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The International FORUM of Fire Research Directors: A position paper on small-scale measurements for next generation standards

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1. The problem

The importance to society of characterizing flammability of materials is attested to by the myriad examples of tests established by different authorities world wide for this purpose (see e.g. Troitzsch [1]). Tests range from small-scale tests with materials exposed to Bunsen burner flames to 15 m high simulations of fire scenarios of building construction materials. Some objectives of these tests include observations of flashover, extent of fire propagation, melting behavior, heat release rates, ignition times, or smoke generation rates. These results are then used to select general end-use applications for materials despite the results being comparative and specific to the test configuration and conditions. Although much more expensive, large-scale simulation tests can at least be viewed as providing results that approximately represent the end-use application.

A telling point concerning the non-fundamental nature of current flammability tests, whether at small or large scales, is that the results of one test cannot typically be used to reliably predict the results of another. Famously, Emmons [2] in 1968 showed that test results for combustibility of building materials from six countries were almost uncorrelated with each other in regard to ranking of the materials. Almost 40 years later, one could argue that a similar demonstration could be made for standardized test methods for flammability. Despite very significant advances made in fire safety science in the intervening years, there appears to be little impact on standardized testing. It is recognized that old tests are difficult to replace due to economic interests and due to their entrenchment within regulatory systems. It is somewhat surprising, however, that we still observe reliance on both old and new tests which provide almost no predictive capability and which provide no fundamental properties of flammability. Illustrative examples include the E-84 Tunnel Test [3] developed in the USA and used worldwide and the single burning item (SBI) [4] test recently developed and introduced for regulation in the EU. It is unfortunate that such a test as the SBI could be developed and implemented with its shortcomings (Axelsson and VanHees [5]) at the same time when performance-based codes are being promoted, which demand reliable flammable properties. However, we believe fire research and fire researchers should focus on the longer-term goal of being able to make small-scale measurements of properties that can be used in first principle computer models to predict fire behavior and product performance.

2. Intimations of progress through small-scale testing

One of the significant advances in fire safety science has been the development of small-scale test methods which have the potential of providing results from which material properties can be extracted for use as inputs to physics-based models. The widely used cone calorimeter (CC) [6]

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and the fire propagation apparatus [7] (FPA) provide, in principle, reliable and cost effective means to measure heat release and smoke generation rates and ignition times from burning materials exposed to external heat fluxes relevant to many fire situations. In the case of the FPA, the reaction of materials to external fluxes may be conveniently measured in controlled atmospheres allowing, for example, pyrolysis rates to be measured in nitrogen. Such measurements should in principle be used to determine flammability properties; however, in practice, the results are often used by material manufacturers as small-scale fire tests, ranking material performance by ignition time or heat release rate. Such small-scale results can be highly misleading when applied to large-scale fire scenarios. Another practice is to correlate small-scale results such as ignition times and heat release rates with results from intermediate-scale tests such as the room corner test [8] (see e.g. Grenier et al. [9]). This approach represents a significant step forward as it attempts to tie the small-scale measurements with larger-scale results; however being a correlation, it is not possible to analyze the applicability of the method to new types of materials not previously tested or to use the method to assess the performance of a material in a situation slightly different from the large-scale test used in developing the correlation. In contrast, a first principle model with material properties as inputs, if properly validated [10], inherently expresses limitations from the stated assumptions of the model, provides a sense of the robustness of the method due its dependence on physics, and allows variations in the fires scenario to be incorporated and investigated. The combination of material properties as inputs to validated models of larger-scale fire tests is what is needed to make progress in flammability and is what is intended here by small-scale measurements for next generation standards.

2.1. *The way forward*

The FORUM for International Cooperation on Fire Research (now the International FORUM of Fire Research Directors) has developed a position paper on evaluation of products and services for global acceptance as regards requirements related to fire hazards [11]. The position paper notes the drawbacks to using ad hoc tests and small-or intermediate-scale tests to correlate with large-scale tests. These drawbacks, related to general fire testing methods, are paralleled in the above discussion, which is more specifically focused on flammability testing. The FORUM foresaw two methods to improve the current situation: the first was the use of property data coupled with a first-principle model of an intermediate scale test that can be correlated with a large-scale end-use test; the second being property data combined with models of the end-use application. While the second method was seen as ideal, it was recognized that fire science and techniques for determining properties had not advanced sufficiently that this approach would be feasible for many years. The first method had the advantage of selecting a test configuration which was more amenable to modeling. Also, an appropriate intermediate-scale test would be sufficiently smaller in scale to allow for more extensive testing, but would include enough of the fire phenomena expected at the end-use scale that it was likely to correlate well the large-scale fire results. An important part of the second step would be the establishment of the correlation between the intermediate and large-scale tests. Even before the results of small-scale tests could be used, the replacement of large-scale tests with intermediate-scale test correlations would greatly reduce test costs. Thus, a method based on intermediate-scale tests is the one, which the FORUM currently encourages researchers and standards developers to adopt in generating new standards related to flammability. An example of progress towards this approach has recently been presented by Nam et al. [12].

3. Elements of the next generation small-scale measurements

Due to the complex nature of fire, the development of a methodology for extracting flammability properties includes development of a model and selection of an appropriate intermediate-scale test. Because properties of commercial materials are likely to be effective rather than true properties, the appropriateness of the technique for extracting properties can ultimately only be judged by comparisons of the model with the results of the selected intermediate test. However, one technique to extract properties without dealing with all the complexities of the full model is to determine properties through a simulation of the results of the small-scale tests. A pyrolysis model such as employed by Yan and Holmstedt [13] could be used to simulate the mass loss, heat release rate, and smoke generation at varying external heat fluxes. Yan and Holmstedt [13] suggest that equivalent properties could be obtained through an optimization program using a pyrolysis model to analyze small-scale results. Depending on the complexity of the pyrolysis model, properties would include, for example, heat of combustion, heat of gasification, pyrolysis temperature, thermal conductivity, density, and specific heat of the virgin material and where appropriate char. Current understanding is probably not sufficient to include melting materials. Modeling of moisture migration within the material may also be important in many cases. Also because of its importance to the thermal response of the material, the back boundary condition created by the sample holder needs to be modeled. Optimally, small-scale testing should occur under thermally thick conditions; however, many situations will be thermally finite, requiring modeling of the sample holder.

After extracting material properties, other challenging problems arise in the modeling of the intermediate-scale test, which may mask the validity of the properties. These complexities include models associated with: wall boundary layer flows, buoyancy-driven turbulent convection, turbulent combustion with soot formation and oxidation, and radiation. Of course, no model to date has been shown to adequately calculate all of these phenomena. However, as a first step flame radiation measured in the intermediate-scale tests, can be used with existing computational fluid dynamics models to model the intermediate-scale problem. If the material properties are correct, global results such as flame height, heat release rate, smoke generation rates, and fire propagation behavior should be reasonably modeled. This assumes that the scale of selected intermediate-scale test is such that radiation is the dominant heat transfer mechanism and that the reaction of the materials has been properly modeled through the small-scale measurements. With experience from the intermediate-scale tests, flame heat flux profiles could be developed which could be scaled potentially using the smoke point [14] or smoke yield [12] of the materials measured at small scale. Thus, models could be usefully applied with small-scale inputs before the fundamental problems of modeling turbulent combustion are resolved.

Clearly, such a program as outlined above is not ready to be used for certification, but the development of these methods can complement the use of intermediate-scale tests which have been shown to correlate with large-scale tests. Eventually, the small-scale tests can evolve into screening tests, which can greatly aid manufacturer costs and begin the process of developing standards, which are rational and suitable for the reliable selection safe materials.

4. Forum position

The FORUM position for making small-scale flammability measurements is as follows:

- Current flammability tests are ad hoc in nature and entrenched within regulatory systems primarily because of economic and commercial interests. Because these tests are not fundamentally based, the data obtained from them cannot be used reliably for predicting either other flammability test results or end-use performance of materials and products.
- Fundamentally based small-scale test methods are available for making material property measurements that can be used as input to validated, first principle, end-use computer models. Though more complex than most current ad hoc tests, they are well-demonstrated, well-documented and repeatable.
- Fire researchers need to pursue and develop such methods further in order to increase the reliability of predictions of end-use performance of products and materials, improve the accuracy of design fire scenario calculations and ultimately lead to a more measurably safe built environment.
- Progress toward the ultimate use of end-use computer models can be promoted and assessed through the application of small-scale property measurements to first-principle models of intermediate-scale tests such as the parallel panel test.

The FORUM takes this position to encourage the development of a reliable method of making small-scale measurements that can be useful in leading to next-generation flammability standards based on the use of accurate end-use computer models.

References

[1] Troitzsch J. Plastic flammability handbook. 3rd ed. CT, USA: Hanser Publishers Munic/Hanser Gardner Publications, Inc.; 2004.
[2] Emmons HW. Fire Res Abroad, Fire Res Abstr Rev 1968;10(2): 133–43.
[3] ASTM E-84, Standard Test Method for Surface Burning Characteristics of Building Materials. American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA, 1999.
[4] EN 13823, Reaction to Fire Tests for Building Products—Building Products Excluding Floorings—Exposed to Thermal Attack by a Single Burning Item. CEN, Brussels, 2002.
[5] Axelsson J, Van Hees P. New data for sandwich panels on the correlation between the SBI test method and the room corner reference scenario. Fire Mater 2005;29:53–9.
[6] ISO 5660, International Standard, Fire Tests-Reaction to FDire-Rate of Heat Release from Building Products. International Organization for Standardization, Geneva, 1993.
[7] ASTM E2058-03, Standard Test Methods for Measurement of Synthetic Polymer Material Flammability Using a Fire Propagation Apparatus (FPA), ASTM, 100 Bar Harbor Drive, West Conshohocken, PA 19428, USA.
[8] ISO 9705: 1993(E), Fire Tests-Full-scale Room Test for Surface Products. ISO, Geneva, 1993.
[9] Grenier AT, Janssens ML, Nash L. Developing cone calorimeter acceptance criteria for materials used in high speed craft. Fire Mater 2000;24:29–35.
[10] Gritzo LA, Senseny PE, Xin Y, Thomas JR. A position paper on verification and validation of numerical fire models. Fire Safety J 2005;40:485–90.
[11] Croce PA. A position paper on evaluation of products and services for global acceptance. Fire Safety J 2001;36:715–7.
[12] Nam S, de Ris JL, Wu P, Bill R. From bench-scale test data to predictors of full-scale fire test results. Eighth International Symposium on Fire Safety Science, IAFSS, Beijing, China, September 18–23, 2005. p. 469–80.
[13] Yan Z, Holmstedt G. CFD and experimental studies of room fire growth on wall lining materials. Fire Safety J 1996;27:201–38.
[14] Ingason H, de Ris JL. Flame heat transfer in storage geometries. Fire Safety J 1998;31:39–60.