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Effect on Comfort Properties of Using Superabsorbent Fibres in Nonwoven Interlinings

Abstract
Moisture and sensations associated with dampness on the skin and in clothing are fundamental to discomfort. A series of subjective trials on dampness perception and tests with a special humidity sensor and a static thermal resistance test device have been made in order to determine the role of superabsorbent fibres in parallel nonwoven interlinings from the point of view of their comfort properties. Five subjects evaluated six parallel nonwoven samples containing polyester, polyester/co-polyester and super-absorbent fibres at different ratios and different excess moisture values. The tests showed that dampness of perception and fibre hygroscopicity were interrelated. The positive role of hygroscopic fibres in preservation of thermo-insulating properties as well as 'dry-hand' at high water content was confirmed.

Key words: *Comfort, parallel nonwovens, super-absorbent fibre, perception of dampness, humidity sensor, thermal resistance, subjective trials.*

Introduction

Moisture and the sensations associated with dampness on the skin and in clothing are fundamental to discomfort. High vapour concentrations in the skin-clothing microclimate, and more so liquid moisture on the skin or in clothing, lead to sensations of clamminess and stickiness during wear [1].

Heat transfer from the body through a fabric is a complex phenomenon affected by numerous factors such as the thickness of the fabric, the quantity of the air entrapped around the body, and the moisture content, transport & motion of external air. Thermal clothing must provide thermal insulation, and must sustain its insulating properties through prolonged usage and cleaning [2].

Hygroscopic fibres absorb water vapour when surrounded by humid air, and release it in dry air. The condensed water present in the clothing creates feelings of discomfort because of dampness. The role of hygroscopic fibres has been investigated by some authors, and the results confirmed that fabric sorption can enhance moisture transport [1, 3, 4].

In this study, we tested six parallel and through-air thermobonded nonwoven fabrics designed for use as interlinings in sportswear and containing superabsorbent fibres at differing ratios. A rapid static method using a heat-flux sensor was used to test the thermal resistance of the wetted samples. The physiological properties were tested by a specially developed humidity sensor. Five subjects evaluated the dampness of the above-mentioned samples at different excess moisture values.

Materials and methods

Thermal resistance test device

The static method is used to measure the thermal resistance of the samples. The measuring device is shown in Figure 1. The upper vessel (3) is heated by constantly circulating water at a flow speed of 5 l/min from a thermostat (1), so that a constant temperature is maintained at the bottom of the vessel which serves as a heat source. The lower vessel (4) is connected to circulating water at room temperature which also proceeds at a flow speed of 5 l/min from another thermostat (2). The distance L is precisely set by an adjustable support (7) placed under the lower vessel to ensure a given pressure on the sample (5). A heat flux sensor (6) with dimensions of 50×50 mm is mounted on the surface of the lower vessel, coincident with the centre of the sample. A time-temperature curve is generated from the recorder (10) to ensure that the heating process has stabilised before a measurement is taken.

In order to determine the exact temperature difference ΔT between the upper and lower surfaces of the sample, a pair of differential thermocouples (8) are placed so that one is on the surface of the heat flux sensor and the other on the upper surface of the sample tested, both being aligned

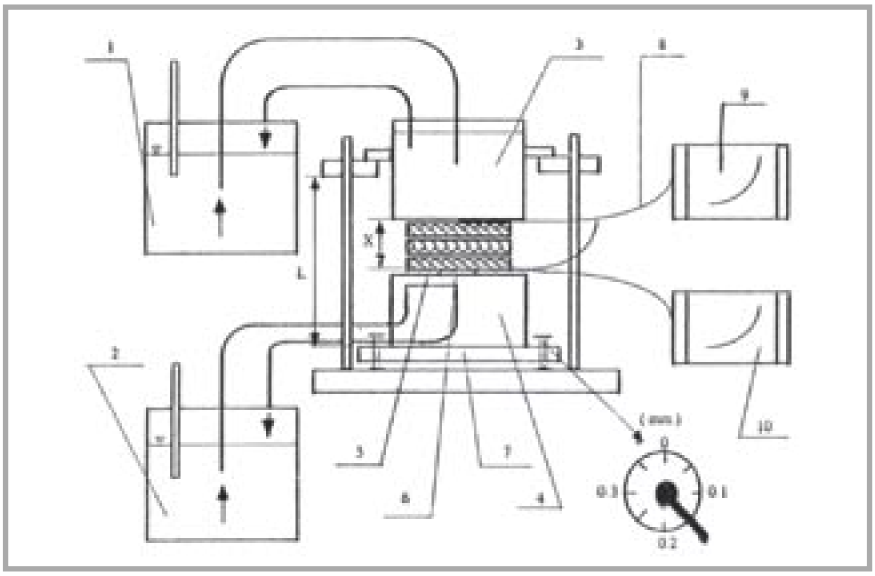

Figure 1. Thermal resistance test device; 1- Thermostat 1, 2 - Thermostat 2, 3 - Upper vessel, 4 - Lower vessel, 5 - Sample, 6 - Heat flux sensor, 7 - Adjustable support, 8 - Differential thermocouple, 9 - Recorder 1, 10 - Recorder 2.

vertically. The signal generated by the differential thermocouples is fed into a recorder (9), and the exact ΔT can be read using a voltage-ΔT calibration graph.

2.2 Humidity sensor

A special humidity sensor was developed to study humidity close to the skin when in contact with a wet textile material or leather. The sensor (Figure 2) consists of a plastic plate with dimensions of 80×80 mm and a net of electric conductors on its surface. A hygroscopic sheet of polyvinyl alcohol of 0.5 micron thickness containing lithium chloride is placed on the net of the conductors and sheltered by a woven web of polyamide monofilament [5].

When a wet textile sample is placed on the sensor, the water is distributed between the textile material and the hygroscopic sheet. The state of equilibrium is reached within 10-20 seconds. The amount of water in the hygroscopic sheet significantly influences the electric conductivity as measured.

The balanced water distribution is represented by the constant K:

$$K = C_S/C_T$$

where C_S is the concentration of water in the hygroscopic sheet of the sensor and C_T is the concentration of water in the textile material.

The balanced concentration of water C_S is a function of the textile material, especially of its hygroscopicity, and of the original water content in the textile material. In this respect, the hygroscopic sheet of the sensor represents human skin. The higher the sensor's electric conductivity, the more 'wet-hand' can be expected in contact with the corresponding wet textile material.

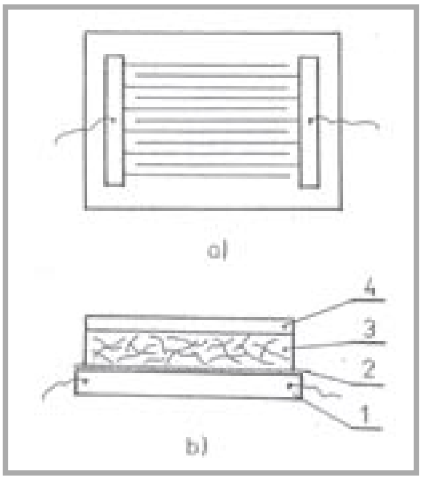

Figure 2. Humidity sensor; a) Plastic plate with conductors, b) Side view of the sensor with the sample on it; (1) Palstic plate, (2) Woven web of filaments, (3) Sample, (4) Load.

Table 1. Fabric Properties.

Sample code	% of SAF	% of PET	% of PET/co-PET	Structure of web	Thickness, m
A	0	70.0	30	Parallel	0.0185
B	1.5	68.5	30	Parallel	0.0175
C	3.5	66.5	30	Parallel	0.0175
D	7.5	62.5	30	Parallel	0.0175
E	15.0	55.0	30	Parallel	0.0170
F	30.0	40.0	30	Parallel	0.0155

Subjective trials

Three female and two male subjects ranging in age from 24 to 34 evaluated the wetted samples. Each person evaluated the dampness of the samples at different content of water percentages in standard atmospheric conditions. Five scores were used for evaluating the dampness such as definitely dry (1), barely dry (2), slightly damp (3), moderately damp (4) and very damp (5).

Before the actual testing began, two 'reference' fabrics, one 'dry' and one 'very damp' were placed over each subject's forearm. The subjects were told that the reference fabrics represented the extremes and that they would not receive fabrics either dryer or damper than these extremes. They were permitted to touch either of these fabrics again during the trial for comparison with a test fabric if they needed a reminder [1].

Wetting the materials

To receive the wet textile samples with constant water content in the sample thickness, the following method was developed. Three layers of the tested textile material-circular samples with a diameter of 0.14 m are conditioned at laboratory temperature and humidity for 24 hours, and weighed. They are then placed over the water level of a temperature of 70°C and covered by a polyethylene foil. The water evaporated from the bath condenses inside the textile material due to the temperature gradient between the bath and the ambient air. It could be shouted that the concentration of water inside the middle layer is constant in the fabric thickness. Only the middle layer is taken for the measurement, by the methods. The excess moisture inside the sample depends on the time of evaporation, and is found by weighing the sample inside a plastic bag.

Materials

Six different parallel thermobonded nonwovens were used for testing. The area weight was measured according to standard EDANA 40.3-90 [6], and the thickness was measured according to standard EDANA 30.4-89 [7]. The fabric properties are listed in Table 1. The Super Absorbent Fibre (SAF) used in this research is produced under the trademark Oasis by Technical Absorbents Ltd. (England). It is a cross-linked acrylate copolymer, partially neutralised to the sodium salt, in fibre form [8].

Results and discussion

At equilibrium with the ambient room conditions, fabrics are said to be at 'equilibrium regain'. The addition of water to fabrics, as may happen during a rain shower or with sweat uptake during wear, increases the water content so that it is in 'excess equilibrium' [1].

The tests were made in standard atmospheric conditions. Throughout this paper, the moisture content of damp fabrics will be expressed as a percentage of 'excess moisture' (EM), and it is calculated according to the following formula:

$$EM = (WW\text{-}CW)/CW \times 100, \%$$

where WW is wet weight and CW is conditioned weight.

Thermal conductivity is calculated thus:

$$\lambda = \mathrm{CLU}/\Delta T$$

where λ is thermal conductivity (W/Km), C is the constant of the sensor (W/m^2/μV), L is the thickness of the material (m), U is the input voltage to the sensor (V) and ΔT is the temperature difference between the two surfaces of the material (K).

Thermal resistance R is calculated thus:

$$R = L/\lambda.$$

Each value calculated for the thermal resistance and conductivity of the humidity sensor are the average of three tests for each sample. I analyzed the experiments using analysis of variance. The results are given in Table 2. All analysis of variance were at the 5% level of significance.

Thermal resistance, the electrical conductivity of the humidity sensor and subjective trial measurements were made for all the kinds of samples prepared (A - F) for 2, 4, 6, 8, 10, 15, 20 and 30% excess moisture levels. As mentioned by Plante et al. [1], Scheurell [9] et al. quoted 10% by weight as being close to the maximum amount of added water accumulated in cold weather clothing, even after heavy exercise. Therefore the levels of moisture experienced in more normal conditions, with lighter clothing and moderate exercise, would be unlikely to exceed this. In this study, superabsorbent fibre (SAF) was used at differing ratios together with polyester and polyester/copolyester fibres. During the measurements, it was seen that the samples with a greater content of SAF could absorb far more than this, above the 10% ratio up to 80% after being wetted for two hours in water steam, so it was decided to take the excess moisture levels of 15, 20 and 30% into account also.

The relationship between thermal resistance and the excess moisture of the samples are given in Figure 3 [10]. Thermal resistance decreases as the content of water percentage increases, as expected.

As seen in Figure 3, samples A and B have more or less similar curves. Sample B contains 1.5% SAF, and this ratio does not seem to cause any significant change in the thermal resistance values, if we compare samples A and B. Samples C, D, E and F seem to have higher thermal resistance values than samples A and B generally.

If we look at Figure 3 again, it is interesting that up to 8% excess moisture, samples C and D have similar curves, samples E and F have more or less similar curves and samples A and B have similar curves. A t-test for paired data to compare the thermal resistance values was applied by SPSS software, and the results are given in Table 2. The difference between sample A and sample B is insignificant. The differences between samples B and samples C, D and E are statistically significant. The difference between sample B and F is insignificant. The difference between samples C and D and the difference between samples E and F are statistically insignificant.

From 8% to 15% excess moisture, the curves tend to cluster close to each other. The differences between sample A and samples C, D, E and F are statistically significant. The differences between samples C, D, E and F within each other are statistically insignificant (Table 3). Over 15% excess moisture, the differences between the samples become insignificant (Table 4). As the excess moisture increases, the thermal resistance values are very close to each other, as seen in Figure 3.

Up to 10% excess moisture, the grading of the curves proceeds similarly to samples C, D, E and F. This is an expected result, because it was observed that if a mass of superabsorbent fibre is wetted and then dried, the fibres lose their fibre form and the mass is shaped as a very hard material. Solidity is a factor that increases thermal conductivity, and the thermal insulation depends on the quantity of the still air trapped/held between the fibres within the pores. So although the free water is absorbed within the fibre structure by SAF (which may be seen as one advantage of using SAF from the point of view of increasing the thermal insulation), using SAF at high percentages may then be a disadvantage. As a result, it can be said that adding 3.5% SAF is enough to improve the thermal properties of the nonwoven fabric, because sample C gives the best results from the excess moisture values from 2% up to 30%.

Table 2. Analysis of variance results; R - thermal resistance, S - electrical conductivity of the humidity sensor.

Source	Dependent variable	F	Sig.
Corrected Model	R S RATING	186,572 330,191 11,303	,000 ,000 ,000
Intercept	R S RATING	60063,551 17945,631 2781,054	,000 ,000 ,000
SAFRATIO * EM	R S RATING	21,464 77,543 5,078	,000 ,000 ,000
SAFRATIO	R S RATING	538,938 911,670 31,020	,000 ,000 ,000
EM	R S RATING	618,264 1163,154 24,594	,000 ,000 ,000

The relationships between the conductivity of the humidity sensor and the excess moisture of the samples are given in Figure 4 [10]. It is seen from Figure 4 that the thermal conductivity of the sensor increases as the content of water percentage increases. This result is supported by Jirsak et al. [6]. It is seen that the values for samples A and B are far larger than samples C, D, E and F. For samples C, D, E and F, at lower excess moisture values such as 2% and 4%, the conductivity values are very close to each other. Over 6% excess moisture, the curves tend to differ from each other, but after 15% samples C, D and E have similar curves. There is no proper order between the samples. This may be because of the condensed water present in the samples, but it is interest-

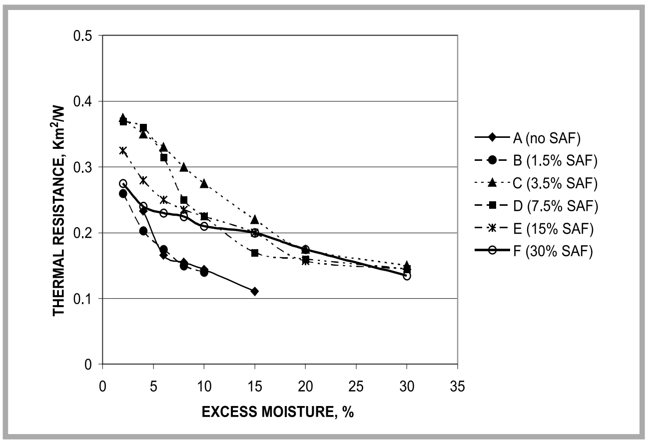

Figure 3. The relationship between thermal resistance and excess moisture.

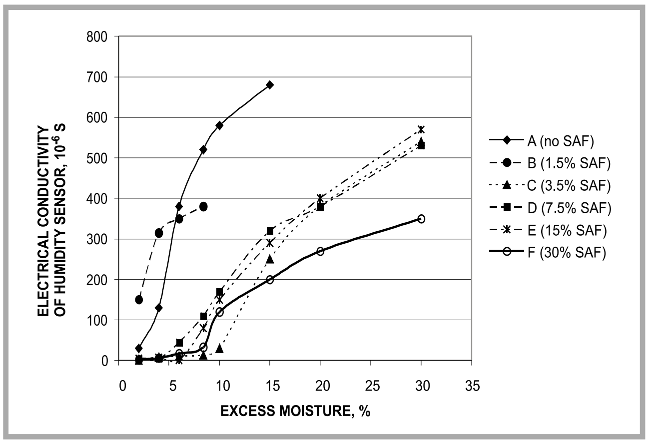

Figure 4. The relationship between electrical conductivity of the humidity sensor and the excess moisture.

ing that the conductivity values of the humidity sensor for sample F are significantly less than the other samples. This situation may be explained by sample F's having a far higher SAF content (such as 30%) than the others. Even at higher excess moisture values, the humidity of it is felt less than in the other samples.

Five subjects, three females and two males, ranging in age from 23 to 34 years, were recruited. For all the subjective test, the results are the average of five individual expressions, each of the tested 3 times which results in averages of 15 values. All the fabrics were perceived as increasing in dampness with increasing excess moisture (Figure 5). Up to 6% excess moisture, samples that have superabsorbent fibre in their content were graded as 'definitely dry', whereas sample A has a curve with an increasing slope as the excess moisture increases. Dampness in sample A was perceived immediately after 2% excess moisture. Between 6% and 15% excess moisture values, sample A was graded as being damper than the others. Samples B, C and D have similar curves; samples E and F were perceived still as being 'definitely dry'. The perception of dampness increased in samples over 15% excess moisture, as the excess moisture increased. Samples B, C and D were perceived as 'slightly damp' at 20% excess moisture, whereas samples E and F were still perceived as 'definitely dry', whereas samples E and F were still perceived as 'barely dry'. samples E and Fwere perceived as 'barely dry' at 30% excess moisture.

Samples E and F contain a very high percentage of superabsorbent fibres, 15% and 30% respectively, so the perception of dampness in them is felt after 20% excess moisture. This is in fact an expected result. There may be condensed water within the samples, but if it is not present on the surface of the samples, they are not perceived as damp. The samples are voluminous nonwoven fabrics, so the condensed water may be trapped/held between the fibres inside the fabrics. Condensed water may affect the thermal conductivity measurements, but may not affect the perception of dampness by subjective trials. The perception of dampness is greater when the moisture is held as free liquid, rather than internally absorbed; thus sample A, which has no SAF, was perceived as damper than the other samples which did contain SAF. Samples B, C and D were intermediate in behaviour to samples E and F. Sample E was perceived as damper than sample F at 30% excess moisture.

Measuring the thermal resistance of wet textiles is a difficult and sophisticated process. First of all, the test must be done quickly in order to prevent the textile from exchanging moisture with the environment. The condensed water present in the textile is another important factor. The distribution of the condensed water is important and should be homogenous. Despite all these factors, it can be said that the results seem reasonable.

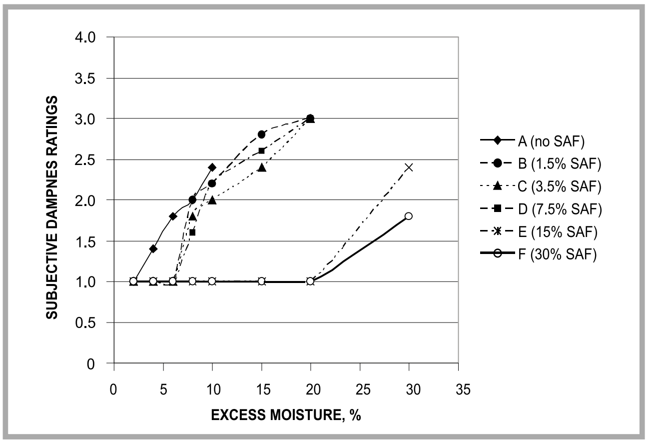

Figure 5. Subjective dampness ratings.

Conclusion

The samples were wetted first, and then the measurements were done until the moisture reaches equilibrium with the environment's moisture. Perhaps the opposite should be done, in order to prevent the superabsorbent fibrefrom solidifying after being dried again affecting the measurements.

The hygroscopicity of the fibres significantly influences the perception of fabric dampness. Fabrics that contain water in excess of the equilibrium regain for the surrounding ambient conditions are perceived as damp during skin contact, which depends on the moisture sorption characteristics of the fibres that they contain. Furthermore, the thermal properties are improved by the usage of hygroscopic fibres, because the free liquid within the fabric structure is an important factor that increases thermal conductivity. For the samples tested in this study, it can be concluded that adding 3.5% SAF is enough to improve the thermal properties of the nonwoven fabric and the perception of dampness, but resistance to washing the fabrics with superabsorbent fibres should be investigated in further study, because thermal clothing must provide thermal insulation and must sustain the insulating properties through prolonged usage and cleaning.

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