Physical properties of ZrC/Al$_2$O$_3$ imbedded heat storage woven fabrics

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Abstract. This study investigated different physical properties of ZrC/Al$_2$O$_3$ imbedded heat storage woven fabrics. ZrC and Al$_2$O$_3$ imbedded heat storage PET filaments were spun on the pilot spinning equipment, respectively. Various physical properties of ceramic imbedded fabrics made of ZrC and Al$_2$O$_3$ imbedded filaments were measured and compared with those of the regular PET woven fabric. The surface temperatures of the ZrC and Al$_2$O$_3$ imbedded fabrics were higher than that of the regular fabric. Water absorption rate of ceramic imbedded fabrics was better than that of the regular fabric and drying property was inferior to that of regular fabric. Breathability by water vapour resistance($R_v$) of ZrC imbedded fabric was superior to that of regular fabric. Heat keepability rates of the ceramic imbedded fabrics were higher than that of the regular fabrics, which revealed a good heat storage property of the ZrC/Al$_2$O$_3$ imbedded fabrics.

1. Introduction

Recently, much attention has been focused on the interactions between textile products and far-infrared radiation emitted from ceramic. Ceramic-imbedded yarn manufacturing technology is one of the positive methods for achieving warmth keepability of the textile materials using heat storage method by far-infrared radiation. There are many commercialized inorganic ceramics imbedded heat storage textile goods. Solar-α by Unitica is a heat storage fiber imbedded with ZrC. Kuraray, Mitsubishi-rayon and Kanebo in Japan developed heat storage filaments using ZrC applicable to bedding textiles. Despite many fiber manufacturing companies providing some technical information as a commercial base, various physical properties including heat storage property of the ceramic-imbedded woven fabrics were less known because of confidentiality. The wavelengths from 6 to 14µm is defined as the far-infrared region. ZrC, a kind of ceramic material, imbedded in the yarn emits far-infrared radiation[1]. The earlier studies [1]–[5] related to the inorganic imbedded textiles were focused on ZrC-imbedded PET fabrics. Furuta et al[2] investigated the moisture permeability of a heat storage fabric using ZrC-imbedded PET. They confirmed the increase in moisture permeability of ZrC-imbedded PET fabrics. Similar study was carried out by Bahng et al[5], who developed heat-generating fibers by imbedding ceramic powder. They also reported quick perspiration absorption and fast dry properties of this ceramic-imbedded fabric. The far-infrared emission characteristics of germanium-imbedded woven fabrics and ZrC imbedded knitted fabrics were examined by Kim et al[1,3]. On the other hand, Shim et al[4] studied the heat-insulating water vapour permeable property...
of the warm-up suit with good thermal performance by applying ceramic powders. Most of the investigations about ceramic-imbedded textiles up to now were carried out on the ZrC imbedded textiles. This study investigated the physical properties of ZrC/Al₂O₃ imbedded heat storage woven fabrics. For this purpose, ZrC and Al₂O₃ imbedded heat storage PET filaments were spun on the composite spinning machine, respectively. ZrC and Al₂O₃ imbedded PET woven fabrics were also prepared and their physical properties were measured and compared with those of the regular PET woven fabric.

2. Experimental
2.1. Specimen preparation

Master batch chip was first made using compounding equipment (SM Platek, Korea). Particle size distributions of ZrC, Al₂O₃ and graphite were assessed using hydro 2000S (Malvem, UK). Particle sizes of these ceramic particles used in master batch manufacturing apparatus were ranged between 0.5 and 0.6 µm, which was filtered using a mesh ranged 600 to 800 nm. Table 1 shows the specification of the master batch.

|                | Al₂O₃ | ZrC | Graphite |
|----------------|-------|-----|----------|
| Content(%)     | 10    | 10  | 5        |
| Uniformity     | 0.564 | 0.548 | -        |
| Intrinsic viscosity | 0.542 | 0.535 | 0.637    |

ZrC and Al₂O₃ imbedded PET filaments were spun using master batch chip on pilot spinning machine, respectively. Two kinds of 75d/24f PET yarns were prepared using master batch chips mixed with 0.8wt% Al₂O₃ and 0.2wt% graphite, and mixed with 0.3wt% ZrC and 0.1wt% graphite, respectively. Mixing ratio of PET polymer is shown in Table 2. Spinning was carried out on the pilot melt spinning equipment MS lab m/c (TMT co. Ltd, Japan), which was shown in Figure 1.

|                | PET (kg) | Chip (kg) | Al₂O₃ (%) | Graphite (%) | ZrC (%) | Graphite (%) |
|----------------|-----------|-----------|-----------|--------------|---------|--------------|
| Al₂O₃ imbedded PET | 455       | 50        | 0.8       | 0.2          | -       | -            |
| ZrC imbedded PET   | 455       | 50        | -         | -            | 0.3     | 0.1          |

Figure 1. Pilot melt spinning machine
Figure 2. Schematic diagram of light heat emission apparatus
Three kinds of fabrics were woven using nylon 70d in the warp with 3 kinds of weft yarns such as 2 kinds of ceramics imbedded yarns and regular PET yarn. Table 3 presents the fabrics specimens.

| Specimen | Yarn count(d) | Fabric density (ends, picks/in) | Remarks |
|----------|--------------|---------------------------------|---------|
|          | Wp           | Wf                             |         |
| 1        | 70Nylon      | 75 PET Al$_2$O$_3$ imbedded     | 160     |
|          |              |                                 | 90      |
| 2        | 70Nylon      | 75 PET ZrC imbedded             | 160     |
|          |              |                                 | 90      |
| 3        | 70Nylon      | 75 PET regular                  | 160     |
|          |              |                                 | 90      |

• Dyeing temp. $\rightarrow$100°C
• Tenter temp. $\rightarrow$175°C

2.2. Measurement

Various physical properties of ceramics imbedded fabrics such as light emission, breathability, heat keepability rate, water absorption property including ingredient analysis(EDS) and SEM image were measured and compared with regular PET fabrics. Ingredient analysis of ceramic-imbedded yarn specimens was carried out by EDS.(JEOL LV 8500, Japan). Thermal radiation measurement by light emission was performed using light heat emission apparatus(UL chemical, Korea) Figure 2 shows this apparatus. Heat keepability rate(I) was measured using KES-F7 at 22±1°C and 70±5% R.H., and was calculated using equation (1):

$$I = \left(1 - \frac{b}{a}\right) \times 100$$ (1)

where, a: the heat emanated from the test plate(W)

b: the heat emanated from the specimen mounted(W)

The moisture absorption of the specimens was measured using the Bireck method(KSK 0815). The one end of strip specimen of 20×2.5 was dipped in distilled water of 27±2°C, the wicking length(mm) after 30 min was assessed. The drying rate was assessed using a measuring device(INTEC. Co. Ltd, Japan) according to KSK 0815A. The specimen of 40×40cm dipped in a water bath of 27±2°C was taken out from the bath. The specimen was hung on the measuring device after observing no water drops and the time until natural drying was measured using a sensor in the apparatus.

Figure 3 and 4 show these wicking and drying apparatus, respectively. The water vapour transmission rate was measured according to KSK 0594. Figure 5 shows schematic diagram of this method. A cup containing calcium chloride of 33gr was covered with a specimen of 7cm diameter. The calcium chloride height in the cup was 22mm, the gap between specimen and surface of calcium chloride was
3mm and the specimen was placed in a controlled environment of 40±2°C and 90±5% relative humidity. Specimen mass($m_1$) was measured after 1 hour and then specimen mass($m_2$) was measured under the conditions of 20±1°C and 65±5% relative humidity. The water vapour transmission rate was calculated using eq.(2)

$$P = 10 \times \frac{(m_2 - m_1)}{S}$$  \hspace{1cm} (2)

where, $P$ : water vapour transmission rate(g/m²-h)
$m_2 - m_1$ : change of the specimen weight(mg)
$S$ : area of specimen(cm²)

The measurement of moisture vapour resistance using a sweating guarded hot plate was performed by ISO 11092 method. The total moisture vapour resistance($R_{e,t}$) of the specimen and air layer was determined by eq.(3) from the measurement of the evaporative heat loss.

$$R_{e,t} = \frac{(P_s - P_a)A}{H}$$  \hspace{1cm} (3)

where, $R_{e,t}$ : total resistance to evaporative heat transfer provided by the fabric system and air layer(m²PaW⁻¹)
$A$ : area of the plate test section(m²)
$P_s$ : water vapour pressure at the plate surface(Pa)
$P_a$ : water vapour pressure in the air(Pa)
$H$ : power input(W)

Intrinsic moisture vapour resistance($R_{e,f}$) of the fabric was calculated by eq.(4).

$$R_{e,f} = R_{e,t} - R_{e,a}$$  \hspace{1cm} (4)

where, $R_{e,f}$ : resistance to evaporative heat transfer provided by the fabric
$R_{e,a}$ : resistance value measured for the air layer and liquid barrier

3. Results and Discussion

3.1. Ingredient Analysis of ZrC/Al₂O₃ Imbedded Fabrics

Figure 6(a) and (b) present the results of ingredient analysis of ZrC and Al₂O₃ imbedded woven fabrics, respectively. As shown in Figure 6(a) and (b), Al and Zr ingredients were shown. Figure 7 (a) and (b) show white spots on the yarn cross-section in the SEM image of the ceramic imbedded specimens. The black spots in the Figure 7(a) were assumed to be ZrC, and the grey spots in the Figure 7(b) appeared to be Al compounds. Figure 8 shows particle size distribution of the ZrC and Al₂O₃. It was shown that the particle size distribution of the ZrC was narrower than that of Al₂O₃, and particle size of ZrC was smaller than that of Al₂O₃.

![Image](a) Al₂O₃ imbedded fabric  \hspace{1cm} (b) ZrC imbedded fabric

Figure 6. Ingredient analysis of the fabric specimens
Figure 7. Image of the ceramic imbedded fabric by SEM

Figure 8. Particle size distribution of the ZrC and Al$_2$O$_3$

3.2. Heat storage characteristics

Figure 9 shows light heat emission diagram of the fabric specimens. As shown in Figure 9, heat emission temperatures of the ZrC and Al$_2$O$_3$ imbedded fabrics were higher than that of the regular PET fabrics. As shown in Figure 9(a), the surface temperatures of the Al$_2$O$_3$ and ZrC imbedded fabrics were higher than that of the regular fabric, and similar trend was shown in Figure 9(b), which was surface temperature from 45cm distance apart. This phenomena were assumed to be caused by heat emission from absorption or accumulation of far-infrared as the Al$_2$O$_3$ or ZrC in the yarn receive light. Table 4 shows the physical properties related to the clothing comfort of the fabric specimens.

Table 4. Physical properties of the fabric specimens

| Experimental items | Al$_2$O$_3$ | ZrC | Specimen 3 |
|--------------------|------------|-----|------------|
| Breathability(g/m$^2$·h) | 385 | 352 | 421 |
| $R_w$(m$^2$Pa/W) | 63.5 | 37.2 | 55.3 |
| Wicking(mm) | 15 | 41 | 3 |
| Drying(min) | 90 | 75 | 50 |
As shown in Table 4, the breathability (CaCl₂ method) of the Al₂O₃/ZrC imbedded fabrics were lower than that of the regular PET fabric, which was attributed to prevent the heat particles form heat emission by far-infrared from moving moisture vapour. By the way, breathability by Ret of ZrC imbedded fabric was better than that of regular PET fabric. Wicking property of the ZrC or Al₂O₃ imbedded fabrics was better than that of regular PET fabric. This was assumed to be attributed to the fast drying of absorbed moisture in the yarn by heat particles generated from the far-infrared radiation by ceramics in the yarn. However, This result was contrary to previous study[1]. Drying property of the ZrC and Al₂O₃ imbedded fabrics was not better than that of the regular PET fabric, which showed a different results to previous researches carried out by Bahng et al.[5] and Kim[1]. Heat keepability rates of the ceramic imbedded fabrics were higher than that of the regular PET fabric, which was caused by far-infrared emitted from ceramics i.e. which gives it heat generating and storage properties. Similar results were reported by Shim et al.[4] This result revealed a good heat storage property of the Al₂O₃/ZrC imbedded fabrics.

4. Conclusion
Summarizing this study, the surface temperatures of the Al₂O₃ and ZrC imbedded fabrics were higher than that of the regular fabric, which was assumed to be caused by heat emission from absorption or accumulation of far-infrared from Al₂O₃ and ZrC. Wicking property of ZrC or Al₂O₃ imbedded fabrics was better than that of the regular PET fabrics and drying property of these fabrics was not better than that of the regular fabric, which were different from the results of the previous papers. Breathability (Ret) of ZrC imbedded fabric by the ISO 11092 was better than that of regular fabric. Heat keepability rates of the ceramic imbedded fabrics were higher than that of the regular PET fabric, which revealed a good heat storage property of the Al₂O₃/ZrC imbedded fabrics.

Acknowledgments
This research was funded by “Development of multi-functional inorganic particle embedded fibres and high comfort sports/outdoor clothing” project.

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