



Flame Retardancy Index

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Conférences

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Bonne Lecture,

## Flame Retardancy Index for Thermoplastic Composites

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**A**bstract : *Flame Retardancy Index, FRI*, was defined as a simple yet universal dimensionless criterion born out of cone calorimetry data on thermoplastic composites and then put into practice for quantifying the flame retardancy performance of different polymer composites on a set of reliable data. Four types of thermoplastic composites filled with a wide variety of flame retardant additives were chosen for making comparative evaluations regardless of the type and loading level of the additive as well as the irradiance flux. The main features of cone calorimetry including peak of *Heat Release Rate* (pHRR), *Total Heat Release* (THR), and *Time-To-Ignition* (TTI) served to calculate a dimensionless measure that reflects an improvement in the flame retardancy of nominated thermoplastic composites with respect to the neat thermoplastic, quantitatively. A meaningful trend was observed among well-classified ranges of *FRI* quantities calculated for the studied dataset on thermoplastic composites by which “Poor”, “Good”, and “Excellent” flame retardancy performances were explicitly defined and exhibited on logarithmic scales of *FRI* axis. The proposed

index remains adaptable to thermoplastic systems whatever the polymer or additive is.

**Keywords:** *Flame Retardancy Index (FRI)*; fire retardancy performance; thermoplastics; cone calorimetry

### 1. Problem Description

Additive selection for developing flame retardant systems based on thermoplastic polymers has been the subject of heated debate within the material science profession. For a given thermoplastic system, the type, loading percentage, size, shape, dispersion state, and thermal stability of flame retardant are factors responsible for the success or failure in design and implementation of a high performance system. The complexity of physical and chemical interactions between polymer chains and additives during the combustion process makes the prediction about the fire behavior of composites difficult. There is quite often a sizeable array of choices among different families of additives for applying, alone or in combination with families of identical or different nature, in a given thermoplastic system. Cone calorimetry

is currently the most advanced test to capture a comprehensive image of flame retardancy performance of polymer composites [1]. Typically, peak of Heat Release Rate (pHRR), Total Heat Release (THR), and Time-To-Ignition (TTI) are the main characteristics obtained hereby. For instance, it is apparent that the lower the pHRR or THR value, the higher the fire retardancy performance of neat thermoplastic of thermoplastic composites [2–4]. By contrast, the more TTI, the better the performance of the system in the early stage of combustion will be [5]. Nevertheless, dissimilar origins of these measurements may bring about confusion of dominance of one criterion to another in thermoplastic systems. Therefore, those having elementary knowledge about flame retardancy, rather than professionals working in the field, may expect a criterion that considers the fingerprints of three factors (pHRR, THR, and TTI) in one.

A careful survey of open literature confirms that there are several arrays of possibilities for fluctuations in pHRR, THR, and TTI values of a given thermoplastic containing different flame retardants or systems filled with one flame retardant at different levels of loading. The variation of these parameters originates from a vast variety of fire scenarios which are likely to occur in thermoplastics filled with different flame retardants

each having a specified action. Some of these scenarios are schematically compared in Figure 1. The filled and dotted curves in each case among (A) to (E) scenarios in Figure 1 correspond to the fire behavior of a given thermoplastic system, whatever the amount or the type of thermoplastic polymer or flame retardant additive are. The comparison of two cone calorimetry curves for each scenario suggests that understanding and patterning the relationship between variations in pHRR, THR, and TTI parameters, even for a given system, is cumbersome. For example, the TTI value is higher for system (I) in Figure 1A compared to system (II), while the pHRR of system (I) is higher than that of system (II). It is best known that a higher TTI at the same time as a lower pHRR is desired for a higher flame retardancy performance. The question to be answered is “which characteristic among TTI or pHRR is more influential on flame retardancy performance of thermoplastic system?”. Since each characteristic has its own specific contribution to flame retardancy action, as reflected in the unit of them with “s” and “kW/m<sup>2</sup>” respectively assigned to TTI and pHRR, the comparison between two curves in Figure 1A for giving rank 1 and 2 to TTI or pHRR to the systems (I) and (II) in view of fire retardancy performance cannot make sense of deduction.

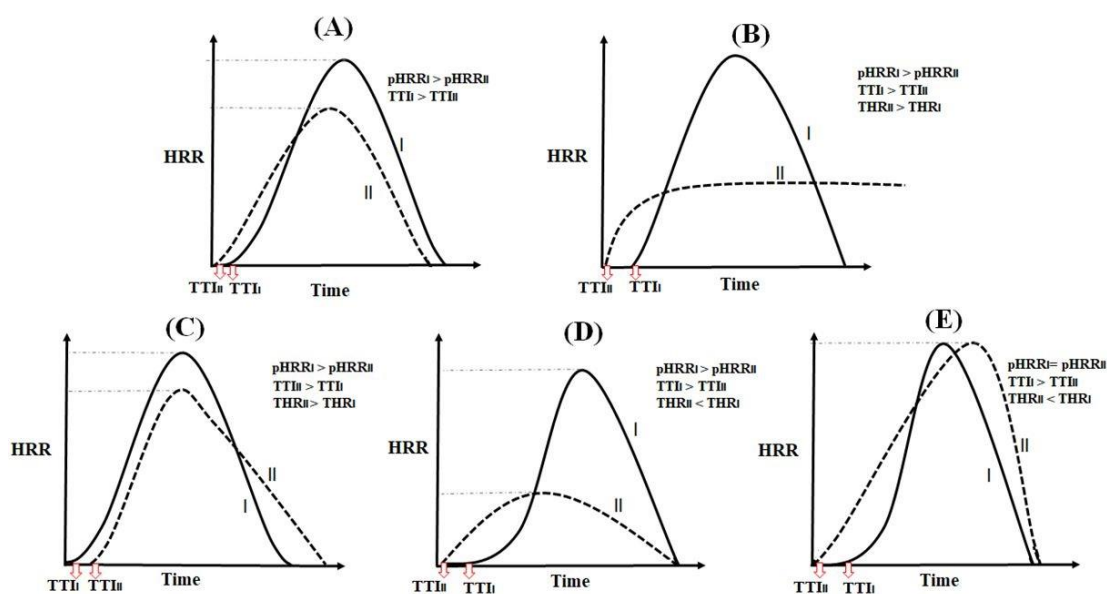


Figure 1. Possibilities in variation fashion of cone calorimetry HRR curves of given systems (I) and (II) that are likely to occur in different thermoplastics or in a given thermoplastic containing different FR systems (A) to (E) schematically patterned in this figure. Attention should be paid to the fact that such hypothetical cases are chosen among a wide variety of cases one may encounter within a conventional cone calorimetry assessment with non-interrelated variations in pHRR, THR, and TTI characteristics.

The problem takes one more dimension in Figure 1B since THR enters the game. An almost different shape of cone calorimetry curves in this case remains as a signature of difficulty of judgment regarding the performance of the system against fire. There are some more possible scenarios illustrated in Figure 1C–E with their own complexities in terms of interdependence between variations in TTI and pHRR, and THR quantities, bearing in mind the fact that ultimately one system should provide the user with a higher retardancy to fire for a real-case application. For example in case (E), even if  $TTI_I$  is higher than  $TTI_{II}$ , the THR value is better in system (II). Moreover, even if the level of pHRR is similar in the two systems, the time to  $pHRR_{II}$  is higher than that of  $pHRR_I$ . The aforementioned scenarios patterned in Figure 1 are examples amongst a wide variety of fire scenarios for which TTI, pHRR, and THR quantities are not alone indicative of fire retardancy character of the system or cannot in such a vague non-interrelated manner reflect flame retardancy performance of thermoplastic systems. Since TTI, pHRR, and THR have a different nature, the lack of a universal criterion for measuring good flame retardancy performance of a thermoplastic composite in the presence of different types of flame retardant systems, would cause decision-making to be very difficult.

## 2. Background and Methodology

For evaluating the flame retardancy performance of polymers, one may need to visualize the hidden phenomena behind fire scenarios. For example, THR has a unit of energy, but TTI is the time scale that demonstrates the resistance of the system against the appearance of flame at the initial stage of a fire. Therefore, they are inherently of a different nature and cannot be considered alone or in combination as a good criterion for evaluating the flame retardancy of thermoplastic composites. The other difficulty with measuring fire retardancy performance is that the situation of interaction of additives with polymers is always unknown. Hirschler [6] defined “Fire Performance Index”, FPI, in brief, as the ratio of the TTI to the pHRR having

the unit of  $sm^2/kW$ . The FPI appeared as a first-order indicator of tendency to flashover. The higher FPI values could principally specify a higher fire retardancy performance when a higher numerator, a lower denominator, or both moving in the aforementioned directions could be observed. A lower pHRR was simultaneously required for achieving higher performance levels. A wide variety of systems have been studied and concluded that such an approach would be a good measure for flame retardancy assessment. Nevertheless, one may need a simpler way to evaluate the function of flame retardants used in thermoplastic composites, such as a dimensionless criterion which could eliminate the need for simultaneous evaluation of two different measures with their own dimensions each reflecting a complexity of explanation. The new criterion had to be simple, universal, including three main parameters (pHRR, THR and TTI), and critically dimensionless to image the fingerprint of fire in a given thermoplastic composite.

To develop the idea that a universal dimensionless index is necessary, there is a prerequisite to distinguish one thermoplastic composite from the other in terms of flame retardancy performance. Following the first steps taken in the aforementioned study, the plot of THR ( $MJ/m^2$ ) (Y-axis) versus  $pHRR/TTI$  ( $kW/m^2.s$ ) (X-axis) could be considered as a new pattern of fire retardancy performance. The lower X and Y axes were looked for when expecting a higher performance from a thermoplastic composite. In this sense, a huge body of literature was searched to find thermoplastic composites in which only one kind of additive was used. To give the research a versatile character, four types of polymer matrices were selected among different families of thermoplastic: polypropylene (PP) as a commodity highly flammable polymer, poly(methyl methacrylate) (PMMA) as an engineering polymer, poly(lactic acid) (PLA) as a biopolymer, and poly(ethylene-co-vinyl acetate) (EVA) as an emerging polymer widely used in the cable industry. Table 1 summarizes the whole data extracted from the literature on cone calorimetry features of selected systems.

Table 1. Cone calorimetry data on pHRR, THR, and TTI characteristics of thermoplastic composites based on PP, PMMA, PLA, and EVA matrices components filled with a wide variety of additives. In the second column, the type and wt % of filler are typically represented as X-N denoting X type additive loaded with N wt % to the base thermoplastic.

Polymer	FR (wt %)	Irradiance (kW/m <sup>2</sup> )	TTI (s)	pHRR (kW/m <sup>2</sup> )	THR (MJ/m <sup>2</sup> )	Ref.
PMMA	-	35	21	790	76	[7]
PMMA	MMT- 2	35	24	725	71	[7]
PMMA	MMT- 4	35	20	634	72	[7]
PMMA	MMT- 6	35	20	579	68	[7]
PMMA	POSS-1	35	17	789	74	[7]
PMMA	POSS-3	35	17	825	68	[7]
PMMA	POSS-6	35	20	765	71	[7]
PMMA	-	50	9	1129	86	[8]
PMMA	LDH-3	50	10	915	77	[8]
PMMA	LDH-5	50	12	790	76	[8]
PMMA	LDH-10	50	9	615	72	[8]
PMMA	MMT-3	50	12	777	82	[8]
PMMA	MMT-5	50	13	625	80	[8]
PMMA	MMT-10	50	13	508	77	[8]
PMMA	Kaolin-3	50	10	1014	80	[8]
PMMA	Kaolin-5	50	10	970	76	[8]
PMMA	Kaolin-10	50	7	875	78	[8]
PMMA	-	35	69	620	110	[8]
PMMA	OMMT-10	35	74	320	110	[9]
PMMA	-	35	31	779	90	[9]
PMMA	Styreneoligomer-containing MMT (COPS)-2.5	35	32	737	88	[9]
PMMA	Styreneoligomer-containing MMT(COPS)-5	35	34	689	88	[9]
PMMA	Styreneoligomer-containing MMT(COPS)-15	35	39	629	84	[9]
PMMA	Styreneoligomer-containing MMT(COPS)-25	35	45	663	88	[9]
EVA	-	35	65	1680	124	[10]
EVA	Boric acid-10	35	35	899	112	[10]
EVA	Melamine polyphosphate-10	35	47	715	112	[10]
EVA	MgAl-LDH-10	35	33	793	117	[10]
EVA	-	35	58	2027	118	[11]
EVA	MgAl-borate LDH-3	35	35	1169	110	[11]
EVA	MgAl-borate LDH-5	35	36	1146	111	[11]
EVA	MgAl-borate LDH-10	35	36	1031	111	[11]
EVA	MgAl-borate LDH-20	35	40	919	99	[11]
EVA	MgAl-borate LDH-40	35	43	530	77	[11]
EVA	ZnAl-borate LDH-3	35	48	1287	116	[11]
EVA	ZnAl-borate LDH-5	35	51	867	117	[11]
EVA	ZnAl-borate LDH-10	35	53	750	111	[11]
EVA	ZnAl-borate LDH-20	35	38	721	102	[11]
EVA	ZnAl-borate LDH-40	35	51	460	77	[11]
EVA	MDH-40	35	63	703	75	[11]
EVA	ATH-40	35	54	743	74	[11]
EVA	Zinc hydroxide-40	35	36	1079	52	[11]
EVA	Zinc borate-40	35	50	231	81	[11]
EVA	-	35	61	1709	121	[11]
EVA	Melamine polyphosphate-10	35	48	689	113	[11]
EVA	-	35	53	836	101	[12]
EVA	expanded graphite-10	35	87	307	68	[12]
EVA	natural graphite-10	35	50	549	76	[12]

Polymer	FR (wt %)	Irradiance (kW/m <sup>2</sup> )	TTI (s)	pHRR (kW/m <sup>2</sup> )	THR (MJ/m <sup>2</sup> )	Ref.
EVA	graphite oxide-10	35	63	536	92	[12]
EVA	Expanded graphite-16 (20phr)	35	186	198	51	[12]
EVA	Expanded graphite- 24 (30phr)	35	409	172	42	[12]
EVA	-	35	48	1550	102	[13]
EVA	MMT- 3	35	44	860	94	[13]
EVA	MMT- 5	35	36	780	107	[13]
EVA	MMT- 10	35	44	630	99	[13]
PLA	-	35	78	427	146	[14]
PLA	Aryl polyphenylphosphonate (WLA)-7	35	87	407	145	[14]
PLA	-	35	60	272	65	[15]
PLA	PCPP-10	35	54	230	57	[15]
PLA	PCPP-20	35	47	123	15	[15]
PLA	-	35	60	272	65	[16]
PLA	APP-15	35	70	208	46	[16]
PLA	-	35	57	549	62	[17]
PLA	Aluminum hypophosphite-10	35	45	368	60	[17]
PLA	Aluminum hypophosphite-20	35	41	285	57.7	[17]
PLA	Expanded Graphite-10	35	46	244	60.2	[17]
PLA	Expanded Graphite-20	35	46	356	43.5	[17]
PLA	-	35	88	324	49	[18]
PLA	MWNT-5	35	95	176	47	[18]
PLA	-	50	64	425	64	[19]
PLA	Expandable graphite-1	50	44	410	70	[19]
PLA	Expandable graphite-5	50	43	380	44	[19]
PLA	Expandable graphite-10	50	60	305	52	[19]
PP	-	50	37	584	75.6	[20]
PP	MDH-10	50	33	471	65.9	[20]
PP	Sepiolite-5	50	24	533	68.1	[20]
PP	-	35	30	2086	90	[21]
PP	Sepiolite- 3	35	26	1534	90	[21]
PP	Sepiolite- 5	35	19	1401	78	[21]
PP	Sepiolite- 10	35	23	957	44	[21]
PP	organoSepiolite- 3	35	24	1368	47	[21]
PP	organoSepiolite- 5	35	25	1193	43	[21]
PP	organoSepiolite- 10	35	24	692	36	[21]
PP	-	35	43	1845	118	[22]
PP	Styreneoligomer-containing MMT (COPS)-2.5	35	47	1953	114	[22]
PP	Styreneoligomer-containing MMT(COPS)-5	35	45	1889	111	[22]
PP	Styreneoligomer-containing MMT(COPS)-15	35	37	1448	108	[22]
PP	Styreneoligomer-containing MMT(COPS)-25	35	38	1191	102	[22]
PP	MAPS-2.5	35	44	2025	123	[22]
PP	MAPS-5	35	42	1738	120	[22]
PP	MAPS-15	35	39	1651	115	[22]
PP	MAPS-25	35	41	1139	105	[22]
PP	-	35	54	1610	106	[23]
PP	Sepiolite-0.5	35	48	1701	108	[23]
PP	Modified Sepiolite-0.5	35	46	1665	106	[23]



The variations of THR versus pHRR/TTI for the composites based on PP, PMMA, EVA, and PLA are then presented in Figure 2. This figure visualizes the actions of additives of different types and families in the aforementioned thermoplastic matrixes for evaluating the flame retardancy behavior of composites. Two points should be cared when using these plots. First, since data are picked out from different sources considering the limited access to reports in which the desired cone calorimetry data could be extracted from, each plot for the assigned thermoplastic contains several symbols denoting the mentioned neat polymer. The diversity of flame retardancy levels of neat polymers in each plot is an indication of the difference in flame retardancy of the selected polymer matrix in terms of molecular weight and viscosity obviously controlled over flame retardancy behavior of the specified thermoplastic. Second, the distribution pattern of flame retardancy of thermoplastic composites featured by THR (MJ/m<sup>2</sup>) and

pHRR/TTI (kW/m<sup>2</sup>.s) in any specified case can be detected with symbols of spread positions in the area of the plot that can be noticed as a signature of complexity of the behavior of system against fire. The mauve arrows in the plots represent the direction toward which a desired flame retardancy improvement was likely to ensue. When THR and pHRR/TTI together take a low value, the desired flame retardancy will be recognized. However, the comparison is qualitative and there is no measure for quantifying the performance of systems. In other words, the unanswered question remaining with such a qualitative plot is: "Which polymer matrix or flame retardant additive would be the best choice?" The main complexity of providing an answer to the above question is that the very broad distribution of symbols (assigned to additives marked in each plot) gives a complex nature to the performance of flame retardant additives, each with its own hidden effect on the fire behavior of the system, and they cannot explicitly be held responsible for their actions.

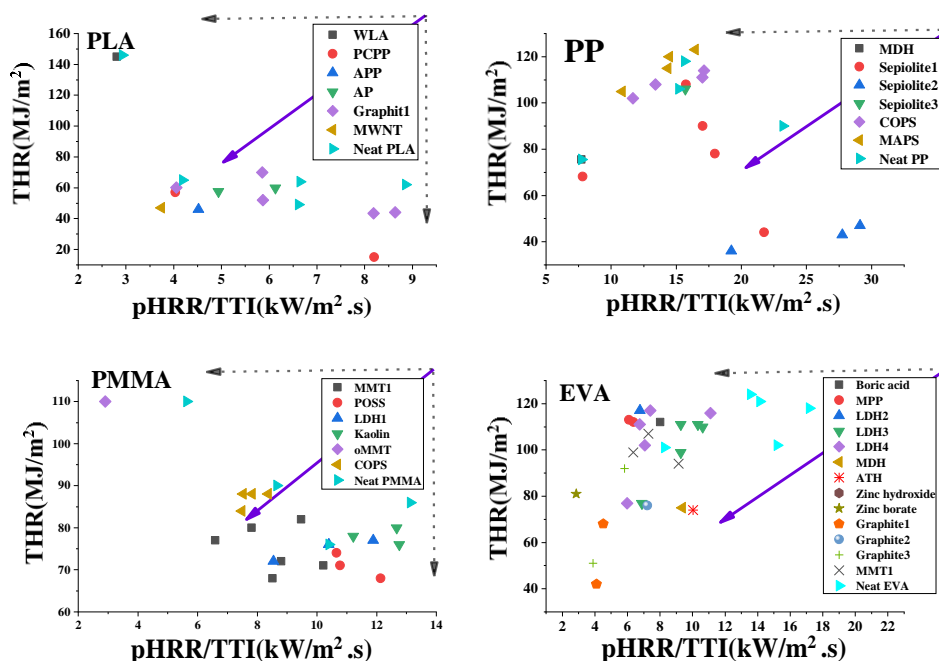


Figure 2. The plots of THR (MJ/m<sup>2</sup>) against pHRR/TTI (kW/m<sup>2</sup>.s) values obtained from cone calorimetry data with mauve arrows signifying improvement in flame retardancy performance for PLA, PP, PMMA, and EVA thermoplastic composites containing bewildering arrays of additives.

Here, we define and put into practice the "Flame Retardancy Index", *FRI*, as a simple yet universal dimensionless index in terms of pHRR, THR, and TTI. The *FRI* was defined as the ratio of  $THR * \left(\frac{pHRR}{TTI}\right)$  between the neat polymer and the corresponding thermoplastic composite containing only one flame retardant additive:

$$Flame\ Retardancy\ Index\ (FRI) = \frac{[THR * \left(\frac{pHRR}{TTI}\right)]_{Neat\ Polymer}}{[THR * \left(\frac{pHRR}{TTI}\right)]_{Composite}}$$

In principal, it is expected that by introducing the flame retardant additive and dividing the term calculated for the neat polymer to that of the thermoplastic composite, a dimensionless quantity greater than 1 is obtained. This operation and incorporation of a neat polymer value in the *FRI* formula lets us compare the different systems regardless of the nature of the used polymer in terms of molecular weight or viscosity. Having this in mind and by calculating *FRI* for reliable data on thermoplastic systems given in Table 1, we defined "Poor",

“Good”, and “Excellent” fire retardancy features assigned to well-classified ranges of FRI quantities colored in red, blue, and green, respectively (Figure 3). Classically saying, the quality of the flame retardancy performance can be assigned to the quantitative levels defined below in terms of ranges in FRI values (Figure 3). It is expected to see the value of  $10^0$  from Equation (1) as the low limit for flame retardancy performance below which the addition of a flame retardant additive is not reasonable. This is representative of a system in which the addition of a flame retardant additive inversely affects performance. Therefore,  $FRI < 1$  is taken as the lowest level of flame retardancy symbolized as “Poor” performance. Since data are gathered from a variety of reports in which different polymers (PP, PLA, PMMA, and EVA) filled with different amounts of various additives are included, the trend in the variation pattern of FRI can be considered as a snapshot of the behavior of thermoplastic composites when subjected to fire. From Figure 3A it can be observed that FRI values up to  $10^1$  ( $1 < FRI < 10$ ) are the most probable case, which are nominated as the “Good” zone colored in blue. A closer view of “Poor” and “Good” situations is provided in Figure 3B. The majority of FRI values calculated by Equation (1) are located in between 1 and 10. Moreover, in contrast to our initial expectation, some FRI values took quantities below  $10^0$ . This suggests that flame retardants can also contribute to combustion and, therefore, even in the presence of a flame retardant, the flame retardancy of a polymer can be worsened. The FRI values between  $10^1$  and below  $10^2$  ( $10 < FRI < 10^2$ ) are labeled “Excellent” and are distinguished by a green background in Figure 3A. Three points are located in the excellent flame retardancy zone. These systems contain EVA and expanded graphite [12] or zinc borate [11]. Expanded graphite is well known as a conventional flame retardant that acts on the barrier effect of a formed char, in terms of quality and quantity, during the combustion. It can also change the thermal conductivity of a polymer. Its incorporation into polymer leads to the increase of thermal conductivity and, therefore, to the dissipation of heat at the surface of the polymer. It is worth mentioning that the loading percentage of expanded graphite is unusually and extremely high for this type of flame retardant in the aforementioned study [12]. Zinc borate is a char promoter and during the degradation, forms compact char, which protects the underlying polymer from fire. Once again, in this study, the incorporation

percentage of zinc borate is higher than the usual quantity [24].

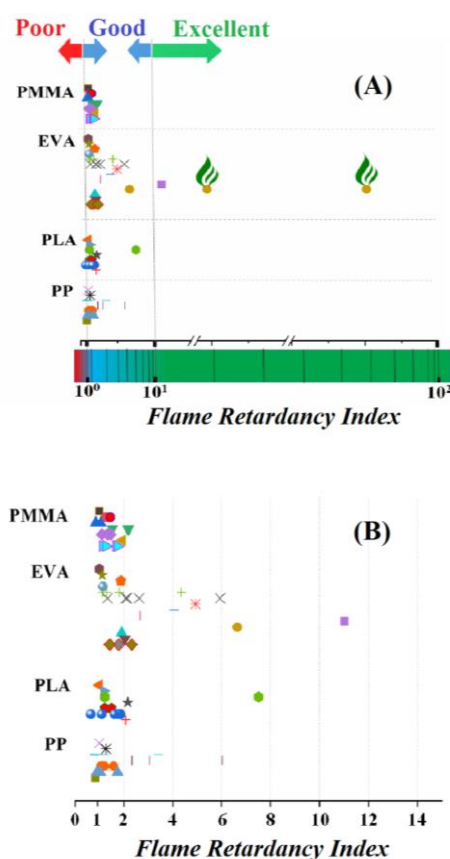


Figure 3. The calculated FRI for PLA, PP, PMMA, and EVA thermoplastic composites containing bewildering arrays of additives demonstrating the quality of flame retardancy in terms of “Poor”, “Good”, and “Excellent” performance: (A) a global view and (B) a closer view.

The dimensionless index nominated as FRI is useful for the comparative evaluation of the flame retardancy performance of thermoplastic systems regardless of the types of polymers and additives used. However, for now, this index is only adapted to simple fire scenarios where one peak of HRR appears during combustion. More complex fire scenarios can happen when two or more pHRR are compared to a second curve. In that case, one may need a high flame resistance rather than flame retardancy and, therefore, the char quantity and quality should be meticulously considered as well.

### 3. Conclusions

Nowadays, the most important challenge in the flame retardancy field is to develop an efficient and low cost flame retardant system with non-environmental threats [25]. The evaluation of flame retardant system efficiency is a crucial step in the development of new materials. In this regard, the use of cone calorimeter data is currently well known as the best fire bench-scale method and provides useful information. However, the complexity and multitude of fire scenarios as well

as the multitude of non-correlated parameters (HRR, TTI, and THR) obtained in the cone calorimeter test remains a source of error and distorted judgment in flame retardancy evaluation. The lack of a universal parameter which can quantify and allow the comparison of different flame retardant systems was pointed out by ScharTEL, Wilkie and Camino in 2016 [25]. This work is the first attempt to define a simple yet universal dimensionless index, hereafter known as Flame Retardancy Index (FRI), which appears informative and utilitarian for making a judgment about the effect of the performance of fillers/additives on flame retardancy behavior and properties of thermoplastics. Regardless of the irradiance flux and concentration of additives within the system, the approach is applied to a series of reliable data on PP, PMMA, EVA, and PLA composites. Surprisingly enough, a meaningful trend on a logarithmic scale was observed among well-classified ranges of FRI quantities calculated for the studied dataset, by which “Poor”, “Good”, and “Excellent” flame retardancy performances are explicitly defined and exhibited on the FRI axis for cases assigned to values below  $10^0$ , in between  $10^0$  and  $10^1$ , and above  $10^1$ , respectively. We believe that this idea can help investigators to, in a simple manner, judge the performance of their systems when subjected to a flame; however, it must still be generalized to more cases for the sake of relevance and powerful evaluation.

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## Grenfell Tower fire versus World Trade Center fire

Jinal Doshi

Structural Engineer and Founder of Structural Madness- Seattle- USA

There is a significant difference between thermal conductivity of steel as compared to concrete. There is a difference when a fire is spread because of localised fire hazard and when a building loses its strength because of the impact of an airplane moving at 400–550 mph.

Let us look at both the points separately:

### 1. Thermal Conductivity of steel vs concrete

Grenfell tower was constructed in 1970s and its basic structural system (a network of structural elements like slabs, beams and columns) was made of concrete. While world trade center had composite slabs (concrete poured over steel deck), steel beams and steel columns with a fireproofing coat. World trade centers were designed by history's one of the most brilliant structural engineer Mr. Leslie E Robertson in the year 1955-1960. They were significantly taller than Grenfell tower, approximately 6 times taller. Talking about thermal conductivity, concrete has a thermal conductivity of 1–1.8 depending on the density. Let us assume it is 1.8. While the thermal conductivity of steel is 43. What does thermal conductivity mean? In layman's term, I would say it is just the sensitivity of a material when subjected to heat. This means that humans (not literally but just to explain what is thermal conductivity) are more conductive to heat (we shout, scream and run away when we are close to fire and just cannot take it anymore), in case of steel, it is much more responsive to heat while concrete is like a saint, doesn't give a shit about what is happening around it unless bothered constantly. So when a building is made of concrete and subjected to fire, concrete does not let the fire expand quickly and keeps it confined unless fire finds some other way to expand; like cladding on buildings. But steel is in a different league. It immediately conducts heat. Ever had a burn just by catching a spatula that was partially dipped inside a vessel while cooking? Yeah it is that fast in conducting heat.

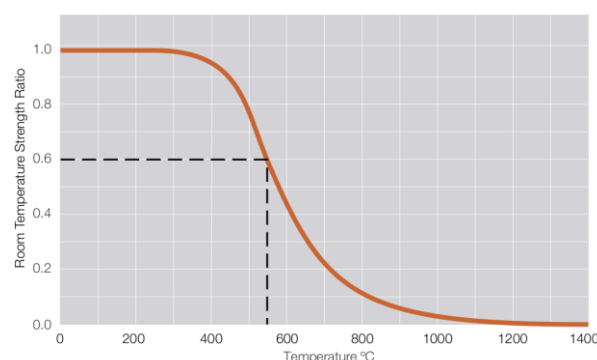


Fig. 1: Steel strength decreases with temperature

Because of this passive nature of concrete and active nature of steel when subjected to fire, steel reaches high temperatures quickly and starts losing its strength. At about 550 degree Celsius steel loses 40% of its total strength. And concrete? Well concrete is so passive to heat that it takes a significantly long time to increase its temperature. So it pretty much does not affect the strength of concrete under such fires.

So that tells you that steel gets weaker when subjected to fire. But hey, steel buildings have fireproof coating which is a 1 hour rating, 2 hour rating and so on. So in case of fire in a steel building, will it collapse? May be not. The reason it, if the structural integrity of steel building is not compromised, it will deform under extreme fire but not collapse. For instance, interstate bank building did not collapse when engulfed by fire for 3–4 hours.

### 2. Difference between types of fires between WTC and Grenfell Tower

The second thing that catches everyone's eye is the type of structural hazard after the accidental fire in Grenfell Tower as compared to intentional impact from Boeing aircraft. In case of Grenfell Tower, the buildings did not have any structural damage before the fire. Even when the fire did spread, the structural integrity of the building was intact. No columns or

beams or slabs were destroyed or even damaged. Combine this with the thermal conductivity of concrete, nothing structural would happen to the building.



But in case of World Trade Center Tower 1 and 2, the flights did compromise the structural integrity of the building. It literally chopped many columns around the boundary and within the building for couple of floors. Slabs were damaged because of the impact and fireproofing was also compromised at the levels of impact. Structural engineers were surprised as in how the towers were standing for 55 minutes and 110 minutes. Nobody expected that. Just because of the level of structural damage these aircrafts caused to the building.



Can you see that huge 3 story diagonal hole one the building surface? This was not acting as the external facade of the building, but it was the important structural system carrying half the weight of the building if all external perimeter columns combined together. That means these columns are not transferring loads anymore to the column below. So the columns surrounding these damaged columns started taking more load. But soon, the super Villain fire came and reduced the strength of the columns. It is something like you were already standing on one leg and suddenly you see someone with a chainsaw trying to chop that leg. You will fall miserably. Same thing happened with WTC T1 and T2. Columns had more load demand along with reduced strength. And so this initiated the collapse. The structural system was compromised.

### *Special Issue "Innovative Flame Retardants"- in "Molecules" journal*

*Deadline for manuscript submissions: 30 September 2019*

*Guest editors: Rodolphe Sonnier, Laurent Ferry, Henri Vahabi*

*Special Issue Information: [https://www.mdpi.com/journal/molecules/special\\_issues/Flame\\_Retardants](https://www.mdpi.com/journal/molecules/special_issues/Flame_Retardants)*

Dear Colleagues,

The research focuses more and more on the development of biobased materials to attain the requirements of sustainability. Developing biosourced materials in the future includes polymers as well as additives. Among these additives, flame retardants are the most important market. Bioresources are numerous and provide many opportunities to develop innovative flame retardants. Solutions based on carbohydrates, polyphenols, lipids or proteins are currently investigated.

To be commercially successful, biobased flame retardants must obviously be as efficient as oil-based ones. However, cost may also be a major drawback. Indeed, the development of biobased flame retardants often needs various extraction, purification and functionalization steps. A solution to be competitive may be to provide multifunctionalities. For

instance, combining flame retardancy with anti-ageing, plasticizing, crosslinking, conductive properties and so on would be highly desirable.

Alongside biobased ones, there are other innovative flame retardants based on various elements or from different classes of materials which offer new opportunities.

This special issue aims to gather high-quality papers about innovative flame retardants. Especially, all aspects of biobased flame retardants are considered, i.e. their extraction, synthesis and functionalization as well as the assessment of their fire retardancy properties and their environmental impact. Papers on other innovative flame retardants are also welcomed. Multifunctional additives combining several properties (including flame retardancy) will be privileged.

## *Conférences à retenir*

### **WORKSHOP: Tenue au feu des composites aeronautiques : du comportement materiau aux interactions avec la flamme**

Le 27 Mars 2019 à l'ONERA Toulouse

L'objectif de cet atelier est de regrouper la communauté nationale des ingénieurs et chercheurs travaillant sur le feu en aéronautique afin de faire un bilan sur les connaissances actuelles, les recherches en cours et les besoins industriels à court et moyen terme. L'accent sera mis particulièrement sur l'étude expérimentale et la modélisation des phénomènes physiques ainsi que sur les outils de simulation numérique, à la fois du point de vue des modélisateurs et des utilisateurs finaux.

\* Dégradation thermo-chimique des composites et propriétés associées

\* Comportement thermo-mécanique et endommagements

\* Interaction flamme/matériau

\* Problématiques industrielles associées au feu

Les détails de cette journée sont disponibles sur le lien suivant

<https://www.onera.fr/fr/agenda/workshop-https://www.onera.fr/inscription-workshop-feu2019feu2019>

### **IV Fire-retardant plastics conference: recyclability, sustainability and future trends (en)**

4 April 2019, Paterna (Spain)

<http://www.plastics-training.aimplas.net/informacion/curso05224/convocatoria009205/docs/agenda.pdf>

### **30th annual FLAME conference**

May 19-22, 2019 San Antonio, TX

A coming together of flame retardancy experts across governments, academia, and industry from around the world: Over the course of three days, the conference sessions span the diverse field of FR coatings science, technology, design and manufacturing.

Whether new to the industry or a veteran attendee, the FLAME conference is designed to give professionals the latest knowledge and tools to advance their work. FLAME 30 is the premier conference in the U.S. about flame retardant research, trends and applications. To learn more, visit the FLAME 30 website at <https://www.bccresearch.com/conference/flame>.

### **European meeting on fire retardant polymeric materials (FRPM19)**

26th to 28th June 2019, Turku, Finland

<http://frpm19.com/>

### **Groupement de recherche feux n° 2864**

A Marseille les 06 et 07 Juin 2019

Cette réunion se scindera en trois demi-journées de présentations (du jeudi matin au vendredi midi), entre-coupées de pauses. La table ronde organisée le jeudi après-midi portera sur " Mouvement des fumées et problématiques opérationnelles – État des

### *Conférences à retenir*

-connaissances sur : les effets sur les personnes, les problématiques d'évacuation, l'ingénierie du désenfumage".

L'introduction de cette table ronde sera faite par Philippe FROMY du LISI et par Eric GUILLAUME d'EFFECTIS.

Les propositions de communications doivent être soumises avant le **03 mai 2019** à l'adresse suivante :

<http://gdrfeux.blog.univ-lorraine.fr/juin-2019-marseille/>

Nous vous invitons à vous inscrire dès à présent à cette réunion en utilisant l'adresse ci-dessus. La date limite d'inscription est fixée au **15 mai 2019**.

#### **INTERFLAM 2019**

1-3 July 2019, Royal Holloway College, UK

<https://www.intersciencecomms.co.uk/html/conferences/Interflam/if19/if19cfp.htm>

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**Si vous souhaitez participer ou apparaître dans le prochain numéro prenez contact avec**

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### *Liens utiles :*

<http://gcf-scf.lmops.univ-lorraine.fr/>

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