

The usage of phase change materials in fire fighter protective clothing: its effect on thermal protection

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Abstract. The thermal protective performance of the fire fighter protective clothing is of vital importance for fire fighters. In the study fabrics treated by phase change materials (PCMs) were applied in the multi-layered fabrics of the fire fighter protective clothing ensemble. The PCM fabrics were placed at the different layers of the clothing and their thermal protective performance were measured by a TPP tester. Results show that with the application of the PCM fabrics the thermal protection of the multi-layered fabrics was greatly increased. The time to reach a second degree burn was largely reduced. The location of the PCM fabrics at the different layers did not affect much on the thermal protective performance. The higher amount of the PCM adds on, the higher thermal protection was brought. The fabrics with PCMs of a higher melting temperature could contribute to higher thermal protection.

Keywords. Thermal protective performance, PCM, fire fighter protective clothing, multi-layered fabrics

1. Introduction

Fire fighter protective clothing is of vital importance for fire fighters during a fire scene. In some fire cases, a flash fire may occur with a heat flux up to 80 kW/m² or more [1]. Under such cases, the protective clothing must provide the wearers with adequate thermal protection for personal safety. Any effort of improvement on the thermal protection could spare the wearers with more time to escape from burn injuries [2, 3].

Nowadays with the development of clothing technologies, various types of wearable clothing incorporated with different materials have been developed. The application of phase change materials (PCMs) is one of the examples. Phase change materials are latent heat storage materials with a very narrow temperature variation during phase change [4]. They could be applied in textiles and clothing by coating, foaming or other methods. With the application of the PCMs the textiles or the clothing are endowed with a capability of thermal regulation. Previous studies of PCMs used in fire fighter protective clothing are rare. Rossi and Bolli have studied the effect of PCMs on the thermal protection of multi-layered fabrics. The orientation of the PCM layer on heat protection, as well as the incident heat intensity was detected [1]. Besides, other researchers, including McCarthy [5], Mercer and Sidhu



[6] have theoretically analyzed the mechanism of the PCMs on heat protection by establishing mathematical models.

In the study cotton fabrics treated by two different PCMs were used in the multi-layered fabric system of the fire fighter protective clothing. They were placed at different layers of the multi-layered fabric system. The thermal protective performance was measured by a TPP tester. The effect of the PCMs on the thermal protection was investigated.

2. Methods

2.1. Materials

A fire fighter protective clothing ensemble consisted of four layers was selected. The four layers from the outside to the inside were the out shell, the moisture barrier, the thermal barrier and the inner layer. The inner layer was the used the same cotton fabric which was the substrate of the PCM fabrics. Their detail construction was summarized in table 1. And they were employed as the reference group. Cotton fabrics coated by micro-encapsulated PCMs were introduced to be used in the fire fighter protective clothing ensemble. The details of the fabrics could be referred to a previous study performed by the authors [7]. Three fabrics were treated with PCM A with a melting temperature of (T_m) of 34 oC and three were treated by PCM B with a T_m of 27 oC. The total six fabric samples were loaded with different amount of PCMs. They were placed either at the innermost layer (Location 1, L1) or between the inner layer and the thermal barrier (Location 2, L2) or between the thermal barrier and the moisture barrier (Location 3, L3).

Tab. 1 Detail of the reference fabrics

Fabric no.	Construction	Thickness (mm)	Weight per unit area (g/m^2)
The out shell	Aramid and Kevlar blended	0.68	225
the moisture barrier	Aramid felt with PTFE film	0.60	108
the thermal barrier	Kevlar felt	2.74	175
The inner layer	100% cotton fabric	0.24	118

2.2. TPP test

The thermal protective performance of the fabric samples were tested by a TPP tester (CSI-206, Custom Scientific Instrument Corporation, USA, figure 1) which was composed of nine heated quartz tubes and two Meker burners. They could produce a nominal heat flux of $84 \pm 2 kW/m^2$ which was a mixture of 50% convective and 50% radiant heat flux. The heat flux was calibrated by a Hy-Cal radiometer. A water cooled shutter was equipped to insulate the fabric samples from heat source. A calorimeter consisted of a copper disk was connected to the computer processing system. The copper face was blackened to obtain a similar emissivity with the human skin. All the fabric samples were cut in a size of 15cm×15cm. They were mounted from the outside to the inside with the orders of the different combinations in table 2. The test was based on NFPA 1971 standard.

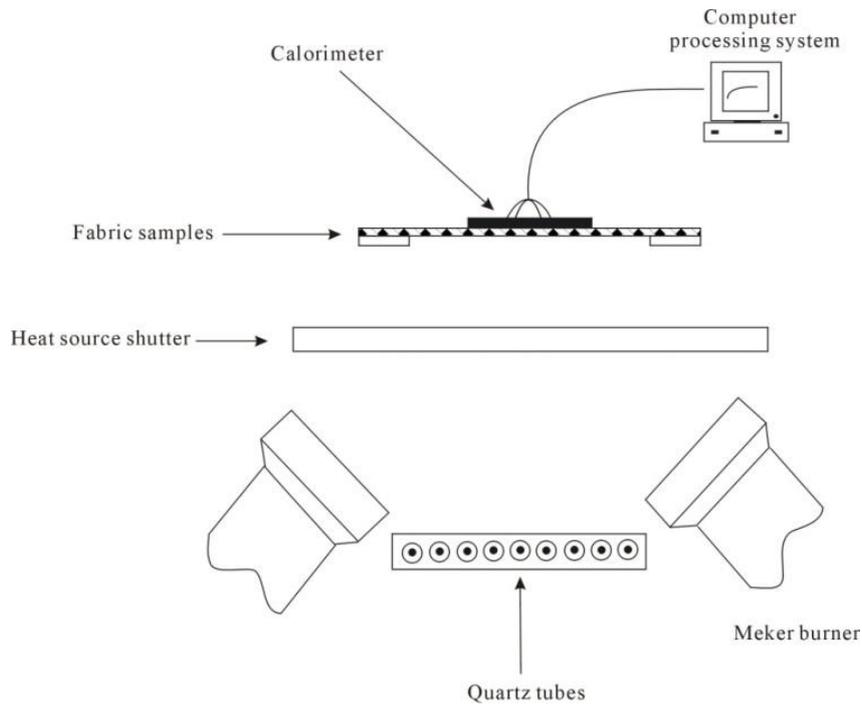


Fig.1 The TPP tester

3. Results and discussion

3.1. The TPP of the multilayered fabrics

Figure 2 shows the temperature evolutions of the innermost layer and one sample with PCM fabric. It can be seen from the figure that with the introduction of the PCM fabric the temperature increase of the innermost layer was much lower compared with that of the reference sample. This was the same situation with other fabric samples.

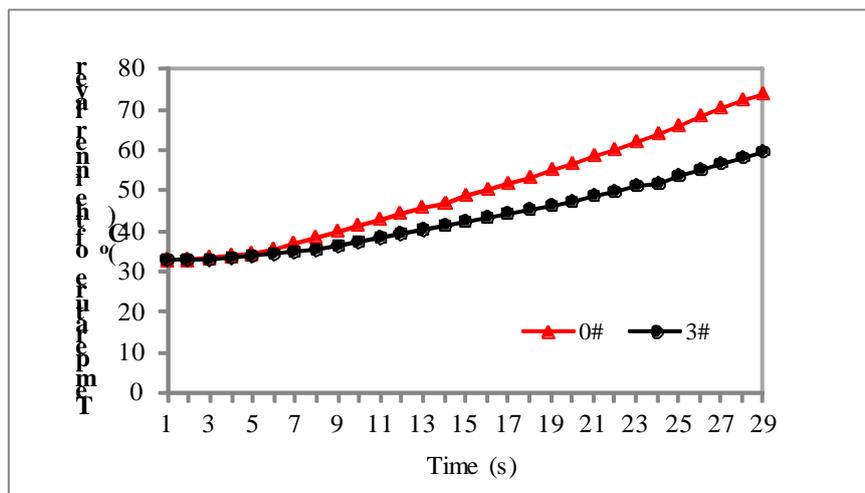


Fig.2 The temperature evolutions of the innermost layers of the reference sample and one sample

3.2. The effect of the location of the PCM layer on TPP

The thermal protection of the different combinations is summarized in table 2. Compared with the reference sample, the thermal protective performance of the different combinations was increased due to the application of the PCM fabrics. However, through a thorough comparison it can be judged that the location of the PCM layers had no obvious effect on the thermal protective performance. The combination of A3L3 contributed to the greatest thermal protection, increased TPP by 52% and reduced the time to reach a second degree burn by 8.8s.

Tab. 2 The thermal protective performance of the different combinations

Fabric no.	Combination	Time to reach a second degree burn, t , (s)	Δt (s)	TPP value (kW.s/m ²)	Δ TPP (%)
0 (reference)	-	16.9	-	34.6	-
1#	A1L1	23.4	6.5	47.9	38
2#	A1L2	21.7	4.8	44.4	28
3#	A1L3	22.3	5.4	45.6	32
4#	A2L1	21.7	4.8	44.4	28
5#	A2L2	23.7	6.8	48.5	40
6#	A2L3	23.8	6.9	48.6	40
7#	A3L1	25.5	8.6	52.1	51
8#	A3L2	24.2	7.3	49.4	43
9#	A3L3	25.7	8.8	52.6	52
10#	B1L1	19.4	2.5	39.6	14
11#	B1L2	21.7	4.8	44.4	28
12#	B1L3	23.2	6.3	47.4	37
13#	B2L1	19.9	3	40.7	18
14#	B2L2	23.7	6.8	48.4	40
15#	B2L3	24.2	7.3	49.5	43
16#	B3L1	24.2	7.3	49.5	43
17#	B3L2	24.2	7.3	49.4	43
18#	B3L3	25.6	8.7	52.4	51

Note : Δ TPP was calculated by comparison with the TPP of the reference sample.

3.3. The loading amount of PCMs on TPP

The TPP values of the fabric samples with the same level of PCM amount were averaged. Figure 3 displays the TPP values of the fabric samples with the two different PCMs. As seen from the figure, the TPP values of the fabrics increased with the increase of the PCM amount. This observation was in line with previous studies [8, 9]. The reason might be that a higher amount of PCM adds on could contribute to a higher absorption of heat source. From the figure it can also be seen that with the similar amount of PCM add on, the TPP values of fabric samples with PCM A were higher than that of the fabric samples with PCM B (A1 and B1 had similar amount of PCM add on, so as A2 and B2, A3 and B3). The melting temperature of PCM A was higher than that of the PCM B. The lower melting temperature of PCM B might make the PCMs melt too early and instantly so that not so much heat was absorbed compared with that of the PCM A. This observation also complied with previous studies [1].

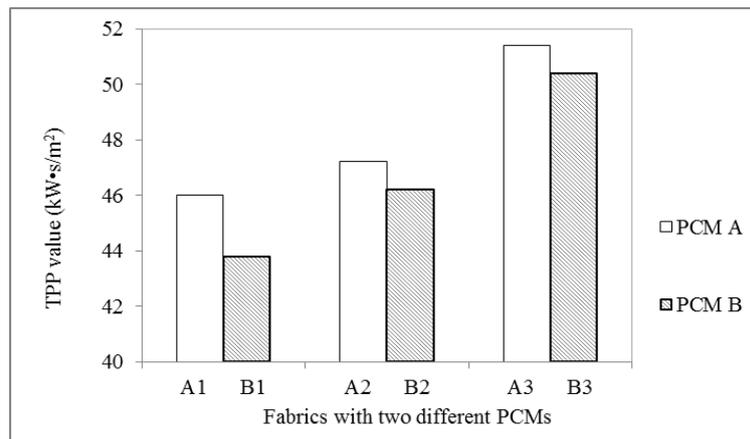


Fig. 3 The TPP values of the fabric samples with the two different PCMs

4. Summary

It was found that with the introduction of the PCM fabrics the thermal protective performance of the multi layered fabrics were greatly increased and the time to reach a second degree burn was largely reduced. The fabric sample which was composed of a 42% PCM A add on and the PCM fabric was placed between the out shell and the moisture barrier contributed to the highest thermal protection. This combination made the thermal protection increased by 52%. The higher amount of the PCM add on the higher thermal protection was brought. PCM A brought a higher thermal protection than that of the PCM B.

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