Evaluating radiant heat resistance for firefighter's hood materials

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Background and purpose Radiant heat exposure is one of the primary thermal hazards faced by firefighters during firefighting. Radiant heat exposure can cause burns and other thermal injuries that impair firefighter physical performance, as well as heat stress that leads to heat exhaustion, heat stroke, and other heat-related illnesses (Song et al., 2016). Protective clothing, including hoods, plays a critical role in protecting firefighters from radiant heat. However, due to the multilayer structure and insulation property, they can also result in considerable perspiration production during activities (Guan et al., 2019). Sweating has the potential to amplify the heat capacity and thermal conductivity of clothing material, which can have an impact on the severity of skin burns during exposure to hazardous conditions (Barker et al., 2006). On the other hand, when firefighters are fighting fires, the internal heat generated by energy exertion can only be dissipated through sweat evaporation as the external hot environment prohibits other means of heat transfer. Therefore, it is essential for the clothing to effectively block external radiant heat while still allowing proper internal heat dissipation through sweat evaporation (Sun et al., 2000). Hence, it is important to examine firefighter hoods as protection of head, neck, and ears for their protective performance in dry wet conditions, and especially the dynamic sweating conditions. This study aims to test the radiant protective performance (RPP) of firefighter hood materials and investigate the effect of moisture content and sweating on their performance by a uniquely constructed Sweat Simulation RPP tester.

Apparatus and methods Sweat Simulation RPP tester realized radiant heat exposure as described in ASTM F1939-15(2020), Standard Test Method for Radiant Heat Resistance of Flame-Resistant Clothing Materials with Continuous heating. A specially designed sample holder with two Skin Simulant Sensors and 8 sweating pores was designed and constructed. Manual controlled and power-operated pumping system was used to pump water out of the sweating pores to simulate active sweating. The experiments were done by exposing conditioned specimen of the hood materials to a calibrated radiant heat flux level of 21 kW/m^2 and measuring the temperature rise on the opposite side of the specimen by the sensors. Mandal & Song (2014) concluded that Skin Simulant Sensor had thermal characteristics resembling those of human skin, and was appropriate for data acquisition for long-time low-heat exposure conditions. In this study two

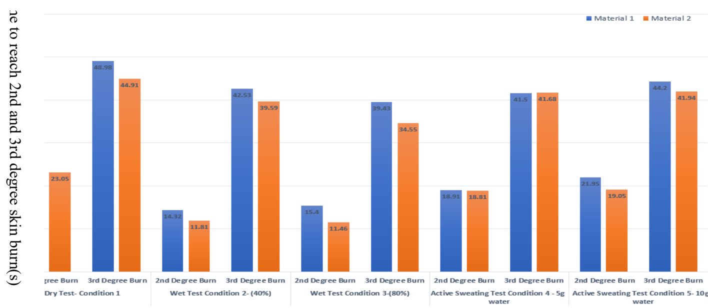
Figure 1. Material 1(M1)

Figure 2. Material 2 (M2)

different hood composites were tested; the first material, shown in Figure 1, is made from 40% P84, 55% Lenzing, and 5% Kevlar while the second material, shown in Figure 2, includes 80% FR Lenzing, and 20% T450 Nomex. As the hoods are usually made from two-layer composite, thus, two layers of fabric were sewn together to be tested. Three test conditions, namely dry, wet, and active sweating were designed for evaluating hood materials for radiant protective performance. All materials are conditioned overnight before treatment and testing. Dry test was done on materials with no treatment, wet test was done after materials being wetted by 40% and 80% weight/weight ratios of water, simulating medium and high levels of water contents. The active sweating condition is set to have medium and high sweating rates of 5g and 10g. For each condition, three replications were tested and then averaged to assess test consistency.

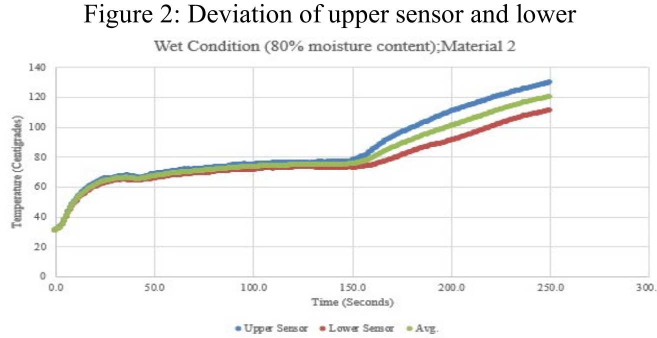
Results and discussion The dry, wet and active sweating tests results are shown in the following Figure 1. RPP tests show that head and neck sweating in firefighters increases burn injury risk.

Figure 1: Test results of time to burn by exposure conditions



The study highlights a strong correlation between sweating, moisture levels in hood materials, and elevated burn risk, leading to more severe injuries than in dry conditions. A moisture increase from 40% to 80% heightens heat transfer, reducing protection for both M1 and M2. Conversely, higher active sweating from 5g to 10g extends time to burns, offering potential additional protection. Material 1 outperforms Material 2, potentially due to higher absorbency. Material properties, especially moisture management, significantly impact radiant heat transfer. Deviation of upper and lower sensors occurred across various conditions, as exemplified in Figure 2. This deviation may result from factors such as fabric shrinkage (He et al., 2016), moisture evaporation, and liquid dripping, unveiling complexities in hood material performance.

Figure 2: Deviation of upper sensor and lower



Conclusion and future work

The study indicates a significant link between head/neck sweating, moisture content in hood materials, and an elevated burn risk, leading to more severe injuries compared to dry conditions. Importantly, it is crucial to note that moisture content in wet conditions increases the risk of heat injuries for firefighters compared to active sweating. This highlights the substantial impact of various moisture conditions on injury severity and emphasizes the vital role of moisture management in ensuring firefighter safety. It is also essential to assess hoods beyond material composition, considering design and construction impact on radiant heat protection, and also evaluating particulate-blocking effectiveness.

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