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PREDICTING THE TIME TO FLASHOVER FOR GRP PANELS BASED ON CONE CALORIMETER TEST RESULTS

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Cone calorimeter tests were conducted to investigate the flammability of glass-reinforced plastics (GRP) panels. The results gained from these bench scale tests were used to predict the time to flashover in the ISO 9705 room, which was partly covered by GRP panels. Östman and Tsantaridis' empirical linear regression model and multiple discriminant function analysis (MDA) were used in the prediction. Three room-scale GRP fire tests were conducted in ISO 9705 room and the results were compared with the prediction.

Keywords: *cone calorimeter, flashover, GRP, ISO 9705 room*

Introduction

Lightweight materials, such as glass-reinforced polyester (GRP), are necessary for aircraft and marine applications. The unique characteristics of interest are high strength to mass ratio; durability and resistance to the marine environment; ease of maintenance and repair; toughness, particularly at low temperatures; and low thermal conductivity compared with metals. However, there is a challenge for these materials to meet stringent fire standards, such as Federal Aviation Administration regulations for passenger aircraft cabins with respect to the fire properties of interior panels in USA [1]. The full-scale room fire test (ISO 9705 [2]) is used for qualifying the materials as fire-restricting or fire properties of surface material. But the ISO room test is expensive to perform, and is inconvenient for use in both product development and product control [3]. Several models have been developed to predict flashover in room based on cone calorimetry test. Cone calorimetry can be used to determine the fire reaction properties of materials at various heat flux intensities [4, 5]. The most important parameter in characterizing the flammability of materials is the rate of heat release (HRR) [6] which is readily determined in the cone calorimeter along with ignitability, heats of combustion, smoke and toxic gas evolution. The HRR and ignition times are important parameters and can be used to estimate the time to flashover in large-scale fire tests [3].

In this paper, we present predicting results based on cone tests for GRP panels and Östman and Tsantaridis' model [7], and compare the results with real room scale tests. The prediction has acceptable accuracy. It is helpful in verifying the validity of this model.

Experimental

Bench scale tests of the GRP panel were carried out on cone calorimeter in accordance with AS/NZS 3837:1998 [8]. For cone calorimeter tests, the specimens of GRP panels were cut as 100 by 100 mm square samples. All test specimens were exposed in the horizontal orientation with the standard pilot operating. Specimens were tested with the use of an edge frame sample holder to retain the specimen as allowed in the standard. The edge frame holder reduces the test surface area to 0.0088 m^2, and this is the area used in calculations. Specimens were packed to the correct test level height using ceramic fiber blanket. The specimen inside the holder was supported horizontally on a load cell and exposed to a set external heat flux with irradiance level of 50 kW m^{-2}. Ignition is promoted using a spark igniter. Five GRP specimens were tested. Three of them were with smooth surface up facing upward cone, and the other two were with rough surface facing upwards. The nominal exhaust system flow rate for all tests was 0.024 m^3 s^{-1}.

The room tests were conducted in ISO 9705 room. The room, smoke collected hood, exhaust duct, and all instrumentations met the specifications of ISO 9705 [2]. The burn room has internal dimensions

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3.6 m long, 2.4 m wide and 2.4 m high. It has a door 2.0 m high and 0.8 m wide in the centre of one of the short walls. It is clad with 13 mm plywood, with 16 mm glass-reinforced paper-faced plasterboard installed over it. The GRP panels cover two sidewalls, one back wall and the ceiling of the room. GRP panels are 1000 mm wide, 1200 mm long and the thickness is from 6 to 8 mm. The door of the room opened under the smoke collection hood. This allows measurement of HRR of the fire inside room.

A wood crib was selected as fire source the room test. Free burning tests were conducted to calibrate HRR of wood crib. The crib consists of three layers of radiata pine wood sticks which are 35 mm×35 mm×500 mm (width×height×length). There are eight sticks per layer. The crib masses around 7 kg. The calculated HRR is 150 kW. It reached peak HRR 200 kW in calibration burning. It would take 300 s to reach this peak HRR. The wood crib was set up at the corner of ISO room and ignited by spirits in two aluminum trays underneath the crib.

Results and discussion

Tests were carried out at the irradiance level of 50 kW m^{-2}. Five specimens were tested. Three of them were with smooth surface up facing the cone, which are labeled as GRP1, GRP2 and GRP3. The other two specimens were with rough surface up, which are labeled as GRP4 and GRP5. The HRR of these tests are shown in Fig. 1. The shapes of the HRR curve for these five specimens have a similar characteristic form. Each curve has multi-peaks, and this is quite different from the commonly smooth double-peak shape of timber samples. The burning time was longer for specimens of GRP2 and GRP5. The thickness of GRP panel influences the length of combustion procedure. More Sinitial mass and thickness of both of these two specimens caused this slightly

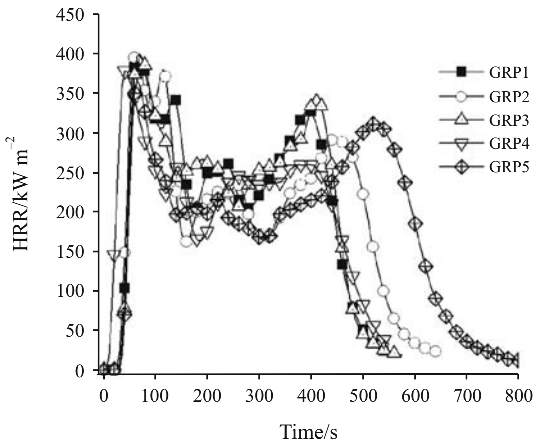

Fig. 1 HRR of GRP panels in cone tests

prolonged burning time. The tests stopped when the flammable content was burned out. The maximum HRRs are from 367.8 to 399.5 kW m^{-2}. The samples with smooth surface facing up have a bit more maximum HRR than those with rough surface facing up.

Table 1 also provides three kinds of HRR gained by cone calorimeter tests, which are average HRR within 60 s, average HRR with 180 s, and average HRR within 300 s. The average HRR at the beginning of combustion describes the heat release performance of material at the early stage of combustion. A larger average heat rate shows that more heat is produced in a short time and radiation to the surroundings easily ignite the adjacent goods to expand the fire, and the smaller value shows the opposite results. Thus, this average rate should be taken into consideration in predicting flashover time inside compartment.

Östman and Tsantaridis' [3] present a very simple empirical linear regression model for prediction of time to flashover in the room corner test. The model is based on empirical data, and was found to predict time to flashover with good accuracy for several products. Cone calorimeter results from tests at 50 kW m^{-2} are used as input data to this model, which also requires information about mean density of the outer

Table 1 Specimens' parameters and results of Cone calorimeter tests

	GRP1	GRP2	GRP3	GRP4	GRP5	Average
Average HRR over 60 s/kW m^{-2}	326.3	311.1	344.7	324.8	281.2	317.6
Average HRR over 180 s/kW m^{-2}	290.0	270.2	290.1	258.1	236.2	268.9
Average HRR over 300 s/kW m^{-2}	267.0	243.0	269.2	246.3	215.0	248.1
Ignition time/s	40	37	43	18	42	35.6
Thickness/mm	6.20	6.97	6.89	6.65	8.00	
Mass/g	103.5	109.1	105.1	104.2	125.1	
Maximum HRR/kW m^{-2}	398.9	396.9	399.5	378.2	367.8	
Time of maximum HRR/s	65	65	70	40	65	
THR_{300}/MJ m^{-2}	80.1	72.9	80.8	73.9	64.5	
ln($FIGRA_{cc}$)	1.741	1.899	1.816	2.247	1.813	

10 mm of the tested product. The regression model is expressed in the following equation

$$t_{FO} = 0.07 \frac{t_{ig}^{0.25} \rho^{1.7}}{THR_{300}^{1.3}} + 60 \quad (1)$$

where t_{FO} is the time to flashover in the room corner test, t_{ig} is the time to ignition in the cone calorimeter at 50 kW m^{-2}, THR_{300} is the total heat release during 300 s after ignition at 50 kW m^{-2} and ρ is the mean density. If we use the average cone test results of the GRP panels (the average t_{ig} is 35.6 s, the average density ρ is 1578.2 kg m^{-3}, the average THR_{300} is 74.4 MJ m^{-2}), we can get t_{FO} is 232 s from Eq. (1). For the five cone tests, five predictions are obtained, which are shown in Fig. 2. GPR2 and GRP5 have relatively lower average HRR over 300 s, and this causes longer predicted time to flashover.

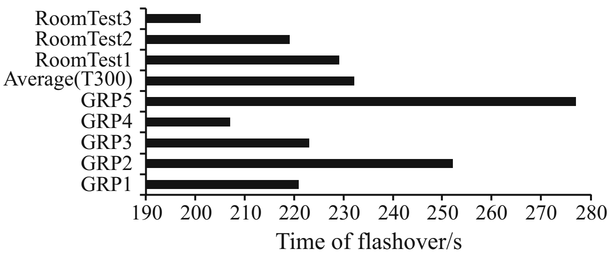

Fig. 2 Time to flashover: room test results and predicted results

Determining surface material belongs to which FO-categories can help to predict the time to flashover. The FO-categories grouping is based on ISO room tests. The ISO room corner test is used for classification of surface materials. A propane burner placed in a corner exposes the test material to a heat release rate of 100 kW for 10 min and then 300 kW for the next 10 min. The test is terminated if flashover has been reached; otherwise the total testing time is 20 min. A set of separation criteria for grouping products according to the time to flashover (t_{FO}) based on above ISO room test. These criteria divide the tested products into four groups, the so-called FO-categories [3] 1 to 4.

Surface material belongs to which category is determined by application of the following set of rules:

- FO–category 1: products not reaching flashover during 1200 s of testing time
- FO–category 2: 600 s≤t_{FO}<1200 s
- FO–category 3: 120 s≤t_{FO}<600 s
- FO–category 4: t_{FO}<120 s

Surface material can be determined to belong to which FO–category based on statistical information from cone calorimeter [3], which is called multivariate statistical method. This method may find links among different variables that are recorded in cone calorimeter tests, such as time to ignition, smoke gas concentrations, heat release rate, specimen mass loss, optical smoke density, density and thickness of samples.

Anne Steen Hansen [3] evaluated the application of multiple discriminant function analysis (MDA) to deal with cone calorimeter data, which could be used to predict the FO–category in the room corner test with satisfactory accuracy. MDA is a multivariate statistical method used to classify cases into groups. The groups are determined based on a categorical dependent variable. By using Fisher's linear discriminant function for classification of cases, the result of this analysis is a set of four linear functions, one for each of the four FO–categories. A new case will be assigned to the FO–category for which the classification function obtains the highest value. Three out of about 20 variables, which give information concerning smoke production, production of CO, HRR, time to ignition, time to extinction, etc., were found to be able to distinguish between the four FO–categories were. The selected parameters were

- $z_1=\rho_{mean}$ (kg m^{-3})=mean density
- $z_2=THR_{300}$ (MJ m^{-2})=total heat release during 300 s after apparent time to ignition.
- $z_3=\ln(FIGRA_{cc})$ where $FIGRA_{cc}$ is the maximum value of the ratio between HRR and time when HRR was measured.

Anne Steen Hansen [3] gave the four classification functions that are expressed as follows:

- $F_{FO1}=0.01789z_1-0.06057z_2+0.971z_3-7.910$
- $F_{FO2}=0.01492z_1+0.03354z_2+1.877z_3-7.418$
- $F_{FO3}=0.008589z_1+0.409z_2+2.721z_3-13.406$
- $F_{FO4}=0.0000256z_1+0.347z_2+3.621z_3-9.215$

For the GRP panel in our tests the mean density is 1578 kg m^{-3}, THR_{300} and $\ln(FIGRA_{cc})$ are listed in Table 1. Substitute these data into above equation, and the results are listed in Table 2.

For the five samples, all F_{FO3} give the largest value of all the four Fisher's liner discriminate functions. Thus, the GRP panel can be determined as a member of FO–category 3, which would reach flashover in ISO room from 120 to 600 s.

Three-room fire tests for the GRP panels were conducted inside ISO 9705 room. The tests are labeled as RoomTest1, RoomTest2 and RoomTest3. Each test was stopped by water mist system inside the

Table 2 Calculation results of MDA for GRP panels

	GRP1	GRP2	GRP3	GRP4	GRP5
F_{FO1}	17.1593	17.7488	17.1897	18.0261	18.1741
F_{FO2}	22.0802	22.1352	22.2444	22.8220	21.6921
F_{FO3}	37.6456	35.1307	38.1360	36.4866	31.4611
F_{FO4}	24.9243	22.9980	25.4387	24.6051	19.7718

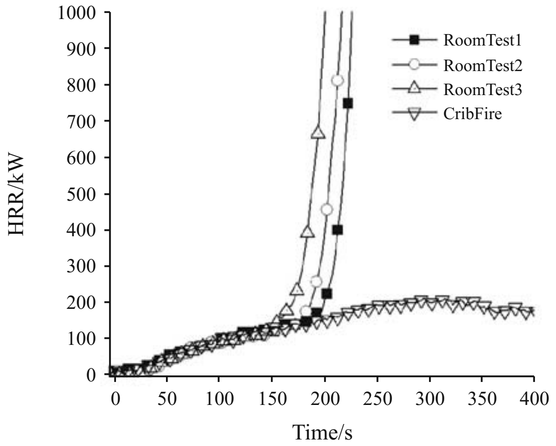

Fig. 3 HRR of GRP panels room tests compared with wood crib free burning result

room at the time of flashover. After RoomTest1 test, the deep damaged GRP panels closed to crib fire were changed with new panels, and less damaged panels were re-mounted on the wall with un-burnt surface inside the room. After RoomTest2, all burnt GRP panels were changed for RoomTest3.

Figure 3 illustrates the HRR for these three room tests of GRP and one free burning test without GRP panel on the wall of wood cribs that was as fire source for GRP test. As shown in Fig. 3, two stages can be determined. The first stage is before 150 s. In this stage, the HRR curves of GRP tests are the same as that of wood crib free burning test. This means that at this stage very little GRP panels caught fire and contributed little to HRR. The second stage is after 150 s, the curve of GRP breaks away from free burning test. More GRP panels caught fire and the combustion of GRP contributed largely to total HRR in the room. For the GRP tests, the beginning of this drift is different. But the time from this drift to flashover (defined as the moment when the sum of the HRR from the burning product and from the burner exceeds 1 MW [3]) is almost the same for all GRP tests, 59 s for RoomTest1, 61 s for RoomTest2 and 62 s for RoomTest3. This time largely depends on fire propagation rate of GRP panels. The time from ignition of wood crib fire to flashover is 229, 219 and 201 s for RoomTest1, RoomTest2 and RoomTest3 respectively. In Fig. 2 these results are compared with predictions from Östman and Tsantaridis' model that is based on cone tests. The room test results are closer to the averaged predicted time.

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