Combination of textiles and phase change materials for temperature management of a new firefighter protective vest – a numerical study

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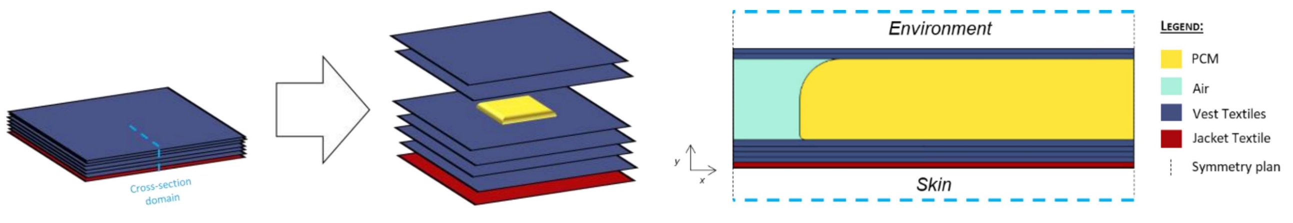
Introduction
Advanced materials have come into sight to increase the thermal protection given by firefighter protective clothing (FPC), either with embedded wearable electronics to monitor environmental/physiological parameters in real time or with integrated phase change materials (PCMs) to minimize the heat stress felt by the firefighter. The thermal protective efficiency of the latter (FPC with integrated PCMs) has been demonstrated in theoretical studies (1,2). Additionally, Santos et al. (3) recently studied a prototype of a PCM vest to be worn over the conventional FPC. The authors proposed a new vest composed of a structure with a removable matrix of individual PCM pouches. This smart clothing system is promising; however, as a drawback, the non-uniform distribution of the vest properties can trigger the appearance of hot spots between the pouches, which can jeopardize the vest thermal performance. With this in mind, a bi-dimensional numerical simulation model was developed to study the effect of different combinations of materials (e.g., textiles and PCMs) for temperature management and uniformity inside the protective vest.

Methodology
The heat transfer across the several domains of the PCM vest (i.e., air gaps, textiles, insulation material, and PCM pouches) was studied numerically using a FEM-based approach. The vest has a matrix with a repetition of units ((3), Figure 1a). Therefore, the simulation domain considers only a cross-section across of one unit covering a wildland firefighting jacket, as shown in Figure 1b. The model considers the PCM phase change, the radiation inside the air gaps, and the heat conduction through the several domains. The model enables the prediction of the thermal exchanges between the PCM vest and the surrounding environment (by natural convection and radiation), providing information about the multilayer assembly's heat distribution and transient behaviour during the exposure to a radiant heat flux (i.e., 11.6 kW·m^{-2}). The time the PCM is fully melted was used as the test stop criteria.

The effects of the properties of highly conductive textile materials (with different thermal conductivities and thicknesses), as well as their best position inside the vest (e.g., covering the entire PCM pouch or only between pouches), were studied to ensure an optimum uniform distribution of temperature along the firefighter's skin. Several configurations of the vest matrix were also studied, considering different amounts of pouches and types of PCMs incorporated in the textile matrix.



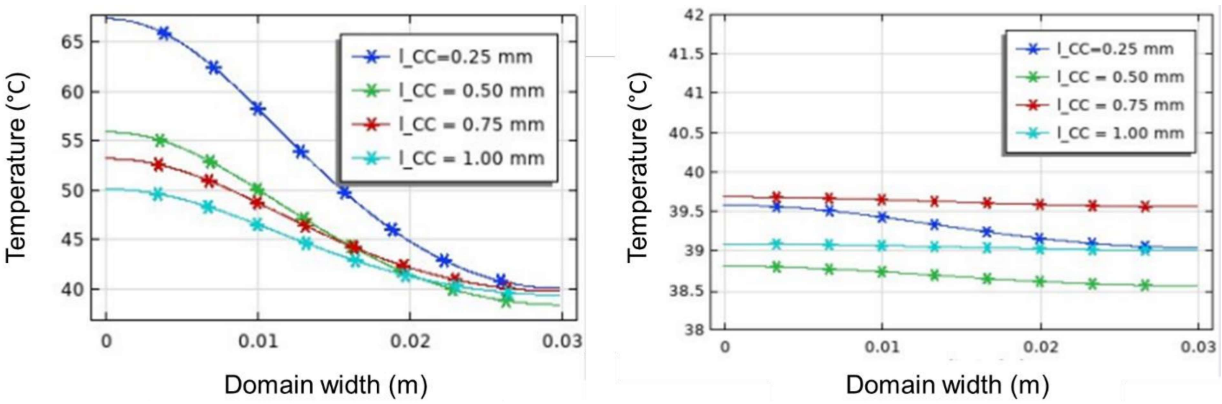
a) b)

Figure 1. a) Example of one unit of the PCM vest and corresponding layers covering a wildland firefighting jacket; b) Simulation domain.

Results and discussion

The obtained temperature profiles compare favorably with data from experimental measurements with PCM pouches.

For the several configurations of the vest, it was observed that a reasonable homogeneous temperature distribution along the firefighter's skin is obtained with textile materials with thermal conductivities lower than 34 W/m/K. Furthermore, it is advantageous that the mentioned textile layer covers the entire vest in direct contact with the PCM pouches. The relative position of the high-conductivity textiles compared to the PCM pouch is also critical. For example, as shown in Figure 2, the difference between the hot and cold spot decreases from configuration a) to b), particularly for thick conductive layers.



a) b)

Figure 2. Skin temperature distribution obtained with different thicknesses of a conductive textile layer (I_CC) located in different zones of the vest matrix: a) covering the entire PCM pouch or b) underneath the PCM pouch.

Conclusions

The thermal performance of a PCM vest was numerically studied. This study demonstrated the advantage of integrating highly conductive textile materials in different PCM vest matrixes to ensure a homogeneous skin temperature distribution without jeopardizing the vest thermal protective performance.

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