Smart Breathable Fabric

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ABSTRACT: Smart breathable cotton fabrics were made using a temperature-sensitive copolymer – poly(*N-tert*-butylacrylamide-*ran*-acrylamide :: 27 : 73). The cotton fabric was coated using an aqueous solution (20 wt%) of the copolymer containing 1,2,3,4-butanetetracarboxylic acid as a cross-linker (50 mol%) and sodium hypophosphite (0.5 wt%) as a catalyst, followed by drying (120°C, 5 min) and curing (200°C, 5 min). The integrity of the cross-linked coatings to the fabric was observed to be excellent. The coatings after integration to the cotton substrate retained temperature-sensitive swelling behavior and showed a transition in the temperature range of 15–40°C. Below 15°C, the coatings swell by 800% while above 40°C they deswell to a swelling percentage of less than 50% (on the basis of dry weight). The transition to swelling was completed in about 20 min while deswelling was quicker in 2–3 min. The response was found to be reversible and stable to repeated cycles of transition. The coated fabrics showed a temperature-responsive water vapor transmission rate (WVTR). The WVTR values of the responsive (copolymer coated) and the nonresponsive (poly(acrylamide) coated) breathable fabric were measured as a percentage (transmission percentage) of control uncoated substrate. The transmission percentage at 20% relative humidity for the copolymer coated fabrics was found to change across the transition temperature (15–45°C) from 58 to 94% compared to the poly(acrylamide)-coated fabrics which changed only from 70 to 94%, showing a clear response to changing environmental temperature.

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1528-0837/05/03 0139–17 $10.00/0 DOI: 10.1177/1528083705047905

KEY WORDS: smart textile, stimuli-sensitive polymer, water vapor transmission, breathable coating, poly(acrylamide).

INTRODUCTION

HYDROPHOBIC COATINGS ARE most prevalent in the breathable coatings and laminates. The hydrophobic coatings are microporous having a pore size of 0.1–50 μm, which allow the passage of water vapor but resist the penetration of liquid water. Fabrics are also coated with copolymers having both hydrophilic and hydrophobic segments. The hydrophobic part provides water resistance and facilitates adherence of the coating to the substrate, while the hydrophilic part allows water vapor permeability [1–7].

Because of their hydrophobic character, hydrophobic coatings tend to show lower water vapor transmission values and therefore do not form the ideal approach for breathability. The fabrics coated with hydrophilic–hydrophobic copolymers have been able to achieve varied degrees of water vapor permeation and protection. But, the hydrophobic segments, which are incorporated in significant proportions to obtain the required durability, lead to lowering of the water vapor transmission rate (WVTR). Ideally, a highly hydrophilic system may provide highly efficient water vapor transmission properties. However, such systems are not used, because they are water soluble and cannot provide a durable coating onto a fabric for normal wash and wear use.

Poly(acrylamide) is a highly hydrophilic polymer, which can provide good breathable properties provided it can be chemically integrated onto a fabric. Recently, we have reported the feasibility of obtaining poly(acrylamide)-coated cotton fabrics using polycarboxylic acid cross-linkers in the presence of a catalyst. The cross-linkers were found to form covalent bonds between amide-side groups and hydroxyl groups of cotton fabric to give highly durable breathable coatings [8].

The above-mentioned approaches produce breathability designed for a particular application. These coatings are passive and they do not adapt to changing environmental conditions such as temperature. A breathable fabric with a temperature-dependent response may be desirable for certain specialized applications where high variations of temperature are encountered over a short period.

One of the approaches may be to use stimuli-sensitive polymer (SSP) coatings integrated into the fabric structure. However, the main challenge is to integrate them chemically and still retain the responsive behavior. This paper is an attempt to apply specially designed SSP copolymer,

poly(*N-tert*-butylacrylamide-*ran*-acrylamide), to a cotton fabric and produce a temperature-dependent breathability.

EXPERIMENTAL

Preparation of Coated Sample Materials

Scoured and bleached cotton fabric of density 1.34 g m^{-2}, with both warp and weft of linear density 148 dtex and a thread density in plain weave of 60 ends and 28 picks per 10 mm was used in the experiments. The fabric was used after washing it at a temperature of 60°C with 1 g L^{-1} of nonionic detergent.

1,2,3,4-Butanetetracarboxylic acid (98+%) (BTCA) was obtained from Lancaster Synthesis, Morecambe, England. Sodium hypophosphite (98%) was obtained from GS Chemical Testing Lab & Allied Industries, Mumbai. Poly(acrylamide) and poly(*N-tert*-butylacrylamide-*ran*-acrylamide) in the composition of 27 : 73 was synthesized using the method described elsewhere [9].

Preparation of Coating Solutions

A 20 wt% solution was prepared by vigorously stirring a purified and dried temperature-sensitive polymer (poly(*N-tert*-butylacrylamide-*ran*-acrylamide) :: 27 : 73) in double distilled water for 20 min. This mixture was left in the refrigerator for 48 h, for deaeration to obtain a highly viscous, clear homogeneous solution. Similarly, a 4 wt% solution of poly(acrylamide) was also prepared in distilled water.

Selection of Suitable Cross-linker

Based on our earlier study [10], BTCA was selected as a cross-linker, while sodium hypophosphite was used as a catalyst. The concentrations of BTCA were selected based on our earlier studies [8,10]. The cross-linker (BTCA) concentration was kept at 50 mol%, which was calculated on the basis of available amide groups in the polymer. The catalyst concentration was varied between 0.05 and 0.5 wt%.

Coating of Fabrics

The required amount of the cross-linker BTCA and the catalyst (sodium hypophosphite) were added to the polymer solutions and used for coating

Table 1. Details of samples prepared.

Sample	BTCA conc. (Mol % of available amide groups in polymer)	Weight of BTCA (g 100 g^{-1} of solution)	Number of coatings	Add-on (%) (dried weight)	Wt. loss (%)	
					Ist wash	IInd wash
Control	–	–	–	–	–	–
SSP50-1	50	4.961	Single	13.36	2.3	Zero
SSP50-2	50	4.961	Double	22.76	11.93	Zero
SSP50-3	50	4.961	Triple	43.21	6.53	Zero
PAM50-3	*	0.9922**	Triple	24.00	11.95	Zero

Control: uncoated cotton fabric.
*Cross-linker concentration on molar basis was maintained similar to SSP50-2.
**BTCA concentration on the basis of 4 wt% poly(acrylamide) solution.

on cotton fabric in Ernst-Benz™ coating machine, model: KST-350. The coating was carried out with a continuous knife-over-blanket arrangement, dried at 120°C for 5 min and cured at 200°C for 5 min in the Ernst-Benz™ curing chamber, model: KTF-MD-350. Different samples were made with 1–3 coatings to achieve desirable add-ons and different concentrations of cross-linker as given in Table 1. For samples obtained using multiple coatings, the sample was dried subsequent to each coating and cured only in the end after the final coating was dried. The add-on was obtained by calculating % change in the weight of the fabric after drying and curing.

Characterization of Coated Samples

Evaluation of Integrity of Coating

The SSP-coated samples were evaluated for integrity of coatings by washing them at a temperature of 6°C, with stirring, for 5 h. A second wash was also given to the fabrics, following the above procedure, to evaluate any further loss. The samples were oven dried and evaluated for weight loss after each washing cycle. The samples coated with poly(acrylamide) were evaluated as per the procedure described earlier [8].

Physical Characteristics of Coated Fabrics

The coated (both SSP copolymer and poly(acrylamide) coated) samples were also evaluated for coating-evenness, resistance to hydrostatic head,

and air permeability. The coating-evenness was evaluated by cutting and weighing the dried, conditioned $100 \times 100\,mm^2$ pieces of coated fabric. The pieces were cut randomly along both the length and width of the fabric. The control and coated fabrics were evaluated for water resistance to hydrostatic head using 'AATCC test method 127–1977' on a 'Shirley Hydrostatic-head Tester.' The control and coated fabrics were evaluated for air permeability according to 'Indian Standards, IS 11056-1984,' using the 'Textest FX 3300, Air-Permeability Tester.'

Transition Properties of Coated Fabrics

The transition properties were evaluated for the SSP-coated fabrics for transition temperature of swelling and deswelling, kinetics of transition, and thermoreversiblity. All the samples were washed twice prior to the test.

The transition temperature of the SSP-coated fabric was evaluated by measuring its swelling percentage (water uptake) with temperature in the range of 6–80°C. The coated fabric was placed in a water bath at a given temperature, till the equilibrium was achieved. The swollen coated fabric was weighed on a microbalance after gently pressing it between two layers of filter paper. To remove the effect of water absorbed by the substrate fabric, separate experiments were conducted to estimate the water retained by the substrate (uncoated control fabric) at different temperatures. The absorbed water by uncoated fabric was found to be 91% at 6°C and 86% at 80°C. Several readings were taken to estimate the variation in reading, which came out to be ±2%.

The swelling percentage at any given temperature was taken as:

$$\text{Swelling } \% = \frac{W_t - W_{\text{wet fabric}} - W_{\text{dry coating}}}{W_{\text{dry coating}}} \times 100$$

where, W_t is the weight of the coated fabric at time 't,' here 't,' is at equilibrium; $W_{\text{wet fabric}}$ is the weight of the wet substrate (uncoated fabric) at the test temperature; and $W_{\text{dry coating}}$ is the dry weight of coating.

The kinetics of transition was evaluated by immersing the SSP-coated samples in water at 6°C, and recording the % swelling with time as given above. Similarly, the deswelling kinetics was obtained, by placing the swollen coated samples at 80°C and recording the swelling % with respect to time.

The reversibility of the thermal transitions was studied by placing the coated sample in double distilled water repeatedly at temperatures of 6 and 80°C for five cycles. The samples were placed at each temperature for 30 min. The swelling % was evaluated as presented above.

Evaluation of Water Vapor Permeability

The water vapor permeability of the fabric samples (both coated and uncoated) was evaluated at different environmental conditions using the British Standards, BS 7209:1990. The experimentation was carried out in an Environmental Test Chamber (ETC) fabricated by International Equipments, Mumbai. The ETC was designed to maintain temperature with an accuracy of $\pm 0.5^{\circ}$C and relative humidity at $\pm 1\%$ in a chamber of dimensions $460 \times 492 \times 606\,\text{mm}^3$. Inside the chamber, a turntable of diameter 402 mm was revolved at a speed of 6 revolutions per minute, using a microcontroller. Four water-filled cups with mouth surface area of $3000\,\text{mm}^2$ were placed toward the periphery of the turntable. The mouths of the water-filled cups were covered with the test samples. The air gap between the water surface and the samples was kept at 10 mm. The samples were secured with adhesive tape. In each experiment, four samples were evaluated: two SSP copolymer-coated fabrics, one poly(acrylamide)-coated fabric, and one uncoated control fabric. The experiments were carried out under different conditions of temperature and relative humidity. Three temperatures used were 15°C, a temperature below the transition, where the polymer coating exists in the swollen state, 30°C, a temperature at the center of the transition, and 45°C, a temperature above the transition, where the polymer coating exists in a deswollen state. The different relative humidity conditions were 20, 35, 65, and 95%.

The fabric samples, secured to the beakers, were conditioned for 12 h at the test parameters, prior to the test. The beakers were weighed at the start of the test. The samples were tested at a given temperature and relative humidity for a predetermined time ('t' h), and the water vapor transmission rate (WVTR) was calculated by measuring the loss of water in the beakers using the following equation:

$$\text{WVTR} = \frac{\text{Weight loss of water in time '}t\text{'} \times 10^6 \times 24}{t \times 3000}\ (\text{g m}^{-2}\,24\,\text{h}^{-1})$$

RESULTS AND DISCUSSION

Coating of Cotton Fabric

The add-on percentage obtained for the various coated samples is given in Table 1. A poly(acrylamide)-coated (nonresponsive) sample was also

prepared with add-on similar to SSP50-2 sample for comparison. This sample was then used as a benchmark for evaluation of the functionality imparted by the stimuli-sensitive copolymer.

Coating Evenness

The CV% of coating add-on percentage at randomly selected places on the coated samples was found to be between 0.7 and 1.4%.

In our previous studies we had found that polycarboxylic acid compounds such as BTCA and citric acid are appropriate for carrying out cross-linking between amide side-groups of acrylamide moieties and hydroxyl groups of cotton. However, BTCA was found to provide superior properties than citric acid and, therefore, in these experiments BTCA was used as the cross-linker [7]. In this study the curing time, temperature, and the concentration of the catalyst have been optimized to obtain a minimum curing time without occurrence of yellowing. The curing time was found to reduce from 25 to 5 min, as the temperature was raised from 160 to 200°C. It was found that the catalyst concentration of 0.5% was necessary to bring about a well-integrated coating.

Integrity of Coating on Cotton Fabrics

The method used for the evaluation of integrity for poly(acrylamide) coatings on cotton fabric [8], was not found to be appropriate in the case of the SSP-coated fabrics. The earlier method used a temperature of 60°C for carrying out harsh wash. However, the same treatment when given to the SSP-coated fabric gave a negligible weight loss. This is because the SSP coatings become insoluble at temperatures above the transition temperature. It was therefore felt appropriate to redesign the test; using temperatures lower than the transition temperature. The loss of weight for the SSP coatings was found to be in the range of 6–14%, for the first wash and undetectable (indicated as zero) during the subsequent wash (Table 1). No weight loss in the second wash indicated that the SSP coatings were properly integrated to the cotton fabric. Weight loss in the first wash may comprise water soluble catalyst, unreacted BTCA, and uncross-linked polymer.

The use of BTCA as a cross-linker has resulted in better cross-linking of polymer coatings to the fabric substrate compared to the case when citric acid was used as the cross-linker. The weight loss percentages of the various coated samples including that of the poly(acrylamide) using BTCA were found to be substantially lower than those reported in our earlier study [8] for poly(acrylamide) using citric acid. This may be due to the fact that the –OH group in the citric acid structure might hinder the esterification with

the hydroxyl groups of the cellulosic structure [11]. Further, BTCA has four carboxylic acid groups compared to three in citric acid resulting in higher efficiency of cross-linking.

Transition Properties

Rate of Transition

It was found that the SSP-coated samples showed a fairly quick response to swelling and even quicker response to deswelling. Samples SSP50-1 and SSP50-2 attained their equilibrium values (swelling %) in approximately 5 and 20 min, respectively, while SSP50-3 took a substantially longer time of about 1440 min (Figure 1).

The significantly longer time taken by SSP50-3 can be explained on the basis of thicker coatings due to substantially higher add-on (43.21%), as compared to 22.76 and 13.36% for the double- and single-coated samples. As swelling and deswelling are diffusion-controlled processes, thicker films are expected to take a longer time for the transition.

The samples SSP50-1, SSP50-2, and SSP50-3 showed identical swelling percentages at equilibrium irrespective of their add-on percentage (or thickness).

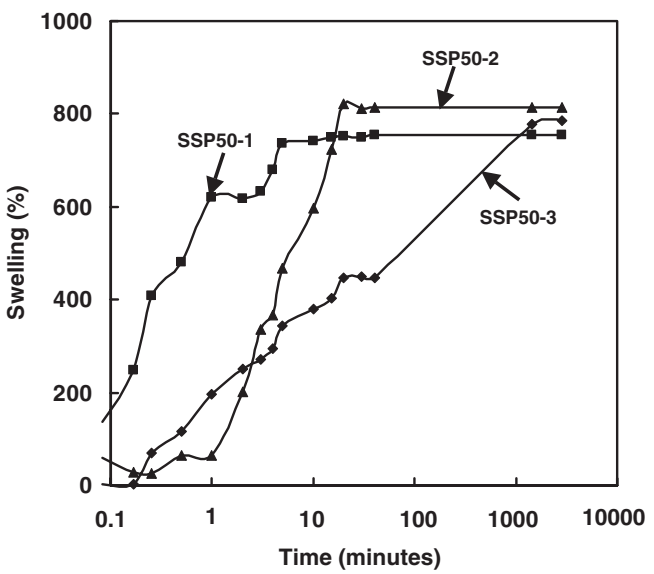

FIGURE 1. Swelling rate below transition temperature of the SSP-coated fabrics.

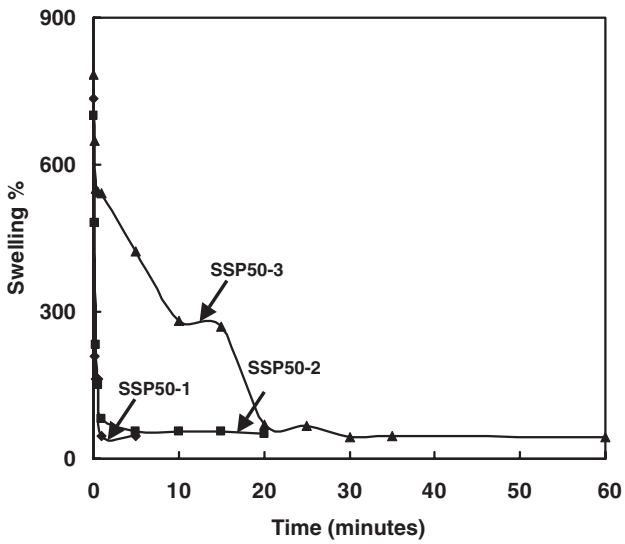

FIGURE 2. Deswelling rate above transition temperature of SSP-coated fabrics.

The deswelling time showed a similar trend to that observed for swelling time (Figure 2). The samples with higher add-on percentage SSP50-3 took longest to deswell (i.e., 30 min), while SSP50-2 and SSP50-1 showed complete deswelling within 5 and 1 min, respectively.

Reversibility

Figure 3 shows a repeated swelling–deswelling of SSP50-1, SSP50-2, and SSP50-3 over five cycles. Samples (SSP50-1 and SSP50-2) show a high swelling % of around 800 and 750% respectively, while the SSP50-3 sample shows a value of about 450%. This should not be mistaken by the equilibrium value as this sample shows a very slow rate of swelling and a final value of 784% in 1440 min. The cycling experiment was carried out by placing the fabrics for only 30 min and therefore the complete swelling could not be reached for this sample. The deswelling of all the samples was nearly complete to about 50%. The results proved that the smart textile samples had good transition reversibility and can be used in applications with frequently changing environmental conditions.

Transition Temperature

The response of the SSP-coated samples with respect to temperature is shown in Figure 4. The transition was found to be broad over a range of

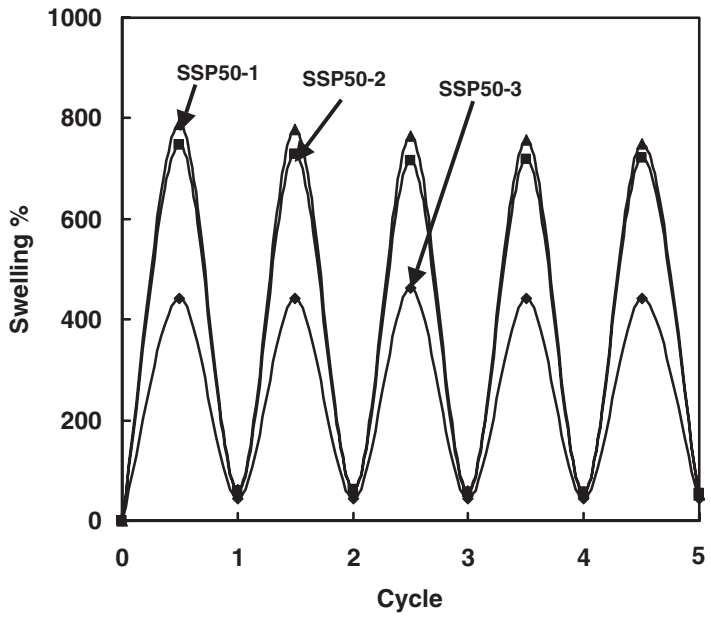

FIGURE 3. Cyclability of transition in SSP-coated fabrics.

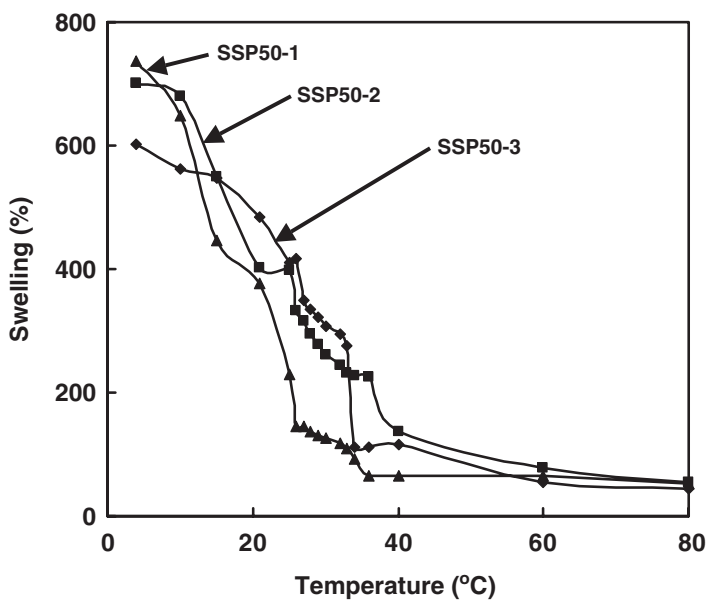

FIGURE 4. Transition temperature of SSP-coated fabrics.

15–40°C. In comparison, in our earlier studies [10], the films of the same copolymer cast on glass substrate had resulted in much sharper transition at around 21°C. The broad transition may be because of the heterogeneous composition of the structure. Since the cross-linking density between the polymer chains and the cotton substrate may vary locally in this composition, the multiplicity in the transition may result in the overall broad response of the SSP-coated fabric. The occurrence of the above transition over a broad temperature range is similar to that observed for grafted poly(*N*-isopropylacrylamide) on cellulose substrates [12,13]. In grafted samples, the transition was reported to occur in the temperature range of 20–40°C, compared to the sharp transition observed in gels of poly(*N*-isopropylacrylamide) (at 32°C).

Water Permeability

The resistance to penetration by water under pressure was found to be highest for the triple-coated (SSP50-3) sample and lowest for the single-coated (SSP50-1) sample for both before and after washing (Table 2). This is expected because multiple coatings and higher add-ons result in the formation of defect-free coating. Surprisingly, the SSP-coated fabric showed significantly lower resistance to water penetration compared to equivalent poly(acrylamide) coating. Figure 5 shows the electron micrographs of the SSP-coated fabrics before and after washing. Before washing, the coatings appear to be continuous with occasional occurrence of small pores (~50 μm diameter). These pores may have appeared during processing due to the presence of some air bubbles in the coating solution. The above pores may be responsible for lower values of hydrostatic head observed in these samples. Upon washing, numerous cracks appear on the coating. These cracks are long, but with microlevel thickness. Also there appears to be a small increase in the pore size due to loss of water soluble components. This may be the

Table 2. Hydrostatic resistance of coated fabrics.

	Hydrostatic head (mm)	
Sample	Unwashed sample	Double washed sample
SSP50-1	80	60
SSP50-2	380	300
SSP50-3	740	580
PAM50-3	1280	800

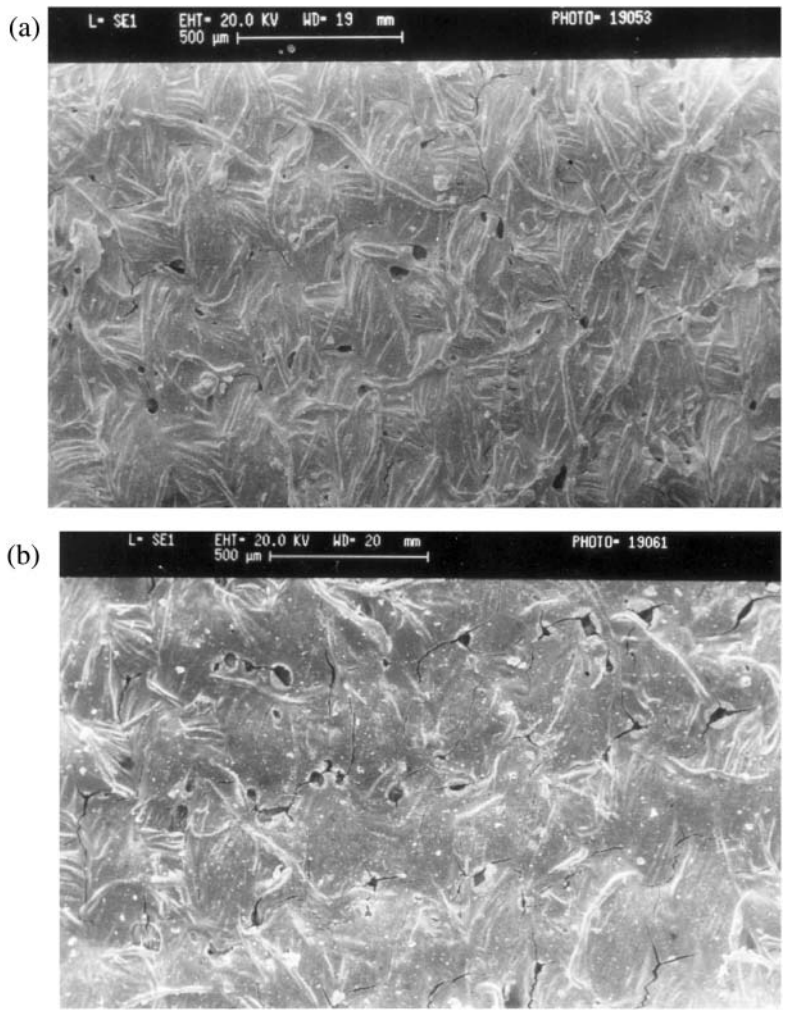

FIGURE 5. Scanning electron micrographs at ×50 of the SSP-coated fabrics (a) before and (b) after washing.

likely reason for further reduction in hydrostatic head values. However, there is no evidence of removal or separation of polymer coating.

Air Permeability

The air permeability values are given in Table 3. The air permeability of the coated fabrics was found to be 1–3 orders of magnitude lower than

the uncoated fabric sample. The air permeability of the coated fabric was found to reduce drastically with increase in the number of coatings or add-on %. Interestingly, the poly(acrylamide)-coated fabric (PAM50-3) with add-on similar to SSP50-2 showed a value lower by one order of magnitude. This difference in air permeability may be attributed to the presence of pores as mentioned above. On washing the samples, only a small increase in the air permeability values was observed. This indicates the proper integration of the SSP layer to the fabric. As expected, air permeability value could not be detected for the SSP-coated samples with very high add-ons (SSP50-3). In these samples, the air permeability value did not change even after washing treatment, indicating continuity of the coated film at a high add-on %.

Water Vapor Transmission Rate (WVTR)

The WVTR values of the control (uncoated fabric), the poly(acrylamide)-coated fabric and the SSP-coated fabrics are given in Table 4. The SSP-coated sample selected for comparison with the poly(acrylamide)-coated sample had similar add-on % and cross-linker concentration. As expected, the WVTR values for all the samples were found to increase with the increase in the temperature and decrease with increase in the relative humidity of the environment test chamber (ETC).

In our previous study, we had reported that high water vapor transmission rates are observed when hydrophilic poly(acrylamide) coatings are used on cotton substrate [7]. These values do not change significantly between lower and higher add-ons. Therefore, in this study we have considered only one add-on for both poly(acrylamide) and SSP coatings.

To determine the responsiveness of the SSP-coated sample, the WVTR values of coated samples at a set of condition (temperature and relative

Table 3. The air permeability values of samples.

	Air permeability values at 250 Pa ($cm^3\,cm^{-2}\,s^{-1}$)	
Sample	Unwashed	After IInd wash
Control	22.34	–
SSP50-1	7.365	12.346
SSP50-2	0.6943	0.8482
SSP50-3	Beyond lower range of detection	Beyond lower range of detection
PAM50-3	0.0236	0.0529

humidity) are plotted as a percentage of the WVTR of the control (uncoated) fabric at the same condition (Figure 6). At 20% relative humidity and 15°C, the percentage water vapor transmitted through the SSP-coated fabric was 58% as compared to the 70% obtained for the poly(acrylamide)-coated fabric. While at a temperature higher than the transition temperature, 45°C, the percentage water vapor transmitted was 94% in the SSP-coated fabric as compared to 96% obtained for the poly(acrylamide)-coated fabric. This shows that a significantly higher change in transmission occurs in the SSP-coated fabrics compared to the poly(acrylamide)-coated fabrics, when temperature is changed across the transition temperature and both the values tend to reach the control sample values. The results clearly demonstrate that the breathability of the fabric could be automatically altered with stimulus from the environment. Similar results were observed when the samples were compared at higher relative humidities of 30 and 65%. However, the change in water vapor transmission

Table 4. Water vapor transmission of coated and control samples at different atmospheric conditions.

	WVTR ($g\,m^{-2}\,24\,h^{-1}$)											
	20% RH			35% RH			65% RH			95% RH		
Sample	15°C	30°C	45°C	15°C	30°C	45°C	15°C	30°C	45°C	15°C	30°C	45°C
Control	1174	2600	6391	968	1926	5491	452	1216	4385	47	126	4551
PAM50-3	827	1957	6113	585	1113	5272	364	796	4138	42	93	4068
SSP50-2	681	1288	6007	442	978	4756	290	744	3452	32	97	3981

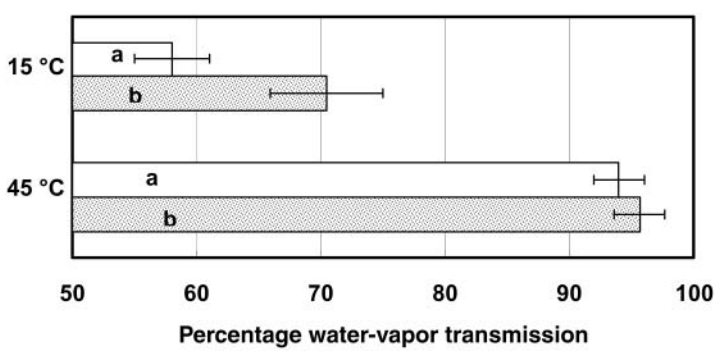

FIGURE 6. Water vapor transmission for coated fabrics shown as a percentage of control (uncoated cotton fabric) at 20% relative humidity. (a) SSP50-2 sample (fabric coated with temperature-responsive polymer) and (b) PAM50-3 sample (fabric coated with nonresponsive polymer).

values was smaller as the relative humidity of the ETC was increased. This may be because WVTR values decrease as the relative humidity is increased. At a relative humidity of 95%, the WVTR values at low temperature are so small that their relative differences cannot be compared.

The WVTR values of the SSP-coated fabrics tend to approach those of the poly(acrylamide)-coated fabrics at a temperature higher than the transition temperature. However, they remain a little lower than the poly(acrylamide)-coated fabrics. There appear to be two mechanisms by which water vapor is transmitted across the SSP- and poly(acrylamide)-coated fabrics. First is through the microcracks present in the coating and second by the diffusion of water molecules through the hydrophilic polymer coating. The lower WVTR values of the SSP-coated fabrics may be attributed to the presence of hydrophobic moieties in the coating. The diffusion of water molecules largely depends upon their molecular interaction with the polymer chains [14], which may get adversely affected with the presence of hydrophobic pendent group, *N-tert*-butylacrylamide, in the stimuli-sensitive copolymer.

The SSP-coated fabrics act as a switch to control the transmission of water vapor. At 15°C, the SSP coating exists in a swollen state by absorbing water from the surroundings. This may result in the closure of the microcracks. While, at a temperature higher than the transition temperature, the SSP coating exists in collapsed state, due to the predominance of hydrophobic interactions, and results in the opening of the microcracks. Another factor which may affect is the change in diffusion flux, which is governed by changes in both the diffusion coefficient and diffusion path of water molecules through the swollen or collapsed coating. As a consequence of these two factors, the diffusion flux is likely to decrease at a lower temperature compared to higher temperatures.

CONCLUSIONS

Smart breathable coatings which respond to changes in ambient temperature were developed using a stimuli-sensitive copolymer. These breathable coatings were produced by a coating solution of the SSP copolymer, poly(*N-tert*-butylacrylamide-*ran*-acrylamide :: 27 : 73), containing 1,2,3,4-butanetetracarboxylic acid as a cross-linker, and sodium hypophosphite as a catalyst on a cotton fabric. The coatings were dried at 120°C (5 min) followed by curing at 200°C (5 min). Cured SSP coatings were found to have good integrity on cotton fabrics. A small weight loss in the range of 7–14% was observed only during the first washing cycle, which was attributed to loss of additives and water soluble components. The SSP

coatings were found to retain the reversible temperature-sensitive behavior after the integration. The transition temperature of these SSP coatings was found to lie in a range between 15 and 40°C. The maximum swelling percentage reached was about 800%. The rate of transition was found to be fast and dependent upon the thickness of the coatings. Fabrics showed reasonably high resistance to water and air permeability. The WVTR values of the SSP and the poly(acrylamide)-coated fabric were measured as a percentage of control uncoated substrate. The transmission percentage at 20% relative humidity for the SSP-coated fabrics were found to change across the transition temperature (15–45°C) from 58 to 94% compared to the poly(acrylamide)-coated fabric which changed only from 70 to 94%. The difference in percentage transmission, due to temperature, depicts the responsive behavior of the SSP-coated fabrics. Similar results were obtained for other relative humidity conditions. However, the changes were smaller at higher relative humidity.

This study opens up a new area of application in producing smart fabric using stimuli-sensitive polymers integrated to textile substrates.

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