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Development of a Fire Door and a Fire Door Frame Optimized for Prevention of Expansion of Fire

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Abstract: A fire door plays an important role in preventing fire expansion in case of a fire outbreak in a protection area. This study is different from previous studies, introducing unprecedented fire door. If an existing fire door is exposed to heat for several hours, it has a difficulty shutting off flame, heat, toxic fumes, being deformed. However, the newly introduced fire door with an insulation and flame interruption performance structure can shut off toxic fumes and heat effectively providing water into a fire door doorframe and the inside of the fire door and expanding water inflating agent at the same time. Also, despite of being exposed to heat for many hours, the fire door is not deformed as certain temperature of a fire door is maintained by pressurized water of the inside of the fire door.

Key words: Fire door, fire door frame, water inflating agent, heat insulation performance, flame interruption performance

INTRODUCTION

A fire door is a door installed in a fire compartment and is divided into a first grade and a second grade. On the one hand, a first grade fire doorframe is steel and steel plate that is over 0.5 or 1.5 mm as steel is placed on both sides or is approved by administer of the ministry of land, infrastructure and transport. On the other hand, a second grade fire door is that over 0.8 mm and below 1.5 mm of steel a glass consisted of steel and net or fire proofing wood as fire doorframe and placed steel plate the inside a house and is approved by a minister of the ministry of land, infrastructure and transport. In case of the closing the fire door, the part that a fire door adjoins a door frame or other fire doors must not have a gap which disturbs prevention of fire and also metal goods for installing a fire door must not be exposed (Jang, 2000).

MATERIALS AND METHODS

Earlier studies on fire door are as follows: in "thermal behavior of a steel door frame subjected to the standard fire of ISO 834: measurements, numerical simulation and parameter study" by Wakili *et al*. (2008), it was intended to evaluate the insulation performance of the brick walls manufactured by means of using the international standard, ISO 834. In order to do this, the thermocouples were installed at each part of the brick walls and the thermal behavior of the fire door was analyzed. In this study, the performance of the fire door was checked based on the analysis of the clearance gap, temperature distribution and warpage of the fire door (Wakili *et al*., 2008).

In the study of Hilary on "occupant interactions with self-closing fire doors in private dwellings," fire doors for reducing fire casualties were installed in residences to observe the occupant's behavior. The observations showed the occupant's tendency to open the fire doors and keep them from getting closed or eliminate the automatic closing function of the fire doors. As a result of the study, it was suggested that the safety consciousness be increased and that use of the fire safety doors be enforced by law in order for the fire safety doors to fully discharge their functions as safety measures.

In the study of Sherman on "the effect of gaps of fire-resisting doors on the smoke spread in a building fire," the building code stipulates that fire doors should be free of gaps. The standard value of the clearance gap for fire doors differs in each country. The clearance gap of the fire door which affects the smoke spread also affects

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the smoke spread according to the temperature and the pressure. If the clearance area is wide, the cold air and smoke exceed legal standards. The results showed that the clearance of 3 mm delayed smoke spread and was most suitable for gently closing fire doors. In the study of Daniel on "experimental investigation of fire door behavior during a natural fire," 2 ignition points were made in a hotel room and the operating status of fire doors made of wooden doors and iron doors in accordance with ISO-fire ratings were analyzed. The experimental results showed that when the fire spread rate was high, it greatly influenced the fire doors and caused the fire propagation within 10~15 min to shorten the fire resistance time.

In "study of the fire resistance performance of a kind of steel fire door" of Wu *et al.* (2013), the fire test was carried out according to the standards by means of using steel fire doors without fillers. The experimental results showed that the filler-free steel fire doors without fillers were completely preserved against fire but had poor insulation performance (Wu *et al.*, 2013).

In "study on the improvement method of evaluating fire doors for buildings" of Choi *et al.* (2012), it showed that in terms of flame interruption performance, the united states and canada specified certain limitations on cracks and gaps for testing. However, Korea and Japan applied crack gauges based on the ISO standards and did not specify limitations of each part according to the measured parts. In terms of heat insulation performance, the average rising temperature of 140°C and the maximum rising temperature of 18°C are applied based on the rising temperature of the test specimens on the unexposed face except for Korea and Japan. However, in the united states and canada, the temperature of the test specimens on the unexposed face is set to 250°C within 30 min after the test if only the fire resistance is required for the fire door. Therefore, this study claims that it is necessary to establish strengthened criteria for the fire performance standards of Korea for fire doors (Choi *et al.*, 2012).

In "a study on the fire resistant performance present situation for fire door in fire compartment of buildings" of In *et al.* (2012), the present situation of verifying fire door's fire resistant performance was reviewed and each reason for the failures in securing the fire resistant performance was analyzed based on the fire safety performance verification tests for fire doors of each material in the last 3 years. As a result of the analysis, even the products developed for ensuring fire safety performance had a very high possibility of fire spread possibility such as 40% or more. In addition, even fire doors with fire safety performance ensured were still expected to have a high possibility of fire spread unless the construction and maintenance were thoroughly managed at the construction site. Therefore, this study argued that attention be paid to production, installation and maintenance (In *et al.*, 2012).

In "numerical study on the effect of damper position on characteristics of thermal flow at the vestibules and fire door (2013)" of Moon *et al.* (2013), it was intended to realize the effect of the damper position on the characteristics of thermal flow at the vestibules and the fire door as well as the phenomenon of the smoke entering the vestibules by means of using Fire Dynamics Simulator (FDS 5.5). In order to realize the actual phenomenon, the effect of opening and closing the fire door was set, assuming the occupant's evacuation and the numerical analysis was performed while changing the heat release rate. As a result of the numerical analysis, it showed the effect of the smoke entering the vestibules more at the damper position in front of the fire door than the other damper positions when the heat release rate was from 200-400 kW. However, the influence of the damper position was not significant when the heat release rate was more than 400 kW (Moon *et al.*, 2013).

In "a study of the improvement of the fire door related to the opening protections in buildings" of Choi *et al.* (2012), the fire resistance performance criteria of fire doors in Korea, the USA and the UK were compared and analyzed in order to identify the problems in the fire resistance criteria of fire doors in Korea. Based on the problems, it was suggested that it be necessary to reexamine the performance criteria of fire doors in Korea and reestablish the performance criteria of fire doors in Korea for preventing the combustion from spreading in case of a fire as well as the relevant test methods for evaluating the performance of fire doors (Choi *et al.*, 2012).

In "a study on the effect of temperature variations on the indoor evacuation space from the heat transfer of fire doors," Chan *et al.* (2013) confirmed that the currently constructed fire doors were non-insulated fire doors and that the temperature rise of the indoor evacuation space was caused by the heat transfer phenomenon of the fire doors when a fire occurred in the living room.

In "the leakage crack calculation of the fire door and the stack effect analysis," Kim and Kwon (2013) analyzed the results and phenomena caused by the difference between design and reality and presented a leakage crack calculation method for the National Fire Safety Codes to be revised. In addition, they analyzed the difference of the air flow for the smoke protection due to the stack effect and reflected the living patterns and evacuation patterns of the apartment to consider the methods to measure the air flow for the smoke protection of the apartment. They also presented a reasonable method to measure the air flow for the smoke protection. As a result of the analysis, they argued that Article 12 (the area of leakage crack, etc.) of the National Fire Safety Codes (NFSC 501A) for the stair halls of the special evacuation stairways and the smoke protection systems of the vestibules in Korea be revised based on the performance criteria of fire doors and that seasonal factors and living patterns be taken into consideration when testing the smoke protection systems. They also argued that it be necessary to revise the national fire safety codes with an incorporated phrase which could specify the method of measuring the air flow for the smoke protection at the front door of a home on the floor to be measured with its front door and windows facing the outside air open and the doors of the stair halls closed in the case of a stairway type apartment. In addition, they argued that it be necessary to review the elevator vent's opening ratio control, the stair hall window's automatic closing, the automatic door's opening and closing status and installation of smoke protection systems on the evacuation floor and such considering the stack effect (Kim and Kwon, 2013).

In "a study on the conditions of injection pressurization in the smoke-control zone ii, analysis of the conditions for closing force of fire door with variation of angular velocity," Lee *et al*. (2013) conducted a study on the performance of the smoke control systems in the structures composed of the air ducts, the vestibules, the living rooms and the stair halls. In order to realize the safety of the air supply pressurization rooms, they manufactured the vestibule pressurization systems as well as the differential pressure regulators and the measuring device for the opening and closing force of the fire doors. The closing force was analyzed according to the size of each fire door and the angular velocity of closing each fire door when the design flow rate for pressurizing the vestibule and the differential pressure for closing the fire door were the same. The analysis showed that the closing force increased as the size of the fire door and the angular velocity of closing the fire door increased and that there was the critical angular velocity which kept the closing force constant when the angular velocity increased above certain angular velocity (Lee *et al*., 2013).

In "a study on the insulation performance and correlation between the temperature rise and radiant heat flux on the unexposed face of the steel fire doors," Choi and Seo (2013) evaluated the heat insulation performance of fire doors in Korea and examined the correlation between the temperature rise and the radiant heat flux on the unexposed face of the steel fire doors. As a result of the review, it was found that all the test specimens obtained the heat insulation performance of about 10 min in accordance with the heat insulation performance criteria depending on their core materials. Especially for the parts of the door frames, the difference in the heat insulation performance occurred up to 26 min depending on whether to apply the KS criteria or the ISO standards. It was considered possible to apply the ISO standards to fire doors with heat insulation performance in the future because it showed that in the case of the fire door the core material of which was a mixtures of gypsum board and mineral wool, the fire door's heat insulation performance could be secured over 30 min when applying the ISO standards to the door frame. It also showed that there was a close correlation between the temperature rise and the radiant heat flux on the unexposed face of the fire doors and that the radiant heat flux could be predicted only by the temperature rise of the unexposed face (Choi and Seo, 2013).

In "an experimental study on the radiant heat of the fire doors in fire," Jun Pyo Jeon confirmed the risk of fire spread caused by the radiant heat of fire doors by means of measuring the radiant heat by the structure and material of the fire doors in Korea. As a result of the fire resistance test, all fire doors satisfied all performance criteria for the non-insulated fire doors. However, the fire doors made of the glass wool heat insulating material, the fire doors made of the honeycomb core material, the glass fire doors and all except for wooden fire doors exceeded 2.27 kW/m^2 deemed as the minimum value that humans could tolerate for 12 min exposure. It was found that the fire doors made of the glass wool heat insulating material, the fire doors made of the honeycomb core material, the glass fire doors and all except for wooden fire doors exceeded 11.64 kW/m^2 after 45 or 20 min, demonstrating the possibility of causing burns when exposed to the heat for 10 sec of the maximum tolerance limit value set for the evacuated people which could interfere with evacuation of the occupants in the event of fire. It showed that the radiant heat of the glass fire doors increased in a short period of time, demonstrating the possibility of causing burns to the evacuated people during the initial fire. It took the glass fire doors the fastest to reach the range of 10~20 kW/m^2 which would ignite an object as the time was 15 min. The range was reached after 35 and 60 min by the fire doors made of the honeycomb core material and the fire doors made of the glass wool heat insulating material, respectively. It could be seen that the fire could be diffused from baggage around the fire doors. Therefore, they raised the necessity to make it required for the performance test of the fire doors by the relevant

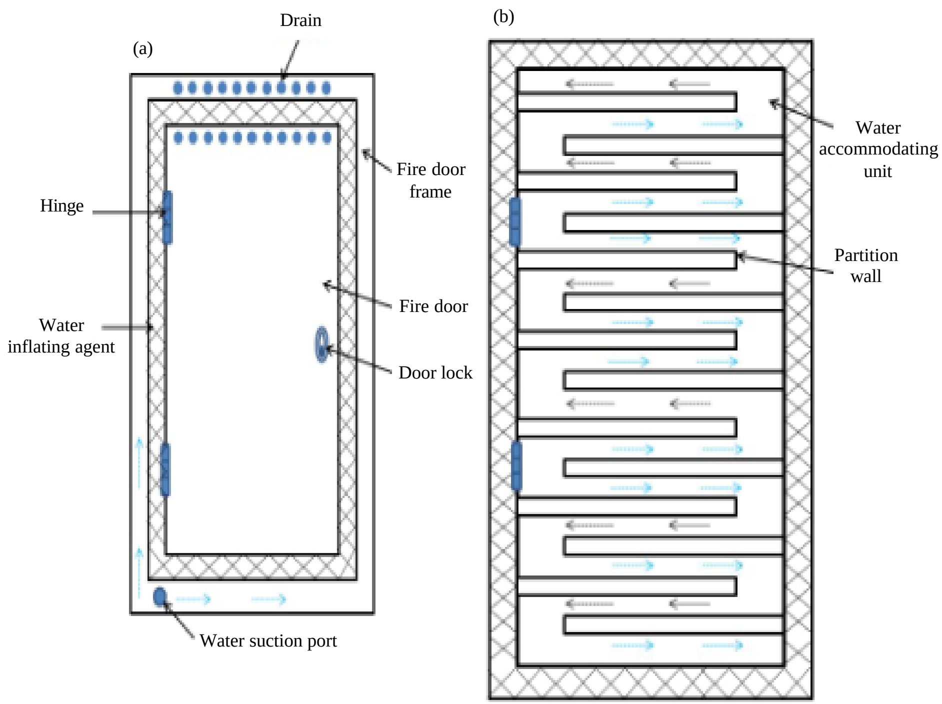

Fig. 1: A structure of the newly introduced fire door and a fire door frame: a) Fire door and fire door frame and b) Inside of fire door plan

regulations that the radiant heat of the fire doors be measured and be based on while restricting fire doors by the structure and use of the buildings in order to prevent the radiant heat from causing the fire to spread (Jeon *et al*., 2011).

As such although, a fire door has been continuously studied, existing studies have focused on performance measurement of steel plate that is used as a fire door, closing force measurement, temperature change caused by an installation of a fire door inside an evacuation space. The purpose of this study is different from of existing studies by allowing water flows inside a fire door in the event of an outbreak of fire and spouting water directly after filling water inside the door frame of a fire door and it shuts off not flame and heat but toxic fumes.

RESULTS AND DISCUSSION

The structure of introduced fire door and fire door frames: The introduced fire door prevents flame and heat by supplying pressurized water to a fire door and a fire door frame in the event of a fire outbreak and shuts off heat and inflow of toxic fumes effectively by using water inflating agent so as to seal the gap between a door frame and a door. A structure of the newly introduced door and fire door frame is shown in Fig. 1. Newly introduced fire door and a fire door frame is composed of hinge, door locks, water inflating agent, orifice, bulkhead, water accommodating unit and a detailed explanation of these is given in Table 1.

Operation mechanism of the proposed fire door and fire door frame: The operation mechanism of the new concept fire door that supplies pressurized water to the inside of the fire door and the fire door frame is as shown in Fig. 2. In case of fire, the valve is opened automatically by the fire alarm system or the fire extinguishing system interlocking with the valve or the valve at the entrance of the fire door is operated manually to open the valve. When the valve is opened, pressurized water is supplied to the fire door through the inlet. The pressurized water flows into the inside of the fire door through the inside of the fire door frame and the hinges of the fire door and the pressurized water flowing inside zigzags on the inside of the fire door along the partition wall to rise up or fall down. The water inflating agent inflates according to the water level and the fire door starts to be sealed. The water inflating agent installed in the fire door frame is inflated by the pressurized water and the gap between the fire door and the fire door frame is completely sealed. When the pressurized water is supplied to the entire fire door, the

Table 1: Main composition of newly introduced fire door and a fire door frame

Main composition	Use
Hinge	Used as pressurized water pathways via inside door through a door frame
Door lock	Door lock pin installed outside an evacuation space to prevent inflow of toxic fumes
Water inflating agent	Used to seal a gap between a fire door and a fire door frame being expanding in case of inflow of pressurized water
Orifice (drain)	Used to create water curtain by enabling pressurized water flows down outside a fire door
Partition wall	Used to help movement of pressurized water by being installed inside a fire door
Water accommodating unit	Used to prevent increase of temperature by storing pressurized water inside a fire door
Inlet	Where the pressurized water flows into the fire door and the fire door frame

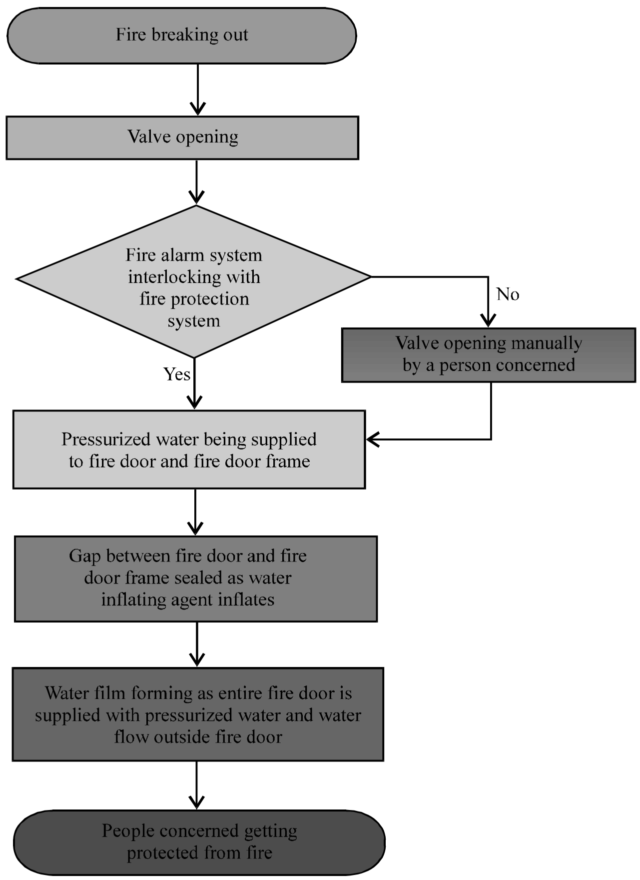

Fig. 2: Operation mechanism of the proposed fire door and fire door frame

water flows to the outside of the fire door through the orifice at the upper side of the fire door to form a water film and the fire door performs its function.

CONCLUSION

In the event of a fire outbreak, a fire door plays a significant role in preventing its expansion. Existing fire doors have limit to shut off flame, heat, toxic fumes due to a deformation of a fire door when it is exposed to heat for many hours. The newly introduced fire door in this study is able to shut off toxic fumes and heat effectively with an expansion of water inflating agent while providing pressurized water to the fire door frame and inside the fire door. In addition to this, it is characterized that in spite of being exposed to heat for many hours it maintains certain temperature with pressurized water inside a fire door so that deformation of fire door is not occurred.

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