Information Sciences Letters
An International Journal

http://dx.doi.org/10.18576/isl/121128

Predicting of The Amount of The Critical Radiant Flux When Carpet Ignites Using Flooring Radiant Panel Device

Sanaa M. Enany[1,2,*]

[1]Department of Home Economics, College of Samtah Governorate, Jazan University, Jazan, Kingdom of Saudi Arabia
[2]Material Testing and Surface Metrology Lab, National Institute of Standards, Giza, Egypt

Received: 30 Sep. 2023, Revised: 24 Oct. 2023, Accepted: 29 Oct. 2023
Published online: 1 Nov. 2023

Abstract: Textile floor coverings especially carpets and rug consider an extremely important role in the spread of flames when a fire occurs، Fire hazards are associated with various properties of combustible materials, including ignition capacity, speed of flame spread, ease of extinguishing, rate of heat release, amount of smoke and toxic gases. It has become clear that the individual characteristic that defines the amount of fire is comparable to the amount of heat release. the main objective of the study is to derive a formula to predict the amount of critical radiant flux expected by the distance burned from textile floor covering, an approach is based on the experimental method, The experimental work focused on measuring the flammability of test samples displayed in table 1. This test method is applicable to all types of carpets, regardless of the manufacturing method (woven or non-woven), the fibers used (natural or synthetic), or the quality of the floor covering (jute or rubber). The test was applied to 27 sample types of carpets were specially manufactured for research with different thicknesses and materials. The study could drive the formula in equation ($Y = 0.00014x^2 - 0.027x + 1.4$) that relate the expected critical energy quantity and the burning distance, where Y is the expected critical energy quantity and X is the burning distance. According to the basic curve of the critical energy required for ignition it was found that a distance of 67 cm achieves the minimum level of the second level (class II) for the amount and magnitude of the critical energy required for ignition (0.22 W/cm2).

Keywords: Radiant Panel, Carpet, Flammability, Burning, critical flux.

1 Introduction

The hazards of fire for the early generations of humanity were limited to thermal hazards only. With the advancement of civilization and the increase of population, the way people live their lives has changed, including their homes (e.g., space, ceiling heights, insulation, and ventilation). With the modern way of living, accidental fires are more likely to occur in compartments than in open outdoor areas. The production of toxic smoke in fires has become a major threat to victims of accidental fires in recent decades. The need for effective methods to quantify and measure these toxic hazards is crucial at this stage of the advancement of fire safety research. [1]

There is a lot of regulatory control because building materials have the potential to fuel the growth and spread of fires. Smoke production, flame spread, and flammability are all simulated and characterized using a wide range of small-scale tests. The Fire Science and Technology Laboratory at CSIRO recently carried out a comprehensive investigation into how well flooring and floor coverings perform in a fire. [2]

Carpet and other floor coverings have the potential to help fires spread through Corridors in structures. Carpets must pass the ASTM E648 standard test1, which evaluates how likely floor coverings are to spread flames when exposed to a thermal radiant flux, in order to be approved for use in commercial buildings. This test procedure simulates a situation where a floor covering is subjected to heat radiation from a fully developed fire in a room next to it. A carpet undergoing this test is subjected to a heat flux that varies smoothly with distance over the sample due to a radiant panel mounted at an angle. The sample is ignited, and the flame spreads towards the lower flux end of the sample. After the test, the distance from the edge of the burned sample to the point of flame extinction is measured and converted to a critical radiant heat flux (CRF) that is necessary to support the spread of flames over the surface of the material. [3]

The most relevant properties to the fire reaction of fiber-polymer composites are Time to ignition, Heat release rate, Mass loss, Extension flammability index, Thermal stability index, Limiting oxygen index, Smoke density, Smoke toxicity, Surface spread of flame. [4]

The burning behavior of carpets of very similar construction and contract commercial carpets made from different fibers

*Corresponding author e-mail: senany@jazanu.edu.sa

and blends were significantly affected by the pile fiber composition in the National Bureau of Standards Flooring Radiant Panel test. [5]

Smoke inhalation has been the leading cause of death for fire victims around the world for many decades. Building fires are responsible for over 75% of all fire fatalities. Several major fire accidents, in which fire toxicity was the cause of death for almost all victims, have been highlighted. Statistical reviews of fire casualties in the UK and the USA over several decades show that fire toxicity is the major cause of death for fire victims.

In the case of smoke inhalation, the degree of injury depends on the length of time the victim is exposed to smoke without receiving an adequate amount of oxygen. Unless adequate oxygen is available to the victim, adverse effects usually occur in the form of breathing difficulty, fainting, respiratory failure, and cardiac arrest. [6]

Burns occur when heat from a fire destroys the body's tissues. The severity of burns ranges from mild, such as sunburn, to large, open burns, depending on the depth of the burn, its location, and the extent of tissue exposure. Large, open burns can lead to contamination, loss of essential fluids, and the inability to regulate temperature. [7]

When ignition occurs, a fire involves three basic processes: creation of fire products (heat, smoke, and toxic gases), transport of fire products from the fire source to the target, Effects of fire products on the target.

As far as the dangers of fire to humans are concerned, it is necessary to analyze the products of fire, which are the effect of heat, lack of vision, smoke toxicity, smoke transmission and spread, decomposition of smoke components, poisonous gases.

Factors, space and time are very important in the impact of a fire. Therefore, if the fire includes sufficient materials that will spread flames, smoke, and toxic gases beyond the original room in which the fire started, it is necessary to direct the people present away from the main room in which the fire is located. In this case, the other three final points are additional trends that you need to consider. [8]

The damage to human health and property comes from the effects of heat and ignition spreading from the first ignited material to other materials, which leads to strong thermal damage to those present in the place of the fire and the destruction of the building, also there is the production of smoke that obscures vision and may hinder fire victims from escaping, and the emergence of toxic substances (gases) in the smoke, which can be inhaled by the victims and harm them. The reason for this is that there is a hierarchical chain between the burning substance and the heat that causes the fire. In the absence of smoke, there will be no toxic substances (poisonous gases). [9]

We must clarify that the toxicity of smoke refers to the toxicity of the smoke in the fire environment, more than the toxicity of the smoke generated by the combustion of an individual substance. [10]

This is important because smoke toxicity is a major factor in fire fatalities. Carpets are a particularly important material to study in this regard, as they can create a very fertile environment for the growth and spread of fire.

we used the flooring radiant panel device to determine the flammability of carpets. According to the standard (ASTM E-648), we found that time must be involved in the test methods in order to obtain the rate of ignition spread. In addition to this, the risk analysis for floor materials must include information about the properties of ignition control and heat release rates. [11]

2 Literature Review

C. Anolick [12] outlined how All of the system's components affect a carpet underlayment system's flammability characteristic. The selection of carpet construction and fiber is crucial. Significant variations in outcomes were observed amongst the diverse carpets examined. Following the selection of the carpet construction—which is typically done for reasons related to comfort and aesthetics—the carpet anchor coat and foam pad have an impact on the flammability of the material. Using a foam pad reduces the critical radiant flux of the carpet system, as determined by the Flooring Radiant Panel Test, in every tested scenario. Compared to foam pads based on SBR, those based on polychloroprene latices have a far less severe decrease in critical flux. This holds true even in cases where the SBR foam formulation contains hydrated alumina filler. This leads to the conclusion that compared to the same carpet with an SBR pad, a carpet with a polychloroprene pad is probably less likely to contribute to the spread of fire. Polyurethane pads have been found by other researchers to be comparable to SBR pads. The lowest feasible foam density and thickness will result in the best flammability characteristics. Whether the pad is affixed to the carpet or not, all outcomes are equal. It is crucial to include hydrated alumina filler in the latex anchor coat used to secure the pile in place when installing a foam pad. The most variety of carpets can be utilized when a designer needs a specific degree of flammability as determined by the Flooring Radiant Panel Test, provided that hydrated alumina is present in the anchor coat and the foam pad is composed of polychloroprene latex. In addition to their outstanding physical qualities, foam pads made from this latex also perform exceptionally well in other flammability and smoke tests.

As Hirschler [13] explained, it was found that the carpets showed a wide range of fire performance, including ranges of peak rate of heat release and of time to ignition of c. 3 and of smoke factor of c. 8. It was not found possible to correlate the results of the NBS smoke chamber or radiant panel tests with any of the results obtained from the cone calorimeter.

L. Benisek [14] reported that in the National Bureau of Standard Flooring Radiant Panel, the pile fiber composition position had a significant impact on the burning behavior of carpets with very similar construction and commercial carpets made from different fibers and blends. Underlays had no effect on the critical radiant flux (CRF) values of carpets made of 100% wool and 80/20 wool/nylon, which were greater than 0.5 W/cm2. The CRF values of nylon carpets were highly dependent on the carpet construction; low weights resulted in low CRF values, which sharply declined with underlays. The CRF values for wool increased significantly, while the CRF values for nylon decreased with an increase in the imposed heat flux. This is most likely related to the two fibers' dissimilar heat outputs and melting or charring characteristics. The Zirpro flame-retardant treatment of wool, shorn pile density, backing fiber composition (polypropylene or jute), and flame-retardant latex are additional carpet parameters that can impact CRF values.

3 Experimental

Materials

The experimental work focused on measuring the flammability of test samples displayed in table 1. This test method is applicable to all types of carpets, regardless of the manufacturing method (woven or non-woven), the fibers used (natural or synthetic), or the quality of the floor covering (jute or rubber). The test was applied to 27 sample types of carpets were specially manufactured for research with different thicknesses and materials using the Flooring Radiant Panel device.

Table 1: Specifications of samples used in the test

sample number	sample Wight (gm)	Overall sample thickness (mm)	pile thickness (mm)	pile density (g/m^2)	pile material
1	4178.5	12	10	2814.5	**%10wool%90 polyester**
2	4185.5	12	10	2937.7	**%10wool %90 polyester**
3	4401	10	8	2991.2	**%10wool %90 polyester**
4	3787.7	10	8	2434.5	**%20wool % 80polyester**
5	3604.5	10	8	2497.7	**%20wool % 80polyester**
6	3397.7	12	10	2261.2	**%20wool % 80polyester**
7	3192.2	12	10	1972	**%30wool % 70polyester**
8	3266	12	10	2062	**%30wool % 70polyester**
9	3896.7	10	8	2531.2	**%30wool % 70polyester**
10	3746.5	10	8	2407.7	**%40wool % 60polyester**
11	3746.7	12	10	2429	**%40wool % 60polyester**
12	3998.2	12	10	2628.2	**%40wool % 60polyester**
13	3017	12	10	1724	**%50wool % 50polyester**
14	3403.5	10	8	2158.7	**%50wool % 50polyester**
15	2997	10	8	1861.2	**%50wool % 50polyester**
16	3270.5	12	10	2036.7	**%60wool %40 polyester**
17	4275.2	12	10	2734.5	**%60wool %40 polyester**
18	4194.2	10	8	2746.7	**%60wool %40 polyester**
19	3640	10	8	2231.2	**%70wool % 30polyester**
20	3485.7	12	10	2064.5	**%70wool % 30polyester**
21	3761.2	10	8	2085.2	**%70wool % 30polyester**
22	3787	10	8	2332.2	**%80wool % 20polyester**
23	3147.2	12	10	1939.2	**%80wool % 20polyester**
24	3702.2	10	8	2280	**%80wool % 20polyester**
25	4016.7	10	8	2483.2	**%90wool % 10polyester**
26	3047.5	12	10	1824.5	**%90wool % 10polyester**
27	3486.5	10	10	2097	%90wool % 10polyester

4 Methods

The test was carried out using the flooring radiant panel – FRP Device in figure 1, flooring radiant panel test is designed to simulate a likely set of conditions which may lead to fire spread in a carpet system. This test method determines a critical radiant flux. measured in (watts/cm2) critical radiant flux is the lowest level of radiant energy necessary for a fire to continue to burn and spread. [15]

The sliding carriage (platform) outside the test chamber is ignited with the radioactive source. We allow the unit to first heat up for 90 minutes to reach equilibrium. Then, the air is adjusted with the amount of gas entering by controlling two valves in the device to reach a temperature of 500 ± 25 m° for the heat source (panel) and 180 ± 5 m° for the test chamber. Figure (2) show the attempts by the gas and air valves to reach the temperature of the test chamber and the heat source.

Upon arrival at the balance, the test is started by inserting the sliding cart containing the test sample and fixing it in the test chamber. After igniting the igniter flame, it is brought into contact with the surface of the sample for a period of 10 minutes.

The readings attributed to combustion time are recorded electronically by the software of the device along the sample at each 5 cm interval until combustion stops completely.

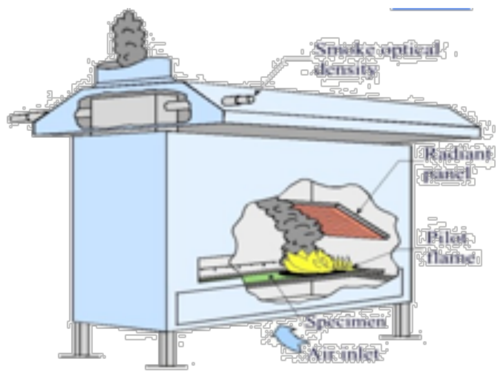

Fig. 1: The Flooring Radiant Panel – FRP Device

Fig. 2: Adjusting the temperature

5 Results And Discussion

The critical radiant flux required for ignition (w/cm^2) for each sample is shown in table 2. According to the international standard (ASTM E-648), and in order for samples to be classified as Class I, the minimum critical radiant flux (CRF) is 0.45 w/cm^2**.** For samples to be classified as Class II, the CRF must fall within the range from 0.22 w/cm^2 to 0.44 w/cm^2**.**

It was clear that samples achieved the minimum international fire code (0.22 w/cm^2) are:

- Sample No. (13) achieved 0.236 w/cm^2 with a burning distance of 65 cm.
- Sample No. (14) achieved 0.217 w/cm^2 with a burning distance of 68 cm.
- Sample No. (15) achieved 0.219 w/cm^2 with a burning distance of 67 cm.

These samples have a mixing ratio of 50% wool: 50% polyester. Therefore, to avoid the excessive economic cost of producing 100% wool carpets that meet the international fire code, we produce carpets with a mixture ratio of 50% wool: 50% synthetic fibers.

It was noticed that the following samples:

- Sample No. (16) with a burning distance of 63 cm^2

- Sample No. (17) with a burning distance of 65 cm^2
- Sample No. (19) with a burning distance of 56 cm^2
- Sample No. (20) with a burning distance of 60 cm^2
- Sample No. (21) with a burning distance of 50 cm^2

could achieve the second level (class II) in higher percentages than samples with a mixing ratio of 50% wool: 50% polyester due to the high percentage of wool in these samples.

It was also observed that samples with a mixing ratio of 80% wool: 20% polyester or 90% wool: 10% polyester achieved the first level (class I) of the International Fire Code due to the high percentage of wool in these samples.

As for samples with a mixing ratio of 10% wool: 90% polyester, 20% wool: 80% polyester, 30% wool: 70% polyester, or 40% wool: 60% polyester, they do not meet the International Fire Code.

Table 2: Critical radiant flux required for ignition attributed to each sample

Sample number	Pile material	Critical radiant flux required for ignition (w/cm^2)
1	%10wool%90 polyester	0.126
2	%10wool %90 polyester	0.127
3	%10wool %90 polyester	0.129
4	%20wool % 80polyester	0.140
5	%20wool % 80polyester	0.162
6	%20wool % 80polyester	0.145
7	%30wool % 70polyester	0.151
8	%30wool % 70polyester	0.145
9	%30wool % 70polyester	0.136
10	%40wool % 60polyester	0.181
11	%40wool % 60polyester	0.175
12	%40wool % 60polyester	0.140
13	%50wool % 50polyester	0.236
14	%50wool % 50polyester	0.217
15	%50wool % 50polyester	0.219
16	%60wool %40 polyester	0.254
17	%60wool %40 polyester	0.236
18	%60wool %40 polyester	0.196
19	%70wool % 30polyester	0.327
20	%70wool % 30polyester	0.284
21	%70wool % 30polyester	0.400
22	%80wool % 20polyester	0.661
23	%80wool % 20polyester	0.626
24	%80wool % 20polyester	0.716
25	%90wool % 10polyester	0.792
26	%90wool % 10polyester	0.916
27	%90wool % 10polyester	0.863

The relationship between relationship between critical radiant flux required for ignition and burning distances was described by the curve in figure 3. The critical energy required for ignition could be achieved through representing several different burning distances corresponding to the critical energy required for ignition whose data is given in table (3).

The study could drive the formula in equation (1) that relate the expected critical energy quantity and the burning distance as follow:

$$Y = 0.00014x^2 - 0.027x + 1.4 \quad (1)$$

where Y is the expected critical energy quantity and X is the burning distance.

According to the basic curve of the critical energy required for ignition it was found that a distance of 67 cm achieves the minimum level of the second level (class II) for the amount and magnitude of the critical energy required for ignition (0.22 W/cm2).

Table 3: The burning distances and the corresponding critical radiant flux required for ignition

The critical radiant flux required for ignition. (w/cm^2)	burning distances (cm)
1.26	5
1.14	10
0.91	20
0.81	25
0.70	30
0.50	40
0.40	46
0.35	50
0.30	53
0.28	60
0.20	65
0.16	70
0.16	75
0.13	80
0.11	85
0.10	90

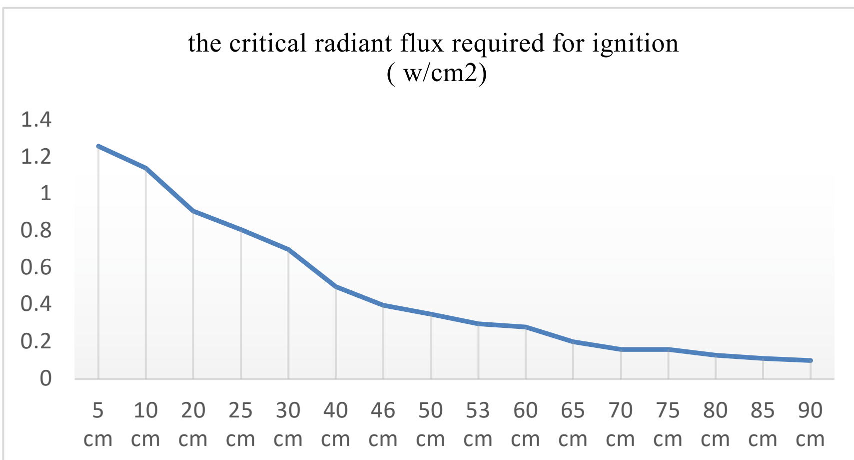

Fig. 3: Relationship between critical radiant flux required for ignition (w/cm^2) and burning distances

6 Conclusion

The importance of this study lies in its attempt to derive a formula for predicting the result of the critical amount of energy expected from the radioactive plate device according to the international standard ASTM E-648. The test was conducted on 27 carpet samples with different types of pile material, pile thickness, and total thickness. Living places, housing institutions, and sometimes transportation and entertainment venues are not devoid of carpets for floor furnishings. The law was concluded by taking many different burning distances and the corresponding critical energy required for ignition. The relationship between the burning distance and the amount of critical energy was found using applied statistics.

Recommendation

1- In the field of carpet manufacturing, it is preferable to work on producing carpets mixed with natural and synthetic fibers, not just synthetic fibers, to reduce the flammability of carpets.

2- In the field of studying ignition behavior, I recommend research into the effect of carpet aging on flammability.

Author Contributions

The author conceived the work, prepared the samples and performed the experiments, conducted the sequence alignment and drafted the manuscript. The author read and approved the final manuscript.

Availability Of Data and Materials

The data sets used and analyzed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest Statement

The authors declare no conflicts of interest. Ethical approval There is no need for ethical clearance since it is a review article.

References

[1] Alarifi, A. A. S., Phylaktou, H. N., & Andrews, G. E.*What kills people in a fire? heat or smoke?*. 9th SSC Proceedings, (2016).

[2] Blackmore, J. M., & Delichatsios, M. A. Flammability tests for assessing carpet performance. *Journal of fire protection engineering*, 12(1), 45-59, (2002).

[3] Butler, K. M., Samant, K. R., & Shields, J. R. *Using the Cone Calorimeter to Develop a Detailed Model of Carpet for Flammability Studies,* (2015).

[4] Mouritz, A. P., & Gibson, A. G. *Fire properties of polymer composite materials* (Vol. 143). Springer Science & Business Media, (2007).

[5] Benisek, L., & Phillips, W. A. Evaluation of Carpets in the National Bureau of Standards Flooring Radiant Panel. *Textile Research Journal*, 53(1), 36-43, (1983).

[6] Alarie, Y. Toxicity of fire smoke. *Critical reviews in toxicology*, 32(4),(259-289), (2002).

[7] Pope, EJ The effects of fire on human remains: Characteristics of taphonomy and trauma. University of Arkansas, (2007).

[8] Irvine, D. J., McCluskey, J. A., & Robinson, I. M. *Fire hazards and some common polymers. Polymer Degradation and Stability*, 67(3), 383-396,(2000).

[9] Liu, X., Hao, J., & Gaan, S. Recent studies on the decomposition and strategies of smoke and toxicity suppression for polyurethane based materials. *RSC advances*, 6(78), 74742-74756, (2016).

[10] Hirschler, M.M. Smoke toxicity measurements were made so that the results can be used for improved fire safety. *Journal of fire sciences*, 9(4), 330-347, (1991).

[11] ASTM E-648 (Radiant panel Test) *Test method for surface of floor covering materials using a Radiant Heat Source*.

[12] Anolick, C, Cook, G. S., & Stewart, C. W. Flammability Properties of Carpets with Polychloroprene Latex Foam Underlayments. *Rubber Chemistry and Technology*, 52(4), 871-882, (1979).

[13] Hirschler, M. M. Smoke and heat release and ignitability as measures of fire hazard from burning of carpet tiles. *Fire safety journal*, 18(4), 305-324, (1992).

[14] Benisek, L., & Phillips, W. A. Evaluation of Carpets in the National Bureau of Standards Flooring Radiant Panel. *Textile Research Journal*, 53(1), 36-43, (1983).

[15] Benjamin, I. A., & Davis, S. Flammability testing for carpet. US Department of Commerce, National Bureau of, Standards, (1978).