FIRE SAFE FURNITURE

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ABSTRACT

Many big building fires were observed to be correlated with furniture. It is necessary to develop fire safe furniture to reduce the probable fire damage. The relevant factors about fire safety of furniture and methods for designing fire-safe furniture will be discussed in this paper.

1. INTRODUCTION

Furniture is highly related to our daily life. Furnishings have been found playing a major role in the growth and spreading of accidental fires, no matter they are direct or indirect fuel. Upholstered furniture is more likely to cause death than other categories [1].

To prevent or reduce furniture fires, many regulations and standards have been worked out. Furniture materials should pass some specified ignition tests such as the regulation 1988 No.1324 of UK [2] and Consumer Protection Circular 1/1999 of Hong Kong [3]. Besides ignition test, heat release rate (HRR) test is required for California TB 133 [4] and Life Safety Code (NFPA 101) [5] of USA.

However, requirements in such test are not sufficient. As shown in Fig. 1, even if the ignition time of a furniture material is longer, there might be great damage afterward. While for items A shown in Fig. 2, the alarming time is short with a higher HRR, but it might cause a lower damage than item B.

The tenability HRR is important for giving available escape time τ [6]. Even when a flame cannot be seen, the furniture materials might be in smoldering [7] such as item C in Fig. 2. This might produce more toxic gases and give more damages.

Fire phenomena and the conditions of using furniture are very complex. The safety of furniture should not be evaluated only by a simple factor. Fire safe furniture should not be easily ignited and give low potential hazard to life safety and ambient items. Thermal and toxic hazards are key factors and should be considered together. Appropriate experiments and relevant knowledge are useful and important. Key aspects affecting the fire safe furniture are the thermal properties of furniture materials, fire retardant, fire load, smoke toxicity, furniture geometry and configuration.

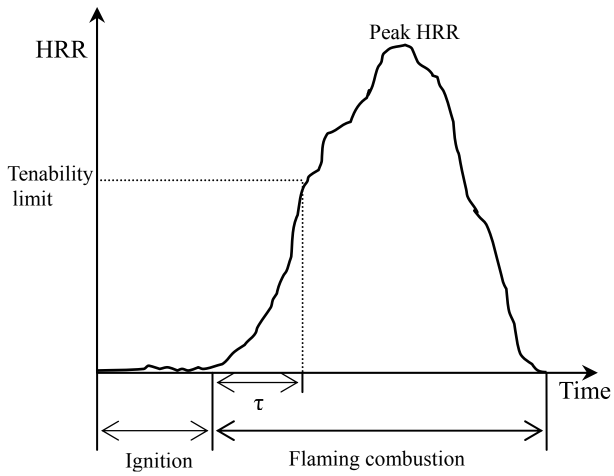

Fig. 1: Typical burning behavior of an furniture item

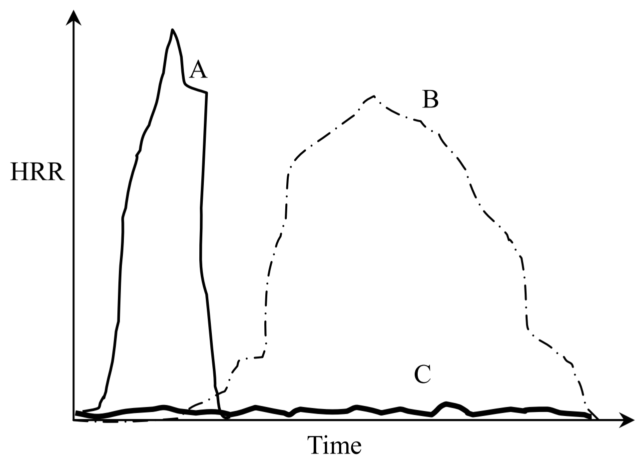

Fig. 2: HRR comparison for different furniture items

2. THERMAL PROPERTIES OF FURNITURE MATERIALS

Fire behaviors of common furniture items are important. There are some similarities between different components of furniture. Most cover fabrics are cellulosic or thermoplastic. Cellulosic fabrics include cotton and cotton derivatives like rayon. Thermoplastics are synthetic fibers such as nylon, polyester and acrylic. Both cellulosic and thermoplastic fabrics burn readily. Cellulosic fabrics are more likely to have smoldering combustion, and thermoplastics are more prone to flaming ignition. A piece of burning furniture, particularly sofa or cushion foam, was observed to be a common starting point of fire. Heat released might then be strong enough to ignite adjacent items such as wood partition walls, floor coverings and some other furniture which are not easy to ignite by electrical faults or cigarettes. The effect of this starting fire on adjacent combustibles is obvious.

Heat release rate is the most important parameter in fire safety engineering. But two scenarios have to be distinguished: one is lower heat release rate with long burning time; another is higher heat release rate but short duration of burning.

Analysis of thermal effects includes a threshold injury value and the exposure time required to reach the threshold for the scenario being considered. Injury can result from exposure to thermal radiation from either flames or heated gases. Properties of furniture materials, such as ignitability, flame spread and heat release rate are important [8].

Protection against ignition for the upholstered furniture would change the possible scenario. As heat flux from a flaming heat source is critical to ignite them, it is reasonable to classify all items to three classes as: easy, normal and hard, the benchmark values as 10, 20 and 40 kWm^{-2} respectively. Heat release rate has been taken as one of the most important parameters. It is important to understand the heat release rate of burning furniture materials and its contribution to a compartment fire. All the test standards should be used appropriately based on the practical requirements.

3. TOXICITY

Among those potential danger factors of fires, smoke toxicity has been claimed to be the dominant cause of residential fire deaths. About half of the accidental fire fatalities were due to the inhalation of smoke and toxic gases, not due to burns [9]. Therefore, toxicity is a very important topic of fire science and should not be overlooked in designing fire safe furniture. Toxic effects result from inhalation exposure to products of combustion. The general effects on humans include reduced decision-making ability and impaired mobility, leading to incapacitation or death. Carbon monoxide and hydrogen cyanide are the predominant toxicants found among over a hundred gaseous combustion products [10].

Burning furniture may produce a great amount of highly toxic gases. The quantity of toxic gases produced depends very strongly on the processes of ignition, smoldering, flame spread, heat release rate, and the chemical composition of the burning materials. Natural materials commonly used in furniture include wood, cotton, and wool. With the rapid development of material science, more synthetic materials are used as structural components and decorative panels of furniture. Nylons and polyurethane foams are good examples. As two major toxicants, carbon monoxide is always present in fires, while hydrogen cyanide will present in high concentration when nitrogen-containing materials such as acrylics, nylon, polyurethane foams, or wool are burned [1]. This explains why more smoke-related casualties were reported.

Smoldering fires may yield a substantially higher conversion of a fuel to toxic compounds than flaming fire. Because of the complex structure and diversified materials used, upholstered furniture may give smoldering fires easily. Experiences show that smoldering transfers easily form cigarettes to medium and heavy weight cellulosic and acrylic fabrics, and then to many commercial padding materials, especially cotton, cotton blend batting, and polyurethane foam.

Further, with so many fire retardants being used, their toxicity upon burning should be tested. The toxicity hazard of fire retardant has been recognized in recent years. Non-commercial fire retarded rigid polyurethane foam produce an unusual toxic combustion product [11]. Toxicity of fire retardant materials was enforced by US consumer Product Safety Commission (CPSC) [1]. The trend of fire safe furniture should be focused on design materials which would produce less toxicants on burning but can stand significant temperature changes.

4. FIRE RETARDANT

To minimize the damage of fire, it is necessary to increase the fire endurance of furniture materials. Commonly used materials, such as wood, polyurethane foam, fabric and other products, should be treated with fire retardant. For example, an effective insulative layer reducing the rate of charring may be formed for wood. Fire retardant, primarily for protecting cellulose-based products, has been widely used in furnishings. The fire retardant can be applied coating or treatment used to reduce the flammability of a combustible material. Coatings may suppress flame spread or to create a non-combustible surface. Other advantages are cost-saving, and easy to apply without weakening the substrate. In UK, compulsory effort has been made on reducing the flammability of furniture and fire retardant foams since 1992.

Whether a fire-retardant coating is effective or not depends upon a number of factors such as the coating thickness and durability under fire exposure. A coating may delay ignition of the substrate for just a few minutes. Because of its vulnerability to damage, the life expectancy of coating is short. Coating solely cannot solve all the problems. The amount of coating applied and whether it can cover up the whole surface are important. The flammability of the original surface to be protected and the severity of an exposing fire are more difficult to manage. In some cases, the use of fire retardant may increase the amount of smoke and toxic gases produced by combustion. Therefore, new fire-retardant materials for furniture should be developed to protect substances which are easy to ignite.

5. FIRE LOAD

Fire load will contribute to the fire length and the severity of fire damage. In the majority of fires, hazards are due to fires occurring in enclosed spaces. If a building fire is well-ventilated, it is easy to control and extinguish a fire at the early stage. However, if the fire is allowed to grow, especially with limited enclosure ventilation and large material surface area, the fire would become ventilation-controlled and thus lead to flashover if there is sufficient fire load.

Decreasing the fire load of upholstered furniture may lead to reduction in fire load for a room, such that it is insufficient to lead to flashover. The fuel elements affecting the fire behavior of upholstered furniture are the cover fabric, the seat cushion material, and the padding material. The interaction of these fuels during combustion is a function of the material composition, thickness, and density. Furniture made by materials with less fuel load should be designed. Effort should be put to minimize the amount of furniture or maximize the room space to reduce the proportion of fuel load to room space. Materials with less fuel load should be designed to substitute or partially substitute the existing components of furniture. For example, some parts of the furniture can be made with lower combustion heat materials.

6. FURNITURE GEOMETRY AND CONFIGURATION

Geometry and configuration of the furniture and its ambient would affect the fire behavior of furniture. Certain design may slow down the fire development, while certain design can produce more rapid fire development. There are many design styles and features in the market. However, some similarities exist in the construction of chairs and sofas, which are far more significant in determining their fire behaviors. For any composite of fabric and padding materials, cigarette ignition resistance is better in flat areas than in crevices. The seats, backs and arms are perpendicular to each other. This may enhance radiant heat transfer which promotes flaming ignition and accelerates burning rates. Similarly, the crevices formed at the intersection of backs, seats, and arms promote smoldering ignition. It has been reported that chairs without armrests show lower peak heat release rate and slower fire development rates.

Further, the air space between the back padding and the rear fabric panel, and the air space within the decking would affect fire development by providing preferential pathways for flame spread within an item of furniture [1]. Because melting seat materials may form a pool fire under the chair soon after ignition, it is also recommended to use panel-mounting rather than webbing to support chair cushioning, which may reduce the tendency to pool burning and cause a major reduction of fire hazard [6].

7. EXPERIMENTAL RESEARCH

Without knowing the fire behavior of common furniture and their constituent materials, it is difficult to establish scientific standards used to develop fire safe furniture, and convince the citizens that the furniture can really give fire safety. Appropriate test methods together with modeling and correlation formulae should be used to determine whether an item of upholstered furniture meets certain requirements of fire safety. The sustained ignition time, heat release rate, mass loss rate, smoke release and toxic gases yielded should all be measured. Data obtained from full-scale and small-scale tests can be used for assessing the possibility to flashover and making re-commendations on what should be considered in selecting furniture.

Both full-scale and small-scale test apparatus are useful. Full-scale burning test is used in testing real size furniture in a certain scenario. However, it is not practical to do it in a routine basis because of the complicity and cost. It is now possible to use the information gained in small-scale tests to predict the behavior of furniture on full-scale experiments through correlation expressions or mathematical models. Cone calorimeter, a bench-scale apparatus, is proved to be very useful in measuring composites or individual components of furniture. Room fire tests are necessary for comparative studies of the influence of the room on the burning furniture and to assess the accuracy of the test method. For each test, well-controlled conditions should be kept. Repeatable and reproducible results should be measured.

Although the emphasis of fire related tests have changed from the cigarette ignition resistance of various upholstery materials composites to flame ignition resistance and post-ignition behavior in assessing the hazard of upholstered furniture, to gain more accurate information, the tests conducted should reveal both the furniture's post-ignition behavior and ignition resistance, either in flame mode or non-flame mode. Further, tests on toxic gases released should not be underestimated.

A full-scale burning facility, known as the PolyU/HEU Assembly Calorimeter, was built in the remote area of China. This is a collaboration project between the Area of Strength: Fire Safety Engineering of The Hong Kong Polytechnic University (PolyU) and The Harbin Engineering University (HEU). There, many full-scale fire tests on furniture had been carried out. The theory basis on measuring the heat release rate has been improved based on the oxygen consumption method.

Moreover, quite a few fire tests had been carried out in the cone calorimeter [12]. Many useful data on furniture materials have been extracted.

8. CONCLUSIONS

Thermal properties of furniture materials, toxicity of combustion products, presence of fire retardant, total combustible mass, geometric configuration of furniture and their applied conditions are all important aspects related to the safety of furniture.

It is not sufficient to assess the safety of furniture only by passing ignition test. Furniture which is not so easy to ignite does not imply a lower fire risk. They might give more severe hazard in real fire. Materials passed the cigarette ignition test might be ignited by flame easily. Although the covering of the furniture is fire retardant, it might burn once the covering is destroyed and result in severe hazard. The larger ignition sources and other ambient conditions should be assessed together.

The heat release rate of burning the furniture items under thermal radiation should be considered as a whole. High peak heat release rate but short burning duration might cause little damage. Fire load or total heat release of furniture is also important for assessing the hazard of furniture fire.

Furniture fire might produce toxic gases, the toxicity effect of furniture materials should be considered. Although many materials have been proved to be more toxic for smoldering fire, some studies [11] have shown that combustion products generated from rigid polyurethane foam in the flaming fire appeared to be more toxic than those produced in the non-flaming mode. Fire patterns of the furniture materials should be considered.

Studying the material properties only is not good enough to improve the fire behaviors of furniture. Fire safe furniture should consider all the relevant factors.

More experiments should be carried out to investigate the fire behavior. Besides toxicity of combustion products and the thermal properties of furniture items such as heat release rate, other relevant aspects should be tested to give a better evaluation. The measurement technology and relevant theories should be duly updated. Fire model will be a useful tool if it can be appropriately used with experimental data.

No furniture is absolutely safe, and fire safe furniture can only be safe to a certain degree. Regulations should be adopted according to practical requirements.

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