influence of new thermosetting resins on the impact resistance of graphite composites was evaluated. The authors found that the through-penetration or puncture test provided the majority of impact response data, but it was, by itself, insufficient to describe the conditions that would be encountered in service. Studies using a number of impact energy levels were recommended for better characterization of incipient damage, augmented by the use of ultrasonics. The paper involving impact testing of aramid composites compares the impact damage tolerance of these fibrous composites to those reinforced with carbon and glass fibers. The fact that aramid fibers are efficient energy absorbers with a level of recoverable deformation during impact was demonstrated by the use of instrumented impact testing of flat plates, honeycomb aerospace panels, and filament-wound pressure vessels.

Partial Impact Testing and Fatigue Response of Plastics

There has been a growing interest in the behavior of materials under impact conditions that are within the initiation phase of the force-displacement curve, prior to maximum load. In the section on partial impact testing and impact fatigue, three papers address different aspects of this subject. The paper on fatigue studies the use of low and constant impact energy as a method for providing toughness measurements on polymers. The paper concludes that crystalline polymers appear to have better fatigue performance than amorphous polymers, and that there seems to be a different energy absorption process occurring in multiple impact tests than in single-blow impact tests. The point is made that the increasing use of polymeric materials in hinges, gears, springs, and automated arms has made fatigue performance a growing concern. The fundamental difference between the fatigue curves of brittle and ductile materials is identified. A means for quantifying the absorbed energy as the area within the closed fatigue loop (force-displacement) is described. Two papers on the subject of incipient crack formation and the impact response at varying depths of penetration show that, at least for the materials studied, the impact trace taken to less than maximum load mirrors traces taken to complete failure. This provides technical justification for using this technique to identify the mechanism of incipient failure of materials. By using shims on a falling dart tester the authors could raise the test specimen height in order to control the distance the tup travels into the specimen. The impact characteristics at crack formation could then be analyzed. Computer simulation of the impact event was explored to determine whether the use of wave mechanics was needed to model specimen deformation and failure.

Fracture Toughness

The last section, on fracture toughness, includes two papers. One of these uses laser-Doppler techniques for velocity measurement in order to characterize the impact behavior of materials. This eliminates the complications of the ringing of a transducer attached to the tup. The results of the paper indicate that this is technically feasible, particularly when the data are stored and analyzed via microcomputer. The other paper investigates the applicability of linear elastic fracture mechanics for treating the fracture of polymers under dynamic loading. Acetal and polymethyl methacrylate (PMMA) were the materials of choice, the first being crystalline and the second amorphous. This approach proved fruitful, with the plane-strain fracture toughness observed to be relatively constant with increasing crack-length-to-specimen-width ratios, except at the highest loading rate. In addition, it was found that fracture toughness was significantly influenced by loading rate, with transitions observed for both polymers. An explanation for these transitions was postulated.

The papers briefly outlined here should provide the reader with much of the very latest information in the area of instrumented impact testing. Virtually all possible combinations of test conditions have been addressed within this volume, as well as types of material and equipment. The symposium committee gratefully acknowledges the efforts of the authors and ASTM personnel that have made this publication possible.

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