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Study on polyester fabric using polyvinyl alcohol in alkaline medium to enhance the hydrophilic character

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ABSTRACT

Polyester (PET) fabric was treated with polyvinyl alcohol (PVA) in alkaline medium. The moisture regain, water retention and wickability of the PVA treated polyester fabric were tested. The presence of PVA in the treated PET fabric was assessed by spot test. The treated fabric was also characterized by scanning electron microscope (SEM). The PVA treated polyester fabric showed improved hydrophilic character over intact and sodium hydroxide treated PET fabrics.

Keywords: Hydrophilic character; polyester fabric; PVA; SEM; wicking.

INTRODUCTION

Polyethylene terephthalate (PET), commonly called as polyester, is the widely used polymer for the production of synthetic fibers over the past 50 years. The wide acceptance of PET as a textile material is due to its excellent physical and chemical properties. Polyester fiber is inherently a hydrophobic material with a moisture regain of only 0.6 - 0.8% even at 100% relative humidity and the fibers do not absorb water as do the natural fibers like cotton. The hydrophobic nature of polyester material is a disadvantage when the material needs to be wettable. The fabric worn next to skin should absorb perspiration and facilitate heat exchange with surroundings (Billmeyer, 1994).

The conventional modification of PET fiber properties is through strong alkaline treatment under high processing temperature. Alkaline finishing of polyester fabric with sodium hydroxide changes fabric weight, strength (Gorrofa, 1980); (Houser, 1983); (Ellison *et al.,* 1982); and (Dave *et al.*, 1987), wettability and aesthetic value (Sanders & Zeronian, 1982); and (Olson & Wentz, 1984). Altering the surface characteristics of polyester is rather difficult due to its inactive chemical nature. But modifications of PET surface have been reported using various techniques such as; modification by surfactant-aided surface polymerization of methyl methacrylate (Siriviriyanum *et al.*, 2007), cyclodextrin based finish for polyester fabric (Halim *et al.*, 2010), surface grafting of polyester fiber with chitosan (Hu *et al.,* 2002), lipase treatment of polyester fabric (Kim & Song, 2006), magnetic activation of water in alkali treatment of polyester fiber (Knovalova, 2005), chemical introduction of sugars onto PET fabric using cyanuric chloride (Ohe *et al.*, 2007), hydrophilic treatment of polyester surface using TiO_2 (Sawada *et al.*, 2003), atmospheric pressure plasma treatment of polyester fabric (Imora *et al.,* 2003), protein immobilization on PET film (Drobote *et al.*, 2010), application of silk sericin to polyester fabric (Gulrajani *et al.*, 2008), and also grafting of polyester fiber with polyvinyl alcohol (Faterpekar & Potnis, 1981a & 1982b).

In this research work, application of PVA on polyester fabric was carried out to modify the surface properties of base polymer to make it hydrophilic and to improve its comfort characteristics. The earlier work related to this emphasized the study mostly based on water contact angle, FTIR analysis, thermal analysis and dyeability of polyester fabric treated with polyvinyl alcohol (Tomasino, 1992); (Chiellini *et al.*, 2002); and (Swarna Natarajan & Jeyakodi Moses, J, 2012). In this work, efforts have been made to chemically bind the PVA onto PET surface in alkaline medium for achieving permanent hydrophilic characteristics suitable for aesthetic values, assessed by the testing of wettability, moisture regain, water retention, wicking and SEM analysis.

EXPERIMENTAL

MATERIALS

The materials used in this study were as follows;

100% Polyester fabric : Plain weave, 55 gsm; epi 92, ppi 80

Polyvinylalcohol $(C_2H_4O)_n$: Degree of polymerization, 1700-1800

(Loba Chemie Pvt Ltd, Mumbai,India).

The chemicals mentioned elsewhere in this study such as hydrochloric acid, sodium hydroxide and sodium sulphate were of analytical grade. A basic dye (supplied by Burgoyne & Burbidges & Co, Mumbai), Para-rosaniline hydrochloride (CI Number 42500) was used for dyeing the polyester fabric.

METHODS

Pretreatment of polyester fabric

Polyester fabric was immersed in 10 gpl HCl at 40°C and treated for one hour at the same temperature with material to liquor ratio 1:50, to get rid of the added impurities (Halim *et al.*, 2010).

Treatment of sodium hydroxide on polyester fabric

The PET fabrics were treated as described elsewhere (Halim *et al.,* 2010) and then subjected to treatment with sodium hydroxide solution of various concentrations.

Application of PVA onto polyester fabric

The pretreated PET fabric was immersed in NaOH (4% w/v) solution containing 1.5% by weight of PVA. It was kept in the bath at boil for one hour. Then the fabric was taken out and immersed in water at boiling temperature for 10 minutes and soaped (Cook, 2005) to remove the physically held PVA, washed and dried at room temperature. In a separate bath similar treatment was carried out on polyester fabric without PVA. This sample was considered as control fabric.

Identification of PVA in polyester fabric

The polyester fabrics were tested for the presence of PVA. The fabric samples were spotted with a drop of reagent A (boric acid) and a drop of reagent B (iodine solution). Photographs were taken after 5 minutes. Polyvinylalcohol reacts with boric acid and iodine to form a blue colour (Zeronian, 1999).

Measurement of moisture regain in polyester fabric

Moisture regain of the polyester fabrics (intact, control, PVA treated) was determined as per the AATCC test method 20A-1995, RA 24 (AATCC Technical Manual, 1996). The moisture regain values were calculated from the following equation.

$$\text{Moisture regain} = \frac{(\text{weight of the conditioned fabric - weight of dried fabric}) \times 100}{\text{weight of dried fabric}}$$

Measurement of wettability of polyester fabric

Wettability is the time taken for a water drop to penetrate into the polyester material. The wettability of PET fabrics was determined as per AATCC test method 79 (AATCC Technical Manual, 1991).

Determination of water retention in polyester fabric

Absorptive capacity of polyester fabrics was measured by standard AATCC 21-1978 test method (AATCC Technical Manual, 1979).

Wickability of polyester fabric

The wicking height of the polyester fabrics, both in warp and weft directions was determined (Tyagi *et al.*, 2009). Fabric samples measuring 10 cm ×I 2.5 cm were taken. Each of the sample pieces was clamped to a scale and held at a position such that the tip of the sample just touched the water surface taken in a 250 ml beaker. The height of water reached after five minutes was measured.

SEM analysis of polyester fabric

The surface morphology of polyester fabrics (intact, control and PVA treated) was observed in SEM (JOEL JSM-6360 model microscope, Japan) (Hearle, 1972).

RESULTS AND DISCUSSION

Many trials were carried out on polyester fabric using sodium hydroxide alone and with PVA in different concentrations, time and temperature. The weight loss from the polyester fabric and characteristic changes were considered. Based on these, the optimized conditions for application on the polyester fabric using sodium hydroxide and PVA were fixed as described in the experimental section. The data are presented in the Tables 1, 2, 3, 4 and 5; and the results are shown in Figure 1 to Figure 5 respectively.

Percentage weight loss of PET fabrics

PET fabrics were treated with various concentrations (1%, 2%, 3%, 4%, 5%, & 6% w/v respectively) of sodium hydroxide at boil for two different time intervals (60 and 120 minutes). The data for the weight loss of PET fabrics after these treatments are given in Table 1. It was found that the weight loss of the PET fabrics increased with increase in the concentration of sodium hydroxide and the treatment time. The increase in weight loss is substantial when the treatment time is increased from 60 minutes to 120 minutes. If both the concentration of sodium hydroxide and treatment time are increased together the weight loss increase is also correspondingly more. Hence, it is decided to keep the treatment time only for 60 minutes.

Table1. Percentage weight loss of PET fabrics

PET fabrics	Concentration of sodium hydroxide (%, w/v)	Treatment time (minutes)	Weight loss (%)
1	1	60	1.43
2		120	3.20
3	2	60	3.26
4		120	4.50
5	3	60	3.51
6		120	6.83
7	4	60	5.77
8		120	8.27
9	5	60	6.48
10		120	9.23
11	6	60	9.48
12		120	12.9

Wettability and tensile strength of sodium hydroxide treated PET fabrics

After the preliminary experiment (Table 1) the PET fabrics were treated with sodium hydroxide (1%, 2%, 3%, 4%, 5%, & 6% w/v respectively) at boil for 60 minutes only. The data of wettability and tensile strength of sodium hydroxide treated (1%, 2%, 3%, 4%, 5%, & 6% w/v) PET fabrics are given in Table 2. It is seen from the Table 2 that the time of wettability of PET fabrics reduces as the concentration of sodium hydroxide increases from 1% w/v to 6% w/v respectively. On the other hand, there is also a high variability in the tensile strength of sodium hydroxide treated PET fabrics. Compared to the untreated PET fabric the sodium hydroxide treated PET fabrics show reduced tensile strength in accordance to the respective concentration of sodium hydroxide. It is evident from the data of Table 2 that after the treatment of 4% w/v concentration of sodium hydroxide on PET fabric there is a substantial change in their properties of tensile strength, wettability and weight loss. The concentration of 4% w/v of sodium hydroxide solution seems to be suitable for the treatment on PET fabric at boil for 60 minutes.

Table 2. Wettability and tensile strength of sodium hydroxide treated PET fabrics

PET fabrics	Sodium hydroxide (%, w/v)	Treatment time (minutes)	Weight loss (%)	Wettability (minutes)	Tensile strength (lb)
untreated	--	--	--	Nil	80.0
1	1	60	1.43	> 15.0	74.5
2	2	60	3.26	14.8	69.0
3	3	60	3.51	11.8	65.0
4	4	60	5.77	7.9	61.0
5	5	60	6.48	5.2	51.0
6	6	60	9.48	4.3	37.5

Wettability of PVA treated PET fabrics

Several trials were carried out earlier on PET fabric with different concentrations of polyvinyl alcohol (PVA) in alkaline medium. It was revealed that the PVA with 1.5 % (w/v) gave overall performance. Hence, in this study the concentration of PVA is retained as 1.5% (w/v).

The PET fabrics were treated with PVA (1.5 % w/v) in sodium hydroxide (1%, 2%, 3%, 4%, 5%, & 6% w/v respectively) solutions at boil for 60 minutes, and the results are given in Table 3. The weight loss and wettability values of PVA treated PET fabrics change in different concentrations of sodium hydroxide solution. When the concentration of sodium hydroxide increases from 1% w/v to 6% w/v, correspondingly the weight loss increases (1.41 % to 9.38 %) and the time of wettability decreases (6.7 minutes to 2.8 minutes) in the PET fabric. There is no substantial difference in the weight loss due to the PVA treatment in different concentrations of sodium hydroxide (Table 2 and Table 3). However the wettability time is substantially reduced in the PVA treated (Table 3) PET fabrics. The concentration of 4% w/v of sodium hydroxide solution with 1.5 % PVA seems suitable for the treatment on PET fabric at boil for 60 minutes.

Table 3. Wettability of PVA treated PET fabrics

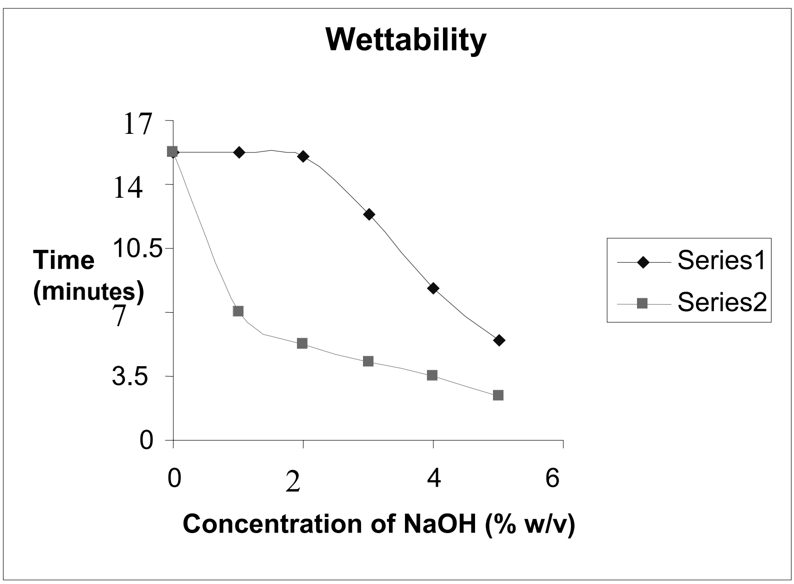
PET fabrics	Sodium hydroxide (%, w/v)	Treatment time (minutes)	PVA (% w/v)	Weight loss (%)	Wettability (minutes)
Untreated	--	--	--	--	Nil
1	Only NaOH 4%	60	--	5.77	> 7.0
2	1	60	1.5	1.41	6.7
3	2	60	1.5	3.2	5.0
4	3	60	1.5	3.4	4.1
5	4	60	1.5	5.22	3.1
6	5	60	1.5	6.22	3.0
7	6	60	1.5	9.38	2.8

Moisture regain, water retention and wicking of PVA treated PET fabrics

The data of moisture regain, water retention and wicking behavior of PVA treated PET fabrics using different concentration of sodium hydroxide (1%, 2%, 3%, 4%, 5%, & 6% w/v respectively) solutions are given in Table 4. From Table 4 it is evident that the moisture regain, water retention and wicking behavior of PVA (1.5 %) treated PET fabrics increase slowly as the concentration of sodium hydroxide is increased from 1% w/v to 6% w/v. There is a substantial increase in the moisture regain (0.4% to 1.02 %), water retention (115 % to 154 %) and wicking (1 mm to 4 mm) behavior of PVA treated PET fabrics compared to the untreated PET fabric (04 %, 99 %, and < 1 mm respectively). The concentration of 4% w/v of sodium hydroxide solution with 1.5 % PVA seems suitable for the treatment on PET fabric, at boil for 60 minutes with respect to the properties of moisture regain (1.05 %), water retention (144 %) and wicking (3 mm). The effect of wettability of PVA treated PET fabrics in alkaline medium and PET fabric treated only in alkaline solutions is graphically represented in Figure 1.

Table 4. Moisture regain, water retention and wicking of PVA treated PET fabrics

PET fabrics	Sodium hydroxide (%, w/v)	Treatment time (minutes)	PVA (% w/v)	Moisture regain (%)	Water retention (%)	Wicking (mm)	
						Warp	weft
Untreated				0.4	99	< 1	< 1
1	1	60	1.5	0.4	115	1	1
2	2	60	1.5	0.45	120	2	2
3	3	60	1.5	0.8	122	3	2
4	4	60	1.5	1.05	144	3	3
5	5	60	1.5	1.02	149	4	3
6	6	60	1.5	1.02	154	4	4



Series 1 shows the wettability of PET fabrics treated with NaOH (%, w/v)
Series 2 shows the wettability of PET fabrics treated with 1.5% PVA along with same strength of NaOH (%, w/v)

Fig. 1. Wettability of PVA treated and NaOH treated PET fabrics

Effect of PVA treatment in PET fabrics

To confirm the concentration of PVA (1.5 %), the PET fabrics were treated in alkaline medium (4% w/v NaOH) with different concentrations of PVA (0.5 %, 1.0 %, 1.5 % and 2.0 %) for 60 minutes at boil. The moisture regain, water retention and wettability of the PET fabrics were assessed. The data obtained in these treatments are given in Table 5. As the concentration of PVA increases from 0.5 % to 2.0% the moisture regain (0.62 % to 1.11 %) and water retention (128 % to 145 %) values also increase correspondingly. Whereas, the respective time of wettability is reduced (3.6 minutes to 3 minutes) in the PET fabrics treated in alkaline medium. From Table 5 it is evident that the results of moisture regain, water retention and wettability are good on the PET fabric treated with 1.5 % PVA in 4% w/v sodium hydroxide solution for 60 minutes at boil. This may be taken as an indication of the fact that the hydroxyl end-groups of PVA binds onto PET surface, via base catalysed transesterification reaction.

Table 5. Effect of PVA treatment in PET fabrics

PET fabrics	Sodium hydroxide (%, w/v)	Treatment time (minutes)	PVA (%, w/v)	Moisture regain (%)	Water retention (%)	Wettability (minutes)
1	4	60	0	0.40	115	> 7
2	4	60	0.5	0.62	128	3.6
3	4	60	1.0	0.87	138	3.2
4	4	60	1.5	1.05	144	3.1
5	4	60	2.0	1.11	145	3

Spot test in the polyester fabrics

Based on the above results (Table 1 to Table 5) the optimum condition for the treatment on PET fabrics is 4% w/v sodium hydroxide, 1.5 % PVA for 60 minutes at boil. The untreated PET fabric is considered as intact and the 4% w/v sodium hydroxide treated PET fabric is considered as control. The PET fabrics (sodium hydroxide treated and PVA treated) were tested for the presence of PVA. Photographs of these fabrics (sodium hydroxide treated and PVA treated) subjected to spot tests are given in Figures 2 and 3 respectively. When the PET fabrics were spotted with reagents blue colour was developed in the PVA treated sample, but no colour was obtained in the control PET fabric. The development of blue colour in the PVA treated PET fabrics confirms the permanent nature of attachment of PVA to PET in alkaline medium. Control fabric did not develop colour confirming the absence of PVA (Gowariker *et al.*, 2008).

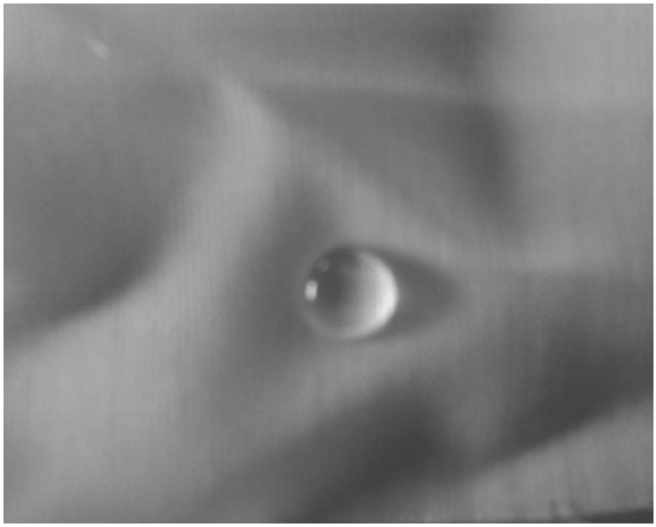


Fig. 2. Spot test on control PET fabric

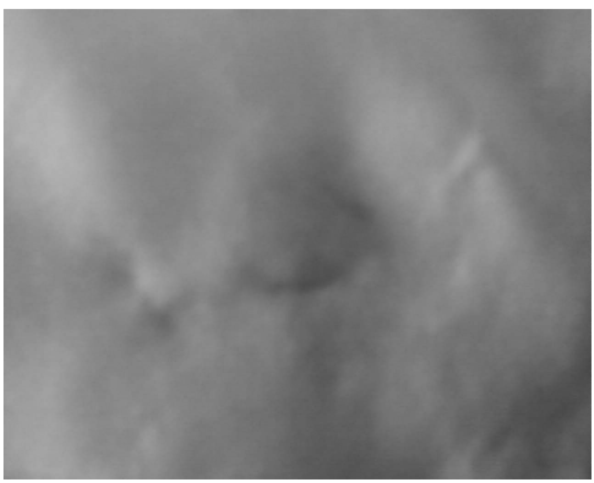


Fig. 3. Spot test on PVA treated PET fabric

SEM analysis of the PET fabrics

The surface morphology of control and PVA treated PET fabrics is shown in Figures 4 and 5 respectively. Figure 5 shows clearly the uniform presence of PVA on the surface of PET fabric and did not fill up the interstices. SEM micrograph of sodium hydroxide treated control fabric (Figure 4) shows that sodium hydroxide caused more swelling of PET fabric than that of intact fabric.

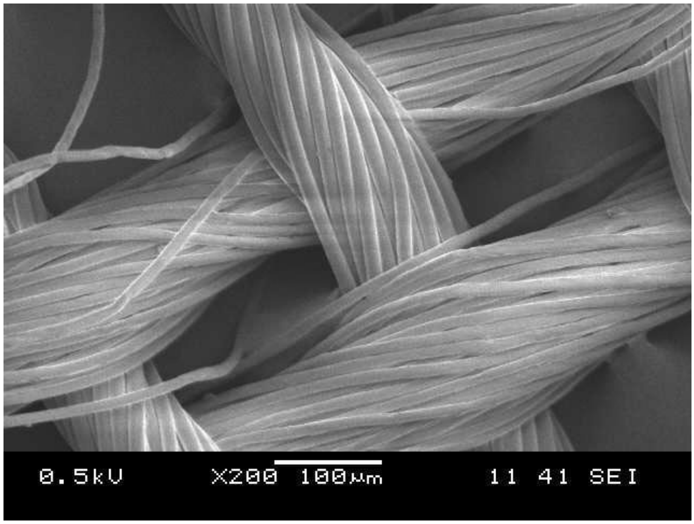


Fig. 4. SEM micrograph of control PET fabric

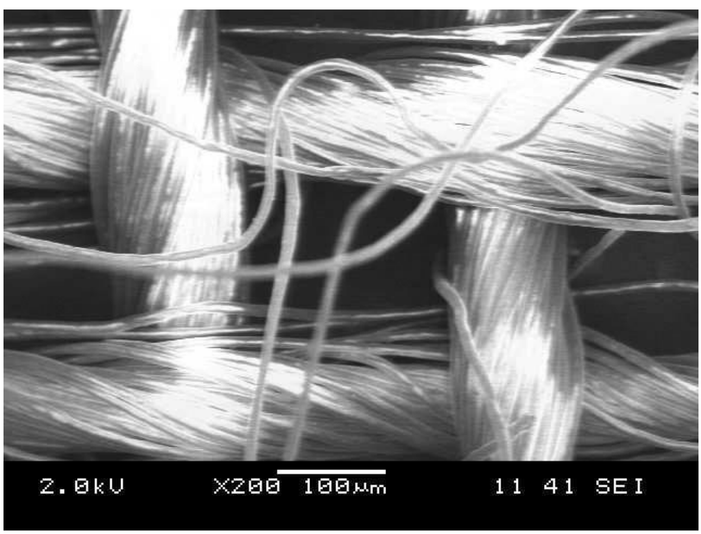


Fig. 5. SEM micrograph of PVA treated PET fabric

CONCLUSION

The wetting behavior of PVA treated PET fabric was increased considerably due to the good linkage between PET and PVA. Increased moisture regain, water retention, wettability and wickability of PVA treated PET fabric highlight the improved hydrophilic behaviour of the PET fabric. The presence of PVA in the PET fabric after its application was confirmed by spot test and SEM facilitating the fabric for the reactive process. PVA treated PET fabric exhibited better hydrophilic character as compared to the sodium hydroxide treated control fabric, due to hydroxyl groups present in PVA molecule attached to PET surface. The increase in concentration of PVA beyond 1.5% does not exhibit much change in the behaviour of PET fabric.

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دراسة حول معالجة ألياف البوليستر البولي باستخدام كحول البولي فينيل في وسط قلوي لتعزيز الخواص الهيدروفيلية (الاتلاف مع الماء)

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خلاصة

علوج نسيج البوليستر (PET) مع كحول البولي فينيل (PVA) في وسط قلوي. تم اختبار احتباس الماء واستعادة الرطوبة، والتفتل لألياف البوليستر المعالجة مع الحكول البولي فينيل (PVA). تم تقييم وجود PVA في نسيج PET المعالج باختبار البقعة. وقد تم تمييز النسيج المعالج أيضاً عن طريق المسح الضوئي للمجهر الإلكتروني (SEM). وقد أظهر نسيج البوليستر (PET) المعالج مع الحكول البولي فينيل (PVA) تحسيناً لإتلاف مع الماء أكثر من المعالج مع هيدروكسيد الصوديوم.