DEVELOPMENT OF BREATHABLE HYDROPHOBIC/HYDROPHILIC FUNCTIONAL TEXTILES

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Abstract: The proposed bi-functional protective structure intended to have hydrophilic interior towards the skin surface and hydrophobic exterior for protection, ensuring fast transfer of moisture between body and external environment. The sandwich structure is prepared using 100% wool jersey and varieties of 100% polyester fabrics. Hydrophilic treatments were given using cutinase (fusarium solani pisi) enzyme and commercial hydrophilic softener Ruco Pur Sly®. The polyester fabrics were given a hydrophobic treatment with Ruco Dry Eco® - a commercial cationic water repellent preparation. Variables include enzyme treatment time, and change in pressure to achieve suitable wet pick up at foulard. Several wool-polyester sandwich structures with optimum hydrophilic/hydrophobic properties were made by thermal adhesion using thin polyamide layer. Drop test and vapour permeability test were conducted to evaluate wetting properties and breathability of the samples. Sandwich structure comprising hydrophilic wool-jersey and hydrophobic PES spacer fabric showed the highest value for water vapour permeability.

Keywords: bi-functional clothing, hydrophilic wool, hydrophobic polyester, water vapour permeability.

1. Introduction

Protective clothing is the largest and most diverse segment of the functional clothing. The functionality of clothing at the very least, can allow people to work in and around hostile environment, improve the quality of life and prevent or reduce injuries. The most important requirements to be met when designing such a product are: to provide metabolic heat and moisture transport in the body, have good insulation, low weight, hydrophilic or hydrophobic characteristics where appropriate, the ergonomically to perform the function of mobility, etc.

The diffusion of moisture vapour through the matrix of a textile system involves many complex interactions that depend mainly on the chemical composition of the fibre and the structure of the textile. During perspiration, the body uses the evaporation of moisture at the skin surface to cool itself. This moisture is stored in the clothing systems microclimate. Water molecules penetrate the textile matrix and can interact with it in a variety of ways: they can stick to the surface of the fibres, penetrate the core and/or congregate in the capillarity spaces created between fibres. Water molecules can also migrate from the interior of the system to the surface where they evaporate into the atmosphere. A key term often used in marketing literature to describe the water vapour resistance properties of a textile is breathability, which refers to a fabric that offers high resistance to liquid water yet low resistance to water vapour [1]. This term is frequently used in the marketing of composite textiles used in outer layer garments especially when one component is a membrane. Another is the wicking property of fibre or fabric, which describe the rate at which the absorbed moisture is dispersed across the volume of the textile and is driven by capillary forces [1]. The term is often used in the marketing to describe a textile ability to draw moisture away from the skin, sometimes to the face of a textile where it evaporates into the atmosphere.

Breathable multifunctional materials are often made using multilayer/composite technology – the ability of a material is added to the property of another material to create a material with two or more properties. Marketing breathable membrane, resistant to wind and water brands such as *Goretex*® [2] and *Sympatex*® [3], led to the introduction of multilayer/composite textile in the clothing sector. For example, the Belgian company *Concordia Textiles* produces a wide composite *Omniclima* [4] brand which is composed of three layers (a layer of polyurethane hydrophilic foam and fabric) to create breathing systems, water and wind resistant. Also Italian companies *Eurojersey* and *Lanifico Bengali* created textiles using combinations of wool and adaptable membrane under the brand *Senzitive*® [5].

Enzymes are biological catalysts for specific chemical reactions and require comparatively mild conditions. All enzymes are proteins and biodegradable. Most of the enzymatic scouring was made for cotton. As the time past, due to AOX restrictions required by EU, researchers attention was focused to enzymatic wool washing. El-Sayed *et al.* reported that the lipase pretreatment in the shrink-resist process of wool fabric could help to improve the wettability of the fibres and enhance shrink resistance about 2–3% [6]. Monlleó *et*

al. also published a paper about the lipases treatment of wool fibres, and they found that none of the commercial lipases changes the surface of wool significantly by using microscopic examination and wettability test [7]. Hutchinson *et al.* studied the activities of *thioesterase* and several lipases with the thioester substratemimic. Although the conversion of the substrate reached 90% under the optimal condition, there was no observable change in the wettability of the wool fabric [8]. The enzymatic process based on the chemically modified proteases has been investigated by Shen J. *et al.* and Silva CJSM *et al.*, a satisfactory anti-felting effect was achieved without any significant weight loss [9,10]. Cutinase enzyme belongs to esterase family. It hydrolyzes the ester bond of fatty acids by addition of water molecules [11]. Compared to most of the lipases and esterases, the efficiency of cutinase toward wax removal is better because of its open lid confirmation and small structure [11]. Agrawal *et al.* [11] demonstrated that cutinase treatment enhanced the degradation of cotton waxes and increased the hydrolytic rate of pectinase during cotton scouring. More recently, Ping Wag *et al.*, demonstrated that cutinase pretreatment could increase the efficacy of the subsequent protease treatment by improving the wettability, dyeability, and shrink-resistance of the wool fabrics [12].

In the present study we propose a simple, low cost, high quality, easy to adopt method using environmental friendly and commercially available materials. Commercially available enzyme cutinase and other functional preparation were applied to improve the hydrophilic properties of the 100% wool jersey structure. For hydrophobic exterior, 100% polyester satin (woven), jersey and spacer fabric have been used. After finishing treatments, the wettability was checked for each material and stable sandwich structures with high functional properties were made, for which the water vapor permeability were analyzed. The sandwich structure was made by attaching them at high temperature and pressure using thin polyamide layer.

2. Materials and methods

2.1 Materials

100% wool in jersey structure and 100% PES in jersey structure obtained from Smirodava, Romania. 100% PES in satin structure obtained from Whaleys Bradford Ltd. England. 100% PES spacer fabric was received from Ames Europe BV Enschede, the Netherlands. Enzyme used for wool pretreatment was NS 29141 cutinase (EC 3.1.1.74, *Fusarium solani pisi*) obtained from Tanatex Chemicals BV, the Netherlands. Commercial eco-friendly hydrophilic softener Ruco Pur Sly® obtained from Rudolf Chemie N.V., Belgium. A Ruco Dry Eco® is a cationic water repellent preparation of hyperbranched dendrimers and polymers received from Rudolf Chemie N.V., Belgium.

2.2. Methods

2.2.1. Enzymatic pre-treatment of wool fabrics: Cutinase pretreatment were applied to remove the bound fatty acids on the wool surface. The optimal conditions such 60°C temperature, 0.5M Tris-HCl buffer at pH8.0 and 100U of cutinase per gram of fabric was used in these experiments. To determine the incubation time that needs to remove the wool fatty acids surface fibre was essential for possible industrial application of cutinase in the wool scouring process. The effect of the incubation time on cutinase activity has been studied for 10 min to 10 hr (600 min); followed by rinsing with water and drying in the oven for 30 min at 50°C.

2.2.2. Hydrophilic treatment of wool fabrics: The wool fabrics were treated with 2% Ruco Pur Sly®, after pre-treatment with cutinase. The cationic softener preparation was impregnated in the samples with the device foulard. The pressure was varied from 1-10 Kp/cm, with a step of 1 Kp/cm, while keeping the foulard speed constant at 1 m/min. Finally wool samples were dried in oven at 50°C for 30 min.

2.2.3. Hydrophobic treatment of polyester fabrics: For super hydrophobic treatment, polyester 100% in satin, jersey and layered structure were used (Figure 1). Each sample with the size 10 x 20cm, were treated with 2-3% concentration of Ruco Dry Eco®. For all foulard impregnation experiments the pressure was varied from 1-20 Kp/cm, with a step of 1 Kp/cm, while keeping the foulard speed constant at 1m/min. All the samples were dried in the oven for 30 min at 70° C.



Figure 1. Polyester 100% a) satin structure b) jersey structure c) fabric spacer

2.2.4. Preparation of sandwich structure: Bi-functional fabrics were produced by inserting thin layer of breathable polyamide adhesive, between two layers of fabrics (satin-jersey, jersey-jersey and jersey-spacer fabric). Polyamide adhesive on silicone paper is first applied on hydrophilic wool through pressing and heat treatment. Removing the transfer paper, leaving adhesive on wool surface. The adhesive coated wool surface comes in contact with the super hydrophobic polyester material, through again pressing and heat treatment. Bi-functional multilayer (wool-polymide-polyester) material obtained in this way.

2.3. Testing procedure

2.3.1. Wettability: The wettability of wool fabric pretreated with cutinase was characterized by the wetting time (in sec). The wetting time of samples was determined according to the drop test (AATCC Test Method 39-1980). Ten measurements were taken on the different places of the fabrics.

2.3.2. Wet pick up (%): The wet pick up percentage for 100 % wool sample treated with Ruco Pur Sly® and for 100% polyester fabrics treated with Ruco Dry Eco® was calculated by following equation. Where 'a' is the weight of the fabrics after treatment (polyester 100%) combination treatments (wool 100%, and 'b' is the weight of the untreated fabrics. All samples were balanced at 25° C for 24h before testing.

wet pick
$$up = \left[\frac{a \cdot 100}{b}\right] - 100$$
 (1)

2.3.3. Vapour permeability of sandwich structures: Water vapour permeability was measured according to standard UNI 4818-26. Weight of the pots was recorded before introducing them into the climatic chamber and weigh again after 24h. The difference in water weight shows vapour quantity that was transmitted through the fabric. The water vapour transmission rate is expressed in (g/m^2) grams per square meter in 24h.

3. Results and discussions

3.1. Effect of cutinase pretreatment on wettability of Ruco Pur Sly® treated wool fabrics.

Enzymatic or chemical treatments can partially destroy or remove the covalently bound fatty layered in the surface of wool fibres that causes wool fibres hydrophobic. The cutinase pretreatment had clear effect on wettability of wool fibres by hydrolysis the hydrophobic outer layer.



Figure 2. Wetting time (sec) for wool treated with cutinase

Figure 2 shows the effects of cutinase pretreatment on the wettability of wool fabrics in terms of wetting time. The untreated wool sample takes more than 7 min for drop to disappear. The wettability improves rapidly, sufficient wettability of 6 sec was achieved after 1-hour treatment time. As can be seen from Table 1, for wool treated with Ruco Pur Sly®, varying the foulard pressure has a high impact on wet pick up. The pretreatment with cutinase for wool, allows accession of other functional finishing agents on 100% wool fabrics. 1h enzymatic treated wool shows high wet pick of 120% at 1KP/cm pressure. The pressure values between 2-6 KP/cm brings ideal 80-90% wet pick up, corresponding to hydrophilicity less than 1 sec. All the samples with lesser wet pick up (60%) showed wetting time of more than 1 sec (less hydrophilic). It was also found out that foulard speed has negligible effect of wet pick up at given pressure. It is important to have optimal (wet) pick of functional materials in order to get desired effect. Wet pick is a function of applied foulard pressure and wettability of starting material.

Speed (m/min)	Pressure (KP/cm)	Dry wt (g)	Wet wt (g)	Wet pick up (%)
1	1	1	2,2	120
1	2	1	1,9	90
1	3	1	1,8	80
1	4	1	1,8	80
1	5	1	1,8	80
1	6	1	1,8	80
1	7	1	1,6	60
1	8	1	1,6	60
1	9	1	1,6	60
1	10	1	1,6	60

Table 1. Wet pick up (%) for wool treated with Ruco Pur Sly®

3.2. Effect of Ruco Dry Eco® treated for super hydrophobic polyester fabrics

The different polyester fabrics were foulard using 2% concentration Ruco Dry Eco® for obtaining hydrophobic functionality. It can be observed from figure 3 that the wet pick up values are influenced by varying the pressure of the foulard device and by the porosity (Figure 1) of the PES materials used for the treatments. As expected spacer fabric shows highest wet pick up followed by jersey and least by PES satin fabric. A very high foulard pressure (around 20KM/cm) is required for spacer fabric to maintain wet pick in the range of 80-90%. PES Satin demonstrate poor wet pick up even at no foulard pressure, owing to it close structure. All PES samples with optimal wet pick up between 80-90 % exhibit hydrophobic (wetting time > 10 sec) without changing the touch or drapability of fabric.



Figure 3: Wet pick up (%) for PES treated with Ruco Dry Eco®

3.3. Vapour permeability for bi-functional fabrics.

Sweating is an important mechanism that the body uses to lose heat when the temperature begins to rise. However, sweat disrupts the comfort feeling of the user. There are two types of sweat: insensitive and liquid. Intensive sweat is transported as a vapour passing through the gaps between the threads of fabric. Intensive sweat removal capacity from a fabric is measured with the help of water vapor permeability, which is equal to the water vapor quantity eliminated in a square meter in 24 hours. A material with low water vapor permeability doesn't allow the sweat to pass through it, which leads to a discomfort feeling [13,14]. As can be seen in Figure 4, that the sandwich structure made of wool jersey and PES satin shows the lowest value of water permeability. Low porosity and low inherent hydrophilicity as reflected from low wet pick up (Figure 3) can be attributed to this behavior. Nevertheless, the structure made of hydrophilic 100% wool jersey and hydrophobic 100% PES spacer fabric shows the highest value for water vapor permeability, hence breathable. There is almost no difference between untreated and Ruco Pur Sly®/ Ruco Dry Eco® treated sandwich structures. Enzymatic, functional treatment has no negative influence on water vapour permeability, hence breathability. In conclusion, it is possible to produce comfortable, breathable bifunctional hydrophilic wool/hydrophobic spacer PES fabric by thermal adhesion using polyamide layer.



1 – 100% Wool jersey and 100% PES spacer fabric

2 - 100% Wool jersey and 100% PES jersey

3- 100% Wool jersey and 100% PES satin/woven

Figure 4. Water vapour permeability for sandwich structures

4. Conclusions

The experimental results demonstrate that the 100% wool fabric pretreated with enzyme cutinase then treated with softener Ruco Pur Sly® and 100% polyester fabrics treated with Ruco Dry Eco®, helped us to develop bi-functional hydrophilic/hydrophobic materials. The multilayer bi-functional structure was produced by thermal adhesion of wool-polyamide-polyester layer. The method to produce this fabric is quick, simple; cost effective, and the most important it uses commercially available ecological materials. Besides protection against environmental conditions (rain), the fabric has very good water vapour permeability. The best vapour permeability from the three sandwich structures is achieved for the fabric made of hydrophilic 100 % wool combined with 100 % polyester fabric spacer.

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