Fire Safety Journal 80 (2016) 38–45

Contents lists available at ScienceDirect

Fire Safety Journal

journal homepage: www.elsevier.com/locate/firesaf

A study on the fire extinguishing characteristics of deep-seated fires using the scale model experiment

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ARTICLE INFO

Article history:
Received 17 November 2014
Received in revised form
28 November 2015
Accepted 9 January 2016
Available online 1 February 2016

Keywords:
Scale model experiment
Penetration performance
Extinguishing performance
Deep-seated fire
Wetting agent

ABSTRACT

NFPA 18 is used as a standard for the performance evaluation of wetting agents used in fire fighting. The performance evaluation of the wetting agent involves three tests: a wood crib fire test, a deep-seated fire test, and a wood fiberboard penetration test. In this study, a scale model experimental device, which can evaluate both extinguishing performance and penetration performance at once, was prepared to evaluate the performance of a wetting agent in various types of porous materials. Then, this result was compared with the results of an NFPA 18 test to validate the result of the novel test. Three types of commercial fire-fighting solutions and water were used as extinguishing agents in the experiment. The experimental materials used in this performance evaluation were wood crib which is used in the existing class A fire test and wood flour from New Zealand pine trees which has 75% of the domestic market share in wood cribs. The discrimination of the study result used in this study to determine penetration and extinguishing performances was found to be equivalent to the results of the NFPA18 test. Moreover, the study established the validity of the scale model that could check on both penetration and extinguishing performance, permitting a more economical and efficient performance evaluation of wetting agents.

1. Introduction

In the case of a deep-seated fire in a wooden building or in a space loaded with porous materials, high temperature could be transmitted into the depths of the structure, in turn increasing the amount of combustion. A deep-seated fire refers to the smoldering status where contact with air is limited so no ignition is possible [1,2]. The incomplete combustion rate of a heat source is much higher in a deep seated fire as compare to a surface fire, which causes a high percentage of fuel to be converted into toxic compounds. In addition, a deep-seated fire cannot be easily detected [3,4]. Because liquid extinguishing agents cannot penetrate far below the surface, deep-seated fires have a risk of re-ignition if they contact air later. Moreover, because a heat source for a deep-seated fire cools down slowly, the penetration performance and internal residence period of the extinguishing agent must be outstanding [5]. Due to these aspects of a deep-seated fire, there is a growing demand for a wetting agent that is effective on a deep-seated fire in a porous material as well as a method for evaluation of the penetration and extinguishing performances of a wetting agent.

For this, Popovicha et al. investigated the effect of physical and chemical properties of the wet liquid on compressed carbon black and silica powders. They found that a change in the fine structure, caused by wetting, is a significant factor for the diffusion of the liquid and that the diffusion is also related to the viscosity of the wet liquid [6]. Lazghab et al. investigated various methods reported in the literature to evaluate the degree of wetting of solid powder and reported their strength and weakness. Their findings have been used to develop a proper method to collect study data as well as the specifications of a system used in this study [7]. To study a scale fire, Chattaway et al. developed an experimental device, which scaled down to a full-scale fire experiment using a wood crib and conducted a fire extinguishing performance evaluation. They succeeded in validating this setup using this experiment conducted with the aforementioned device [8]. In addition to these studies, there are continuous efforts on the study of a deep-seated fire and its transmission speed and extinguishing of a deep-seated fire [9–11]. The previous study was conducted by separating the penetration and extinguishing performance of the wetting agent in a porous material. However, there is no ongoing study on the complex fire extinguishing property; a correlation between penetration and extinguishing performance.

NFPA 18 evaluates the performance of the wetting agent through three independent tests [12]. The wood crib fire test is an actual scale fire test using a wood crib in accordance with UL 711

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http://dx.doi.org/10.1016/j.firesaf.2016.01.003
0379-7112/

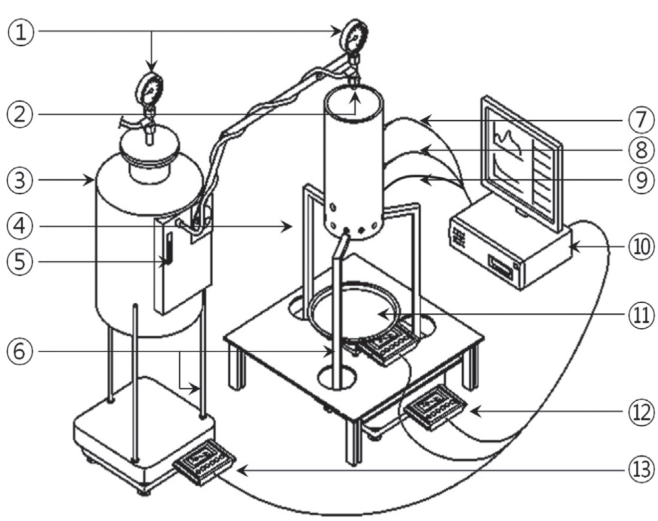
and it incurs a high experiment cost. Moreover, because both the deep-seated fire test and the wood fiberboard penetration test require specific experimental specimens, their applicability is limited [13]. In this study, a scale model experimental device was planned and constructed. This scale model experimental device was designed to evaluate both the penetration and extinguishing performance of the wetting agent in a comprehensive and quantitative fashion, and it can be used for various porous materials including a powder-phase porous material. Also, the experimental device of this study can measure the penetration amounts of liquid extinguishing agents and the internal temperature of holder simultaneously. Thus, it is possible to determine a results comprised correlation between the penetration and extinguishing performance of the wetting agent, which previous studies were not able to ascertain.

2. Experimental methods

2.1. Experimental apparatus

Fig. 1 shows a scale model experimental device, devised for the study. This experimental device is designed to evaluate both penetration and extinguishing performances.

This scale model experimental device is composed of [1] a manometer that displays the internal pressure and watering pressure of a pressure tank [2], a spray nozzle [3], a pressure tank that stores and pressurizes the liquid extinguishing agent [4], a holder that is used as a combustion space by charging specimens [5], a flow regulation valve that controls the flux of the liquid extinguishing agent [6], supports to hold the weights of the specimen holder and pressure tank [7–9], K-type thermocouple to measure a temperature below the surface [10], a data logger and display to show experimental data in real time [11], a scale equipped with a pan to collect and measure the amount of liquid extinguishing agent running off the outside of the holder [12], a scale for measuring the level of penetration by detecting a change in the weight of the holder, and [13] a scale for measuring of the amount of watering.



①Pressure gage
②Nozzle
③Fire fighting water tank
④Sample holder
⑤Flow regulating valve
⑥Supporting legs
⑦Thermocouple 1
⑧Thermocouple 2
⑨Thermocouple 3
⑩Data logger and display
⑪Scale for amount of runoff and drain pan
⑫Scale for amount of penetration
⑬Scale for amount of watering

Fig. 1. Schematic diagram of experimental apparatus.

The specimen holder is designed as a cylindrical stainless steel holder with a diameter and height of 20 cm and 40 cm, respectively, and the bottom of the holder is attached with a mesh net to prevent the runoff of liquid extinguishing agent. On the side of the holder, a 1.5 cm flange is installed every 3 cm for thermocouple insertion. The spray nozzle has a gauge of 1 mm and a spray angle of 45°. The thermocouple can measure temperature up to 900 °C and the scale is a digital strain gauge type which has a minimum measurement unit of 0.1 g. The weight and temperature measured in real-time are saved in the data logger in 1 s increments, and program it to be displayed on the test instrument in real time as to allow real-time observations of movement and extinguishing phenomenon of a deep-seated fire.

2.2. Experimental materials

In this scale model experiment, wood cribs and wood flour were used as experimental materials. For the wood crib, a pine wood crib generally used in a class A fire test was chosen for the study. In the case of the wood crib, a surface carbonization process initializes during combustion and this prevents any further increase in the internal temperature. Consequently, the surface carbonization process stops at a certain stage and the wood crib can maintain its shape [14]. This phenomenon can be observed in wood cribs above a certain level of width. Therefore, if the wood crib is scaled down to a scale model experiment, there would be an increase in the surface area in contact with heat source as well as a decrease in the wood thickness and consequently, accelerate the carbonization process and collapse of the wood crib. To prevent such a collapse of the wood crib in a scale model experiment, the wood cribs were scaled down to a size of 1.5 × 1.5 × 1.5 cm and six wood cribs were loaded on top of each other. The volume of the scale model was determined to be 2.205 cm^2, or 1/185th of the volume of a wood crib used in a typical fire experiment as described in Chattaway et al. [8]. Fig. 2 shows the formation of wood cribs loaded for the experiment.

Radiata pine wood flour, which occupies more than 75% of the domestic wood market, was used and the grain size was maintained between 500 and 1000 μm with a sieve shaker.

To maintain a controlled level of moisture content, the wood cribs and wood flour were dried in a dryer at a temperature of 80 °C for 62 h, and their mass was measured every 4 h. The drying process was continued until the change in specimen mass was (±0.1) g. In accordance with Eq. (1), the resulting moisture contents for the specimens were 15% for wood cribs and 10.6% for wood flour [8,15]. Eq. (1) states:

$$MC = \frac{W_m - W_d}{W_d} \times 100 \tag{1}$$

where MC is the moisture content, W_m is the weight of sample before drying, and W_d is the weight of sample after drying.

Fig. 3 shows wood cribs and wood flour used in the experiment.

To validate the performance of the scale model experimental device, the experiment was conducted with wetting agents typically used in fire safety evaluation performance. Three types of wetting agents, commercialized in South Korea, were selected, and the concentration of these wetting agents was limited to the median of the recommended concentration for use (if any), to minimize experimental errors. The average concentration of these wetting agents diluted in liquid extinguishing agent was 0.77