BEHAVIOR OF POLYMERIC MATERIALS IN FIRE

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Foreword

This publication, *Behavior of Polymeric Materials in Fire,* contains papers presented at the symposium on Polymeric Material Behavior in Fire, which was held on 23 June 1982 in Toronto, Canada. The symposium was sponsored by ASTM Committee E-5 on Fire Standards. Erwin L. Schaffer of the U. S. Department of Agriculture, Forest Service, presided as chairman of the symposium and also served as editor of this publication.

Related ASTM Publications

ASTM Fire Test Standards, 1982, 03-505082-31

Fire Risk Assessment, STP 762 (1982), 04-762000-31

Design of Buildings for Fire Safety, STP 685 (1979), 04-685000-31

Fire Standards and Safety, STP 614 (1977), 04-614000-31

A Note of Appreciation to Reviewers

The quality of the papers that appear in this publication reflects not only the obvious efforts of the authors but also the unheralded, though essential, work of the reviewers. On behalf of ASTM we acknowledge with appreciation their dedication to high professional standards and their sacrifice of time and effort.

ASTM Committee on Publications

ASTM Editorial Staff

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Introduction

This publication was generated as a result of a symposium titled Polymeric Material Behavior in Fire, presented during the 1982 June Meeting of ASTM in Toronto, Ontario, Canada. The symposium was planned and conducted under the auspices of ASTM Committee E-5 on Fire Standards and its Subcommittee E05.32 on Research (T. Z. Harmathy, chairman).

Intense effort is under way throughout the world to model the progression of fire growth analytically as a necessary first step to the eventual provision of fire-safe environs. A prime example of this modeling is the effort under way in North America to describe fire growth in compartments. As important as this type of research is, it quickly leads to the need for precise data on the response of combustible materials to fire or intense energy for reliable model predictions to be made. Synthetic and natural polymeric materials used in furnishing and constructing structures were of specific interest. Because of the range of polymeric materials that would need to be included in a program, a call for papers was made to prospective authors who would comply with the general theme of the symposium and would address either fundamental or applied aspects of a material's response to heat or fire. The final program was based on accepted papers.

A simple perusal of the table of contents provides a fine view of the range of materials and techniques discussed at the symposium to characterize response and effects.

Critical to the acquisition of response data that meaningfully reflect a given imposed environment are the test methods used. ASTM provides the nation and the fire safety community with a consensus medium for valid interpretation of existing test results and development of improved tests to describe the behavior of materials. Models of fire growth or damage progression will indicate what material behavior parameters need quantification. It is then necessary to formulate tests that will provide the parametric data for such models reliably and precisely. The search and refinement continues for the best test methods for determining the material parameters needed to predict response in fire environs until all are "adequately" defined.

The first paper, by Robertson, expands on the role of fire tests in serving the fire safety community. Subsequent papers by Martin, Chamberlain, Alvares et al, Day and his associates, and Sutker each discuss one of many response characteristics for polymeric materials—ignition, combustion, energy release rate, thermal degradation, smoke, and the influence of fire-retardant additives. King et al examine the protection provided by clothing in high-energy exposures. Park concludes the series with the proposal of a risk rating system for plastics, based upon test results using both large and small fires.

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Alexander F. Robertson [1]

Fire Test Methods: Classification and Application

REFERENCE: Robertson, A. F., **"Fire Test Methods: Classification and Application,"** *Behavior of Polymeric Materials in Fire, ASTM STP 816,* E. L. Schaffer, Ed., American Society for Testing and Materials, 1983, pp. 3–12.

ABSTRACT: It is shown that traditional fire test methods have in many cases represented physical models of real prototype fires. The results of applying them serve in a significant way to predict the behavior of a prototype system when exposed to fire. Consequently, the fire safety community has thought of fire tests as yielding information on the behavior of a fire system. Most of the new consumer protection fire tests adopted by the government may be considered as typical of the fire system type. Recently, there has been a trend toward introduction of a new series of tests that measure, often in technical terms, one or more specific fire properties. Many of these properties must usually be considered together to predict the behavior of a fire system. Thus, it becomes important for the user of the fire test to understand the nature of the test he plans to apply. It is unfortunate that explanatory material to assist the user in such understanding is usually not considered an integral part of the test method and is often omitted by those adopting the test for regulatory purposes. Action is proposed to correct such a defect. A table is provided to show the way in which the author has classified representative fire tests.

KEY WORDS: fire safety, fire tests, materials tests, modeling, property tests, system tests

In earlier papers [*1,2*], it was proposed that test methods may be classified into two general groups. There are *property tests,* which search out and relate, to the extent practical, to a single property of the material or system under study. Others, which attempt to measure the overall behavior of a complex system, are referred to as *system tests*. Property and system tests may be subclassified as destructive or nondestructive. Obviously, these subclassifications relate to whether or not the item studied is damaged through application of the test in such a way that a second confirmatory test either is not or is possible on the same object. It was suggested in the earlier work that probably all fire system tests are destructive. On the other hand, a few of the fire property tests of the non-destructive type may exist. The latter might include tests related to thermal, optical, and some mechanical properties. There may be objections to this on

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the basis that such tests really are not fire tests. Nevertheless, the results of such measurements are surely of great importance in defining the behavior of a fire system.

In summary, it was proposed in the earlier work that most conventional fire test methods are of the destructive system type, since the outcome of their application results in destruction of the specimen and is influenced by many different internal and external variables. The complexity of these variables—physical, chemical, and now, with toxicity being considered, biological—has been part of the reason for the continued empiricism in the fire safety field. This paper briefly reviews the situation and warns of possible misuse of both types of tests. It suggests tolerance by the computer fire modeling community, with the continued appropriate routine use of fire system tests until the new modeling methods prove practical for general application by building and code officials.

Early Developments

Fire test methods have been developed through a lengthy series of experimental studies, revisions, and refinements [*3*]. In the process comparisons have been made between behavior experienced in accidental fires and the results predicted by the laboratory test. The process of refinement of the test for appropriate prediction of real fire behavior has been largely guided by practical experience and the subjective understanding of concerned consensus groups. The test methods developed have been in many cases methods of physically modeling some aspects of real fires. In many instances, these test methods have formed a very successful basis for fire prevention engineering. However, there are numerous exceptions to this, especially as new types of materials and assemblies must be evaluated that were not available or considered when the test method was developed. Care must also be taken to avoid the use of such a test as an indication of performance of a system for which it fails to adequately provide a suitable model.

The early workers in the field of fire safety recognized many of the limitations of the test methods they helped develop and proposed as standards. For instance, the proposal for adoption as a standard of a test for fire doors was delayed for ten years because of the concern that no adequate means had been developed to measure the effectiveness of the door as a barrier to smoke and fire gases. When the test procedure was finally adopted as ASTM's Fire Tests of Door Assemblies (E 152) in 1941, this deficiency was still recognized [*4*], but it was considered that the need for a test to assess the mechanical behavior of doors under fire exposure was of overriding importance.

The E 152 fire system test is typical of most of the fire test methods developed for building regulatory use. They make use of a physical model, often close to full size, of a portion of a building assembly or occupancy item. Under fire exposure, the various components react interactively with other portions of the assembly in response to the thermal load imposed in a prescribed fashion. The outcome of a door test is a result of the overall mix of reactions between the internal construction details of the door and its mounting fittings with the frame and wall within which it is mounted as a result of the fire exposure. In this case, the test procedure is an imperfect model, so far as an overall system test evaluation is concerned. The thermal exposure is specified in terms of a temperature-time curve. There is no freedom for interaction between the door and the heat source in modifying the thermal exposure or furnace temperature. Moreover, although observations are required of the smoke and flame penetration or passage around the door, no provision is made for their quantitative measurement.

The E 152 test and other fire test methods in use in the 1950s prompted attempts to approach fire testing and performance assessment in a different way. An attempt was made to develop test methods through which the various fire properties of the assembly considered could be determined [*5*]. These, through a mathematical or computer modeling method, could be combined to predict fire performance.

In this country a number of fire property test methods have been developed that provide for quantitative measurements. These include the ASTM Test for Surface Flammability of Materials Using a Radiant Heat Energy Source (E 162), which measures two fire properties that were combined in an arbitrary way to yield a flammability index [*6,7*]; the National Fire Protection Association's Potential Heat Test Method (NFPA 158) [*8,9*]; the ASTM Test for Specific Optical Density of Smoke Generated by Solid Materials (E 662) [*10,11*]; and the ASTM Test for Critical Radiant Flux of Floor Covering Systems Using a Radiant Heat Energy Source (E 648) [*12*]. Each of these provides a specific measure of fire properties. A number of these, together with the physical and chemical properties of the fire system, could presumably be combined through a mathematical modeling process to predict fire behavior of the system. Even before full development and refining of the theoretical modeling process it seemed likely that such tests would provide useful guidance to the fire protection community.

Classification of Tests

The design and development of fire test methods of either the fire system or fire property types is not as simple as may be suggested by brief consideration. One of the reasons for this is that while we expect test methods to be consistent, yielding reproducible results, unwanted fires are usually very complex in their behavior. As a result, the process of fire test method development usually involves important compromises to increase the methods' range of applicability while permitting their adoption as acceptable test methods. Thus, most fire test methods will, when classified, fall into a spectrum between system and property type tests.

Table 1 presents the writer's subjective classification of some of the roughly 80 to 100 fire test methods used in this country. The width of the table spans the range from fire system to fire property tests, while the vertical order of listing is roughly chronological with respect to test method development or acceptance as a standard. Prime emphasis has been placed on tests sponsored by ASTM Committee E-5 on Fire Standards, although some other test methods are also included. Tests adopted by foreign standards organizations, as well as many other U.S. tests, have not been listed, primarily to limit the size of the table. It is believed that the tests listed are adequate to demonstrate the range of classification that should be considered in application of tests. This table should not be interpreted as a justification for or against any test method. It is simply the writer's expression of the way in which he would classify them on the basis of his knowledge of the measurement resulting from their use.

In order to understand the way in which the tests have been classified it is important to understand what is implied by the use of the two descriptors *system* and *property*. Thus, it seems useful to present definitions:

System test— A test that through a standardized procedure provides a means for simulating, measuring, and reporting the combined effect of all physical, chemical, and, in some instances, biological factors that interact to influence the susceptibility of some specific prototype system to unwanted fire.

Property test— A test that through a standardized procedure provides a means for deriving one or several physical, chemical, or biological properties important in contributing to the overall behavior of a fire system, product, or material.

The distinction between the two types of tests is not whether or not the measurement is made through use of a realistic physical, chemical, or biological model. Rather, it is based on whether the measurement process reflects in a useful way the overall behavior of the intended prototype, or instead only yields information, usually in a technical form, on one or more of the properties influencing a system, product, or material.

Another way of expressing the distinction is that a system test models in physical, chemical, and biological complexity the prototype fire. The test is usually convincing, since it closely simulates the fire conditions considered. The results obtained are often only expressible in terms of the test method used. On the other hand, property test results may be derived through test procedures of different types. In some cases they may model the prototype fire system. Most frequently, however, the model used is not complete or has been specifically modified to permit a more appropriate or quantitative measurement of the property in question.

The system test provides an indication of the overall prototype fire behavior. A property test yields technical information on one or more of the factors influencing overall fire behavior. The system test result may be assumed to provide a direct indication of the prototype behavior when involved in fire. The property measurement is usually, by itself, incapable of predicting overall fire behavior of the prototype.

Table 1 illustrates how most of the early E-5 fire tests can be classified as yielding a result approximating that of a fire system test. For instance, ASTM

Fire Tests of Building Construction and Materials (E 119) covers procedures for measuring fire endurance of walls, floors, and columns. Aspects of this test that were considered in the classification shown in Table 1 are presented in Table 2. Thus, the failure to classify this as a full system test is primarily because the test method specifies a fixed fire exposure temperature-time program. The freedom of the specimen and furnace enclosure to modify the fire exposure conditions has been prevented.

The need to standardize a fire exposure condition is common to most fire test methods. The difficulty is that real fires seldom behave as if the fire and the specimen are independent: They usually involve a strong fire-specimen interaction. Thus, the fire exposure is not usually uniquely constant. Some fire tests permit such fire-specimen interaction, but many fail to model real fires in this way. The fire modeling community is trying to permit this type of freedom in its computer models.

Again, considering Table 1, it will be observed that while many of the early tests are classified as tending towards system type, there has been a marked trend in recent years toward acceptance of fire property tests. In some cases, these yield information on a single fire property. In others, two or more properties may be defined. Notice, however, that the three mandatory federal flammability tests all closely simulate real fire conditions and have been classified here as fire system tests. (These tests are given in the Code of Federal Regulations [CFR] as the Standard for Surface Flammability of Carpets and Rugs [CFR 1630, FF1 = 70], the Standard for the Flammability of Children's Sleepwear: Sizes 0 through 6x [CFR 1615, FF3-71], and the Standard for the Flammability of Mattresses and Mattress Pads [CFR 1632, FF4 = 72] [*13*].) They assume the form they do both because the most common ignition source is used and the fact that public consensus and acceptance of a test is much more readily achieved when the test method itself closely models the prototype.

The ASTM Test for Surface Burning Characteristics of Building Materials (E 84), also known as the tunnel test, has also been classified as closely resembling a fire system method. The propagation of the fire down the tunnel is controlled partly by the imposed draft conditions but also by heat transfer from burning gases to unexposed portions of the specimen. The smoke developed during the test reflects the fire-specimen interaction and thus seems appropriate. However, the method of reporting smoke development—in terms of the area under an absorption-time curve—is unfortunate because of the nonlinearity of optical attenuation with smoke production.

The classification of the adiabatic furnace test method [*14*] as a property test provides an illustration of the apparent anomaly of a fire system method yielding a fire property result. The test method allows a small sample of material to self-heat under conditions similar to those existing at the center of a large pile of the material tested. However, the experimental results are only validly reported in terms of activation energy and rate constant data. These can be used together

TABLE 1 — *Classification of fire tests.*[a]

Chronology	Test Type: Fire System .... Fire Property
1920	Fire Tests of Building Construction and Materials (E 119)
	Fire Tests for Flame-Resistant Textiles and Films (NFPA 701)
1940	Fire Tests of Door Assemblies (E 152)
	Test for Combustible Properties of Treated Wood by the Crib Test (E 160)
	Test for Combustible Properties of Treated Wood by the Fire-Tube Apparatus (E 69)
	Test for Incandescence Resistance of Rigid Plastics in a Horizontal Position (D 757)
1950	Test for Surface Burning Characteristics of Building Materials (E 84)
	Test for Flammability of Clothing Textiles (D 1230)
	Fire Tests of Roof Coverings (E 108)
	Test for Behavior of Materials in a Vertical Tube Furnace at 750°C (E 136)
1960	Fire Tests of Window Assemblies (E 163)
	Adiabatic furnace test[b]
	Test for Surface Flammability of Materials Using a Radiant Heat Energy Source (E 162)[c]
	Test for Surface Flammability of Building Materials Using an 8-ft (2.44-m) Tunnel Furnace
	Test for Ignition Properties of Plastics (D 1929)
1970	Surface Flammability of Carpets and Rugs Carpet pill (CFR Part 1630)
	Measuring the Minimum Oxygen Concentration to Support Candle-Like Combustion of Plastics (Oxygen Index) (D 2863)
	Flammability of Children's Sleepwear: Sizes 0 Through 6X (CFR Part 1615)
	ASTM Test for Heat and Visible Smoke Release Rates for Materials and Products (E 906)[b,c]
	Flammability of Mattresses (and Matress Pads) (CFR Part 1632)
	Test for Flame Height, Time of Burning, and Loss of Weight of Rigid Cellular Plastics in a Vertical Position (D 3014)
	NBS and other heat release tests[b]
	potential heat (NFPA 259)
	Guide for Room Fire Experiments (E 603)[d]
	Test for Critical Radiant Flux of Floor Covering Systems Using a Radiant Heat Energy Source (E 648)
1980	Test for Specific Optical Density of Smoke Generated by Solid Materials (E 662)

TABLE 1—*Continued.*

Chronology	Test Type: Fire System	.... Fire Property
	Fire Tests of Through-Penetration Fire Stops (E 814)	
		Guide for Measurement of Gases Present or Generated During Fires (E 800)[d]
	Proposed Method for Room Fire Test of Wall and Ceiling Materials and Assemblies[b,e]	

[a]Lateral position of beginning of each standard indicates placement on spectrum from fire system to fire property tests. Tests are listed in approximate chronological order of adoption or development. Unless otherwise noted, all tests are ASTM standards.
[b]Not yet accepted as a standard.
[c]Two or more properties.
[d]This is a guide document and thus the applicable classification may vary with use.
[e]Includes property measurement.

with thermal properties to yield the performance of various bulk piles in terms of critical pile size and ambient temperatures likely to lead to fire development.

The test for critical radiant flux (CRF) of floor covering materials is another example [*12*]. The test provides a means of modeling the combined effects of the floor assembly, often simulated by an insulated backing, together with the finish, carpet, or other wearing surface and the calibrated incident flux at which the burning surface self-extinguishes. The experimental result is a thermal flux incidence level. This is a fire property characteristic of the combined thermal and chemical characteristics of the finish of the floor surface together with the substrate. The CRF has been used as a basis of qualifying floor coverings as acceptable for use under certain situations. Nevertheless, several other fire property characteristics are required if overall fire behavior is to be predicted.

Fire property tests have the attractive technical advantage that one has much greater confidence of knowing what has been measured. Sometimes, it may be

TABLE 2—*Factors influencing proposed classification of ASTM E 119.*

Supporting System Classification	Opposing System Classification
1. Large representative structure tested.	1. Fire exposure is specified and not influenced by the combustible nature of the construction or possible changes in fire ventilation.
2. Structure tested under load and lateral restraint.	2. The test does not evaluate wall-wall and wall-ceiling interactions.
3. Severe fire exposure.	3. No measurement is provided for smoke and pyrolysis gases.
4. End point criteria: a. Temperature rise unexposed face. b. Development of through cracks. c. Load carrying capability.	

possible to make the same measurement in a different way and obtain the same or similar results. However, it is discouraging to see that such test results are often used by themselves as the basis of selecting or rejecting materials or products, without consideration of the many other factors or properties that will influence the fire behavior of the system. The fire safety community has been accustomed to think of a fire test as a fire system test.

For this and other reasons there has been an increased tendency to develop appendices or commentaries for the various fire test methods, to make clear the extent to which the test in question is likely to provide useful information to those who apply it. It is unfortunate that because of legal considerations such commentaries are seldom considered a mandatory part of a fire test. Thus, when such tests are adopted by code and regulatory groups, the commentary is seldom if ever retained, and whether the tests are of the property or system type may no longer be evident. This situation should be changed. The current ASTM fire test caveat required in all standards relating to fire test methods (for example, paragraph 1.3 in Fire Tests of Building Construction and Materials [E 119]) does not really help solve the problem. It just says that no fire test gives the complete answer and all relevant aspects of the likely fire situation as well as the results of other fire tests should be considered in applications of the item tested. It thus presents an innocuous disclaimer of responsibility rather than helping the user distinguish between the types of tests.

The traditional use of fire system test methods has resulted in the general belief that the test that best physically simulates the intended fire situation being assessed is likely to yield the best indication of the character of the fire that may develop. This may often be the case, but the costs in both time and financial outlay may be very high. It is the contention of the fire modelers that with computer techniques, which they are still in the process of developing, it will be possible to use the fundamental physical and chemical properties of materials, together with selected fire property test data, to predict the character of fire growth and spread as well as the mechanical behavior of building elements during fires. There are some impressive indications that these predictive methods are nearing the stage of practical applicability. Probably their earliest useful applications will be found in situations where fire testing would be unusually expensive. An example is the design of building ventilation systems with means for disposal of the smoke resulting from fires [*15,16*]. Another example is the design of steel frame or reinforced concrete buildings for desired fire endurance behavior [*17*]. Significant progress has already been made in both these areas. Still another example [*17*] relates to modeling the development of fires in rooms or compartments. However, computer-based fire models can only give accurate predictions when all important aspects of the problem are recognized in such a way that actual fire behavior is simulated. The migration of smoke in a building is not likely to be usefully modeled if the influence of broken windows in the fire compartment or the importance of wind are not correctly simulated. Similarly, if the loss of strength of a ceiling fire-protective supporting system or the spalling of concrete