Characterizing and Improving Thermal Protective Performance of Multilayered Garment in Critical Condition

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Characterizing and Improving Thermal Protective Performance of Multilayered Garment in Critical Condition

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Firefighter's outer garment, multilayered, consists of outer shell, moisture barrier and thermal liner. Together they are designed to protect firefighter in the different fire environment, categorized as routine, hazardous and emergency [1], [2]. Various assessments on this garment have been conducted using a bench scale apparatus in a horizontal orientation and at the maximum incident flux of 84 kW/m^2 [3]–[7], a flashover fire condition in compartment. However, modern furnishing in buildings and the new trend of high-story housing have recently demonstrated an increase in fire load [8]. Subsequently, increasing the average thermal load in buildings, of magnitude greater than 84 kW/m^2. As thermal protection capability provided by the garment needs to be stipulated under this severer condition, a new calibration method was proposed in a vertical orientation with a thermal load of 126 kW/m^2. This study addresses the performance level and presents time-temperature data on thermal protection provided to firefighter in such critical conditions. In addition, the reduction in skin temperature has been investigated by the use of auxiliary protection in terms of additional layers. Three different sets of multilayered garment system were prepared as; (A) conventional (B) conventional with the addition of underwear layer; and (C) conventional with the addition of Nomex® Honeycomb structure layer. The configuration of each layers is presented in fig. 1. Type A, B and C were exposed to an incident radiant flux of 84 and 126 kW/m^2 using a vertical bench scale test for three different exposure times. Irradiance at skin level was measured using a heat flux gauge and is used to estimate the temperature of the skin surface.

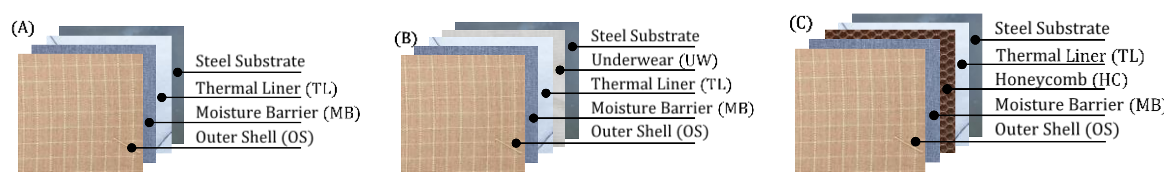


Figure 1: Tested layers configuration: type A (left), type B (middle) and type C (right).

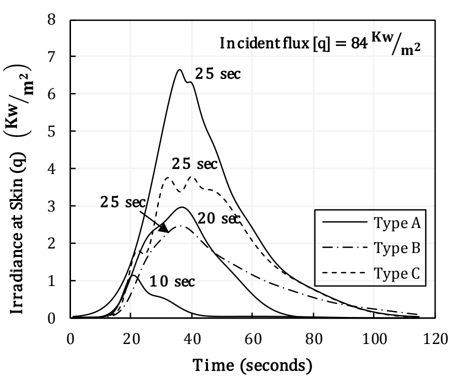
METHODOLOGY

The test apparatus utilized for this study is developed by mutual cooperation of Korean Conformity Laboratories (KCL) and Ulster University [9]. It uses 2-layers of halogen quartz tubes capable of generating radiative heat flux up to 126 kW/m^2. Consistence level of irradiance at the exposed surface area of the tested sample was attainable. Required irradiance was obtained either by adjusting heat source power or by adjusting the distance between heat source and sample. Sample assembly is $200 \text{ mm} \times 200 \text{ mm}$ with an exposed area of $100 \text{ mm} \times 100 \text{ mm}$. The air gap between fire protective clothing and skin has been reported being in the range of 2mm – 24mm for stationary standing individual [10][11] where a different range of 0 – 73mm incorporating all postures was suggested by Li and colleagues [12]. So 2mm air spacing was ensured between fabric layers and an air spacing of 6.5mm between the thermal liner and sensor plate was established. These air gaps are an average representative of their respective domain.

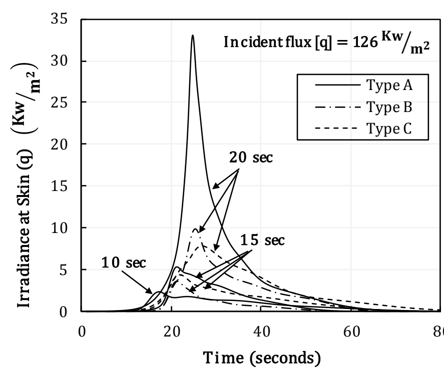
RESULTS

The performance of each layup at an incident flux of 84 kW/m^2 is presented in **Error! Reference source not found.**. Three curves for type A layup at three different exposure level can be seen together with one type B and type C for 25 seconds of exposure time. Peak irradiance observed at skin level for type A layup, is ≈ 6.8 kW/m^2. When an additional layer Nomex® underwear (type B) is used, the protection level is improved by $\approx 55\%$. When a Nomex® honeycomb structure is used, the protection level is improved by $\approx 42\%$. Irradiance presented in **Error! Reference source not found.** is the transmitted heat flux observed at skin level. It is evident from the curves that type B and type C performed better than type A under exposure time of 25 seconds, where type B proved to perform well than type C. Performance of type B and type C under 10 and 20 seconds of exposure time is not plotted to keep clarity in the graph, however, it is seen from 25 second curve that type B and C will perform better under later exposure conditions as well. Basel layer temperature for type A at 10 and 20 seconds exposure remains below the suggested threshold value of 44℃. For exposure time of 25 seconds, this threshold no longer holds, and skin temperature reaches near ≈ 55℃. For type B, under similar conditions, skin temperature stays below the threshold value, at ≈ 42℃ . In the case of type C, it reaches near ≈ 48℃.

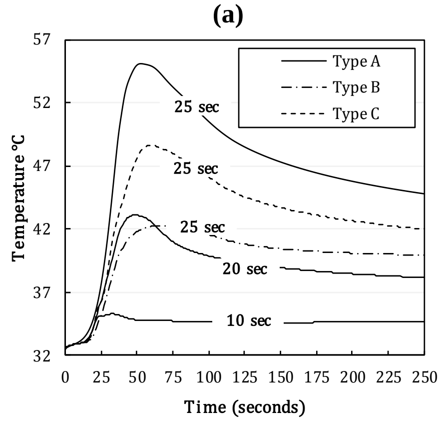
Type A layup was exposed to an incident flux of 126 $\mathrm{kW/m^2}$ for 10, 15 and 20 seconds. Type B and C layup was exposed under similar conditions for 15 and 20 seconds. Peak transmitted thermal energy to skin for type A when exposed for 10 seconds is ≈ $2.5\,\mathrm{kW/m^2}$, for 15 seconds is ≈ $5\,\mathrm{kW/m^2}$ and for 20 seconds a high peak is ≈ $30\,\mathrm{kW/m^2}$, former representing failure. This failure is associated with a tear in the outer shell, responsible for direct radiant heat transfer. Type B tested under similar conditions performed better than type A by limiting irradiance at skin level to ≈ $10\,\mathrm{kW/m^2}$, an improvement of 32% for 20 seconds of exposure time. Type C performed well than type A and B under 20 seconds of exposure, limiting irradiance to ≈ $7\,\mathrm{kW/m^2}$. Type A layup performed well for exposure time up to 15 seconds. When the exposure time is more than 15 seconds, type A layup fails. Type B retained skin temperature 36 % below the type A maximum estimated temperature and type C at 31% as compared to type A, for Basel layer.



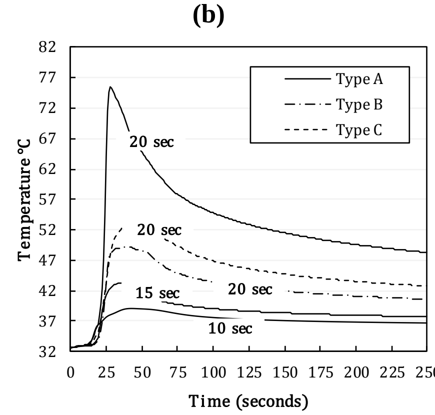
(a)



(b)



(c)



(d)

Figure 2: Fabric assemble performance; (a) at incident heat flux of 84 $\mathrm{kW/m^2}$ (b) 126 $\mathrm{kW/m^2}$ (c) skin temperature profiles of Basel layer at incident flux of 84 $\mathrm{kW/m^2}$ (d) skin temperature profile of Basel layer at incident flux of 126 $\mathrm{kW/m^2}$.

CONCLUSION

The application of adding extra underlayer to existing multi-layered protective suit has proved to beneficial in mitigation burn injuries a firefighter might face when exposed to extreme or life-threatening conditions. Thus, the use of extra Nomex® underlayer used by formula drive can provide added protection and can be worn inside a protective suit with ease. All burn injuries were due to stored thermal energy and occurred after exposure has ended. This effect is mitigated when an extra layer of Nomex® fabric (type B) is added between thermal and skin at a distance of 5mm away from thermal liner and 2mm behind the skin. Care must be taken while implementing the result of this study to real-life conditions as the assessment is done under laboratory conditions. Under the heat flux of 126 $\mathrm{kW/m^2}$, it is recommended to use extra protection to mitigate fatalities. The use of honeycomb structure is not recommended due to its physical limitation. This study opens a new domain to assess protection level at the newly proposed limit of exposure level. More works need to be done on thermal comfort, moisture transport and effect of physical changes for the 4-layered garment.

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