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"Characterization of the Combustion Behaviour of Different Types of Carpets using A radiant Panel Device"

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Abstract:

Carpets are considered one of the most important elements of interior decoration in residential, commercial, and public buildings, as they cover large areas of flooring and provide comfort, thermal insulation. However, its dense presence in enclosed environments makes it one of the materials that may contribute to the rapid spread of fire within the building if exposed to an ignition source, especially since most of the fibres used in carpet manufacturing are combustible, whether natural like wool and cotton or synthetic like polypropylene. For this reason, a set of standard fire tests is applied to carpets to determine their flammability, the speed at which flames spread on them, This research aims to characterize the ignition behaviour of different types of carpets in terms of the type of fibre used or the carpet backing, whether latex or rubber. It also aims to determine which types of carpets can achieve safety levels according to the standard specification (ASTM E648). Fifteen carpet samples were used, and the results showed that all carpet samples with 100% wool or blended wool achieved a safety level (such as Class I or Class II in the American system) regarding flame spread rate. They achieved a relatively high percentage due to the rapid ignition of wool, but it self-extinguishes afterward. As for the carpets made with 100% synthetic fibres and also cotton, they did not meet the minimum safety level, as the results for all samples were 0.11watts/cm2, as for the flame spread rate, it was somewhat lower, which is attributed to the time it takes for the fibres to melt before ignition**.**
Keywords: Critical, Radiant Flux, Flammability, Flam spread.

Introduction:

One of the most critical and significant tests is the flammability test, as floor coverings are exposed to numerous external factors that affect them, such as direct or indirect exposure of facilities, buildings, and various means of transportation (land, sea, air) to fire. This can lead to the burning of these coverings and the resulting material and human losses due to exposure to the by-products of that combustion, such as smoke and deadly toxic gasses (Delichatsios, 2003).

Fire tests for floor coverings have been given attention during the first decade of this century, as flooring materials can play a fundamental and primary role in the growth and spread of fire (Delichatsios, 2003).

Therefore, producers must subject all floor coverings to fire tests to ensure their compliance with the international fire code according to the applicable standard (Hirschler, 1994).

The occurrence of ignition in carpets involves the appearance of fire products (heat, smoke, and negative products), the impact of fire products on the target.

As much as there was concern about the fire hazard to humans, how can we not know the effect of each, Heat effect, Lack of visibility, Toxicity of Smoke, Smoke Transport, Decay of Smoke Components, the first three points depend on the area and time, and whether the fire involves or will extend to other places, meaning it is not limited. Therefore, both the smoke transfer and the decay of its components are taken into consideration (Buchanan, 2001).

Therefore, there is a hierarchical chain between the heatgenerated by the fire, which causes the ignition of materials, leading to smoke that is considered toxic poisonous gases (ASTM E 1354-02).

Accordingly, the importance of the connection between fire hazards and the presence of numerous properties of fire materials becomes clear, including flammability, flame spread, ease of extinguishment, and the quantities and rates of heat, smoke, and toxic gas emissions (Kennon, 2018).

The current understanding of the phenomenon of fire and its risks has shown that the important issue is obtaining the correct test design to measure the main fire characteristics, taking into account the effects of heat. The best way to estimate fire risks is to assess the actual fire growth rate and the time available before the fire occurs.

Fire tests for floor covering have also undergone a complex history, which is reviewed. Tests for the different products are in various stages of development. It would appear that the fire testing of furnishings and contents in the future will entail mostly finished products and heat release equipment (Govmark, 1982).

A flurry of activity is characterizing the present emphasis on floor covering. Moreover, the majority of the new tests being developed generate results that can be used as input for models to carry out fire hazard or fire risk assessments (Dalton, 1976).

The potential of building materials to contribute to fire growth and spread has led to extensive regulatory control. Various and numerous small-scale tests are used to simulate and characterize flammability, flame spread and smoke production (Blackmore, 2002).

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Recently, the Fire Science and Technology Laboratory at CSIRO conducted an extensive research project into the performance in fire of flooring and floor coverings. Specifically, on an evaluation of four tests that could be used for controlling floor coverings, namely the Cone Calorimeter, the Flooring Radiant Panel (FRP)(Benjamin, 1987), the LIFT Apparatus and the Early Fire Hazard Test (EFH).
The reason behind the test selection was that the first three tests are internationally recognized while the fourth is a valuable, well-documented and validated Australian test that is referred to in the Building Code of Australia. EFH was originally developed to regulate wall lining materials but its use has been extended to regulate almost everything else, including floor coverings. Detailed test measurements in these apparatuses included ignition times in the Cone and EFH, critical heat flux in the Cone, FRP, LIFT and EFH, and rate of heat release and smoke yield in the Cone and EFH (Arlington, 1993) Comparisons of similar parameters were made to investigate consistency of test results within the present regulatory requirements for floor coverings. In addition, prediction of flooring material behaviour in each of these tests based on results from the rest of the tests was explored. Based on this comparison, the significance of each test with regard to providing information for flammability properties of relevance to control of floor coverings is established (Blackmore, 2002)

Experimental (Materials and Methods)

In this research, the method of testing radiant floor panels was relied upon. As it was developed in the mid-1960s and continued to evolve according to a joint program between a company and the National Bureau of Standards (NBS) (Kennon, 2018).
In the early seventies, the concept of the device became clear, which is the spread of flames from the combustion chamber to the corridors. This is considered a very important factor related to flame spread on floor coverings, (Figure 1) showing the fire behaviour of four corridors of the same length. The first corridor requires 2.9 kg/m², the second corridor needs 5.4 kg/m², the third corridor needs 10.7 kg/m², and the fourth corridor needs 13.7 kg/m² (Kilinc, 2013)

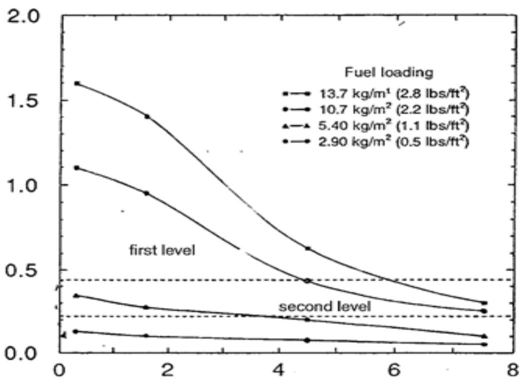

Figure (1): showing the fire behaviour of four corridors of the same length

The test used has evolved, and the process of radiant flux is defined as the level of radiant thermal energy on the surface of floor coverings at the self-extinguishing ignition point, expressed in thermal energy units. The test procedure was conducted by the American Society for Testing and Materials (ASTM) and the National Fire Protection Association (NFPA) (Quincy, 1981) Regulatory authorities have established classification rates for the fire test of floor coverings, and the evaluation regarding the rate of fire spread has been divided into two main categories.
The first level is 45 watts/cm² or more, the second level starts from 22 watts/cm² to 44 watts/cm² (ASTM E-648)
The Carpet and Rug Institute (CIR) has worked with the National Institute of Standards and Technology (NIST) With the National Institute of Standards and Technology (NIST) In order to improve testing procedures.

This method describes a test procedure to measure the critical heat flux of various horizontal floor coverings by exposing them to a radiant heat source, which is the radiant panel, and imposing potential thermal radiation levels when buildings and structures are exposed to direct flame or flammable and rapidly igniting Radiant Flux gases (Bajaj, 2000).

The test chamber is in the form of a structural base on which the horizontal test sample is placed, and the radiant source is at a 30-degree angle to the horizontal test sample (Figure 2).

This method simulates the exposure of corridors and exit ways in important buildings and facilities, where the combustion behavior of floor coverings and their combustion products, including toxic gases and smoke, has been characterized (Enany, 2025).

This test aims to establish regulatory standards for the acceptance of specifications for floor coverings and the items manufactured for them.

This test is a precise measurement of flame spread and is the only one designated for all types of floor coverings. The minimum energy required for ignition is 0.1 watts/cm² and the maximum is 1.1 watts/cm² (ASTM E-648).

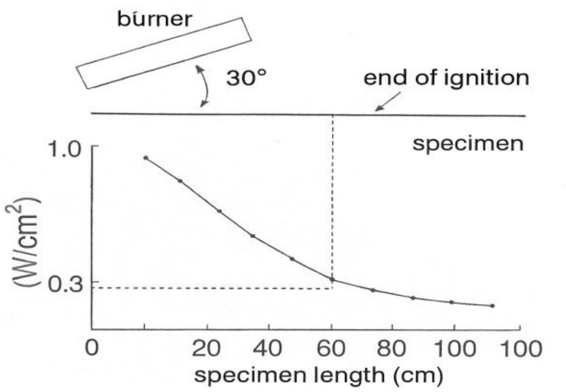

Figure (2): showing curving heat flux

In this study, 15 samples of various pile materials, whether natural (such as wool and cotton), synthetic (such as polypropylene or acrylic), or blended (such as wool and synthetic fibers) as well as the type of carpet backing (such as latex or rubber) and pile thicknesses were tested.

Table (1): Specifications of the samples

Sample Number	Thickness of the pile (mm)	Type of pile material	Comb kit (door/10 cm)	Type of spinning pile yarn	Yarn count	Total sample thickness (mm)
1	4.5	cotton	30	heat set	8/4cotton	5.7
2	8.0	100% Polypropylene	34	BCF	2600 dinars	9.8
3	8.0	80%wool 20%polyester	37	heat set	10/3wool1200tex	10.0
4	10.5	100% Polypropylene	30	heat set	1200tex	12.0
5	6.0	100% Polypropylene	33	BCF	2600 dinars	7.8
6	10	80%wool 20% nylon	32	heat set	10/3wool1200tex	12.7
7	9.0	100%wool	33	heat set	10/3wool	11.0
8	8.0	100%wool	34	heat set	10/4wool	10.7
9	11	100% Acrylic	31	heat set	2600 dinars	13.0
10	8.0	100%Polypropylene	33	BCF	2600 dinars	10.8
11	10.5	100%wool	37	heat set	10/4wool	13.6
12	4.5	100%Polypropylene	32	BCF	1700tex	6.4
13	3.0	100%Polypropylene	34	BCF	6000 dinars	5.3
14	5.0	cotton	35	heat set	10/4cotton	6.3
15	6.0	100%Polypropylene	31	BCF	2600 dinars	8.7

Table (2): Specifications of the samples

Sample Number	Weight /m2 of the pile (gm)	Weight /m2 of the sample (gm)	Type of background	Number of pile rows	Type of the loop for the pile
1	1546	2159	rubber	31	cut
2	691.2	1934	latex	33	cut
3	1936	3345.7	latex	32	cut
4	2272	3254	latex	34	cut
5	525.4	1553	latex	33	cut
6	2603	4110	latex	31	cut
7	1211	2152	latex	32	cut
8	1744.4	3099	latex	33	cut
9	1266.4	3264	latex	33	cut
10	1169	1953	latex	31	cut
11	1056	3578	latex	34	cut
12	815	1500	latex	31	loop
13	553	2210	rubber	25	loop
14	1059	1875	rubber	33	loop
15	1067	1702	latex	30	loop

Preparing test samples

The test samples are taken with an area of 20 x 100 cm and with an additional 5 cm in each direction to ensure proper fitting in the outer frame of the sliding cart of the device (ASTM E-648)

Sample conditioning

The samples are conditioned for 24 hours at a temperature of 21±3, Relative humidity 50±5 % (ASTM E-648).

Procedure

The sliding platform (Plat Form) is placed outside the test chamber and ignited with the Radiant Flux source (Figure 3).

The unit is allowed to preheat for 90 minutes to reach equilibrium. The air is adjusted with the incoming gas to reach a temperature of 500 ± 25°C for the Radiant Flux thermal source (Figure 4).

180±5°C for the test chamber and upon reaching this equilibrium, the test begins by inserting the sliding cart with the test sample into the test chamber after igniting the flame in the pilot burner (Figure 5) so that it is in contact with the surface of the sample for 10 minutes, Readings are taken relative to the burn time every 5 cm along the sample until combustion stops (ASTM E-648).

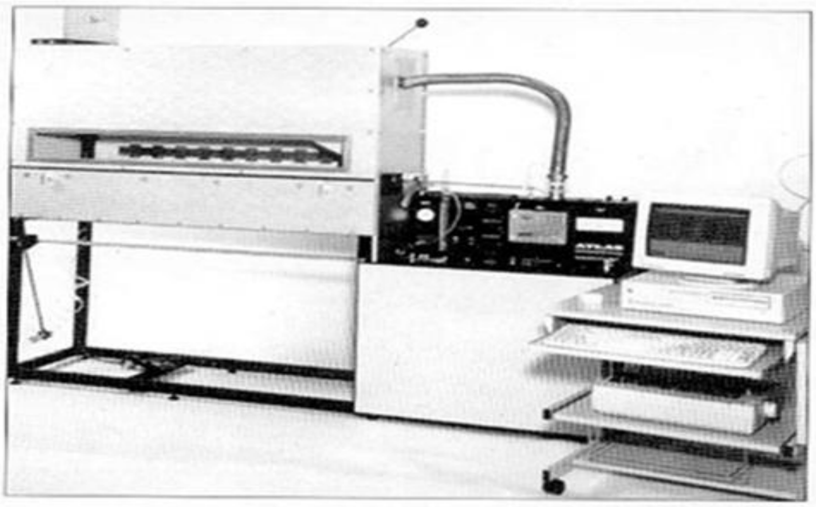

Figure (3): Critical Radiant Flux Device

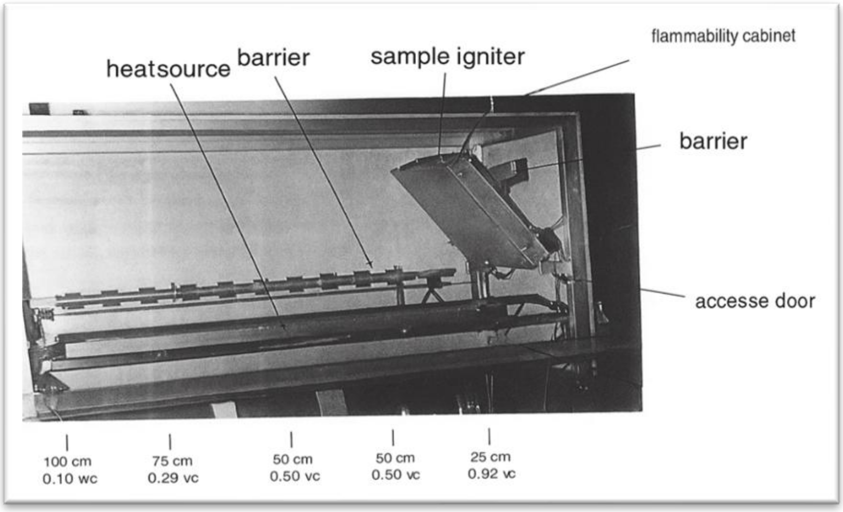

Figure (4): Layout of the test room

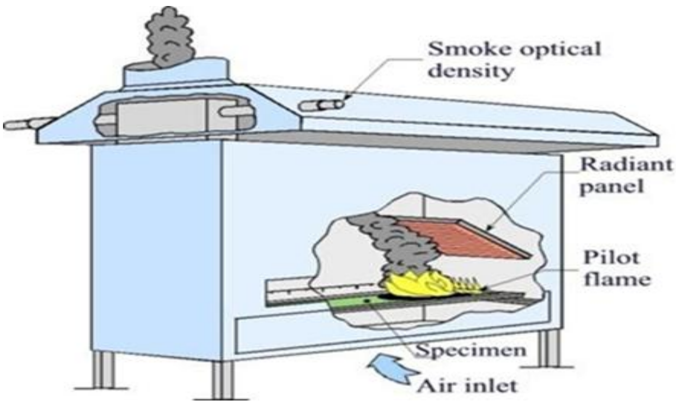

Figure (5): How to ignite the sample

Characterization of the combustion behaviour during testing:

Polypropylene pile

The fibres of the polypropylene first melt, then there is a noticeable rise and bending of the sample, followed by a return to the horizontal position in the first distance of the sample opposite the radiant panel. This melting helps sustain the flame, and with an increase, the amount of flame increases along with the release of dense smoke and suffocating gases. The flame spread rate is high in the first distance, and as one move away from the heat source (panel), the flame spread rate decreases with the continuation of combustion.

Cotton pile

The speed of flame spread very high on the surface of the pile, and then when the flame reaches the backing of the carpet and cotton, no melting occurs if there is a second rubber backing. However, if there is synthetic fiber padding, melting occurs and the flame continues.

Nylon

When nylon is exposed to flames and radiant energy, the fiber material melts and ignites. Initially, the sample curls and bulges on the side facing the radiant panel, and the burned part separates. As we move away from the heat source, the sample's bulging decreases, and the ignition becomes horizontal.

Acrylic

The wool fabric melts, producing a large amount of thick smoke and suffocating gases, but it takes on the appearance of burning wool. The structure of the burning fibers turns black, unlike the burning of other synthetic fibers like polypropylene, and at the end of the fire, it turns into ash (ASH).

Results and Discussion

Table (3): Results of the test

Sample Number	Critical Radiant Flux (CRF) (watts/cm²)	The speed of flame spread (cm /s)
1	0.11	0.562
2	0.11	0.040
3	0.80	0.119
4	0.11	0.019
5	0.11	0.192
6	0.42	0.215
7	0.40	0.217
8	0.96	0.126
9	0.11	0.260
10	0.11	0.030
11	0.84	0.144
12	0.11	0.206
13	0.11	0.101
14	0.11	0.061
15	0.11	0.056

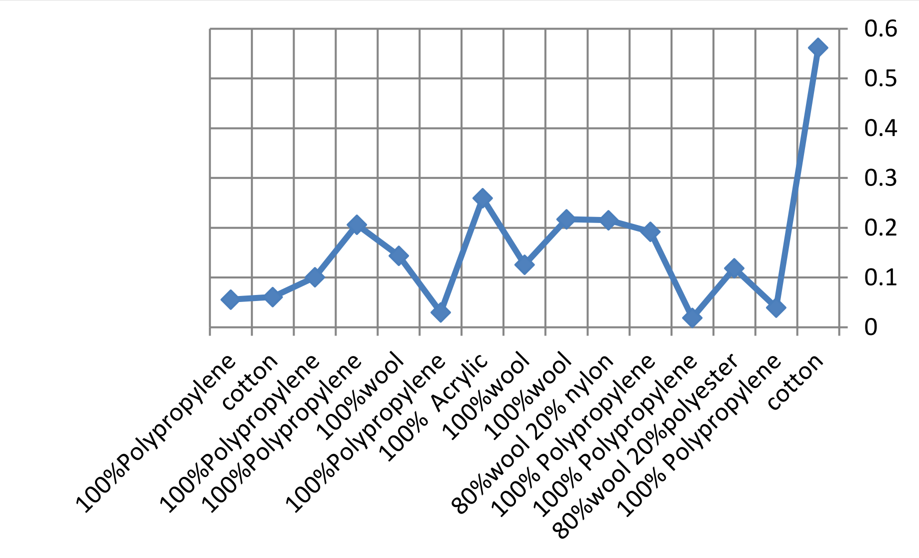

Figure (5): Results The speed of flame spread

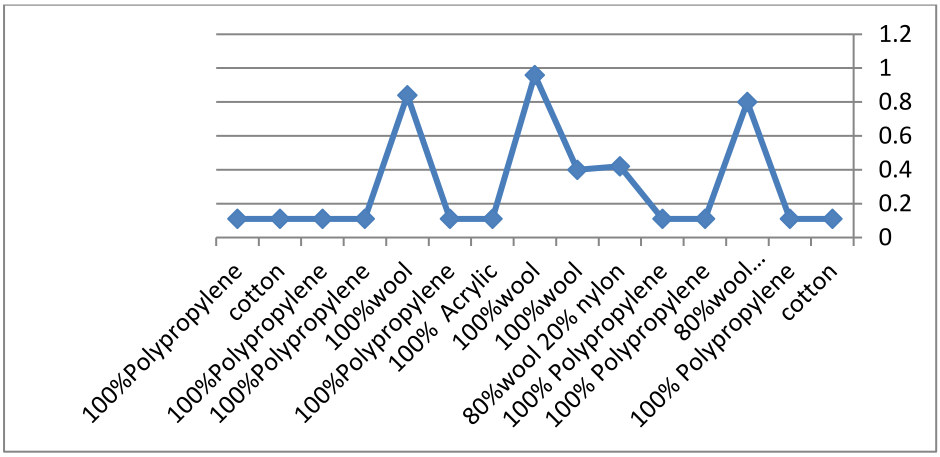

Figure (6): Results of the Critical Radiant Flux (CRF)

As evident from the obtained results, the critical heat flux (CRF) required for ignition of polypropylene, nylon, polyacrylic from (Figure 6) shows that synthetic fibres require a critical heat flux of 0.11 W/cm², which places them outside the classification of both Class I and Class II. Additionally, cotton, being a natural fibre, also requires a critical heat flux of 0.11 W/cm². As for the polypropylene material, with variations in both the fibre thickness and the total sample thickness, the fibre weight per square meter, the sample weight per square meter, and the fibre density per square meter, the critical energy quantity is always 0.11 watts/cm². The notable difference in the results was observed in the 100% wool and blended wool samples, where the critical energy quantities were found to be (0.4 watts/cm², 0.96 watts/cm², 0.84 watts/cm²) for samples number (7, 8, 11) respectively. Meanwhile, the result for sample No. (3), which is 80% wool and 20% polyester, showed a critical energy quantity of 0.80 watts/cm².

Sample number (6), 80% wool and 20% nylon, had a critical energy quantity necessary for ignition of 0.40 watts/cm²

Sample number (8) had the highest critical energy required for ignition, which is attributed to the highest pile density per m² in 100% wool samples. This indicates that with an increase in pile density and a decrease in pile thickness and overall sample thickness, the critical energy amount is greater.

This is due to the reduction in the amount of oxygen present between the pile fibres.

As for blended wool, the amount of critical energy decreases with the increase in combustion distance due to the presence of synthetic fibres (polymer), which helps to increase flammability. Generally, pure wool is classified in the first level, while blended wool falls into the second classification.

And because the radiant panel test for floor coverings is very important in classifying the use of textile floor coverings, it requires that the floor coverings in corridors and care homes in hospitals be classified at level one (0.45 watts/cm² or more).

It is required that the floor coverings in hotel exits and accommodation places be classified at level two (from 0.22 W/cm² to 0.44 W/cm²).

Conclusions

Carpets play a significant role in interior decoration, providing comfort and thermal insulation. However, their combustible nature makes them a potential contributor to rapid fire spread in enclosed spaces, highlighting the importance of assessing their fire performance. To evaluate this, the Radiant Panel Test (ASTM E648 / ISO 9239-1) is widely used, as it effectively simulates real fire conditions and determines the Critical Radiant Flux (CRF), which reflects the carpet's resistance to fire. The results of this test are then used to classify carpets into safety levels, such as Class I or Class II, which are essential for fire safety in public building, In this study, fifteen carpet samples were examined to understand how fibre type and backing material affect fire behaviour. The results showed that carpets made of 100% wool or wool blends met the required safety levels, owing to their ability to self-extinguish after ignition despite rapid initial burning. In contrast, carpets made of 100% synthetic fibres or cotton did not meet the minimum safety requirements, showing CRF values of 0.11 W/cm². Their slightly lower flame spread rate is attributed to the time required for the fibres to melt before ignition.

These findings demonstrate that fibre composition and backing material play a critical role in carpet fire performance, emphasizing the importance of selecting carpets with appropriate fire-resistant properties to enhance safety in public buildings.

Recommendation

1-Fire tests on carpets are essential to protect lives and reduce losses.
2-The application of international standards ensures that the carpets used in public and private buildings have a high level of safety.
3-Relying more on fire-resistant fibres and flame-retardant chemical treatments.

Author Contributions
The authors 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 analysed 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.

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