Thermal resistance and water vapor permeability of compound woven fabrics containing silver multifilament

M J Toghchi1,2,3, C Loghin2, C Campagne1, I Cristian2, P Bruniaux1, L Ciobanu2, A Cayla1, Y Chen3 and L Wang1
1ENSAIT, GEMTEX-Laboratoire de Génie et Matériaux Textiles, F59000 Lille, France
2Faculty of Textile, Leather and Industrial Management, Gheorghe Asachi Technical University, Iasi, Romania
3College of Textile and Clothing Engineering, Soochow University, Suzhou, China

E-mail: marzieh.javadi-toghi@ensait.fr, marzieh.javadi-toghi@tuiasi.ro

Abstract. Two sets of compound woven fabrics containing three layers of simple woven fabrics were manufactured (five samples made of cotton yarns and five samples with one-third hybrid cotton/silver yarns). The thermal resistance and water vapor permeability of all the fabrics were measured and compared. It should be noted that the small dissimilarity in the thickness of the manufactured fabrics was due to the movement of the yarns through the thickness in the relaxing state of the fabrics. However, they were designed in a way to have the same thickness on the weaving loom. The results stated that the thermal resistance of asymmetric fabrics for both sets of fabrics (with and without silver) was different regarding which exterior face (face or back) was in contact with the hot plate (20°C). It should be noted that the fabric is not symmetric through its thickness due to the dissimilarity of weave pattern of the layers or the orientation of silver yarns. It affirms that the internal voids of each ply (which is correlated to the wave pattern) play a significant role in thermal resistance of the manufactured compound woven fabrics. As a result, the asymmetry of a compound woven fabric throughout the thickness makes it a potential fabric to be applied as double-face fabric for different climate conditions as the order of the layers changed the thermal resistance of the compound fabric due to the porosity of each ply. Furthermore, a reduction was observed in thermal resistance for the fabrics with silver presence (~40%) while the other parameters remained unchanged (e.g. yarn density, fabric structure, and fabric porosity). The reason is correlated to the high conductivity of silver as conductive materials improve the heat transfer of the fabrics. Moreover, the influence of silver presence on water vapor permeability was not significant although the water vapor permeability was slightly increased for the fabrics having silver in their structures.

1. Introduction
Comfort has been familiarized as a pleasant state of psychological and physical harmony between a human and his environment [1]. The comfort of functional fabrics (e.g. electrical conductive fabrics) is also of great importance [2] since lots of textile products are made of metallic yarns with high electrical conductivity like copper, silver, nickel and stainless steel for electromagnetic shielding applications [3,4]. However, the metal yarns presence affects the comfort of the manufactured fabrics. In the present study, the thermal comfort and water vapor permeability of a number of the
manufactured compound woven fabrics containing silver multifilament yarns were studied. It should be noted that compound woven fabrics contain at least three systems of yarns. The manufactured compound fabrics in the present work consist of three weft yarn systems and three warp yarn systems.

2. Experimental
Two sets of compound woven fabrics were designed and produced using ARM AG CH-3507 Biglen weaving loom manufactured in Switzerland. A set of five different compound woven fabrics was produced when all the yarns were cotton yarns. On the other hand, another set of five different compound woven fabrics was manufactured while each sample consists of one-third hybrid cotton/silver yarns and two-third cotton yarns.

It should be mentioned that the other parameters remained unchanged (e.g. yarn density and fabric structure for both sets of the fabrics). The face and back of a set of the developed fabrics are shown in Figure 1 (a and b). Also, the structural characteristics of the fabrics are listed in Table 1. The warp density was 33 (yarns/cm) for all the samples and the weft density was 21 (yarns/cm) for sample (1 and 1’), sample (2 and 2’), sample (3 and 3’) and sample (4 and 4’) when the weft density was altered to 14 (yarns/cm) for sample (5 and 5’).

| Sample code | Pure Cotton fabrics | Silver/Cotton fabrics |
|-------------|---------------------|-----------------------|
|             | 1  | 2  | 3  | 4  | 5  | 1’ | 2’ | 3’ | 4’ | 5’ |
| Areal density (g/cm²) | 588 | 615 | 657 | 602 | 453 | 791 | 826 | 879 | 831 | 750 |
| Fabric thickness (mm) | 2.2 | 2.5 | 2.4 | 2.3 | 1.9 | 2.2 | 2.5 | 2.4 | 2.3 | 1.9 |
| Warp density (yarns/cm) | 33  | 33  | 33  | 33  | 33  | 33  | 33  | 33  | 33  | 33  |
| Weft density (yarns/cm) | 21  | 21  | 21  | 21  | 21  | 21  | 21  | 21  | 21  | 14  |
| Symmetrical structure* | ✓  | ✓  | ✓  | ×  | ✓  | ×  | ✓  | ✓  | ×  | ✓  |

* ✓ indicates the symmetrical structure and × indicts asymmetrical structure.

Table 1. Structural characteristics of the compound woven fabrics.

![Face](a) Face
![Back](b) Back

Figure 1. Face (a) and back (b) of the compound woven fabrics.

3. Thermal resistance and water vapor permeability measurements
The thermal resistance and water vapor permeability of two sets of compound woven fabrics (with and without silver) was determined using Permetest skin model apparatus (response measuring instrument
for the non-destructive determination of water-vapor and thermal resistance or permeability of textile)
manufactured by Czech Sensor company which works on the heated plate principle (ISO 11092) [5,6]. The Permetest apparatus is illustrated in Figure 2. The instrument description can be found in [5,7].

![Permetest instrument](image)

*Figure 2. Permetest instrument.*

All the fabric samples were cut in 15 × 15 cm² and positioned to Permetest instrument equipped with a skin model measuring head. Each sample was tested at least three times from different area of the fabric. It should be mentioned that a resistant semi-permeable polytetrafluoroethylene membrane covered the measuring head in order to shield the system from liquid water penetration. Permetest characterizes the model of real human skin as a result of the short time delay between the start of the moisture transfer and cooling heat recording. All the tests were performed at 20± 2°C and 45% RH while all the samples have conditioned in 45% RH and 20 ± 2°C for 24 h before measurements.

4. Results and discussion
The thermal resistance results are presented in Figure 3 (a and b) for two sets of compound woven fabrics (with and without silver). As all the manufactured samples were compound woven fabrics, it was decided to determine the thermal resistance coefficient and absolute vapor permeability for both the face and the back of the samples, independently. The idea was to investigate the effects of fabric structure through its thickness together with the presence of metal on the comfort of the fabrics. The results stated that the thermal resistance of the asymmetric fabric (sample 4 and 4’) for both sets of fabrics (with and without silver) was different regarding which exterior face was in contact with hot plate. It was suggested that this dissimilarity is due to the order of the layers through the thickness of the fabric although the total porosity was the same when the test was conducted for both faces of each fabric. In other words, the porosity of each ply (layer) plays an individual role in the measurement. As a result, the thermal resistance was different when the ply with higher porosity was in contact with hot plate compared to that of lower porosity. The thermal resistance and water vapor permeability of sample 1 without silver for face and back were similar as the structure was symmetric. However, the results showed a significant difference in thermal resistance measured for sample 1´ with silver regarding which exterior face was in contact with hot plate. The reason correlated to the presence of silver which interrupted the inner symmetry of the structure as the silver yarns are not placed in the middle of the fabric thickness. In other words, sample 1´ with silver is not symmetric throughout the thickness of the fabric because of the silver alignment in the structure. It should be noted that this cannot be observed from the fabric appearance shown in Figure 1 as the exterior layers look exactly the same. Therefore, it confirms that the internal voids of each ply play a significant role in the thermal resistance of the compound woven fabrics. This parameter can be taken into consideration to design a double-face fabric for different climate conditions as the order of the layers had a significant influence on the thermal resistance due to the porosity of each ply in the compound woven fabrics. It should be noted that a compound fabric consists of at least three yarn systems which make more than one layer
(ply) of simple fabric while these layers are connected by a binding yarn system (e.g. binding warp or binding weft) in weaving.

Figure 3. Comparison of thermal resistance and absolute vapor permeability of the samples with and without silver for the face and back of the compound woven fabrics.

In addition, the dissimilarity between thermal resistance for face and back of the samples (sample 4, 4’ and sample 1’) was remarkable in comparison with absolute vapor permeability as can be seen in Figure 2. It was because of silver multifilament yarns presence as silver is highly conductive and the presence of it along with the position of silver multifilament yarn and internal void of each ply played a significant role in the thermal transfer of the fabrics.

Furthermore, a reduction was observed in thermal resistance for the fabrics with silver (~40%) while the other parameters remained unchanged (e.g. yarn density, fabric structure, and fabric
porosity). Moreover, the influence of silver presence on water vapor permeability was not significant although the water vapor permeability was slightly increased for the fabrics having silver in their structures.

5. Conclusion

Two sets of compound woven fabrics were manufactured (a set of five different compound woven fabrics made of cotton yarns and a set of five different compound fabrics with one-third hybrid cotton/silver yarns). Then, the thermal resistance and water vapor permeability of all the fabrics were determined based on ISO 11092 standard. The results showed that the thermal resistance of asymmetric fabrics throughout the thickness for both sets of fabrics was dissimilar with regard to whether face or back of the fabric was in contact with the hot plate. It confirms that the internal voids and composition of each ply of the compound fabrics play a significant role in thermal resistance. It should be noted that a compound fabric consists of at least three yarn systems which make more than one layer (ply) of simple fabric in the woven structure while these layers are connected by a binding yarn (e.g. binding warp or binding weft). Consequently, it was suggested that the asymmetric compound woven fabrics are suitable to be applied as double-face fabrics for different climate conditions. In fact, the order of the layers and the position of conductive yarns (silver yarns) altered the thermal resistance of the compound woven fabrics when the fabric structure was asymmetric throughout its thickness due to the porosity of each ply. Moreover, the thermal resistance of the fabrics with silver presence was relatively low (~40%) compared to the pure cotton fabrics in which other parameters were the same (e.g. yarn density, fabric structure, and fabric porosity). In addition, water vapor permeability was not meaningfully influenced by the presence of silver although it was increased for the fabrics having silver in their structures.

6. References

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