Evaluation of the performance of three ASTM E 2058 and NFPA 287 fire propagation apparatuses

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EVALUATION OF THE PERFORMANCE OF THREE ASTM E 2058 AND NFPA 287 FIRE PROPAGATION APPARATUSES

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ABSTRACT

As a result of a fruitful collaboration initiated in 1994 between Factory Mutual Research and INERIS, round robin tests have been carried out in three Fire Propagation Apparatuses (FPAs), previously known as FMRC flammability apparatuses in the USA or 'Tewarson' calorimeters in Europe. The apparatuses (two operated by Factory Mutual Research and Approvals in Norwood in USA and the more recent one by INERIS in Verneuil-en-Halatte in France) are all meeting the requirements of recently issued American standards ASTM E 2058 and NFPA 287. This poster briefly describes the development of the FPA, followed by the description of the round-robin testing programme carried out so far that includes ignition, combustion and propagation tests for seven commercially-important plastics. The materials have been characterised carefully from the thermo-chemistry point of view. Round robin results for the global flammability parameters such as CHF, TRP and FPI, as defined in the standards, are very encouraging, both in terms of repeatability of measurements in each laboratory and reproducibility of data from one lab to the other.

INTRODUCTION

Factory Mutual Research is historically the first user of the polyvalent Fire Propagation Apparatus in U.S.A. described in both recently issued standards ASTM E 2058[1] and NFPA 287[2] In Europe, INERIS commissioned in 1997[3] the first FPA meeting the mentioned standards, although early use of previous versions of equipment was there identified, in particular in France[4,5,6].
Factory Mutual Research was responsible for the original design and has clearly shown the polyvalence of the apparatus for both material performance approvals and research purposes regarding flammability properties[7,8,9]. INERIS on the other end has mainly contributed thus far to the promotion of the equipment in learning about the fire behaviour of materials and chemicals in both well and under-ventilated conditions[10,11,12].

Towards the end of year 2000, a new collaborative work was agreed between Factory Mutual Research and INERIS to study the reproducibility of data. We hereafter give the background of work, description of FPAs used in the study and materials selected for the comparisons, as well as preliminary results. The study is expected to be completed by the end of this year.

FROM EARLY 'FMRC' FLAMMABILITY APPARATUS TO FIRE PROPAGATION APPARATUS (FPA) OF TODAY

Considerable efforts were made by the Factory Mutual Research to refine the design of the 50kW lab-scale flammability apparatus as it is referred to in early technical papers. So doing the evolution through 25 years of development have led to a very mature and polyvalent concept. The reader may appreciate the importance of the underlying technological evolution by comparing early drawings of the equipment provided by first users (see for instance references[13,14]) to upgraded version of the FPA that was issued in the mid 90's (see figure 1).

The efforts have continued for the last five years to promote the recognition and the use of the Fire Propagation Apparatus in a collaborative way for important purposes such as for testing materials (figure 2) for clean rooms[15] by Factory Mutual Research and Approvals or for the qualification of under-ventilated fires of chemicals[12] by INERIS (figure 3).

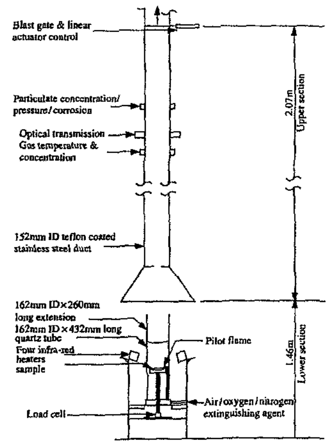

Figure 1 : Sketch of the current version of the FPA, as finalised by FMR, Research division

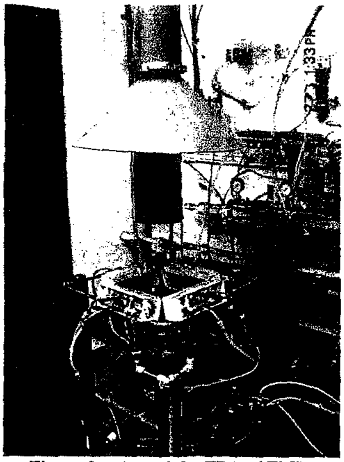

Figure 2 : view of the FPA of FMR, Approvals division

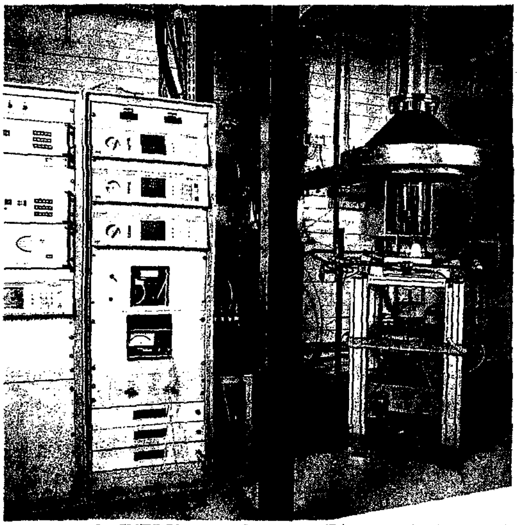

Figure 3 : the INERIS FPA laboratory *(Photograph : P. Robin)*

ROUND ROBIN TESTS PROGRAMME

For the round robin testing, a first series of seven commercially available plastics were selected :
1. Polymethylmethacrylate (PMMA) (FPI > 20)
2. Polyoxymethylene (POM), Delrin® (FPI of the order of 14)
3. Polycarbonate (PC), (FPI in the range between 12 and 14)
4. Polysulfone (POS) (FPI ≈ 11)
5. Rigid Polyvinyl chloride (PVC) (FPI in the range between 7 and 8)
6. Polyetherimide (PEI)
7. Nylon (PA 6-6)

All 7 selected polymers are listed in table 1 with information on commercial designation of the materials and their suppliers. Table 2 lists the theoretical composition of each polymer.

Enough samples had been ordered in a single procedure in the form of sheets such that the tests could be performed in at least four apparatuses. Indeed, a fourth apparatus which is the prototype of the commercial version delivered by the UK company F.T.T. Ltd to Factory Mutual Approvals was also available. This latter apparatus was not used in the overall round-robin tests, as a separate evaluation process was in progress[16]. The samples (about 100 mm by 100 mm by 25 mm thick slabs for ignition and combustion tests, and 100 mm wide, 300 mm high and 25 mm thick slabs for propagation tests) were prepared at Factory Mutual Research by a single operator according to requirements of FM 4910 testing standard[17] and distributed to all operators involved. All samples were blackened using a *Thermalox 250* spray paint.

	Manufacturer /supplier	**Commercial designation**
Polymethylmethacrylate (PMMA)	Polycast technology (USA)	Poly 76 polycast acrylic sheet
Polycarbonate (PC)	Sheffield Plastics, Inc, Sheffield, MA (USA)	Hyzop GP polycarbonate sheet
Polyoxymethylene (POM)	A.L. Hyde Company (supplier) E.I. Dupont de Nemours & Co (Inc), Wilmington, DE, (USA)	Delrin® acetal resin
Polysulfone (POS)	Scientific Polymer Products (USA), Ontario, NY (USA)	Polysulfone resin 046-C
Rigid PVC	Vycom (Pa) USA	Polyvinyl chloride sheet
Polyetherimide (PEI)	DSM Engineering Plastic products Inc Reading, PA (USA)	Ultem product, natural (1000)
Nylon (PA 6-6)	A.L. Hyde Company (supplier) E.I. Dupont de Nemours & Co (Inc), Wilmington, DE, (USA)	*Zytel® nylon resin*

Table 1 : technical identification of test materials

The testing procedures described in ASTM E 2058 were followed by all laboratories involved in the study to perform consistently ignition, combustion and propagation tests.

	mass % of overall sample weight					
polymers	**C%**	**H%**	**O%**	**N%**	**S%**	**Cl%**
PMMA	60	8.0	32.025	0	0	0
PC	75.6	5.5	18.9	0	0	0
POM	40.0	6.7	53.3	0	0	0
POS	73.3	5.0	14.5	0	7.2	0
PVC	38.4	4.8	0	0	0	56.8
PEI	75.0	4.05	16.2	4.73	0	0
PA 66	63.7	9.73	14.2	12.4	0	0

Table 2 : theoretical chemical composition of selected polymers (no additives)

RESULTS

Detailed characterisation of the test samples

Table 3 summarises the results from chemical analysis performed by INERIS to accurately qualify the chemical nature of the plastics selected for the round-robin tests. A comparison with the theoretical composition in table 2 shows that all the polymers are relatively pure except PVC. Also POM contains some nitrogen compound as an impurity.

	mass % of overall sample weight					
materials	**C%**	**H%**	**O%**	**N%**	**S%**	**Cl%**
PMMA	60.1 ±0.1	8.56 ±0.04	32.14 ±0.25	< 0.1	< 0.04	< 0.02
PC	75.7 ±0.1	5.50 ±0.05	18.40 ±0.25	< 0.1	< 0.04	< 0.02
POM	41.4 ±0.1	6.91 ±0.09	51.40 ±0.25	0.15 ± 0.05	< 0.04	< 0.02
POS	72.9 ±0.1	4.82 ±0.04	14.39 ±0.25	< 0.1	8.2 ± 0.1	0.02 ±0.1
PVC	38.9 ±0.1	4.77 ±0.04	4.33 ±0.25	< 0.1	0.36 ± 0.02	49
PEI	73.83	4.07	17.98	4.89	< 0.02	< 0.02
PA 66	61.86	10.24	17.82	11.96	< 0.02	< 0.02

Table 3 : Results of the elemental analysis of test samples performed by INERIS

INERIS also measured the complete heats of combustion of all plastic samples selected for the round robin tests using an oxygen bomb calorimeter by INERIS following the French standard AFNOR NF M 03-005. Results are reported in table 4 that also includes predicted values as given by the *Boie's* and *Garvin's* correlations[18]. The comparison between predicted and measured values shows good agreement, except for rigid PVC where the measured value is somewhat higher than expected. The agreement for the heats of combustion is consistent with the true elemental analysis of the materials (table 3).

	Predicted values for pure polymers(a)[18]		Measured values on samples
	Boie's correlation	Garvin's correlation	
PMMA	25.14	25.57	24.76 ±0.03
PC	29.71	30.35	29.88 ±0.02
POM	14.48	14.88	15.72±0.02
POS	29.64	30.27	30.42±0.02
PVC	18.07	17.1	19.31±0.04
PEI	28.72	29.48	28.27 ±0.02
PA 66	30.84	31.36	29.17 ±0.03

(a) with use of the theoretical elemental composition of pure polymers for the calculations)

Table 4 : Net heats of combustion (all values in MJ/kg)

The data show that except for rigid PVC, the commercial products selected are very close in terms of chemical composition to the parent pure polymers. Rigid PVC sample contains some non identified oxygenated additive, that results in lower content of the chlorine element compared to pure PVC and thus in slightly more energetic product.

One may notice the presence of minor amount of nitrogen in the POM sample (confirmed during the combustion tests of POM samples though the detection of nitrogen oxides in the INERIS FPA (see figure 3), which is equipped with some additional on-line chemical analysis capabilities[19]). Some sulfur (in addition to oxygen) in also present in the PVC sample.

Basic findings from preliminary comparisons of round robin tests

Ignition tests

Time-to-ignition for sustained ignition is measured visually by a stop watch. Its measurement was found to be remarkably similar between various operators (rarely more than 1 second of difference between two operators monitoring a single test run in one lab), although recording of the time is not always easy.

From preliminary comparisons of data, a reasonable agreement was found between the raw data and data derived for the flammability parameters CHF (critical heat flux) and TRP (Thermal Response Parameter). A potential improvement of ignition test procedure was identified for further tightening the agreement. The improvement consisted of repeating each measurement at least three times for each heat flux applied during the test and do the relevant statistical treatment of the data. This would be essentially useful for difficult heavily charring materials or when "transient" ignition processes occur prior to sustainable ignition.

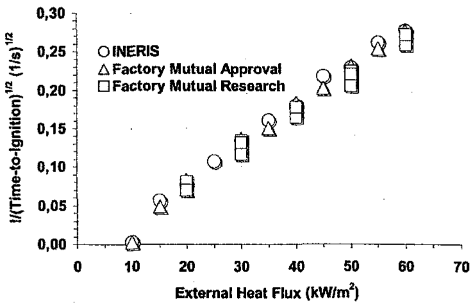

Figure 4 : graphical determination of TRP (slope of the curves) in the case of PMMA

Propagation and combustion tests

Combustion tests were performed in normal air with samples exposed to 50 kW/m^2 to quantify yield o smoke. Fire propagation tests were performed in 40% oxygen concentration for 300 mm long vertical samples with bottom exposed to 50 kW/m^2 to quantify the heat release rate during upward fire propagation. The measured heat release rate was combined with the TRP value from ignition test to calculate the Fire Propagation Index (FPI). The value of FPI was multiplied by the smoke yield to determine the Smoke Development Index (SDI).

In the round robin testing, rate of heat release was in remarkably close agreement between the three labs. The agreement was excellent for non charring materials (both peak values of HRR and HRR profile versus time) and in good agreement for charring materials (at least peak values). In the latter case, the very complex charring process causes minor discrepancies in the detailed evolution of rate of heat release versus time, but not the peak value and the final ranking of the material, in terms of FPI.

CONCLUSIONS AND PERSPECTIVES

A series of round robin tests on a selection of seven plastics have been successfully carried out by three laboratories operating a Fire Propagation Apparatus meeting the technical requirements of the recently issued ASTM E 2058 and NFPA 287 standards. A detailed characterisation of the materials has been performed and recorded.

Basic observations confirm satisfactory repeatability of measurements in each lab and the analysis of the results for the appraisal of reproducibility of data from one lab to the other looks very encouraging. The reproducibility of the ignition, propagation and combustion test procedures is reasonable, in particular in terms of the time to ignition measurements, and calculated rate of heat release for all samples. However, improvements of test protocols such as using cross wires for the sample conditioning whenever the material to be tested is charring or not and repeating at least three times the time to ignition measurement protocol (to eliminate isolated aberrant data plot) for each heat flux increment in the series of ignition tests have been identified as immediate simple things having clear positive impacts.

It is intended to analyse the data further in terms or reproducibility (according for instance to standard ISO 5755) and related calculated flammability parameters such as CHF (critical heat flux), TRP (thermal response parameter), FPI (fire propagation index) or SDI values (smoke development index). Further testing on samples of 2 foam plastics (PUR and PIR) and fire retarded polyester is also planned. Once the work is completed, the results will be published in the open literature.

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