

FLAMMABILITY TESTING

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Understanding how composites burn

The study of how composites and plastics burn has been, and continues to be, a major area of research at universities, in industry, and at various national, military, and private laboratories around the country. No one has yet been able to sort out all of the factors that occur during the combustion of composites and plastics. Even less, no comprehensive model of combustion exists for these materials. Nevertheless, some aspects are quite clear, taken by themselves. Other aspects, especially when several effects are combined (as occurs in real fires), will permit only gross approximations. But, we can get a surprising amount of information just by making some reasonable observations.

What is most clear is that under the conditions that normally exist for fires, fiberglass does not burn and does not, therefore, contribute to the combustion of the material. The other common fiber reinforcements — carbon fibers, aramid fibers, and UHMWPE fibers — will burn under normal fire conditions, but their contributions to the fire are generally much smaller than the resin matrix and will be ignored. Some minor effects may arise from orientation effects of the fibers (such as when the outer layers of fiberglass insulate the inside from the flame), but these effects are small and will also be ignored.

Most inorganic fillers do not burn either, but they can decompose in a fire and can strongly effect the combustion process. One obvious example is aluminum tri-hydrate (ATH) which releases water molecules when heated. These water molecules tend to reduce the flammability of

the composite, affecting both flame and smoke. Other fillers which can strongly affect combustion include those containing halogen atoms (fluorine, chlorine, bromine, and iodine). These fillers reduce flammability, although they often increase smoke density. Many minor additives, such as antimony oxide can effect the behavior of the combustion process. Sometimes even the color pigments can have an effect. The best practice in understanding the effects of fillers in your products is probably to run some flammability tests. The most important tests will be described as soon as we discuss a few concepts regarding the flammability of the resin matrix.

The resin matrix (or plastic component) is, by far, the most important aspect of the composite in determining the combustion characteristics. The reason is simple — most organic resins will burn. If you want to reduce that burning, then some modifications will usually have to be made to the resin or one of the few inherently flame-resistant resins will have to be used. Other articles have addressed the changes that are most often made to make the resins less combustible so they will not be treated here. The most common methods of modifying the resin are, in brief summary, to add halogens to the resin or to increase the amount of aromatic (benzene) groups in the resin.

The focus of this article is to examine the tests that are being done on composites and to try and understand when certain tests are appropriate. Before the tests are examined, however, we should note the fundamental characteristics of the combustion process. These characteristics are the properties that are actually measured by the various tests. Understanding what these properties are will lay the foundation for choosing the proper test for your application and for interpreting the results which are obtained.

Combustion characteristics of organic resins and plastics

The following properties are usually those considered when examining the burning of composites and plastics:

- Ease of ignition/flame resistance — How readily does the material ignite? What kind of ignition source is required?
- Flame spread/fire retardancy/surface flammability — How rapidly does the fire spread? Is it different in different directions?
- Heat release rate — How much heat escapes from the material during combustion and at what rate?
- Fire endurance — How rapidly will fire penetrate a barrier of the specific material? What are the orientation effects on fire penetration?
- Ease of extermination — How easily will the fire go out?
- Smoke emission/toxicity — How much smoke is released? What is the rate of smoke release? Is the smoke toxic or corrosive?
- Physical characteristics — Does the material drip, droop or sag as a result of burning?

Why do flammability testing?

The most obvious and prevalent reason for testing is to satisfy the requirements of some agency that controls the specifications for use of the product. Other reasons might include improvement of the composite materials, study of the nature of the combustion process, establishment of a specification, and assessment of overall design for fire safety.

Flammability tests can be divided into three groups, generally reflecting the purpose for performing the test. These categories are: “Official Tests” or those that are performed to meet some official requirement, lab tests or those which are usually done within a manufacturing facility

for informal studies, and full scale tests which are used to simulate actual use conditions. Each of these groups of tests will be discussed separately.

“Official tests”

For numerous reasons (including historical and performance) various market sectors have developed their own combustion requirements and tests. The test procedures have been carefully specified so that all parties performing the tests do them in precisely the same way. The agencies which control the specifications usually change the procedures only with considerable study and experimentation, thus guaranteeing continuity over time in interpreting the test results. The procedures are also studied to ensure that variations from lab to lab are kept statistically small. In many cases, equipment used in the tests has also become standardized, often requiring the purchase of equipment from approved sources.

In light of these requirements and equipment requirements, places where these tests can be run are usually limited to two groups — commercial testing laboratories and major research facilities (such as those owned by resin manufacturers).

The major market or use sectors for composite products and the fire requirements generally associated with each sector are summarized in Table 1. These include infrastructure (bridges, roads, etc.), transportation, and military. Other product use sectors may similarly require specific combustion performance, but they are less common within the composites usage and are not listed in Table 1.

Note that each test procedure is designated by a alphanumeric code in which the agency controlling the test procedure is designated, such as ASTM (American Society for Testing of Materials), NHTSA (National Highway Transportation Safety Administration), FMVSS (Motor

Vehicle Safety Standard), FRA (Federal Railroad Administration, ISO (International Organization for Standardization, NBSIR (National Bureau of Standards, now the National Institute of Standards and Technology, NIST), and MIL-STD (Military Standard). Details about the test can be obtained from these agencies.

Space in this article does not permit a detailed analysis of each of the tests which are used to investigate combustion of composites, but a brief summary of the most important of these official tests follows:

- Cone calorimeter (ISO 5660/ASTM E-1354) — This test, which is only about 10 years old, appears to be the best possibility for a single, comprehensive test that might satisfy most of the marketing/use sectors. Several advantages of this test include: the sample size is modest (4 x 4 x 1/4 inches) so that preparation costs are low, costs are usually modest (in the \$200 to \$500 range at commercial labs), and most of the fundamental combustion characteristics (ease of ignition, rate of heat release, weight of sample as it burns, temperature of sample as it burns, rate of weight loss, rate of smoke release, and yield of smoke) can all be determined under a wide range of heater and ignition conditions. As a result of the vast amount of data available from this test, a model of the combustion of a material might be developed, thus enabling an estimation of the potential effects of a fire on surrounding areas and occupants.

Pictures of the cone calorimeter equipment, a cut-away diagram of its components, and a view of an actual sample during testing are shown in Figures 1, 2, and 3, respectively.

- Radiant Panel Test (ASTM E-162) — The principal result of this test is a flame spread index. This index is the product of a flame spread factor and a heat evolution factor which are determined as the material is subjected to a radiant heat source. The sample size is not large

(6 x 18 inches) and the costs of the test are modest (\$200 to 300). Furthermore, this test has been used extensively for many years and so much comparative data is available. However, results are often confusing, especially when different materials are compared, thus limiting the broad applicability of this test.

- **Smoke Chamber Test (ASTM E-662)** — Combustion research has shown that many fire fatalities occur in rooms where the flames never reach. Hence, the nature of the smoke generated in a fire is very important. This test is designed to measure the density of the smoke generated as a function of time, under both flaming and smoldering conditions. Because this test was originally developed by the National Bureau of Standards (NBS), the test is sometimes referred to as the NBS smoke density test. The test apparatus is a closed box (smoke chamber), approximately 3 x 3 x 2 feet which contains an optical light source and detector to measure the reduction of optical density from the smoke generated by the burning of a sample placed inside the chamber. The sample is small (3 x 3 x 1/4 inches, usually) and the cost is moderate (\$300 to \$500). Results are usually expressed as a smoke density, D_s , after a 1.5 or 3.0 minutes.
- **Steiner Tunnel Test (ASTM E-84)** — This test measures the flame spread and smoke generated by the burning of a sample within a large (25 x 2 foot) chamber. The principal use of the test is for building materials. The sample is attached to the top of the chamber and a fire is started at one end. The rate and extent of burning are reported. The cost of performing this test (about \$500 per run) is relatively high, as is the cost of the materials because of the large sample size.

Lab tests

Sometimes official tests are either too costly or too time consuming to run. Such a case might occur when a company is trying to adjust the formula or design of a product. The company might go to an outside testing agency (commercial lab or resin supplier) and have an official test run on a candidate formula or design and then use lab tests to monitor the effectiveness of changes. In this way, nearly immediate results can be assessed and, because the nature of the materials are usually similar, the lab tests will general give the same ranking of materials as would be obtained in the official tests. Lab tests are not, however, as useful as official tests in ranking the combustion characteristics of widely different materials.

Some of the most common of these lab tests are:

- Limiting Oxygen Index, LOI (ASTM D-2863) — This test is probably the most accurate of the lab tests. In the LOI test a sample is suspended vertically so inside a closed chamber (usually a glass or clear plastic enclosure). The chamber is equipped with oxygen and nitrogen gas inlets so that the atmosphere in the chamber that it can be controlled. The sample is ignited from the bottom and the atmosphere is adjusted to determine the minimum amount of oxygen to just sustain burning. This minimum oxygen content, expressed as a percentage of the oxygen/nitrogen atmosphere, is called the oxygen index. Higher numbers are associated with decreased flammability.
- Vertical Burn Test (ASTM D-568 and D-3801) — The sample is suspended vertically so that it can be ignited at the bottom. After ignition, the ignition source (usually a bunsen burner) is withdrawn and the length of burn of the sample in a set period of time (10 seconds) is measured. If the sample does not burn for the entire time, the time to extinguish is noted. Materials which burn while the ignition source is in contact but go out quickly when it is

removed are termed self-extinguishing. This test is most useful in measuring the burning characteristics of similar materials. Dripping of the resin should be noted.

- Horizontal Burn Test (ASTM D-635) — This test is similar to the Vertical Burn Test except that the sample is supported vertically. This test is less stringent and is used when the vertical test cannot distinguish between materials. Only self-supporting materials should be tested in the horizontal test.

Full scale tests

The major problem with all the official tests and the lab tests is that performance in actual combustion situations can only be guessed at. In fact, the standard procedures often caution against using the results of the test for any determination of performance in actual burning conditions. The best that can be hoped for in the official and lab tests is a correct ranking of materials as to their performance in real burning conditions. In most of the tests, failure is considered “bad,” but passing cannot necessarily be extrapolated to being “good.”

To determine actual performance, full scale tests should be run. These full scale tests are only rarely controlled by standard test procedures. Therefore, the company or agency requiring the results is usually free to configure the test as they believe to be best. Often, because of the complexity of combustion, companies will request assistance from private testing organizations (often the same people who run the official tests). Some of these testing organizations have even established full-scale test facilities (rooms, vehicles, etc) that can be used as a framework on which the test materials can be attached.

Full scale tests often examine temperatures in and around the test enclosure, smoke generation in and leaking out of the enclosure, and heat generation in and around the chamber.

Ignition often simulates a likely fire hazard such as a burning waste basket, or may be a controlled source such as a gas burner or an assembly of wooden slats.

Summary

Flammability testing will continue to be important in assessing composite behavior. The use of this type of testing in specifications will likely continue to rise as more agencies see the value in trying to protect the public and limit liability through testing. Therefore, it behooves manufacturers of composite parts to assess the combustion characteristics of their products so that should reformulations be necessary, they can be anticipated and worked on before a crisis situation exists.

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