Hindawi Publishing Corporation
Advances in Materials Science and Engineering
Volume 2015, Article ID 168143, 6 pages
http://dx.doi.org/10.1155/2015/168143

Research Article

Analysis on Thermal Hazard of Foam Decoration Materials

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Received 25 June 2014; Accepted 8 September 2014

Academic Editor: Shoou-Jinn Chang

The occurrence and spread of fire often result from the flammables in interior decoration materials, which mostly contain fireproof foam to avoid fire damage. In this study, the foams with reportedly fire resistance, such as general foam, PU foam, melamine foam, and rubber foam, are compared via thermal gravimetric analysis (TGA), Fourier transform infrared spectroscopy (FTIR), scanning electron microscopy (SEM), and energy dispersive spectroscopy (EDS) analysis to build a thermal parameter database of decoration materials of fireproof foams and provide green building materials, technologies, and fire preventive measures to the industry or consumers.

1. Introduction

In recent years, many major nightclub fire accidents occurred internationally, such as Taiwan Taichung Municipal ALA Pub fire on March 11, 2011; dancer's performance caused a fire; the fireworks let off on the stage caused a fire on the foam above the stage, 9 died and more than 12 injured [1]. There are many R&D and experimental techniques to enhance analysis on the wreckage of decoration materials after a fire. However, for investigation on the cause of a fire, the most important job is to collect clues afterwards and complete the reconstruction of the fire scene to determine the process of occurrence and spread.

For decorative materials fixed on ceilings, walls, and floors, such as artificial boards, furniture, and cabinets, the "CNS 14705 testing method for combustion heat release rate of construction materials—cone calorimeter method"—is used domestically as the basis for classification of flammability of aforementioned materials, while for flame resistance of carpets, window curtains, cloth curtains, advertisement display board, and other items specified in Item 1, Article 11 of Fire Control Law, the "testing basis of flame resistance," is used as the determination criteria for flame resistance. For the aforementioned fixed decoration materials and hanging flameproof items, effective fire preventive management is available gradually. However, for adhesive and other nonfixed interior decoration materials, such as acoustic insulating foam, wall paper, and wall covering, no associated regulations or material testing standards are available at present, leaving a loophole in fire prevention and safety management on nonfixed interior decoration materials. In response to the international trend, the Bureau of Standards, Metrology and Inspection, by referring to ISO 5660, announces the purpose of "CNS 14705 testing method for combustion heat release rate of construction materials—cone calorimeter method," which is widely used to explore the combustion performance of materials in the fully developed stage, where the heat release rate and total heat release are used to evaluate the fireproof performance of materials, and the smoke density, carbon monoxide, and carbon dioxide concentrations are used as the references of smokiness and toxicity. However, the current CNS 14705 method is applicable for the classification and combustion test of flame resistant materials; as for non-flame resistant building materials, such as foam decoration materials and double-sided plastic tapes, due to fast burning, surface irregularities, and other factors, it is unable to meet burning time, specimen size, and other test conditions, and thus it is impossible to measure the associated combustion parameters.

For this reason, a better package of material testing methods and processes should be developed for the current nonfixed interior decoration materials. In this study, a range of materials is analyzed with a thermogravimetric analyzer (TGA) aiming at foam decoration materials for the parameters of thermodynamics, thermal reaction, and related material properties at a rate of temperature rise, where the functional groups of these flameproof polymers are analyzed with a Fourier transform infrared spectroscopy (FTIR), the surface configuration of microstructure is observed with a scanning electron microscope (SEM), and the constituent elements and ratios are explored with an energy dispersive spectrometer (EDS). These analyses help us to under fireproof foams by getting the results of the combustion reaction parameters, heat reaction parameters, smoke measurement parameters, and other reaction parameters of thermal experiments of the foam decoration materials with different properties and to select correct materials through the scientific experimental data. In addition, it is very important to provide a fire dynamics simulation (FDS) to simulate parameter applications and to explore the cause of fire via scene reproduction, that is, the time for evacuation and fire safety measures, in order to enhance the accuracy and reliability of fire simulation technology.

Purpose of this study is as follows.

(1) With the help of the TGA, FTIR, and other devices, we obtain the combustion property parameters, heat reaction parameters, smoke measurement parameters, and so forth of acoustic insulating foams commonly used as building materials domestically and establish a preliminary systematic database, identify the advantages and disadvantages of these compounds, and select the samples appropriate for the needs of the environment to enhance the fire resistance of foams.

(2) The combustion parameters of thermal analysis experiments are taken as the input for computer-aided fire simulation analysis to improve the accuracy of localized computer simulation technology, time for evacuation, and fire safety measures.

2. Materials and Methods

The experimental materials of this study will refer to "Giving priority to promotion of application for fireproof regulations and planned experimental study (July 2011) at Class B1 and other entertainment places" initiated by Ming-ju Tsai, researcher of Architecture and Building Research Institute, Ministry of the Interior (ABRI), for the full-scale fire burning test, which was originated from the fire occurring at Taichung ALA Pub when a spark ignited the acoustic insulating foam fixed to the walls and ceiling, causing heavy casualties in fast fire spread and smoke emission. The experimental results are analyzed by comparing general foams with FRB (melamine board) which complies with flameproof performance testing (CNS 10285) Class 1. The thermal analysis is to study the relationship between the physical or chemical changes and temperatures under temperature-controlled conditions. Its measurement tools for research on basic material properties are widely applied. The most commonly used methods are thermal gravimetric analysis (TGA) and differential scanning calorimetry (DSC). A series of thermal analysis tests are carried out for the foam materials (four kinds) to get the parameters of thermodynamics, heat reaction, and associated material properties at the rate of temperature rise.

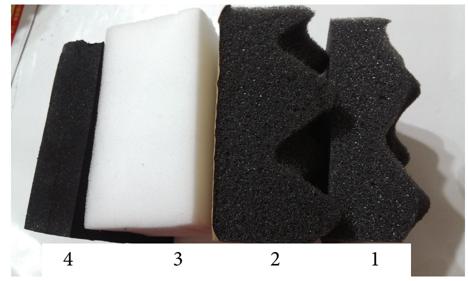

Figure 1: Foam experimental material.

2.1. Material Sample. Figure 1 shows the experimental sample of the fireproof foam used in this study refers to the report of "Giving priority to promotion of application for fireproof regulations and planned experimental study (July 2011) at Class B1 and other entertainment places" initiated by Ming-ju Tsai at ABRI on July 2011. This study refers to the four kinds of comparable fireproof foams in [1], regarding flame resistance and flame proofness (Table 1), market price, type, and thickness (Table 2), and then a series of thermal analysis tests are carried out on the four kinds for the parameters of thermodynamics, thermal reaction, and related material properties at a rate of temperature rise.

3. Results and Discussion

Figure 2 shows the foam with PU as the main body generally has a porosity (samples 1 and 2). During cross-linking and condensation, gases, liquids, or solids which do not participate in the reaction are added to occupy a certain amount of room in the mixed polymer solution and are removed upon completion of the reaction to produce a porous polymer foam material. The two kinds of polymers immiscible with each other have a relationship of compatible permission, and once the content of the added additive exceeds the critical point at which the polymers are compatible, island phenomenon appears with "nodules" on the bubble wall, resulting in unevenly dispersed polymers and intensifies with the increase in additive. Its foam material has a reticular structure with high porosity. It is soft and flexible absorbent foam when it is wet and tough and impact resistant hard foam when it is dry. The properties of these PU can be obtained from [2], where the pore structure contains a cell window. A similar discussion by Strut and Strut joint is also available [3].

The Al-containing additive is also discussed in [4], which forms cellulose materials [5] (sample 4 in Table 1) after reaction with oxygen. The Zn-containing one is usually the thermal-resistant hydrate ZnO-H_2O (sample 4), with similar

TABLE 1: Summary of flame proofness and flame resistance of foam.

Number	Model	Flame proofness		Flame resistance	
1	General foam	Total heat release rate (MJ/M2)	1.5	Remained flaming time (second)	0
				Remained burning time (second)	0
		Duration (second) of maximum heat release over 200 KW/M2	Over 10 seconds without persistence	Charring distance (CM)	7
				Charring area (CM2)	28
		Harmful cracks and cavities on the back throughout the nonfireproof items	Burned to ashes	With dissolved drip	Without dissolved drip
		Class		Class	Class 1
2	FRA (PU foam)	Total heat release rate (MJ/M2)	13.5	Remained flaming time (second)	0
				Remained burning time (second)	0
		Duration (second) of maximum heat release over 200 KW/M2	27	Charring distance (CM)	29
				Charring area (CM2)	325
		Harmful cracks and cavities on the back throughout the nonfireproof items	Burned to ashes	With dissolved drip	Without dissolved drip
		Class	Outside the class	Class	Outside the class
3	FRB (melamine white)	Total heat release rate (MJ/M2)	15.7	Remained flaming time (second)	0
				Remained burning time (second)	0
		Duration (second) of maximum heat release over 200 KW/M2	Over 10 seconds without persistence	Charring distance (CM)	6
				Charring area (CM2)	27
		Harmful cracks and cavities on the back throughout the nonfireproof items	Burned to ashes	With dissolved drip	Without dissolved drip
		Class	Outside the class	Class	Class 1
4	FRC (CR 25 degrees rubbers)	Total heat release rate (MJ/M2)	12.6	Remained flaming time (second)	0
				Remained burning time (second)	0
		Duration (second) of maximum heat release over 200 KW/M2	29	Charring distance (CM)	11
				Charring area (CM2)	44
		Harmful cracks and cavities on the back throughout the nonfireproof items	Burned to ashes	With dissolved drip	Without dissolved drip
		Class	Outside the class	Class	Class 2

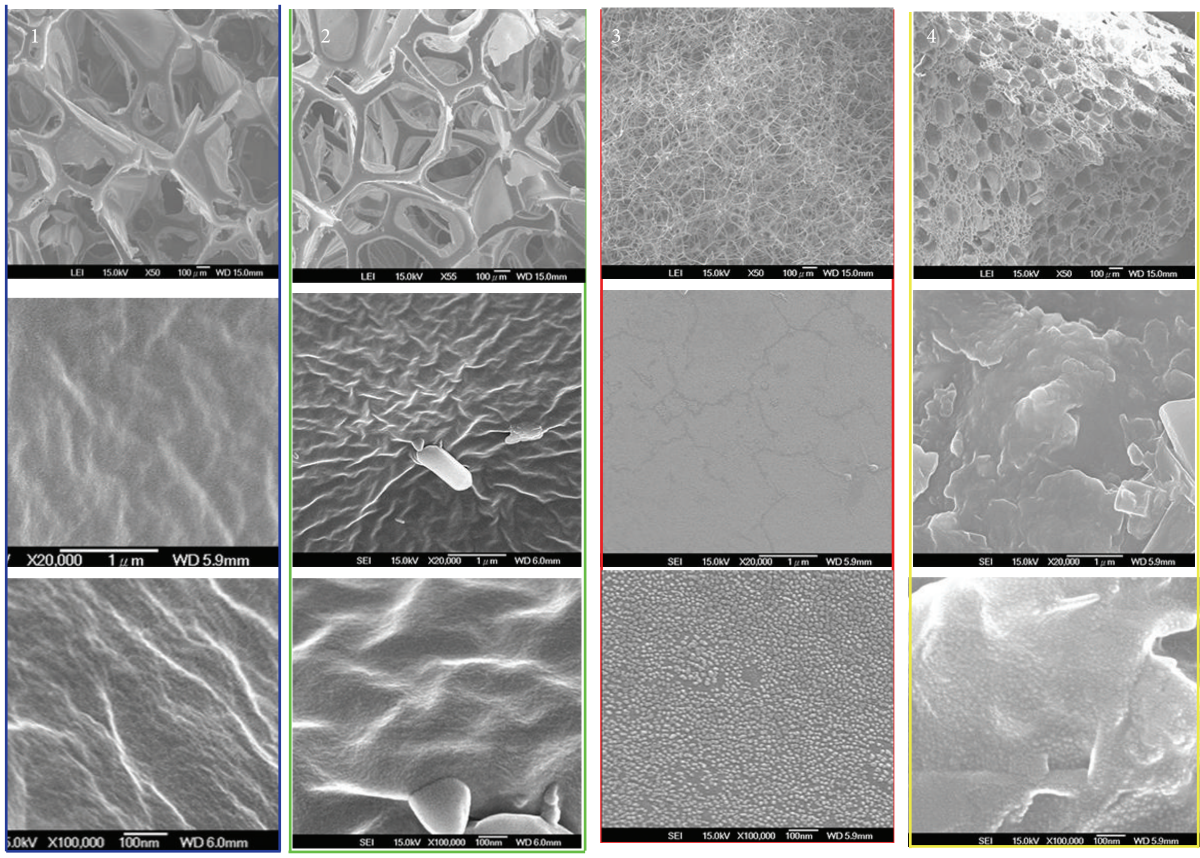

Figure 2: Surface configuration of different fireproof foams in magnifications of 50, 20000, and 100000.

Table 2: Foam types.

Number	Type	Color
1	General foam	Blue
2	FRA (PU foam)	Green
3	FRB (melamine white)	Red
4	FRC (CR 25 rubber)	Yellow

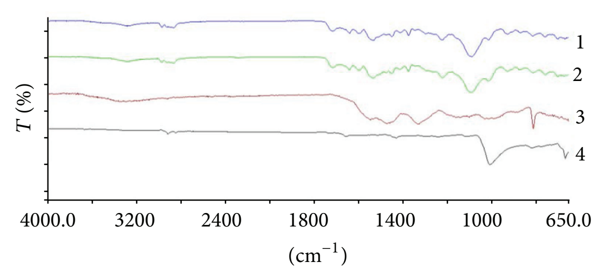

Figure 3: Infrared spectroscopy of different fireproof foams.

results coming from [6]. The N-containing complex (sample 3) is easily produced due to UV light-induced chemical reaction, so that the nitrogen atom adjacent to a benzene ring becomes vulnerable, even yellowing to impair physical properties.

The polymers containing the functional groups such as –CO–, –COO–, –CONH–, –S–, $–SO_2–$, –O–, $–[CF_2]–$, and $–[C(CF_3)_2]–$ can increase the stability. Figure 3 shows the FTIR wavelength at 3670 cm^{-1} and 1031 cm^{-1} are the derived wavelength of Si–OH and Si–O bond; however, due to the different proportions of Si in samples 1 and 4 with composite concentrations, there are strong and weak ones, where sample 4 contains a higher proportion of Si (as shown in Table 3). The NCH wavelength occurs at 1520 cm^{-1} indicating the presence of amide (amide bond), without synthesized foam via modification. At the high frequency of 3330 cm^{-1}, there is a slightly wide moderate absorption peak, which resulted from hydrogen bonding generated from the secondary amine (N–H) and other oxygen-containing functional groups, with apparent free NH peak, indicating that the synthesized nonpolar foam has a relatively low phase separation, as shown in sample 3.

Also at 1700–1800 cm^{-1}, a distinct peak is found (samples 1 and 2), while the unmodified PU may be less distinct. This is where C=O is located. At 1704 cm^{-1}, it is the C=O affected by hydrogen bond, while the one on the left is free C=O, located at 1735 cm^{-1}. It is found from the figure that, with the increase in modified content, the absorption intensity of free C=O will be more apparent.

Table 3: EDS composition analysis on different fireproof foams.

	Energy dispersive spectrometer (EDS) %										
	C	O	Si	Ca	P	Ci	N	S	Mg	Ai	Zn
1	62.83	34.85	1.21	1.11							
2	68.87	26.97			0.77	3.39					
3	36.60	12.40					48.3	1.53			
4		39.07	11.7	4.36		30.13		3.99	7.53	0.85	2.37

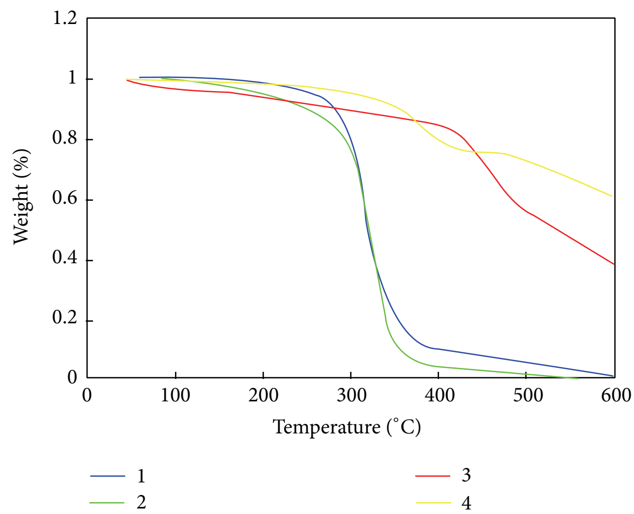

Figure 4: Thermal weight loss of different fireproof foams (TGA).

There are also similar reports on a single sample in nitrogen and atmosphere [7], where Figure 4 shows the metal-containing compounds have a higher thermal decomposition temperature. Therefore, when it reaches 600°C, the proportion of weight loss is limited only to those with relatively low molecular weight since it has not reached its boiling point (typically over one thousand degrees, such as SiO_x and MgO); while the polymer with higher proportion has poor heat resistance, the material will lose more than a half around 350°C (such as samples 1 and 2).

Figure 5 shows the TGA results of different kinds of foams. Since most of them belong to the hybrid structure of polymers and inorganic materials, their Tg points are not obvious, while the peaks of endothermic and exothermic reactions generated by other crystalline are not as sharp as pure substances due to integrated thermal reaction of different substances but have a widespread phenomenon. As shown in sample 4, when silica content increases, the coefficient of thermal expansion decreases; the silica with functional groups can be effectively bonded to polymers to improve the interface force, thereby having a good thermal stability by inhibiting movement of segments when the material is heated. In sample 1, due to higher polymer content, it has a poorer thermal stability than the sample. Therefore, the force between the substrate and the filler has a great influence on the properties of the composite material, and strengthening the bonding between the substrate and the inorganic material is the key to enhance the performance of the material.

4. Conclusion

By investigating the characteristics of a series of fireproof foams to find out the advantages and disadvantages of these complexes, it is possible to select appropriate samples to meet the need of the environment to enhance the fire resistance of foams. It is possible to measure many different kinds of materials via thermal analysis to get the relationship between physical and chemical properties and temperature or heat and to quantitatively determine changes in weight and temperature, which is often used to detect thermal decomposition temperature of a material to explore the characteristics of a series of fireproof foams; therefore, the thermal hazard analysis on the material should be concerned about when applied to interior decoration materials. General foams and those flammable foams, in addition to the flammable hazard, can burn and spread quickly and it is easy for them to produce heavy smoke and toxic gases. They should be inspected and used safely. We carry out a simulation analysis on the parameters available from the experiments of fireproof foam decoration materials of this study with proper use of FDS computer simulation technology to create a new fire simulation scenarios and determine in advance the simulation scenarios generated by a variety of materials in case of fire as a preventive test, so that we cannot only reduce the severity of the fire occurred, but also prevent in advance a variety of the unexpected situations and reduce fire risk and danger.

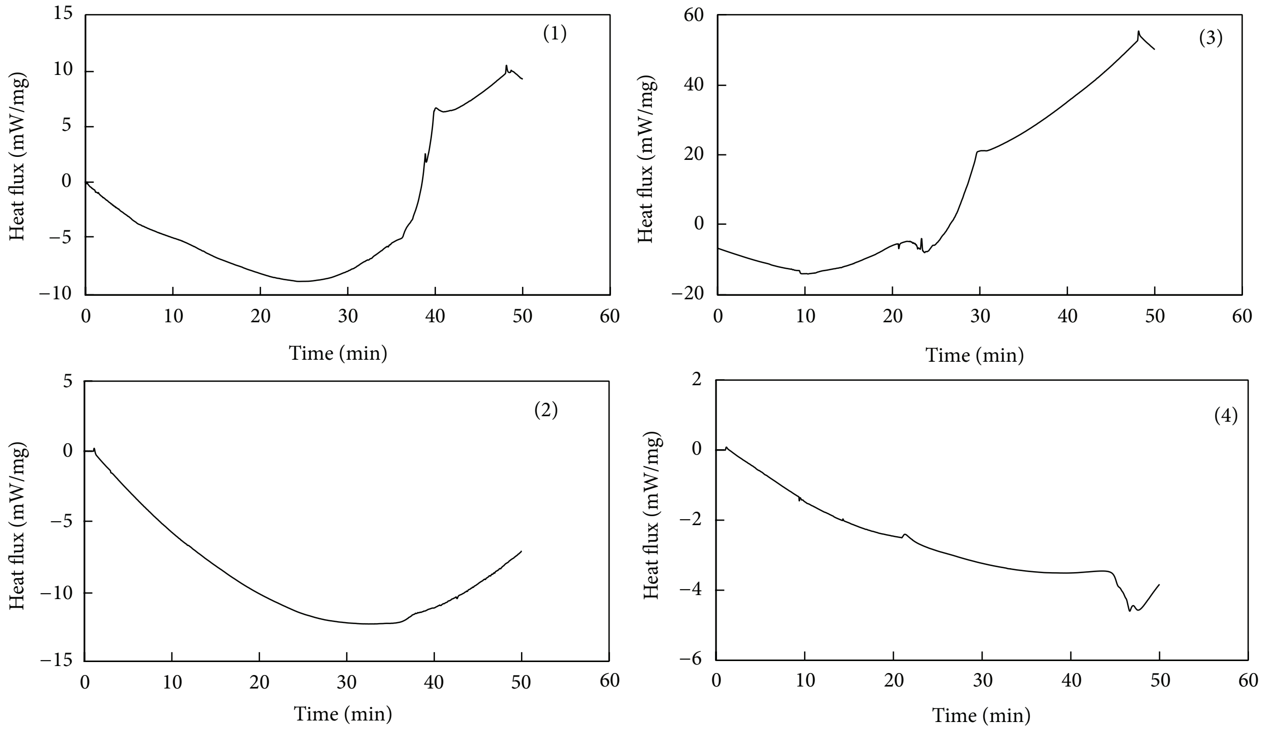

FIGURE 5: Thermal phenomena of four different types of fireproof foams by differential scanning calorimetry (DSC).

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

Acknowledgment

This paper refers to the related research findings by courtesy of Ming-ju Tsai, the researcher of Architecture and Building Research Institute, Ministry of the Interior (ABRI), who promoted initially the application for fireproof regulations and planned experimental study (July 2011) at Class B1 and other entertainment places. The authors would like to express their sincere and deepest gratitude to him.

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