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U. S. Department of Commerce
Norman Y. Mineta, Secretary
Technology Administration
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MODELING FIRE GROWTH IN ROOM/CORNER CONFIGURATIONS

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ABSTRACT

The results of this project show that it is possible to learn a great deal about the expected performance of materials in the ISO 9705 Test from bench-scale tests like the Cone Calorimeter and the LIFT Apparatus. Both the simple correlation using the Flammability Parameter deduced from the Cone Calorimeter and the mathematical model using Cone Calorimeter and LIFT data provided clear insights into the burning behavior of materials in the ISO 9705 Test.

The Flammability Parameter deduced from the Cone Calorimeter was able to correlate the heat release rate (peak and average) and time to flashover in the ISO 9705 Test. The Flammability Parameter is based solely on Cone Calorimeter Tests performed at 50 kW/m^2 incident heat flux. This provides the opportunity to obtain significant information concerning expected ISO 9705 performance from a few tests of 10 cm by 10 cm samples. As such, the Flammability Parameter is a powerful material development tool. It is significant that LIFT results are not required to allow correlation of the material performance.

The mathematical model performed well in predicting the heat release rate and time to flashover in the ISO 9705 Test. This more sophisticated method provides additional confidence in the ability of bench-scale tests to be used to predict the performance of materials in the ISO 9705 Test. Further, the model has the potential to allow prediction of realistic scenarios, which differ, from the ISO 9705 Test. Different initiating sources, different ceiling heights, different room sizes and ventilation rates are among the significant variables that are included in the model that significantly impact fire performance. Blind tests of the model under a wider range of experimental conditions are required to realize this potential.

Neither the correlation from the Cone Calorimeter nor the mathematical model adequately predict the smoke generation rates in the ISO 9705 Test. The inability to predict smoke generation is particular significant for materials that pass the heat release rate criteria in ISO 9705 Test. There are indications in this work that smoke generated by materials which are pyrolyzing but are not ignited during the test contribute significantly to smoke production. This is not considered in the existing methods and the Cone Calorimeter Tests needed to support modeling of this effect are not currently performed. Cone Calorimeter Tests at heat fluxes where ignition is not expected are not currently conducted to study thermal degradation of materials and the associated smoke production. Significant additional work is needed in this area.

INTRODUCTION

As the father of computer fire modeling, Howard Emmons always understood that the prediction of the development of the fire needed to be an integral part of compartment fire modeling. From the beginning of the Harvard Fire Code, simple models of fire growth were included. The prediction of fire growth was an active research area in Professor Emmons' laboratory throughout the period during which the Harvard Code was conceived and developed.

While his vision was clear, our progress in realizing the objective of modeling fire growth for situations of practical interest has been slow. Modeling fire growth involving interior finish materials has been an active area of research in recent years. This work has been motivated by the recognition that the varied international methods for assessing interior finish fire performance are both widely divergent and poorly related to the actual hazards of interior finish materials. This recognition has its roots in Emmons survey of national fire test methods in use around the world in which he recognized and documented the lack of consistency among the nationally used reaction to fire tests.

The room/corner fire scenario has been recognized to be a challenging configuration and tests like ISO 9705 are recognized as real scale fire tests, which reasonably represent the hazards of interior, finish materials. While the room/corner fire test is recognized to be realistic, it is not useful for material development due to its high cost and large material requirements. Further, the results from ISO 9705 tests cannot be used to predict the material's performance in other fire scenarios of importance. As a result, there is an ongoing interest in relating bench scale fire tests to more real scale fire tests like the ISO 9705 test, and in the use of results of bench scale tests in models that can predict material performance over a wide range of fire scenarios of importance. The most highly developed bench scale fire tests, which have potential to relate to actual fire performance, are the Cone Calorimeter and the LIFT tests.

Two means of relating Cone Calorimeter data to full scale performance will be evaluated; correlations and mathematical models of corner fire flame spread. The correlational method and the mathematical model were developed by HAI in prior work for the U.S Navy (Beyler, Iqbal, and Williams (1995), Lattimer *et al.*, 1999). In this work, the correlation and model will be used to predict the results of ISO 9705 tests performed by Janssens *et al.*, (1998) for the U.S. Coast Guard. Model inputs were deduced from Cone Calorimeter test results also performed by Janssens *et al.*, (1998). The work described in this extended abstract is detailed in Beyler *et al.*, (1999).

CORRELATION OF ROOM/CORNER FIRE BEHAVIOR

The correlational method used here was that previously developed by Beyler, Iqbal, and Williams (1995). The method is a modification of the correlational method of Mowrer and Williamson (1991) and is based upon the linearized upward flame spread model of Quintiere, Harkleroad, and Hasemi (1986). The correlating parameter is the parameter in the linearized upward flame spread model, which determines if the flame spread accelerates or decays. The parameter, which has been called the Flammability Parameter, FP, is given by

$$FP = k_f \dot{E}'' - t_f / t_b$$

If FP is greater than one, the linearized model results in acceleratory spread.

Mowrer and Williamson (1991) used this parameter to correlate corner fire tests involving textile interior finish materials. They used the time to ignition in the Cone Calorimeter as t_f and the time to the peak heat release in the Cone Calorimeter as t_b, and used the peak heat release rate as E". They found that the correlation was most satisfactory if cone data at 50 kW/m^2 was used. Beyler, Iqbal, and Williamson (1995) attempted to use this method to correlate additional data from U.S. Navy room/corner tests and found that the two data sets did not follow the same correlation. On examination, it became clear that by redefining the means of deducing t_b and E", a single correlation for the two data sets could be accomplished. Beyler *et al.*, defined t_b to be the duration of burning of the sample and E" to be the average heat release rate over this period. Using these definitions the peak heat release rate in the room/corner tests could be correlated for the two data sets together.

The reasons for the improved performance of the new correlation lie in both the theoretical and practical realms. First, the duration of burning is more relevant to the ability to sustain flame spread than is the time to peak heat release rate. Both thick and thin materials can have the same time to peak burning but have very different burning durations. This significant difference was not captured in the original correlational method. Secondly, the ability to measure times to peak heat release rate and the magnitude of the peak heat release rate is not satisfactorily resolved in the cone calorimeter for thin materials. Thus, there will be difficulty in achieving adequate correlations when relying upon these Cone Calorimeter results. The modified method uses the duration of burning which is ideally evaluated visually, but can be deduced from heat release rate histories. The modified method uses this time and the integrated total energy release from the Cone Calorimeter to deduce E".

The modified correlational method was applied to a wide range of available data for materials which have been tested in the cone calorimeter and in room/corner tests (USCG: Janssens *et al.,* (1998), U.S. Navy PFP: Beyler *et al.*, (1995), Textile Wall Coverings: Mowrer and Williamson (1991) & Harkleroad (1989), Swedish Materials: Sundstrom, B. (1986) & Tsantaridis, L., and Ostman, B., (1989), EUREFIC: Soderbom, J., (1991) & Thureson, P., (1991), and LSF: Dillon *et al.,* (1998)). The peak heat release rate results are shown in Figure 1. The correlation of the actual heat release values for the materials above 400 kW has no meaning as some of these tests flashed over and the tests were terminated at flashover. The key in the performance of the correlation is the transition in behavior around FP=1. Figure 2 shows the time to flashover as a function of the flammability parameter. The time 1100s indicates no flashover.

IMO (1995) defines performance requirements for use with ISO 9705. The peak heat release rate must be less than 500 kW and the test average heat release rate must be less than 100 kW. Based on all the testing, all materials with FP<0 passed the IMO heat release rate criteria and none of the materials caused flashover. The results are mixed in the range 0 > FP> 0.5 transition range, with some materials in this range passing while others fail. Materials with FP > 0.5 overwhelmingly fail the IMO criteria, though there are several materials (Swedish and LSF) with FP> 0.5 which pass one or both of the IMO heat release rate criteria. Based on the available information, the reasons for the failure of the correlation for these materials is unclear. Nonetheless, the value of the flammability parameter as a screening tool is well established by this work, and the potential for the use of the cone calorimeter and the Flammability Parameter as a regulatory tool at some time in the future is promising.

The ability of correlations based on the Flammability Parameter and the smoke data from the cone calorimeter to predict smoke production results in the ISO 9705 was explored, but the results were unsatisfactory. This issue will be addressed in the modeling section.

ROOM/CORNER FIRE GROWTH MODELING

The HAI/Navy Corner Fire Model was originally developed as a wall fire spread model (Beyler *et al.*, 1997), but was always intended to be generalized to the corner configuration. The gridding of the corner configuration is two-dimensional, so that the prediction of heating of the material surface is more spatially refined than the other models. Heat flux mapping experiments were performed to develop heat flux maps for use in the model. Heat of gasification methods are used in this model to determine burning rates. The room gas temperature is predicted using the MQH correlation and the predicted burning rate.

The current version of the flame spread model is an expanded and improved version of the earlier vertical wall flame spread model [Williams *et al.*, 1997, Beyler *et al.*, 1997]. Additional features include two dimensional flame spread, area source fire exposures, corner/ceiling configurations, and hot layer effects. The model retains the ability to calculate flame spread on vertical walls that are not influenced by a corner or ceiling. All new features incorporated into the current flame spread model are summarized in this report. A model verification section is also included. The model results when used to predict the USCG ISO 9705 full-scale room fire tests are presented and compared with the test data. The ISO 9705 room fire tests were performed on a variety of composite materials for the U. S. Coast Guard. A complete description of the model is included in Beyler *et al.*, (1999) and the bases for the model is more fully described in Lattimer *et al.*, (1999).

The flame spread model retains the element and node concept and the surface-heating algorithm that was part of the original version. A node has a specific coordinate relative to the base of the corner and an element is a region bounded by four nodes, one at each corner. This version of the flame spread model divides the corner-ceiling configuration into uniformly spaced horizontal and vertical nodes. Symmetry requires that the ceiling be square and that it be discretized in the same way as the horizontal wall dimension. The flame spread model calculates the temperature and burning condition at each element.

This study was motivated by the need to evaluate the performance of composite materials. A means of predicting the heat release rate and the flame spread potential of materials with known properties was sought. A computer flame spread model seemed ideally suited for this goal, offering the ability to calculate conditions on an elemental basis where simple hand calculations fall short. The corner version of the flame-spread model was developed for the U. S. Navy to predict the performance of composite materials in an open corner test configuration [Lattimer *et al.*, 1999]. When this code was adapted for use with the U. S. Coast Guard ISO 9705 tests, it was apparent that the effect of the hot layer had to be included. Hence, an expanded version of the corner flame spread model was developed to include room gas temperature predictions using the MQH correlation. The compartment temperature effects on fire development were included in the model.

Table 1 shows a summary of the comparison of the HAI/Navy model with the USCG test data. The model correctly predicts which materials will cause flashover and predicts the time of flashover to within 2 minutes in all tests. For those materials that do not cause flashover, the tendency is to underpredict the average and peak heat release rates. The comparisons of peak heat release rate for materials that flashover the compartment are not meaningful, since these tests were terminated artificially. The average heat release rates in these tests is the average up to the time of flashover, so this comparison is meaningful. Overall the performance of the model in predicting flashover and heat release is quite good.

Predictions of smoke generation make use of the heat release rate predictions and the specific extinction area measured in the cone calorimeter. The predictions are generally very low, especially among the materials where flashover did not occur. It is hypothesized that this is the result of smoke production from material, which did not burn during the test. The model includes smoke generated during burning and does not include smoke generated by simple pyrolysis of material beyond the flame front. Since the standard cone calorimeter testing does not evaluate smoke generation from material, which is not burning, there is no means to include this contribution. Additional work is needed in this important area. At this time, the model does not adequately predict smoke generation in the ISO 9705 test.

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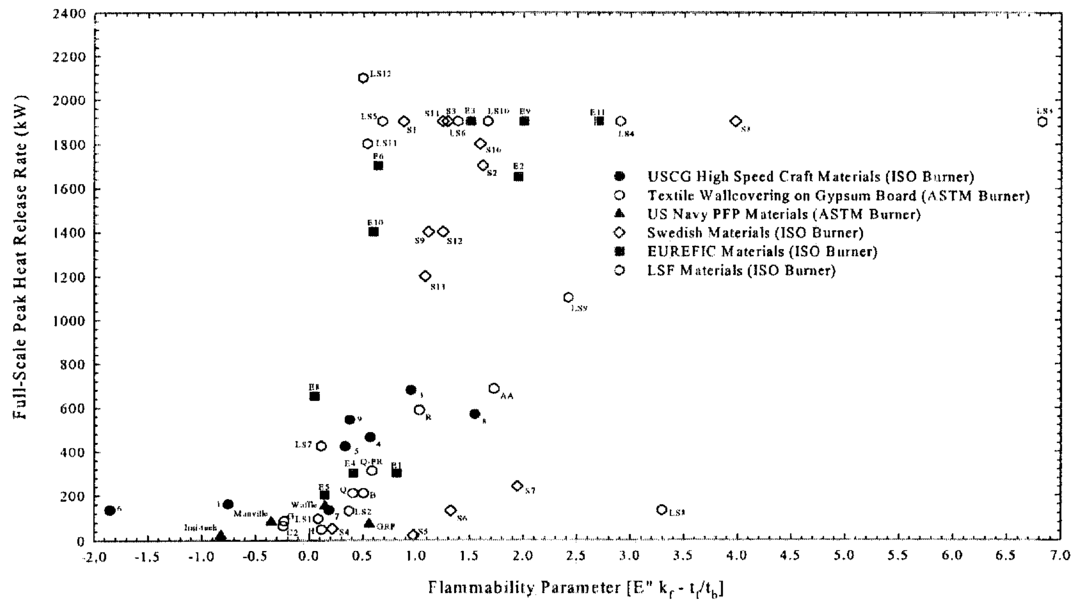

Figure 1 – Comparison of USCG High Speed Craft Materials Results With PFP Navy, Textile Wall Covering On Gypsum Board, Swedish, EUREFIC, and LSF Materials Results

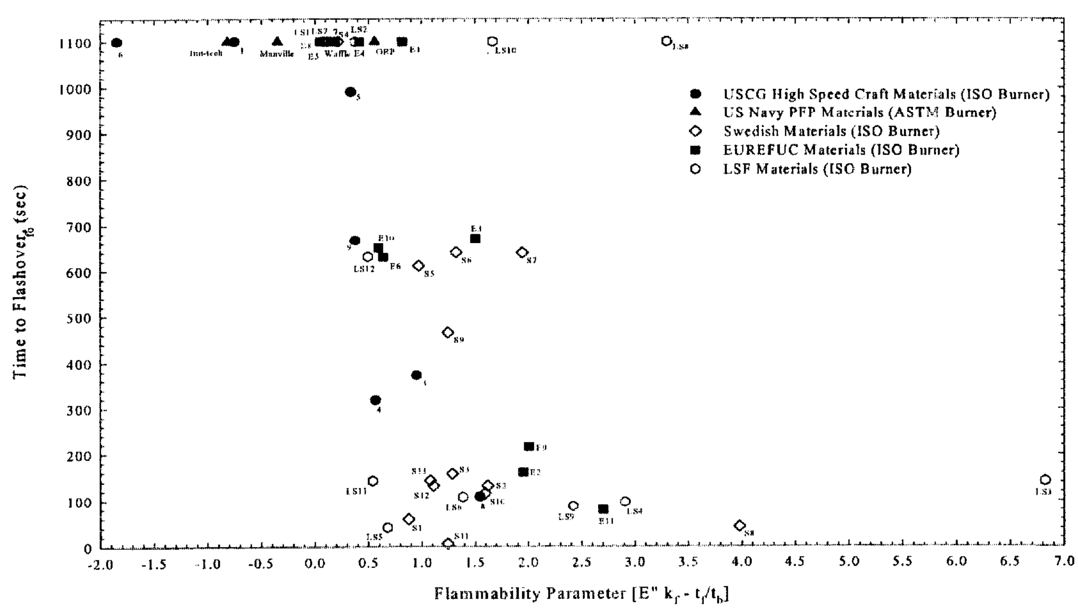

Figure 2 – Comparison of USCG High Speed Craft Materials Results With PFP Navy, Swedish, EUREFIC, and LSF Materials Results.

Table 1 – Summary of ISO Room/Corner Test Results and HAI/US Navy Room/Corner Model Results for the US Coast Guard High Speed Craft Bulkhead Lining and Ceiling Materials

US Coast Guard High Speed Craft Materials	Time to Flashover t_{fo} 1 MW (500 °C)		ISO 9705 Room/Corner Test Full-Scale Heat Release Rate		Predicted Heat Release Rate from Room/Corner Model		ISO 9705 Room/Corner Test Full-Scale Smoke Production Rate		Predicted Smoke Production Rate from Room/Corner Model	
	ISO 9705 Room/ Corner Test (min)	Room/ Corner Model (min)	Peak 30 sec Average (kW)	Net Average (kW)	Peak (kW)	Net Average (kW)	Peak 60 sec Average (m^2/sec)	Net Average (m^2/sec)	Peak (m^2/sec)	Net Average (m^2/sec)
1-FR phenolic	∞	∞	159	62	56	31	5.40	1.5	0.68	0.38
2- Fire restricting Material	∞	∞	129	31	33	18	0.48	0.15	0.05	0.03
3-FR polyester	5.7 (5.5)	7.5 (7.3)	[illegible]	191	[illegible]	140	21.7	10	[illegible]	9.1
4-FR vinylester	5.1 (5.0)	6.5 (6.2)	[illegible]	190	[illegible]	150	32.0	9	[illegible]	11
5-FR epoxy	16.5 (15.2)	15.7 (17.7)	[illegible]	115	[illegible]	54	25.50	6.5	[illegible]	1.6
6-Coated FR epoxy	∞	∞	134	28	36	15	3.50	1.5	0.8	0.3
7-Textile wall covering*	∞	∞	131	17	45	23	0.16	0.1	0.31	0.17
8-Polyester	1.7 (1.5) 441 °C	0.8 (0.8)	568	170	10780	130	[illegible]	2.3	[illegible]	57
9-FR modified acrylic	11.2 (11.5)	10.3 (10.0)	[illegible]	109	[illegible]	102	[illegible]	0.4	[illegible]	0.64
IMO Critera (Resolution MSC.40 (64))			≤500 kW	≤100 kW	≤500 kW	≤100 kW	≤8.3 m^2/s	≤1.4 m^2/s	≤8.3 m^2/s	≤1.4 m^2/s

Shaded regions indicate tests that were terminated due to severe fire conditions. As such, the peak heat release rate and smoke production rate comparisons are invalidated by the test termination. Average heat and smoke release rates are averaged up to the time of predicted flashover to be consistent with the tests.
*Material No. 7 (textile wall covering) fell off the wall during the Room/Corner test.