The 24th National Conference on Combustion and Energy Paper ID: 080
Tainan, Taiwan, April 19th, 2014

Heat Resistance of a Fireproof Curtain with Water Film

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NSC Project No: NSC102-2622-E-006-023-CC2

Abstract

Fire tests of fireproof curtains incorporated with the water film system were conducted to investigate the heat resistance performance of this proposed system. The experiment resulted in the case of the curtain without water film system showed that commercial fireproof curtain has a limited heat resistance. The maximum temperature of unexposed surface reached 693°C and the curtain was torn after 30 minutes of testing. On the other hand, in the case of curtain with water film system, the temperature of unexposed surface remained below 50°C during the test, and the integrity of curtain was conserved for 60 minutes. The heat resistance and fire integrity were greatly improved by the water film system.

Keywords: Fire Test, Fireproof Curtain, Heat Resistance, Water Film

1. Introduction

In Taiwan, floor areas in buildings have been kept increasing during past three decades. According to the Building Technical Rules of Taiwan [1], buildings with floor area larger than 1500 m^2 should be separated into isolated fire compartments by fireproof walls, doors, or windows that have a fire resistance rating of at least one hour every 1500 m^2. Fireproof walls are often regarded to be inconvenient for business and management. Fireproof roller shutters and other fireproof devices are preferred than fixed walls. However, common fireproof devices like fireproof roller shutters often have good flame resistance but no heat resistance. In other words, the spreading of fire can be stopped in the earlier stage of fire. But the thermal radiation from the fireproof device under heating for long periods is worth considering. The device can be heated up to high temperature and produce a great amount of thermal radiation to ignite nearby combustibles or injure occupants in the later stage of a fire. Thus, the heat resistance capability of fireproof devices must be improved.

An ideal fireproof device should be smoke preventing, low in mass, and have high spatial degree-of-freedom. When fire occurred in small compartments, people may injure each other during escaping, or suffocated. Thus, fireproof curtains were designed. The curtains are light, high transparency, and no extra fireproof doors are required. Comparing to other fireproof devices, the curtains are more simple and convenient in design installation, and the estimation after used.

Common technical methods of improving heat resistance for fireproof curtains may be categorized into three types: (1) additional heat-resistant paint on the contact surface; (2) curtains of multi-layer, non-combustible fiber; (3) curtains with various water-cooling systems. The former two types are widely applied to fireproof devices, and achieve 60A ratings. The 60A rating means 60-minute fire integrity and heat resistance rating from CNS 11227 [2], CNS 14803 [3], and CNS 14815 [4]. However, the cost of heat-resistant paint is much higher than the 60B rating devices which have 60-minutes fire integrity but no heat resistance. And the strength of curtains with multi-layer, non-combustible fiber is lower than common curtains. Therefore, curtains with water cooling systems are highly interested.

The concept of cooling solid surface with water spray has drawn much attention. Thomas and Sunderland [5] and Aihara et al. [6] employed sprays to cool down heated solid surfaces. Both the increased temperature and evaporation of water dissipated heat and lowered the surface temperature. Richardson et al. [7] conducted full-scale fire tests with water spray. The results showed that over 90% of the thermal radiation to the glass was absorbed. These results indicated that water spray on solid surfaces is a good cooling solution. Chang et al. [8] and Yan [9-10] studied a vertical tube covered with water film on the outer wall. The results showed high heat absorption rates due to the evaporation of the water film.

Wu and Lin [11-14] conducted a series of experimental studies to investigate the heat resistance and fire protection of a glass pane by a downward-flowing water film system. The objective was to protect the glass in intensive fires. Wu et al. [12] designed a small-scale apparatus to investigate the heat resistance property of the water spray on a glass pane. Water of 37.8 l/min was sprayed on the exposed surface of the glass pane to form water film. Furthermore, Wu and Lin [13] examined the fire insulation and fire integrity of glass panes with a down-flowing water film in a standard full-scale 3 m × 3 m door/wall refractory furnace, which based on ISO 834-1 [15]. The experimental results [13, 14] showed that the period of fire insulation and fire integrity for a non-heat-resistant fireproof glass and a common tempered glass can be extended from 6 to 100 minutes. And the temperatures on surface of the glass panes were kept to below 210 °C with a water film. These results proved the feasibility of replacing a fireproof glass by common tempered glass with a water film. Additionally, Chen and Lee [16] applied the hybrid inverse scheme to solve a 2D transient inverse heat conduction problem with the temperature measurement data given by Wu and Lin [12, 13] to estimate the transient total heat flux and overall heat transfer coefficient on the hot surface of the glass pane with the down-flowing water film exposed to a fire environment. The estimated results showed that the evaporative latent heat dominated the total incident heat flux for the glass pane with the down-flowing water film. The total incident heat flux decreased with increasing the water flowrate. With sufficient water supply, the overall heat transfer coefficient on the exposed fire surface can approach to a constant value even when the temperature of the furnace keeps rising. A full-scale room fire test was conducted by Wu and Lin [14] to investigate the performance and variations of the absorption of convection heat and the resistance of radiation by applying a water film or a closed-pendent-type sprinkler to non-heat-resistant fireproof glass panes. The results showed that in the initial stage of the fire, the surface temperature of the glass pane was supressed by the water film system. After flashover occurred and the fire proceeded to intense burning, the temperature of unexposed surface was still controlled to around 100°C. Comparing two cooling systems, the water film system was more effective than the sprinkler system in heat absorption and heat resistance.

The application of water film cooling was also extended to roller shutters. Recently, roller shutters with water cooling have been studied intensively in China. Chen et al. [17] employed a common steel roller shutter with a water curtain cooling device for fire protection. Sidewall sprinklers were installed on both sides or only on one side of the roller shutter in the fire test. The concluded that the amount of cooling water is related to height and width of the roller shutter. Liu et al. [18] investigated the influence of design parameters for the water spraying roller shutter, including the operating pressure, the interval of nozzles, and the distance between the nozzle and the shutter slats. The results indicated that the two most influential parameters on the average water spraying density were the interval of nozzles, and then the operating pressure. Lin et al. [19] conducted a full-scale (3 m × 3 m) heat resistance fire test on the shutter slat surface of a roller shutter with a water-mist system. A water-mist sprinkler with flowrate of 94.2 l/min and operating pressure of 3 kgf/cm^2 were used to form water film on the unexposed surface of the roller shutter. Most of the heat from the roller shutter was removed by water film. The temperature criteria on the unexposed surface were satisfied for most of the points. However, a small part of the surface failed to meet the criterion due to the incomplete coverage of the water film which caused by deformation of the shutter slats. Thus, the coverage of water film is the most important issue for a water film cooling system.

For fireproof curtains, heat resistance is now required for more advanced fire safety engineering. Currently, the standards of fireproof curtains may include: BS 476-20 [20], UL 10C [21], UL 555 [22] and also CNS 11227 [2], CNS 15038 [23] in Taiwan. However, the heat resistance and smoke preventing performance of commercial fireproof curtains at real fire scenes are often disappointing. To improve heat resistance, additional water cooling has been proven an effective strategy. However, applying water cooling on curtains is much difficult than on solid surfaces (e.g. glass panes, roller shutters). Yang [24] conducted numerical and experimental studies based on CNS 12514 [25] for fireproof curtains with double-layered design and water mist nozzles. In his experiment, two fireproof curtains spacing 40 cm to each other were used. And three water mist nozzles were set between the curtains to provide cooling water for the curtains. The fire load was 25 kg/m^3 and the area of ventilating openings on the wall was 1.2 m^2. The experiment failed after 30 minutes. The curtain on the exposed side was torn and the nozzles were damaged by smoke and flue gas leaked through. During the experiment, high temperature gases accumulated due to the deformation of curtain and generated hot spots which leaded the breakdown of curtain. The results indicated the importance to maintain tension and shape of fireproof curtains in fire tests.

In the present work, we extend our findings of the previous evaluations to design a water film cooling system to enhance the heat resistance of a fireproof curtain and further justify its performance.

2. Experimental apparatus and method

The experimental apparatus was consisted of a refractory furnace, temperature measurement systems, and a water film system if water was supplied.

A refractory furnace was used to test fire-proof and thermal resistance capability of specimens. Figure 1 shows a photograph of the refractory furnace. In the furnace, a flat-flame burner fired by liquefied petroleum gas (LPG) is used to provide the standard heating curve for the heat resistance and fireproof tests. The furnace was designed and operated according to ISO 834 [15] and CNS 14514 [26] standards. The internal dimension of the furnace is 1.2 (W) x 1.2 (H) x 1.2 (L) m which provides a 1.2 (W) x 1.2 (H) m area of heating, and the maximum testing duration is 4 hours.

Fig. 1 Photograph of refractory furnace.

To obtain surface temperature on the non-exposed-to-fired (unexposed) side of the curtain, nine K-type thermocouples were used, and their positions are shown in Fig. 2. Nine thermocouples were set from the right-top to the left-bottom corner with spacing 30 cm to each other on the unexposed surface of curtain. The limit of error of the K-type thermocouple is ±0.4%. The measured temperatures were recorded and used to evaluate the fire resistance performance of the system. Two different methods were applied to keep thermocouples in place during the experiments. In the first experiment without water film, thermocouples were attached on the unexposed surface of curtain directly by high temperature resistance sealant (Permatex® Muffler & Tailpipe Sealer) which resists up to 1000°C (Fig.3). However, this method was proved inappropriate in the experiment as shown in Fig. 7. Thus, a framework for the thermocouples were built and employed in the later on experiment. The framework was set in front of the curtain with thermocouples as shown in Fig. 4. The nine thermocouples were installed on the framework instead of the curtain which allowed continuous contact between thermocouples and curtain surface without attachments on the curtain.

The material of the curtain employed in experiments is KM1000 high temperature textiles (Kumtek International Co., Ltd.) and the main component is amorphous silica fiber. KM1000 was chosen for its high melting point (1650°C), high temperature resistance (1000 to 1260°C), and qualified for the rating 1 of CNS 10285/A2 flammability test. The fabric was prepared in the dimension of 1.5 (W) x 1.5 (H) m, and then confined by a steel frame to maintain its position and surface tension during experiments. After the confinement, the fabric part was reduced to 1.2 (W) x 1.2 (H) m which fitted the refractory furnace.

In the experiment with water film, an additional water film system was installed. The schematic of water film system is shown in Fig. 5. Water was supplied through a hydraulic pump to the perforated pipe which generates water film on the unexposed surface of curtain. The perforated pipe is 1050 mm in length and 28 mm in diameter with twenty-eight holes which are 4 mm in diameter and spacing 40 mm to each other. To ensure uniform distribution of the water film, the water inlet was placed in the middle of perforated pipe. Moreover, a sink with a blocking wall was set outside the perforated pipe. Water from the perforated pipe has to overflow the wall first, and then forms water film on the surface of curtain. In preliminary experiments, this design showed great improvement in uniformity and stability of the water film. And it can also maintain the uniformity under low water pressure. To generate water film with high uniformity, both the design of water supply and the operating pressure of hydraulic pump are important factors. A series of preliminary experiments were done to determine the operating pressure in the fire test. The results showed that the minimum operating pressure required to generate uniform water film on the surface of curtain without any heating was 0.6 kgf/cm^2. Therefore, the operating pressure for the pump in the fire test was 0.6 kgf/cm^2 which providing a total flowrate of 81.2 l/min. The average thickness of water film was calculated to be 3.63 mm.

In the fire tests, the objective of heating duration was one hour. Tests of the fire-proof curtain were conducted with and without water film in contrast. The experimental data are collected and converted by a data acquisition system (Yokogawa DA100), and then transmitted to a personal computer for further operation.

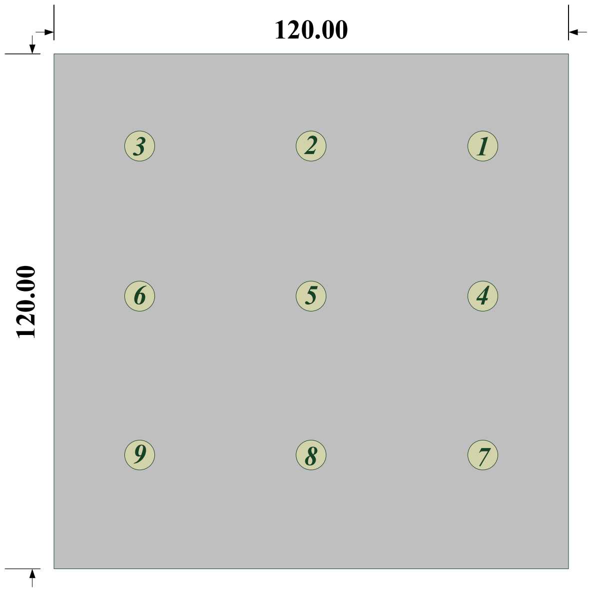

Fig. 2 Positions of temperature measurement.

Fig. 3 Photograph of thermocouples attached on curtain.

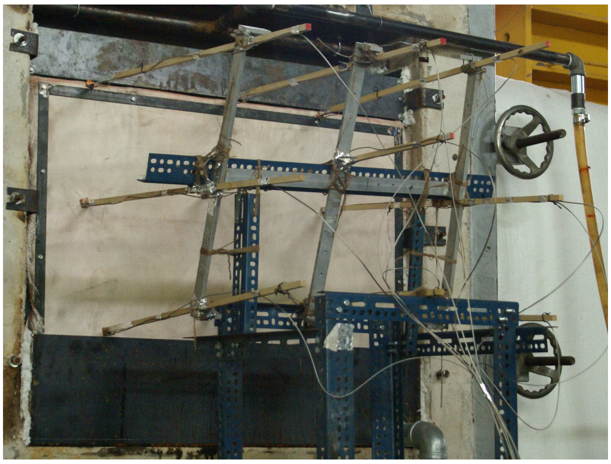

Fig. 4 Photograph of temperature measurement framework with thermocouples installed.

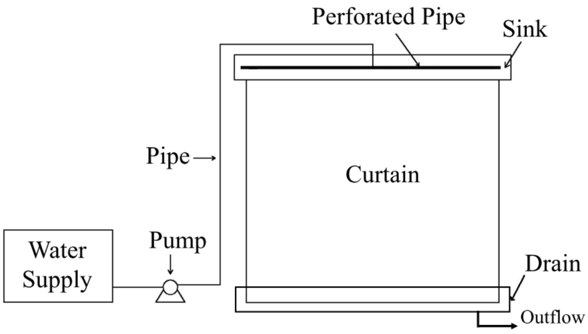

Fig. 5 Schematic of water film system.

3. Results and discussion

3.1 Fireproof curtain without water film

The objective of the fireproof test on the curtain without water film was one hour. However, experimental results showed breakdown of the curtain occurred at 30 minutes after ignition (Fig. 6) and the test was terminated. Figure 7 shows the temperature variation of each thermocouple on the unexposed surface of curtain and the average temperature inside the furnace during the fire test. The furnace temperature curve was kept in the acceptable range of CNS 14803. The temperature on the unexposed surface basically followed the furnace temperature with a difference around 200°C, and the distribution was quite uniform expect for the middle-bottom and left-bottom (TC8 and TC9). The surface temperature increased rapidly at 5 minutes after ignition. Temperature of the surface ranged from 270 to 420°C when the furnace reached 576°C. As the growth of furnace temperature became slower after 5 minutes, the increase of surface temperature was also slowed down, and the distribution of temperature was improved. In the end of the test (30 minutes), the furnace reached 841°C, and the surface temperature ranged from 614 (TC3) to 693°C (TC8).

From the temperature variation of the unexposed surface (Fig. 7), we found that although commercial fireproof fabric has fire resistance and non-flammability, only very limited heat resistance was provided. While the poor heat resistance causing the high temperature of unexposed surface, the fabric deteriorated. The curtain was torn at 30 minutes after ignition as shown in Fig. 6. The breakdown started from the position near TC4, and then the small crack grew the both vertical and horizontal directions. Although the main reason of breakdown was due to the deterioration of fabric, the attachments on the curtain and pressure variation in the furnace caused the breakdown to accelerate greatly. Therefore, the setup of temperature measurement was modified as aforementioned. Summarily, the result showed that using a fireproof curtain without water film can only provide fire resistance for 30 minutes and heat resistance for less than 5 minutes.

3.2 Fireproof curtain with water film

The objective of the fireproof test on the curtain with water film was also one hour. And experimental results showed that the integrity of curtain was conserved after testing for one hour (Fig. 8). Figure 9 shows the temperature variation of thermocouples on the unexposed surface of curtain during the fire test. The furnace temperature curve was kept in the acceptable range of CNS 14803 (not shown). Nine thermocouples (TC1-TC9) can be categorized by heights. Temperatures measured from TC1-TC3 were the lowest, and TC2 only reached 35°C at the end of test. As water flowed downward, the temperature increased. TC4-TC6 were in the middle of curtain, and the final temperature ranged from 42-45°C (TC4 malfunctioned at 6 minutes after ignition). The final temperature of TC7-TC9 ranged from 39-44°C.

The temperature of unexposed surface with water film remained very low and stable in the test. The temperature still increased with time and the furnace temperature, but the maximum temperature was below 50°C during the test. Theoretically, temperature increases with the decrease of height. As water flows over the heated surface from the perforated pipe at the top, the temperature should increase with its traveling distance. However, the non-uniformity of water film led to temperature differences at identical heights. The non-uniformity of water film was partially caused by the non-uniformity inside the furnace and partially from measurement system. As the thermocouples keep contact with the curtain, the disturbance of the water film is unavoidable. Nevertheless, from the integrity of the curtain, this non-uniformity was still acceptable.

The experimental results of fire tests showed that the performance of fireproof curtain was significantly improved. The temperature of unexposed surface was supressed from over 600°C to only 45°C by water film. The maximum temperature can be controlled below 100°C as long as the water coverage is maintained uniformly. Heat resistance of the curtain was improved since most of the heat was transferred by convection and vaporization of water. Lowering the temperature of the curtain surface also decreases the rate of deterioration, so the flexibility and integrity of the curtain can be conserved. However, the performance of water film system is sensitive to the operating condition. The coverage and uniformity of water film should be maintained which a steady water supply is required. Non-uniformity of the water film may cause hot spots which lead to local deterioration and breakdown.

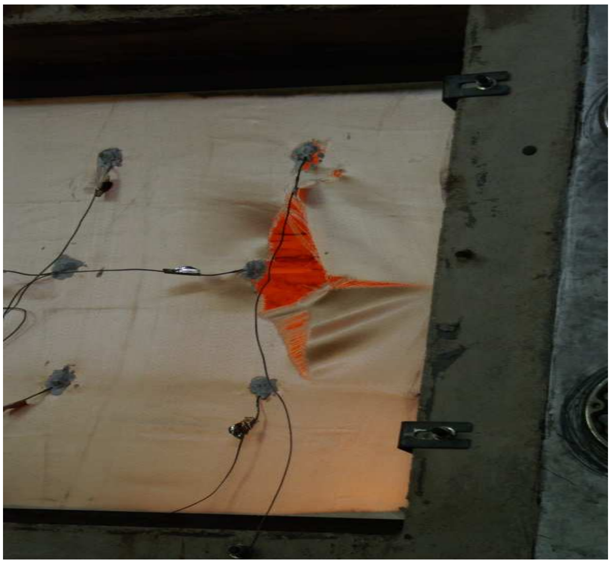

Fig. 6 Breakdown of fireproof curtain without water film.

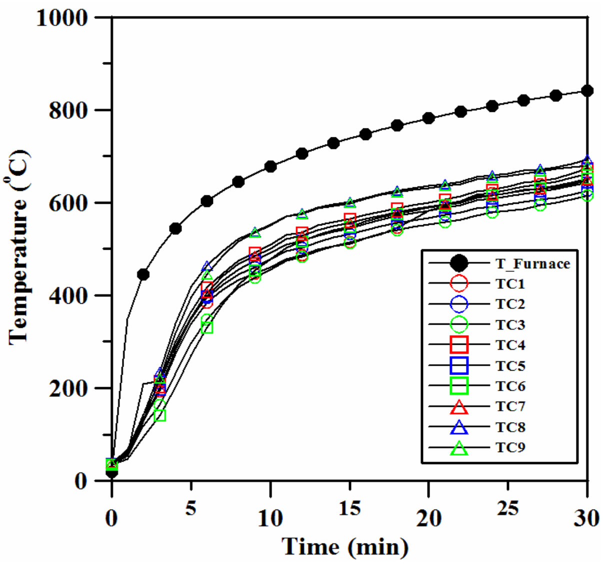

Fig. 7 Temperature distribution on the unexposed surface of fireproof curtain without water film.

4. Conclusions

Fire tests of the fireproof curtain with and without water film system were conducted in this study. Experimental results showed that commercial fireproof fabric exhibits fire resistance, but very limited heat resistance. The maximum temperature of unexposed surface reached 693°C when the breakdown occurred at 30 minutes. The fireproof curtain can only provide fire resistance for 30 minutes and heat resistance for less than 5 minutes. In contrast, the temperature of unexposed surface remained below 50°C during the test, and the integrity of curtain was conserved for 60 minutes with the water film system. Conclusively, great improvements on heat resistance and fire integrity were provided by the water film system.

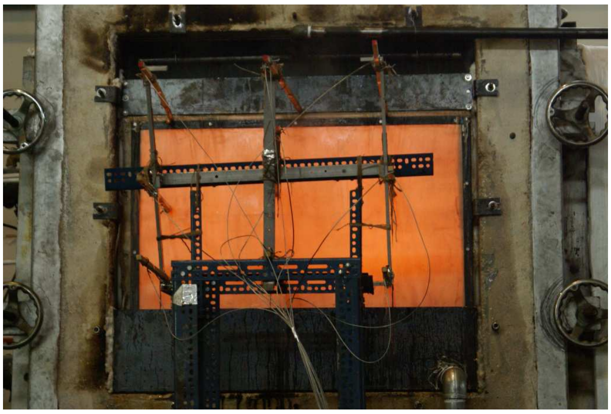

Fig. 8 Photograph of fireproof curtain with water film during test.

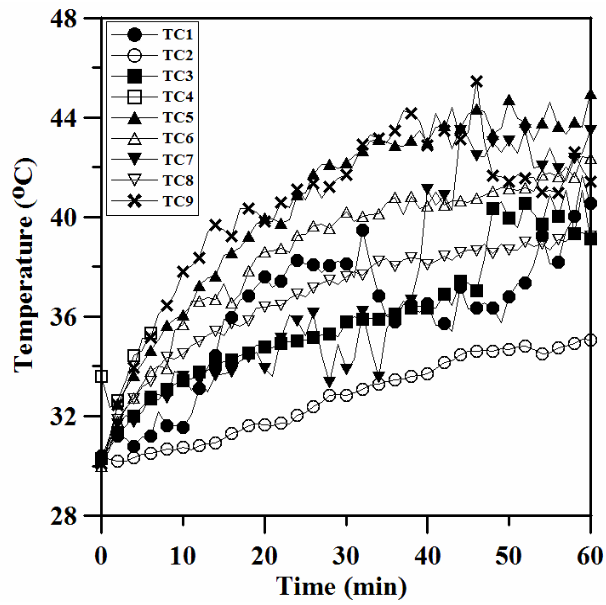

Fig. 9 Temperature distribution on the unexposed surface of fireproof curtain with water film.

Acknowledgments

This work was supported by the National Science Council, Taiwan, ROC, under contract. NSC102-2622-E-006-023-CC2. Architecture and Building Research Institute, Ministry of Interior, Taiwan, ROC.

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利用水膜冷卻系統增進防火布幕之阻熱性能

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摘 要

本研究之目的在於利用水膜冷卻系統以加強防火布幕之阻熱性能。研究中使用相同之防火布幕進行無水膜及有水膜下的防火試驗。結果顯示，一般市售防火布幕雖有一定之耐焰性，但阻熱性能不佳。在無水膜的試驗中，布幕非曝火面最高溫可達693°C，且試驗開始30分鐘後，布幕破損。若防火布幕結合水膜冷卻系統，則布幕之耐焰性及阻熱性皆可大幅提昇。當非曝面有水膜保護時，其表面溫度可保持在50°C以下，且在60分鐘的試驗中，布幕皆保持完好、無破損。故外加水膜冷卻系統於防火布幕上，可大幅增強其耐焰性以及阻熱性。

關鍵字：防火測試、防火布幕、阻熱性、水膜