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Study of Performance Characteristics of Fabrics Coated with PVC based Formulations

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Abstract

The cotton base fabric with plain weave was coated with different coating formulations for exploring the best possible formulation for achieving reasonably good waterproofing and breathability. The coated fabrics were manufactured with Polyvinyl Chloride (PVC) resin, mixture of PVC and Polyurethane (PU) and PVC mixed with Polyethylene Glycol (PEG)/Ethylene Glycol (EG) additives. The properties of coated fabric were studied for two solutions of coagulation bath. The characteristics of coating film were studied by subjecting the coated fabric samples to water treatment. The film porosity was found to be high for all cases, corresponding to low rate of coagulation. Also it was observed that on washing the porosity of film was increased. The fabric coated with mixture of PVC and PU formulation found to give best breathability (around 60 to 75% of control fabric) with water penetration resistance exceeding 150 cm head of water.

Keywords: Cotton fabric; Coating resins; Knife over roll coating; Wet coagulation; Water penetration resistance; Water vapor permeability

Introduction

The waterproofing and breathability are the essential requirements of fabrics for the applications such as rain wears, fabrics for foul weathering, defence wears, marine wears etc. Earlier the attempts were made to develop such fabrics by application of water repellent finishes but could sustain low water pressure and the focus was shifted to physically coating the fabric surface by polymeric materials. Various resins such as Polytetrafluoroethylene, Polyvinyl chloride, Polyacrylates, Polyurethanes etc. Saunders [1] has been used as coatings. The coating layer does prevent the entry of water but it traps the body heat and moisture in the microclimate which makes the wearer uncomfortable [2]. In dealing with thermo-physiological comfort, which relates the maintenance of constant body temperature, can be achieved by transfer of body heat through conduction, convection, radiation as well as evaporative cooling [3,4]. Especially the moisture transmission can be achieved by developing the microspores in coating layer through which the diffusion of moisture takes place [5].

In last few decades the constant efforts were taken to develop the waterproof breathable fabric which can fulfil the necessary requirement at the economic cost. At present many such fabrics are commercially available in the market for different applications with various brands. The rubber, polyurethane etc. [6] have been used on larger scale due to their good adhesive and mechanical properties. In this study an attempt was made to develop waterproof breathable fabric with cotton as base fabric, with PVCresin based coatingformulations. PVC resin was used because it becomes soft, flexible on adding plasticizer and remains thermoplastic. In one formulation PVC was mixed with PU.

Experimental

Materials

Substrate: 100% cotton fabric with the following specifications was taken as base fabric (Table 1).

The following commercial or laboratory grade reagents, chemicals were used

- Polyvinyl Chloride (PVC) resin-commercial grade
- Polyurethane adhesive (PL-2)-commercial grade
- Polyethylene Glycol (PEG) –laboratory reagent
- Ethylene Glycol (EG)-Laboratory reagent
- DioctylPthalate (DOP)-laboratory reagent
- Dimethyl Formamide (DMF)-solvent

Coating formulations

- PVC solution in DMF-33 gm of DOP mixed with every100 gm of solid PVC. The mixture was dissolved in DMF to get 16% PVC solution.
- The effect of water soluble additives was studied by adding 3% PEG/EG in PVC solution.
- 16% PU solution in ethyl acetate (commercial sample) PL-2 adhesive (viscosity 12 poise) from Pidilite industries limited. PVC and PU was mixed in 60:40 proportion.

Methodology

Coating method: Coating was carried out on Benz coating machine. It is laboratory machine with number of controls. Coating head consists of a blade, rubber blanket supported by rolls. The clearance between knife and fabric was varied to give different weight add-ons. The fabric after coating was passed through coagulation bath wherein the microporous structure was expected to develop and in the subsequent step the fabric was dried at 120°C for 3 minutes. The coagulation was carried out in 100% water and mixture of DMF and water in the ratio 50:50. The process of coating, coagulation and drying was continuous. The coating was carried out at three levels of knife clearance.

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Characterization

Coating viscosity: The coating viscosity was measured by Brooke Field Viscometer. The viscosity was measured as the torque required rotating the spindle through polymer solution.

Add on (%): The percentage add-on of coated fabric was measured by weighing the fabric of given area before and after coating. The difference was expressed in percentage with respect to the weight of base fabric.

Bending length: The bending length of fabric was measured on Shirley stiffness tester. The test was carried out according to ASTM D1388-14E01 standards.

Air permeability: The air permeability of coated fabric was measured by textest instrument, with suction principle, at the pressure difference of 2000 Pa. The test was carried out according to ASTM D737-04 (2012) standards.

Water penetration resistance (WPR): The water penetration resistance of fabric was measured by Shirley hydrostatic head tester. The waterpenetration resistance of fabric was measured in terms of head of water the fabric can sustain. The test was carried out according to ASTM D3393-91(2014) standards.

Water vapor permeability (WVP): The water vapor permeability was measured by Ludlow method. In principle the cell measures the humidity generated under controlled conditions as a function of time. This is based on the application of the gas permeability equation and the ideal gas law. The test was carried out according to ASTM F1868-98 standards.

Launderability: The integrity of coated film was determined by subjecting the fabric to laundering. The test was carried out according to ASTM D4265-14 standards. The performance of the fabric was evaluated after laundering in terms of add-on (%), water vapor permeability, water penetration resistance, bending length. Qualitative assessment was also made to see the distortion or puckering of the coated film.

Results and Discussion

The characteristics of the coated fabrics were measured and the results were analyzed which have been presented as follows.

Effect of coating with PVC

Coagulation in water: The cotton fabric was coated with 16% PVC and then passed through coagulation bath containing water and finally dried. The characteristics of fabric are summarized in Table 2.

All the samples, excepting corresponding to 40% add on, show excellent WPR, which exceeds 150 cm head of water. On the other hand, air permeability is drastically reduced from 2630 l/m^2/sec of control fabric to 3.34 at highest level of add-on. This is expected because control fabric has open structure as against the coated fabric. The air permeability seems to decrease with increase in add-on but only marginally. The WVP also decreased with coating level. For all cases it varies from around 25% to 40% with respect to the control fabric. Bending length found to increase with add-on, reflecting the increase in stiffness with level of coating.

On laundering, marginal weight loss was observed (around 3-5% of the actual add-on). The increased WVP indicate that some residual solvent might have come out during washing, producing additional micro-pores. After washing, the fabric became relatively softer as indicated by decrease in bending length.

Coagulation in water/DMF mixture: The effect of rate of coagulation was studied by passing the coated fabric through coagulation bath containing 50:50 mixtures of water and DMF. The results are summarized in Table 3. It may be noted from Table 2, that all the fabric samples crossed water head of 150 cm, meaning add-on levels in excess of 50% produce strong uniform film. The WVP values show marginal increase in comparison with that of previous case (Table 1) which shows the increased micro-porosity on slow coagulation. Also there is significant increase in air permeability with respect to the previous case. Interestingly even bending length is reduced with slow rate of coagulation.

On washing treatment, slight loss in weight was recorded due to removal of solvent traces. The removal of solvent traces improved WVP and softness. All the fabric samples passed WPR test crossing 150 cm head of water indicate that the integrity of film was maintained even after washing.

Effect of PEG as additive in PVC

Coagulation in water: The effect of water soluble polymer additive was studied by adding 3% PEG in PVC solution. The fabric was then coated withmixture and subsequently passed through the coagulation bath containing water. The results are summarized in Table 4.

It may be noted that the water-vapor permeability and the air permeability have been found to decrease with add-ons. All the coated fabrics pass the water penetration test. Bending length too increased with add-on. But in comparison with PVC coated samples the bending length is quite low. This may be due to the presence of PEG which may act as plasticizer. However, the expected improvement in WVP was not observed in this set of experiments. The reason could be that coagulation time may not be sufficient for effective removal of PEG. On washing a considerable increase in WVP was observed. The bending length was further reduced after washing.

Coagulation in water/DMF mixture: In this set of experiments, the fabric was first coated with mixture (PVC+3% PEG) and then passed through 50:50 water/DMF bath and dried. The results are summarized in Table 5.

It may be noticed from Table 5, that slow rate of coagulation does improve the properties, in particular WVP values which confirms the improvement in porosity. The bending length and air permeability are also improved as a result of slow coagulation. On washing a significant weight loss of around 8-10% of the actual add-on was observed. It may be related mainly to removal of large PEG molecules entrapped in the film during coagulation. All the fabric samples passed the WPR test even after washing, indicating that the film was intact even after removal of PEG.

Effect of EG additive

Coagulation in water: The fabric was coated with a mixture containing PVC and water soluble additive Ethylene Glycol (EG). The coated fabric was then passed through the coagulation bath containing water. The results of the experiment are summarized in Table 6.

The fabric coated with this mixture show improved WVP and bending length in comparison with PVC coated fabric. But its performance is almost similar to that of fabric coated with PVC and PEG mixture. This indicates that the addition of EG does not affect much on performance of fabric compared with the PVC+ PEG coated

Fabric type	GSM	Ends/inch	Picks/inch
Cotton with plain weave	120	40	29

Table 1: Fabric type.

Add-on (%)	WPR (cm head of water)	WVP (gm/m²/day)	Bending length (cm)	Air permeability (l/m²/sec)
40.0(38.6)	120(109)	291(382)	4.40(4.20)	5.46
62.0(59.7)	>150	214(236)	4.60(4.35)	4.30
74.0(71.6)	>150	189(229)	5.20(5.00)	3.34
control	--	730	1.65	2630

*Quantity in the bracket indicates the corresponding figures after washing.

Table 2: Performance of PVC coated fabric with coagulation in water.

Add-on(%)	WPR (cm head of water)	WVP (gm/m²/day)	Bending length (cm)	Air permeability (l/m²/sec)
54.8(53.4)	>150	289(330)	4.10 (4.00)	8.80
61.0(59.3)	>150	220(283)	4.30(4.10)	8.00
76.6(74.2)	>150	193(253)	4.50 (4.30)	6.70
control	--	730	1.65	2630

* Quantity in the bracket indicates the corresponding figures after washing.

Table 3: Performance of PVC coated fabric with coagulation in water/DMF.

Add-on(%)	WPR (cm head of water)	WVP (gm/m²/day)	Bending length (cm)	Airpermeability (l/m²/sec)
48.0(46.4)	>150	269 (330)	3.10 (2.95)	7.10
65.0(62.6)	>150	244 (286)	3.40 (3.20)	5.20
76.0(73.2)	>150	220 (271)	3.65 (3.40)	4.32
control	--	730	1.65	2630

*Quantity in the bracket indicates the corresponding figures after washing.

Table 4: Effect of PEG additive on the performance of PVC coated fabric with coagulation in water.

Add-on (%)	WPR (cm head of water)	WVP (gm/m²/day)	Bending length (cm)	Airpermeability (l/m²/sec)
52.0(48.9)	>150	313 (398)	2.75 (2.65)	7.46
61.0(57.5)	>150	275 (330)	2.90 (2.80)	6.60
73.0(68.9)	>150	239 (288)	3.20 (3.00)	6.20
control	--	730	1.65	2630

*Quantity in the bracket indicates the corresponding figures after washing.

Table 5: Effect of PEG additive on the performance of PVC coated fabric with coagulation in water/DMF.

Add-on(%)	WPR (cm head of water)	WVP (gm/m²/day)	Bending length (cm)	Airpermeability (l/m²/sec)
54.0(51.6)	> 150	272(341)	3.20(3.10)	6.70
65.0(62.7)	> 150	240(289)	3.40(3.25)	5.86
72.0(69.8)	> 150	208(248)	3.55(3.45)	4.20
control	--	730	1.65	2630

*Quantity in the bracket indicates the corresponding figures after washing.

Table 6: Effect of EG additive on the performance of PVC coated fabric with coagulation in water.

fabric. As usual the WPR exceeds the 150 cm mark of water head. On washing, around 3 to 5% weight loss was observed. This has improved the WVP by around 20%. The WPR resistance value continues to show better performance after washing, as the water head remained above 150 cm.

Coagulation in water/DMF mixture: The effect of reduced rate of coagulation was studied by passing the coated fabric through mixture of DMF and water. The performance characteristics of fabric coated with PVC/EG mixture at reduced rate of coagulation is summarized in Table 7. As expected the reduced rate of coagulation has considerably improved WVP. The bending length which varied from 3.10 to 2.70 cm, represents a good handle. All the fabric samples pass the WPR test. The WVP values have been found to increase further on washing. The bending length also shows improvement on washing. The film remained intact and continuous which can be confirmed by high values of WPR even after washing.

Coating with PVC/PU mixture

In this set of experiment PVC was mixed with PU so that the benefit of excellent adhesiveness of PU along with possibility of improvement of porosity can be explored. In preliminary experiments the composition was optimized by taking different combinations of PVC and PU. It was observed that for equivalent add-ons the combination of 60:40 PVC/PU coat show excellent results as far as the WVP and WPR are concerned. Therefore, it was decided to use 60:40 mixtures for the study.

Coagulation in water: Cotton fabric was coated with 60:40 mixtures of PVC/PU resins and passed through the coagulation bath containing water. The results are summarized in Table 8. It can be observed from the Table 7 that the properties are greatly improved. The WPR resistance continues to show excellent figures as it crossed 150 cm mark. The WVP found to increase drastically in comparison with previous cases. Also bending length shows excellent figures varying between 2.60 to 2.90 cm in comparison with earlier experiments. This shows the excellent hand of the fabric coated with this mixture. The properties are improved considerably on washing treatment.

Coagulation in water/DMF mixture: The mixture of PVC/PU coated fabric was passed through the coagulation bath containing water/DMF mixture and then dried. The results are presented in

Add-on (%)	WPR (cm head of water)	WVP (gm/m²/day)	Bending length (cm)	Airpermeability (l/m²/sec)
53.0(50.8)	>150	344(426)	2.70 (2.60)	6.90
64.6(62.9)	>150	290(347)	2,95(2.80)	6.50
71.7(69.4)	>150	254(287)	3.10(3.00)	5.90
control	--	730	1.65	2630

*Quantity in the bracket indicates the corresponding figures after washing.

Table 7: Effect of EG additive on the performance ofPVC coated fabric with coagulation in water/DMF.

Add-on(%)	WPR (cm head of water)	WVP (gm/m²/day)	Bending length (cm)	Airpermeability (l/m²/sec)
59.0(58.0)	>150	429(536)	2.60 (2.50)	6.70
69.0(66.9)	>150	327(400)	2.50 (2.60)	6.74
77.0(74.2)	>150	300(351)	2.90 (2.70)	4.80
control	--	730	1.65	2630

*Quantity in the bracket indicates the corresponding figures after washing.

Table 8: Performance of PVC/PU coated fabric with coagulation in water.

Add-on(%)	WPR (cm head of water)	WVP (gm/m²/day)	Bending length (cm)	Air permeability (l/m²/sec)
58.0(56.3)	>150	464(548)	2.35 (2.30)	7.50
68.0(65.7)	>150	368(467)	2.40(2.35)	6.80
76.2(73.9)	>150	340(423)	2.50(2.40)	6.10
control	--	730	1.65	2630

*Quantity in the bracket indicates the corresponding figures after washing.

Table 9: Performance of PVC/PU coated fabric with coagulation in water/DMF.

Table 9. It is observed that the WVP is improved further because of slow rate of coagulation. For the equivalent add-ons the WVP for this case is improved by around 10% compared with that for high rate of coagulation.

On washing the WVP is further increased. For add-on level of around 58% the WVP is increased to 548 gm/m^2/day which is nearly 75% of the WVP of control fabric, and certainly fulfils the breathability requirements. The air permeability and the bending length follow the trend and show the improved performance. The bending length dropped further on washing indicating the improved fabric hand**.** As far as the WPR is concerned all samples crossed 150 cm water head.

Conclusion

All the coated fabric samples give excellent WPR even at low levels of add-ons.

All the coated fabric samples at slow rate of coagulation show better performance characteristics. Washing treatment had no effect on film integrity as well as fabric film bonding. Thecoated samples containing PEG and EG additives in PVC, show loss of fabric weight indicating the effective removal of additives with improved film porosity. The water vapor permeability of PVC/PU coated fabric at slow coagulation condition is exceptionally good which is the major success of the study.

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