

Test Method

Flame spread of flexible polyurethane foam: comprehensive study

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Abstract

Polyurethane foams are widely used in many industrial applications: automotive, upholstered furniture and mattresses, insulating panels for building, etc. By its chemical nature, polyurethane is very flammable and the flammability of polyurethane foams is an important industry issue. Depending on the final application, many test methods are in place to characterise foam combustion and legislation exists to ensure that foams comply with specific standards. This paper deals with the fire properties of flexible polyurethane foams. It provides basic correlations between some existing fire test methods and the data recorded under cone calorimeter conditions. The long term target of such an investigation is to predict the burning behavior of foams under specific test conditions from the data of the cone calorimeter.

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1. Introduction

Flexible polyurethane foams (PU) are used in many applications because of their ease of handling, excellent cushioning and physical properties [1–4]. They are used in a variety of commercially established applications like mattresses, automotive and furniture cushions, carpet backing and packaging to name a few. Being organic by nature, these foams ignite when subjected to a source of intense (heat) energy. In 1998, 11,600 residential fires started in the USA because of ignition of upholstered furniture and 543 people died in the course of fires [5]. As a consequence, the study of the fire behavior of PU

foam is a major topic of research from a social as well as from an economic point of view. Three points have to be particularly studied.

First, the flammability of flexible polyurethane foams strongly depends on the physical properties of the foams which are strongly linked to the chemical ingredients (polyol, isocyanate, catalyst systems). The density, the hard segment content (urea content) [6,7] and porosity are examples of properties that have to be controlled during the foam processing.

The foam density (water index) is the most important property because it has a parallel relationship with both cost and load bearing. Higher density means higher costs and improved load bearing properties. Highly porous light weight combustible foams tend to have a fast flame propagation rate and a high thermal emission [8]. On the contrary, combustion modified high resilience (CMHR)

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foams are intrinsically fire retardant because of the presence of solid particles in the polyol used [9,10].

The porosity is a measure of the openness of the foam [11]. Only foams of about the same porosity should be compared with respect to their physical properties. Closed cells give resistance to the airflow through the foam. Porosity values are very sensitive to the orientation of the sample in the foam block. The porosity of a flexible foam is measured as its resistance to the passage of a constant flow of air. It seems obvious that a variation of porosity leads to variable fire properties of the foam.

The predominant reaction in PU foam processing is polycondensation of polyhydroxyls compounds (polyols) with isocyanate. The choice of the polyol has a profound effect on the physical and fire properties of the polyurethane foam formed. The two main classes of polyols are polyesterols and polyetherols. Eighty to ninety percent of polyols used today are polyetherols. These polyols are characterised by their functionality, the hydroxyl number (OH value in mg KOH/g), their molecular weight and their ethylene oxide content (EO content) [6]. The polyetherols are produced by the alkali-catalysed polymerisation of ethylene oxide and propylene oxide. The ethylene oxide/propylene oxide weight ratio is denoted as the weight percentage of ethylene oxide used (wt.% EO). The ethylene oxide distribution in the polyol chain can also be varied. The final physical properties of foams also depend on the solid content of the polyols used: conventional foams are produced using standard polyols and CMHR polyurethane foams using polymer polyols (solid containing polyols from 10 up to 40% of solid micro particles).

The isocyanates most commonly used for foam manufacture are mixtures of toluene-2,4-diisocyanate and toluene-2,6-diisocyanate (TDI) most often in an 80/20 ratio but also in 65/35 ratio and sometimes in blends between those ratios.

Water is used as a chemical blowing agent due to the carbon dioxide produced in the reaction of water and isocyanate, both being contained within the polymerising mix expanding to form the foam.

Most of the reactions occurring during the foaming process are catalysed to allow extremely short reaction times. The most widely used catalysts in conventional flexible polyurethane foam production are *N,N'*-dimethyl ethanolamine (DMEA) and stannous octoate (SnOct). In CMHR flexible polyurethane foams, two catalyst systems are used: SnOct and diethanolamine (DEoA) [12].

In the production of flexible foams, surfactants are used to stabilise bubble formation thus helping to control cell size [13,14]. They are also used to control cell opening, thereby enhancing the operating margin between the extremes of foam collapse and shrinkage due to a high closed cell content. Most flexible foams are made using silicone based surfactants.

Secondly, numerous small-scale test methods are used

to classify the combustion behavior of flexible foam. Typical examples are Motor Vehicle Safety System no. 302 (FMVSS 302) and British Standard 5852 part 2. These tests differ in the size of foam sample tested, its orientation, the presence of composite (fabrics) and, of course, the intensity of energy supplied to initiate the combustion. Legislation based on these test methods is introduced in various countries to ensure a high level of safety. Others lab-scale fire tests are available but not yet used as classification tools—such as the cone calorimeter. To obtain correlations between these fire tests is an important task to understand the “philosophy” of the test and the fire behavior of the foams. The evaluation of the flammability of flexible polyurethane foams using a cone calorimeter is a suitable way to predict the fire behavior of foams when subjected to normalised fire tests.

Thirdly, some correlations should exist between the physical properties of foams and the rate of the propagation of the flame under fire testing conditions.

As a consequence, the object of this paper is first to put forward correlations between the formulation and the physical properties of the flexible polyurethane foams and then between normalised and non-normalised fire tests. Finally, the influence of physical properties on the flame spread of PU foams has been investigated.

2. Experimental

2.1. Materials

2.1.1. Ingredients

In this study the following ingredients have been used for the manufacturing of the flexible PU foams:

- *Polyol*TM: Three standard type of polyols, SHELL *CARADOL*[®] at 0, 7 or 15 wt.% EO. These polyols have the same functionality (3), molecular weight (3000 g/mol) and hydroxyl value (56 mg KOH/g). Polyisocyanate PolyAdditionTM polyol (SHELL *CARADOL*[®] *SP50-04*, hydroxyl value: 50 mg KOH/g, functionality: 3, EO content: 18 wt.%, molecular weight: 4700 g/mol, solid content: 10 wt.%).
- *Isocyanate*: *Caradate 80* is a 80/20 mixture of 2,4-Toluenediisocyanate (TDI) and 2,6-TDI supplied by Shell Chemicals.
- *Blowing agent*: Demineralised water.
- *Catalysts*: *SnOct*TM (Stannous Octoate) is a polyaddition catalyst supplied by O.S.I. *DiEthanol Amine*TM (DEoA) is a cross-linking agent and hard-domain softener supplied by Boucquillon BV.
- *Surfactants*: *Silicone 868I*TM is a cell stabilizer supplied by Goldschmidt.

- *FR additives*: *TMCP*TM (Tris(2-chloroisopropyl) phosphate) and *TDCP* (Tris(1,3-dichloroisopropyl) phosphate) are two liquid flame retardants studied, commonly available from numerous suppliers. In the present study, they are provided by Rhodia Chemicals.

MelamineTM supplied by DSM (solid flame retardant, type 003, with average particle size of 50 µm).

2.1.2. Conventional flexible PU foams

A first set of conventional flexible polyurethane foams have been considered. These foams differ in their density, in the amount of catalyst used and in the EO of the polyol. The following formulations have been processed:

- *Blowing agent*: water (at 2.8, 3.8 or 4.8 pbw).
- *Catalyst system*: SnOct at 0.08, 0.1, 0.12, 0.14 or 0.16 pbw.
- *Polyols*: three polyols SHELL *CARADOL*[®]. These polyols have the same functionality, molecular weight and hydroxyl value but differ in their EO content.

2.1.3. Combustion modified high resilience flexible PU foams

To obtain correlations between the cone calorimeter and the BS5852 data, a second set of CMHR flexible polyurethane foams have been manufactured. The CMHR foams have intrinsically better flame performance than the conventional ones and enable results to be discriminated under BS5852 Ignition Source Crib 5 testing. The tested foams have been processed as follow:

- *Blowing agent*: water at 3 pbw.
- *Catalyst system*: SnOct at 0.1 pbw and at 0.8 pbw.
- *Polyols*: SHELL *CARADOL*[®] SP50-04.
- *TMCP and TDCP* at 2, 10 or 18 php.
- *Melamine* used at 0, 10 or 20 php.

2.2. Physical characterisation of the foam

2.2.1. Density measurement

The apparent density of a flexible foam is the mass per unit volume measured at a stated temperature and relative humidity. The density of each foam was measured on two specimens of 100 × 100 × 50 mm (length × width × thickness). Each specimen was weighed to the nearest 0.01 g, and the mean of two separate measurements of each dimension noted to the nearest 0.1 mm. The apparent density was calculated by mass/volume (rounded off to the nearest 0.1 kg/m³), and the mean of the two specimens reported as the density of the foam.

2.2.2. Porosity measurement

The foam test specimen was clamped in a suitably designed apparatus and air is passed through it at a speci-

fied rate of flow. The pressure drop over the specimen was measured by means of a manometer. A schematic diagram of the porosity apparatus is shown in Fig. 1.

Two specimens, dimensions 100 × 100 × 50 mm (length × width × thickness), were used to measure the porosity of each foam. The airflow was started and adjusted to a level that gives a reading of 40 mm on the flowmeter (8 l/min). The test specimen was pressed on the air outlet tube by means of the two retort stand rings, which were positioned concentrically with respect to the air outlet tube. The upper supporting surface of the lower ring should be located 10 mm below the mouth of the air outlet tube. The pressure drop on the ethanol manometer was read to the nearest 1 mm. A measurement is made and the test piece is turned over and the measurement repeated. If the result of each side differs by more than 5 mm, both results should be reported.

The mean of the two specimens was calculated and the porosity of the foam reported as the average pressure drop to the nearest 1 mm ethanol.

2.3. Fire tests

2.3.1. FMVSS no. 302 testing

Flame spread rate from a small flame source of flexible PU foams was determined using FMVSS no. 302. This standard (Federal Motor Vehicle Safety System) specifies burn resistance requirements for materials used in the occupant compartments of motor vehicles [15].

In this test, a horizontal specimen (356 mm long, 102 mm wide and 13 mm thick) was exposed at its end to a small flame for 15 s. The distance and time of burning or the time to burn between two marks (51 mm away) was measured. The burn rate is expressed as the rate of flame spread in mm/min according to the following formula:

$$B = 60'(D/T)$$

where B is burn rate in millimeters per min, D is length the flame travels in millimeters, and T is time in seconds for the flame to travel D millimeters.

According to the fire behavior of the specimen, we can give a classification so called FMVSS 302 classification of the foam (Table 1).

2.3.2. Cone calorimeter ISO 5660

The principle of the cone calorimeter is based on the relation between oxygen consumption and the heat release during combustion [16–18]. The ratio between the heat release and the weight of oxygen consumed is a constant (Huggett constant) equal to 13,100 kJ/kg.

Samples of flexible foams (10 × 10 × 5 cm³) were exposed in a Stanton Redcroft Cone Calorimeter according to ASTM 1356-90 under a heat flux of 35 kW/m². An electric spark ignited volatile gases from the heated specimen. Several specimens (at least three) have been

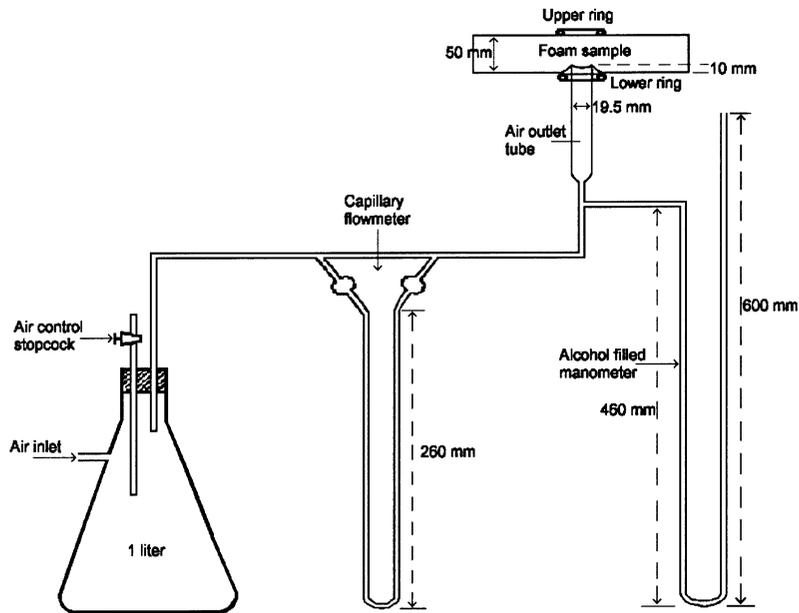


Fig. 1. Schematic diagram of porosity apparatus.

Table 1
FMVSS 302 classification

FMVSS 302	Interpretation
<i>Non-combustible</i>	
DNI (does not ignite)	The material does not burn or self goes out when the flame front is no more in contact with the Bunsen burner.
<i>Autoextinguible</i>	
SE (self-extinguishing)	The material burns and the combustion stops before the flame gets over the first reference mark.
SE/NBR (self-extinguishing/no burn rate)	The material burns and stops burning less than 60s after the beginning of time-keeping and has not burnt over a distance superior to 51 mm from the reference mark.
SE/B (self-extinguishing with burn rate)	The material burns and the flame self extinguishes between the two reference mark (previous case excluded).
<i>Combustible</i>	
B (burn rate)	The combustion crosses the second reference mark.

tested for each formulation. Data were recorded with a computer connected to the cone calorimeter. The test gives the opportunity to evaluate:

- RHR: rate of heat release (kW/m^2)
- Figra: curve of RHR/time ($\text{kW/m}^2/\text{s}$)
- Weight loss (wt.%)
- Emission of CO (ppm)
- TVSP: total volume of smoke production (m^3)
- THE: total heat evolved ($\text{kJ/cm}^2/\text{g}$)

The combustion of flexible polyurethane foams under cone calorimeter conditions occurs in two steps (Fig. 2):

- The first step is attributed to the degradation of the foam to produce a tar
- The second step is attributed to the combustion of the tar produced.

These two degradation steps lead to two distinct peaks of rate of heat released.

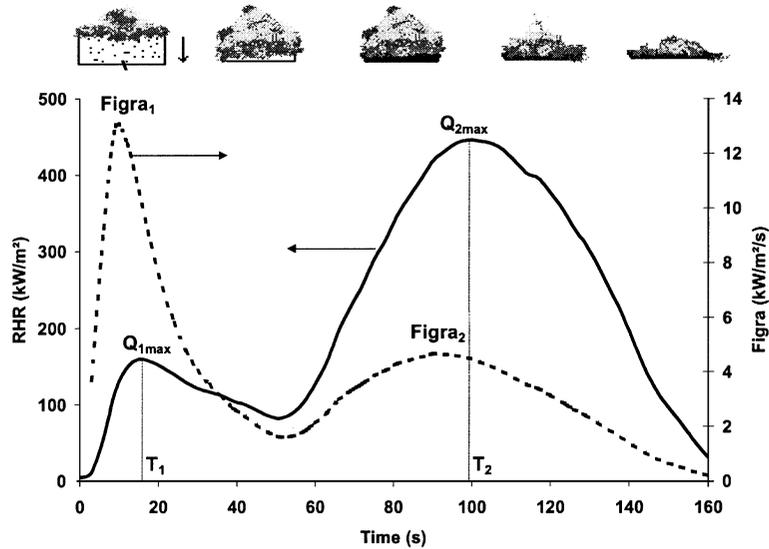


Fig. 2. Combustion of a flexible polyurethane foams: a two-stage process.

The statistical study is done considering the following data:

- The RHR_1 and RHR_2 values (the values of RHR of the first and the second RHR peaks).
- The T_1 and T_2 values (times at which RHR_1 and RHR_2 occur).
- The $Figra_1$ and $Figra_2$ values (the two maximum peaks on the Figra curve).

2.3.3. British Standard Ignition Source Crib 5 test to SI 1324 Sch. 1 Pt. 1

The measurement of the weight loss of a burning foam is defined in Statutory Instrument 1324 Schedule 1 Part 1 [19]. This regulation uses the method of British Standard 5852 with ignition source no. 5 [20] but with modified pass/fall criteria.

In this test, the foam to be tested (two pieces: $30 \times 45 \times 7.5 \text{ cm}^3$ and $45 \times 45 \times 7.5 \text{ cm}^3$) was assembled in the form of a seat on a grid-like metal rig, hinged together at right angle to each other (Fig. 3). The foam was covered with a standard FR polyester fabric (Trevira CS). The crib was centrally placed at the intersection of the back and bottom portion of the seat and wetted with 1.5 ml of isopropyl alcohol before the test. The complete assembly was placed on a balance to measure the dynamic weight loss. The test was carried out in a fume cupboard with an extraction of about 0.2 m/s. Each foam was tested at least three times.

As the crib is ignited, it initiates foam combustion, which accelerates with time. The assembly shown in Fig. 3 loses weight. Viscous brown–black liquid (tar) can sometimes drip down through the seat bottom and collect in a special receptacle placed above the balance. This

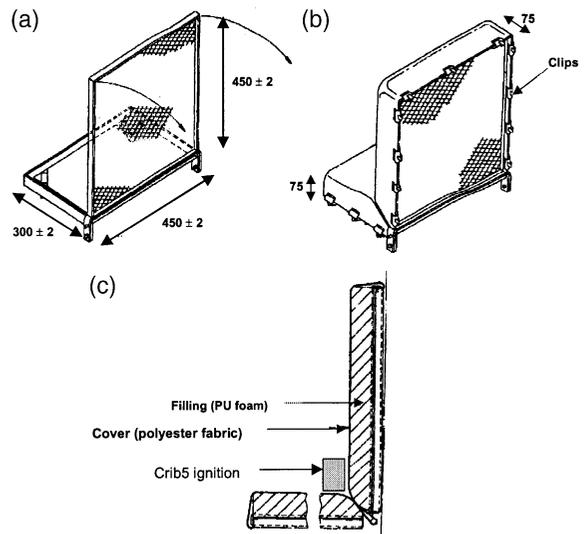


Fig. 3. Statutory instrument 1324 (ignition source crib5) test apparatus.

weight loss is called dripping weight loss (DWL). The total weight loss (TWL) is the sum of the DWL, the weight loss due to foam combustion (CWL) and also the weight loss of the crib.

In order to understand how the TWL changes with time, we also deduct the “rate of TWL” from the dynamic TWL profile. The requirements of SI 1324 Sch. 1 Pt. 1 are that flames do not burn for more than 11 min, specimens do not smoulder progressively and the total weight loss is less than 60 g.

2.4. Statistical method

Principal components analysis (PCA) has been carried out using the computational method STATBOX-ITCF [21,22].

Interpretation of the results consists first in checking the representation of the variables in the circles of correlation. The correlations between variables are deduced from the relative position and the length of their corresponding vectors on the circle of correlation. An example of interpretation is done in Fig. 4. The angle between two vectors defines the intensity of the correlation (vectors 1 and 5). If $\alpha = 90^\circ$, no relation exists between the variables. The strength of the correlation is higher when the angle α is close to 0° or 180° . So, orthogonal vectors (vectors 1 and 2) means no correlation between the variables. Data are strongly correlated if their vectors are co-linear (vectors 1 and 3, and vectors 1 and 4). The nature of the correlation also depends on the direction of the vectors: if vectors have the same direction (vectors 1 and 4) the variables are correlated, i.e. an increase in the variable linked to the vector 1 corresponds to an increase in the variable linked to the vector 4. Inversely, if vectors are opposite (vectors 1 and 3), the variables are anti-correlated.

The correlation between two variables is also a function of the length of the vectors. As example, vectors 2 and 6 are co-linear and so should be anti-correlated. But the weak length of the vector 6 means that its corresponding variable does not influence the variable linked to vector 2.

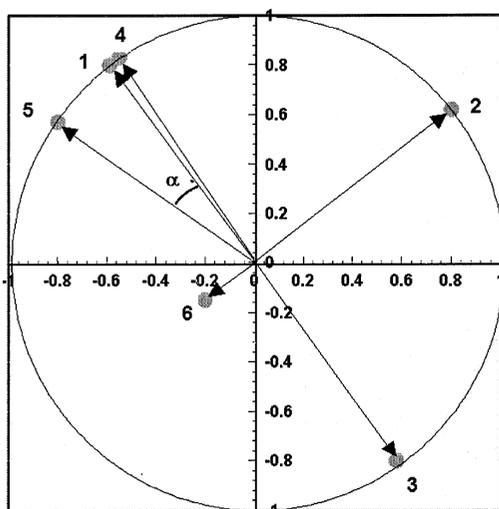


Fig. 4. Interpretation of principal components analysis.

3. Results and discussion

The statistical study considered the following parameters:

- *Foam formulation*: water index, SnOct, EO content, density, porosity index, FR additives
- *FMVSS no. 302*: flame spread rate from small flame source
- *Cone calorimeter*: values of heat release for each of the two RHR peak values when specimens are forced to burn at 35 kW/m², time at which peaks occurs and corresponding Figra peaks
- *SI 1324 Schedule 1 Part 1*: TWL, DWL, maximum rate of weight loss (Max rate), time of maximum rate of weight loss (TMR) and burn time when FR polyester covered PU foam composite is exposed to wood crib5 to BS5852 Part 2 1982.

3.1. Relations: physical–chemical properties of the foams

In a first step, PCA was carried out using the composition and physical characteristics of the materials. This allows determination of basic relations between the chemical composition and the physical parameters of the foam (EO content, SnOct range, water index, porosity and density of the foam). Fig. 5 presents the results of the statistical computation.

We can conclude from this study that:

- *Porosity index* is strongly correlated with the *SnOct* range. The higher the SnOct range, the higher is the

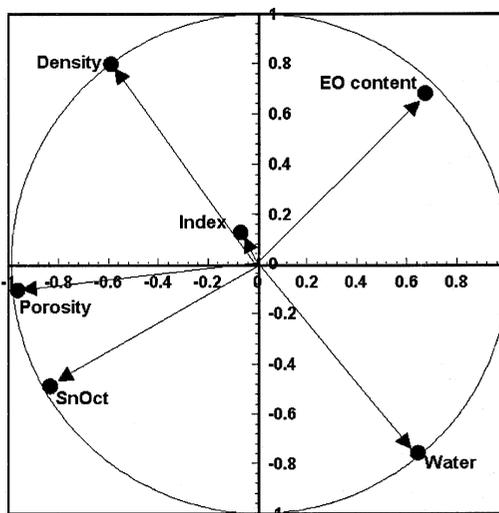


Fig. 5. Correlation circle—relationship: physical and chemical properties of foams.

porosity index. An excessively fast reaction time modifies the physical properties of the foam.

- *Density* is inversely correlated with the *water* index. The higher the water index, the lower is the density.
- *SnOct* is inversely correlated with the *ethylene oxide (EO) content*. Indeed, the EO is a very reactive agent during the polymerization step and if the amount of EO increases, the quantity of SnOct must be decreased.
- *Porosity index* is inversely correlated with the *EO content*. This fact should be explained by the fact that the EO has affinity for water via hydrogen bonding. The higher the EO content, the lower is the amount of water available for the blowing reaction of the foam. Hence, the amount of carbon dioxide released decreases and the porosity index of the foam decreases.

3.2. Relations: cone calorimeter–FMVSS 302

The principal components analysis from cone calorimeter and FMVSS 302 data shows the following correlations (Fig. 6):

- *RHR₁* is moderately correlated with *Figra₁*: *Figra₁* is a variable that depends on the first peak of HRR (also called *q₁max*), *d* the time it occurs. So, it seems quite coherent to find this kind of relation if the relative variation of the time is low.
- *RHR₁* is correlated with *Figra₂*. In the cone calorimeter, the foam degradation occurs in two main steps. It is obvious that an important consumption of fuel in the first step leads to a lower *Figra₂*.
- *FMVSS* is strongly correlated with *Figra₁* and *Figra₂*

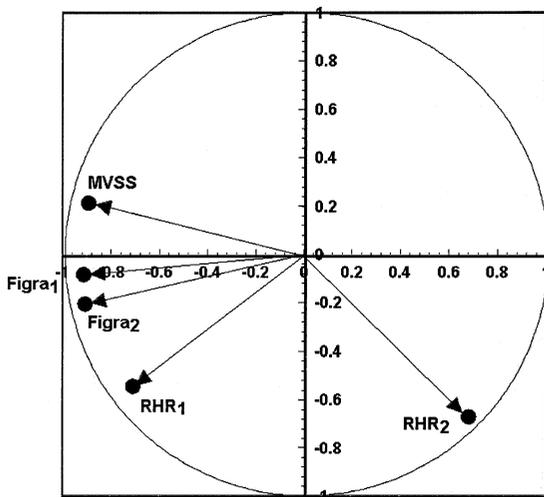


Fig. 6. Correlation circle—relationship: cone calorimeter/FMVSS.

and inversely correlated with *RHR₂*. The lower *Figra₁* and *Figra₂*, the slower the flame spread. A high *RHR₂* means loss of heat by dripping.

From the energy assessment of the foam consumption during 1 s, we can find a relation between the propagation speed of the flame and the energy of the tar produced by the combustion (Fig. 7).

As a first hypothesis, we can consider the following relation:

$$q_1 + q_2 - \Delta Q = Q = \text{constant}$$

- ΔQ corresponds to the part of heat used to melt the polymeric matrix leading to dripping.
- q_1 corresponds to the energy released during the first stage of the combustion that leads to the formation of the tar (*Figra₁*).
- q_2 corresponds to the energy released by the combustion of the tar (*Figra₂*).

This relation indicates the different strategies to decrease the value of *RHR₁* (and so *Figra₁*), that is to say the flame spread in the FMVSS 302 test:

- to decrease the total heat evolved *Q* using specific FR additives.
- to decrease the heat released during the first stage of degradation of the foam and as a consequence to decrease the heat fed back to the virgin polymer (decrease in *Figra₁*).
- to increase *RHR₂*, that is to say to reduce the energy of combustion by dripping.
- to delay the heat released by the tar. When the foam is molten, the tar starts to burn and this tar is not immediately lost by dripping. Hence, it is of interest to delay the combustion of this tar to enable it to drip (decrease in *Figra₂*). An increase in *RHR₂* is not sufficient to reduce the flame spread and it is important that the high energy tar degrades at a later stage.

Hence, we may propose that the flame propagation

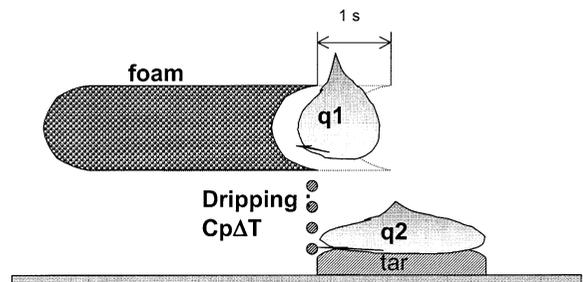


Fig. 7. Principle of FMVSS.

rate in FMVSS 302 testing is much lower when easy melting and dripping allows heat reduction and tar dripping. It may be proposed that q_2 corresponds in fact to the almost complete combustion of the tar.

Comparing the RHR curves of foams processed with variable water level, we note that the density of the foam strongly influences the first RHR peak (Fig. 8). The higher the water content (the lower the density) the faster the step of melting under cone calorimeter conditions. The effect of density on RHR₁ may explain the previous correlation found between density and FMVSS 302. A low density leads to rapid melting and to a high flame propagation rate.

3.3. Relations: cone calorimeter–British Standard Ignition Source Crib 5 test to SI 1324 Sch. 1 Pt. 1

The statistical computation was made considering the two different sets of foams: the foams containing TMCP–melamine and the ones containing TDCP–melamine. The level of fire retardant additives has been included in the computation but is not shown on the circles of correlation.

Considering the TMCP–melamine foams (Fig. 9) it is of interest to note that the lower are *Figra*₁ and *Figra*₂ the lower are the burn times, TWL and DWL. We also note that T_2 is strongly inversely correlated with the data of SI 1324 Sch. 1 Pt. 1, that is to say the higher T_2 the better results under the SI 1324 test (lower TWL, DWL and burn time).

The statistical computation of the data from the formulations TDCP–melamine clearly shows that the fire behavior of these foams in the SI 1324 test is linked to the second stage of degradation of the foam in the cone calorimeter (*Figra*₂ and T_2). Indeed, the *Figra* curve represents the fire growth rate of a foam during combustion. A high *Figra* means a high rate of flame propagation and so leads to a high weight loss of the material. Hence, it is not surprising that *Figra* curves are strongly linked to the BS5852 results. The combustion of a PU foam occurs

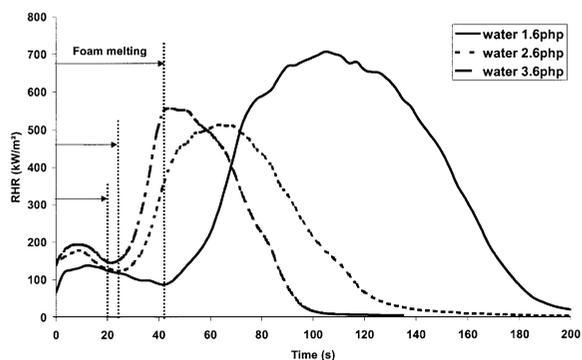


Fig. 8. Effect of density on the melting stage of polyurethane during combustion.

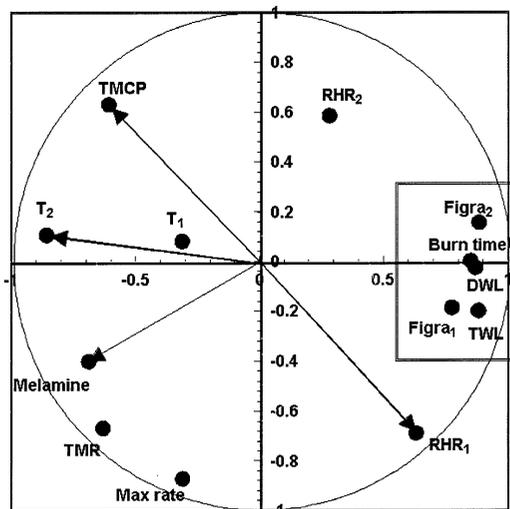


Fig. 9. Correlation circle—relationship: cone calorimeter/SI 1324, TMCP–melamine formulations.

in two steps: the “melting” of the foam and the combustion of the tar. The tar combustion is the most exothermic part of the combustion. A decrease in the heat released by the tar reduces the flame propagation and leads to a decrease in the weight loss of the foam (Fig. 10).

The TDCP and TMCP additives differ in their chlorine and phosphorus content and also in their temperature of degradation. TMCP degrades earlier than TDCP (150 °C and 210 °C, respectively; this temperature corresponds to a 5 wt.% weight loss under thermogravimetric analysis conditions). A previous study [23] has clearly shown that TMCP is efficient in the early stage of combustion but

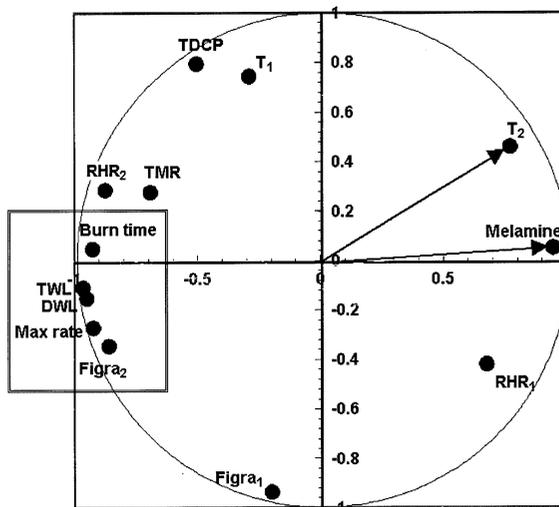


Fig. 10. Correlation circle—relationship: cone calorimeter/SI 1324, TDCP–melamine formulations.

no interaction with melamine is observed (temperature of 5 wt.% weight loss of melamine is 290 °C). TDCP acts later and when melamine starts to degrade about 50 wt.% of TDCP is available in the system, so a strong TDCP–melamine synergy is observed. The use of TDCP or TMCP in combination or not with melamine leads to very distinctive fire properties of the foams.

Considering the TMCP–melamine foams, it is of interest to note that the higher the TMCP content the lower is RHR_1 . That confirms the early effect of TMCP that acts by decreasing the heat released by the foam in the first stage of the combustion. Secondly, the melamine content is inversely correlated with RHR_2 . As described previously, the temperature of decomposition of melamine is high (290 °C) and this inverse correlation indicates an efficiency of melamine during the combustion of the tar.

Regarding the TDCP–melamine formulations, we note a positive effect of the TDCP amount on the RHR_1 peak. Even if TDCP degrades later than TMCP, a part of the TDCP is efficient in the first stage of the combustion. The melamine content is strongly correlated with the SI 1324 data. High melamine content leads to a decrease in TWL, DWL burn time and maximum rate of weight loss. The $Figra_2$ and RHR_2 peaks are also correlated with these data.

3.4. Relations: properties–FMVSS 302

The statistical treatment shows that the FMVSS 302 rating is an inverse function of the density of the foam which is itself a function of the water index (Fig. 11). No significant relations may be proposed between

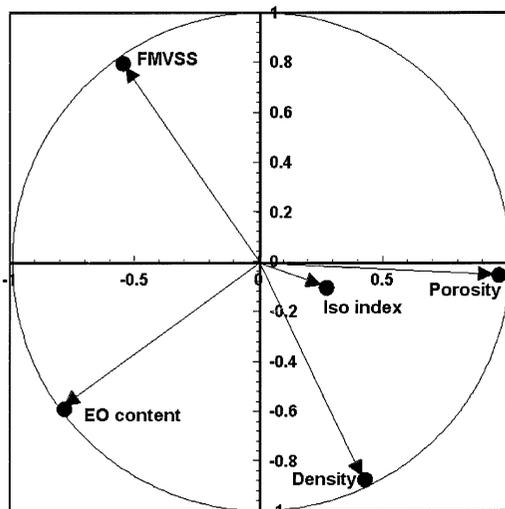


Fig. 11. Correlation circle—relationship: physical properties/FMVSS.

FMVSS 302 and porosity or TDI index because data did not show any variation of the porosity (same SnOct content) and only a low variation of the TDI index.

The porosity index of the foam is strongly correlated with the SnOct range used in the foam manufacturing. The previous study of conventional foams has revealed correlations between the FMVSS 302 testing and these parameters. The PCA study shows the absence of correlation between the EO content, the porosity (and so the SnOct range) and the index of the foam with the FMVSS 302 testing. However, it clearly shows that FMVSS 302 is strongly and inversely correlated with the density of the foam as it has been previously supposed.

4. Conclusion

The combustion of flexible polyurethane foams under cone calorimeter conditions may be described as a two step process. First, the foam melts to give a carbonaceous part and a tar. Secondly, the tar burns with a relatively high production of heat. The density of the foam tested influences significantly the first RHR peak. A high density foam leads to slower melting of the foam.

The data obtained using a cone calorimeter have been correlated with the flame propagation rate under the FMVSS 302 test. The flame spread variation appears to be related to the variation of the first and second peaks of $Figra$. Moreover, the effect of density on the RHR_1 peak (and so on the $Figra_1$ peak) agrees with the correlation shown between the density of the foam and the flame propagation rate. That is to say, a high density leads to a lower flame spread (FMVSS 302) and to a longer step of melting of the foam (cone calorimeter).

The $Figra$ curves have also been linked with the general behavior of the foam in the SI 1324 test. During a SI 1324 test, the flame spread and the heat of combustion of the tar are two major factors. Indeed, a part of the heat released by the tar is fed back to the virgin foam and speeds up the combustion. Hence, to decrease the total weight loss under SI 1324 test conditions, it is necessary to slow the rate of melting of the foam and to decrease the heat evolved during combustion.

Whatever the first test considered, the step of combustion of the tar appears to be one of the most important variables to reach satisfactory flame retardancy of the foam. From the cone calorimeter assessment, the improvement of the fire properties lies in the decrease in the second $Figra$ peak and in the delay of the second RHR peak (high T_2), that is to say in obtaining a tar of lower energy and that degrades later in the combustion.

The correlations found between the cone calorimeter data and FMVSS 302 and SI 1324 tests should be a major contribution in the prediction of the burning behavior of flexible polyurethane foams in these tests.

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