Investigation of thermal comfort properties of firefighters' gloves: effects of glove type, material, size, and wind speed

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Introduction Firefighters encounter complex environments and conditions while performing their duties within a wide range of possible hazards (e.g., thermal, chemical, and physical). Gloves as subsystems in personal protective equipment (PPE) are critical to ensure firefighter safety and health as they protect the hands and maintain the proper manual functions (Santee et al., 2017). However, the current firefighter gloves receive many complaints due to insufficient protection, poor comfort, and decreased dexterity. Actually, more than one third of injuries received by firefighters are on hands, among which burn and cold injuries, as well as bruise and traumas caused by decreased dexterity all exist (Haynes & Molis, 2017; Routley, 2009). As key traits of comfort properties, thermal insulation and evaporative resistance determine the satisfactory thermal protective and moisture management capabilities of gloves. These properties are usually affected by the material and structure of the gloves and the usage environments. Thus, the purpose of the present study was to investigate the relationships among material, structure, and environmental conditions and the resulting comfort properties of firefighter gloves.

Samples Seven types of firefighter gloves including two types of single-layered wildland firefighter gloves and five types of three-layered structural firefighter turnout gloves were selected for this study. Their average thickness at palm and dorsal parts according to ASTM D1777 were measured. The basic sample properties are listed in the following Table 1.

Table 1. Basic sample properties

Samples	A	B	C	D	E	F	G
Type	Wildland	Turnout	Turnout	Turnout	Turnout	Wildland	Turnout
Size	M-L-XL	M-XL-2XL	XL-2XL-3XL	M-XL-3XL	M-XL-2XL	M-XL-3XL	M-XL-2XL
Outer shell	Pig hide	Cow hide	Cow hide	Kangaroo & Elk hide	Cow hide	Cow hide	Cow hide & Kevlar
Moisture barrier	NA	Polyurethane	Thermal Urethane	e-PTFE	Polyurethane	NA	e-PTFE
Thermal liner	NA	Modacrylic	Modacrylic	Kevlar	Modacrylic	NA	Kevlar
Average thickness (mm)	1.24	2.79	2.36	2.73	2.11	1.33	2.26

Methods An 8-zone thermal hand manikin (Thermetrics, Seattle, USA) was used to investigate the total and intrinsic thermal insulations (R_{ct} & R_{cf} [°C ·m^2/W]) and evaporative resistances (R_{et} & R_{ef} [Pa·m^2/W]) of the gloves. Additionally, a total heat loss (THL [W/m^2]) value was calculated according to ASTM F1868. The hand surface temperature was set at 35.0 °C. The tests were carried out in a wind tunnel positioned in a climate chamber, in which the air temperature and relative humidity were controlled at 25 ± 0.5 °C and 65 ± 5 %, respectively. The air velocity was precisely controlled at the accuracy of ± 0.01 m/s for different wind speeds, 0.5, 1, and 2 m/s. Data analysis including descriptive statistics, one-way analysis of variance (ANOVA), and regression analyses were conducted by statistical software JMP 15.

Results and Discussion The test results ranged as following: R_{ct} (0.085-0.201°C ·m^2/W), R_{cf} (0.045-0.143°C ·m^2/W), R_{et} (13.07-70.97 Pa·m^2/W), R_{ef} (7.98-63.16 Pa·m^2/W), and THL (112.24-408.06 W/m^2). Generally, increasing number of layers, thickness, and size of gloves resulted in increased R_{ct}, R_{cf}, R_{et}, R_{ef} ($p < 0.01$), and decreased THL ($p < 0.01$). Whereas wind speed had negative impact on thermal and evaporative resistances, thus positively affected THL ($p < 0.01$). The following Figures 1 and 2 present the effects of thickness on R_{ct} and wind speed on THL, respectively. Outer shell materials significantly affected R_{ct} and R_{cf}, while materials of thermal liner significantly affected R_{cf}. Results showed that Kangaroo and Elk hide and Modacrylic provided higher thermal insulation. Furthermore, types of outer shell, moisture barrier, and thermal liner all significantly affected R_{et} and R_{ef}. Specifically, cow hide had the highest evaporative resistance among outer shells, while e-PTFE and Kevlar provided lower evaporative resistances compared to other types of moisture barrier and thermal liner.

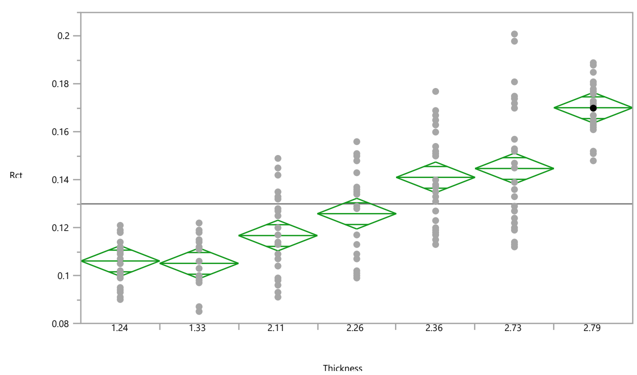

Figure 1. R_{ct} associated with material thickness

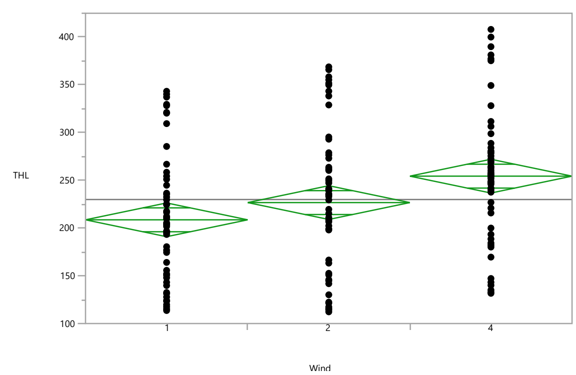

Figure 2. THL associated with wind speed

In addition, some two-way interactive effects also manifested. For example, the negative impact of wind on R_{ct} differed by the types of outer shell, while the positive impact of size on R_{et} differed by the types of moisture barrier. These interactions indicated that some other properties, such as the surface properties and air permeability might also play a significant role in affecting glove thermal comfort.

Conclusions This study confirmed that the material type and thickness, layer construction, and usage environments all affect resulting thermal comfort properties of firefighter gloves. Some two-way interactive effects revealed that various combination of glove layers can result in significantly different thermal comfort. The results of current study suggest that strategically arrange various material compositions at different location of glove is a promising way to achieve improved and balanced protection and comfort.

Reference

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