Improvement in Tensile Strength of Bamboo Knitted Fabric by Sol-Gel Coating

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ABSTRACT

Textiles made of bamboo regenerated fibre are reported to have lower tensile strength than the other cellulosic fibres, due to high porosity of the fibre. This paper was aimed to modify the bamboo knitted fabric by the sol-gel coating to improve the tensile strength with minimum effect on its inherent morphology and ultimate relevant properties such as good absorbency and air permeability. The pad-dry-bake process was employed for the coating where tetraethyl-orthosilicate and nano-titanium-dioxide were used as the active ingredients. The treated fabrics were tested for the tensile behaviour in terms of breaking strength and elongation and the sol-gel process recipe and parameters were optimised. The absorbency, air-permeability and washing durability of the coating were also tested for the optimised process. Results showed the increase in tensile strength of the fabric by sol-gel coating, whereas absorbency and air-permeability were almost unaffected. The coating results were unaffected even after a washing treatment (equivalent to 5 industrial washings). Additionally, the wrinkle recovery angle of the coated fabric was also tested and found improved.

Key Words: **Bamboo Fibre, Sol-Gel Coating, Tensile Strength, Air Permeability.**

1. INTRODUCTION

Apparels are the most common textiles that are used to protect human bodies, beautify human look and bring soothe to human lives [1-2]. Thus, the ultimate goal of apparel manufacturing is to produce protective, comfortable and attractive textile fabrics. Fabric finishing processes have the key importance in the production line of apparels. The aesthetic, handle and performance characteristics of the fabric can be modified by chemical finishing. However, normal chemical finishing processes alter the inherent properties of the textile substrate, such as the comfort of cotton cellulose mainly due to natural softness and absorbency, which may be useful for the end-use. Using nano-sized chemical finishes generally reduce this problem [3]. Further, development in nano-finishing processes adds enhanced functionality.

Bamboo fibre is a cellulosic fibre regenerated from the bamboo grass [4]. Bamboo is considered as one of the major sustainable resources [5]. It has very high moisture

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content due to low degree of crystallinity and high porosity in its structure [4-6]. Such microstructure of the bamboo leads to a textile substrate with high water absorbency, air-permeability, breathability and dyeability [7-10]. However, due to the same reason, the tensile strength of the substrate is relatively lower. Inherent characteristics of bamboo fibre are very useful for comfort and functionality of the textile material, but there is a need of improving the strength of the material to make the textiles durable. Therefore, this study was aimed to improve the tensile strength of a bamboo fabric with minimum effect on the inherent fibre characteristics by one of the most widely used nano-finishing techniques known as sol-gel coating.

Sol-gel coating is a process where an ethanol based acidic solution containing an alkyloxide precursor and the colloidal nanoparticles is applied to the textile substrate [11-12]. The application of high temperature baking in acidic pH causes the hydrolysis and poly-condensation of the precursor solution (sol) and the 'sol' converts to a 'gel' formation, thus fixing the nanoparticles. Sol-gel coating of various textile substrates has widely been reported to improve various properties of the textiles [3, 11-17]. This is because the precursor serves as a bridge between nanoparticles and the textile substrate, which does not alter the inherent properties of the substrate. Further, the chemicals applied by this technique are very durable to washing.

The pad-dry-bake process was employed for the sol-gel coating where tetraethyl-orthosilicate, as the precursor, and nano-titanium-dioxide, as the colloidal nanoparticles, were used as the active ingredients. The treated fabrics were tested for the tensile behaviour in terms of breaking strength and elongation, and the sol-gel process recipe and parameters were optimised. The absorbency, air-permeability and wrinkle recovery angle, and washing durability of the coating were also tested for the optimised process.

2. MATERIALS AND METHOD

2.1 Fabric and Chemicals

In this study, the single jersey 100% bamboo knitted fabric was used. The fabric had an absorbency of less than one second (AATCC 79-1995); therefore, the bamboo fabric was treated with sol-gel coating process without any pre-treatment. The commercially available tetraethyl-orthosilicate (Dynasylan A, obtained from Evonik Degussa Germany), nano-titanium dioxide (TiO_2 P25 obtained from Evonik Degussa Germany), ethanol and acetic acid were used for sol-gel coating.

2.2 Sol-Gel Coating

The padding solution was prepared by dissolving 5-20ml of tetraethyl-orthosilicate in 80-95ml of ethanol to make the total solution of 100ml, and at the pH of around 4 (adjusted with acetic acid). 1-5% of nano-titanium-dioxide was added and thoroughly stirred for five minutes to make the final solution ready to apply. The fabric sample was evenly padded in the solution (100% liquor pick-up, ambient temperature) on a Rapid laboratory horizontal padding mangle, dried (80^{o}C, 5 min) on an oven dryer, and then baked at 130-170^{o}C for 2.5-10 min on a Rapid laboratory stenter.

2.3 Testing and Measurement

The treated and untreated fabric samples were tested for tensile breaking force and elongation (ASTM 5035-95, Strip Method), absorbency (AATCC 79-2000), air-permeability (ASTM D 737-96), and wrinkle recovery angle (AATCC 66-1998).

2.3.1 Washing to Assess Durability of the Coating and Fabric Shrinkage

The treated and untreated fabric samples were subjected to washing on a domestic top-loading washing machine with previously warmed (40°C) 1g/l solution of the SDC standard detergent. The duration of the washing was 15 min (equivalent to five industrial washing cycles). After washing, the samples were rinsed in cold water, squeezed, and then dried by hanging at the room temperature. The shrinkage of the washed and unwashed fabric samples was determined as a percent lengthwise reduction. The washed and unwashed samples were also tested for breaking force, elongation, absorbency, air-permeability, and wrinkle recovery angle.

3. RESULTS AND DISCUSSION

3.1 Optimizing Sol-Gel Coating Process Variables for Tensile Behavior

Table 1 shows the effect of the amount of tetraethyl-orthosilicate (with corresponding amount of ethanol) and the concentration of nano-titanium-dioxide on breaking force and elongation. All other variables such as pH (~4), baking temperature (150^{o}C) and baking time (5 min) were kept constant. The Table 1 revealed that the tensile strength of the fabric increased by the sol-gel coating. Increasing the amount of tetraethyl-orthosilicate increased the strength whereas increasing the amount of nano-titanium-dioxide reduced the strength. This may be because the tensile strength is improved by cross-linking of tetraethyl-orthosilicate within the textile substrate [3], where the non-reactive colloidal nano-titanium-dioxide particles would be creating hindrance in the cross-linking. However, the values obtained for maximum strength are 10ml of tetraethyl-orthosilicate and 1% of nano-titanium-dioxide. On the other hand, elongation of the fabric was reduced by the sol-gel coating and by increasing the amount of any active ingredient. This means that the modulus of the fabric slightly increased, that may increase the wrinkle recovery angle. The wrinkle recovery results are given in Table 4 and discussed in Section 3.2.

Tables 2-3 presents the effect of baking temperature (for constant dwell time of 5 min) and time (at constant temperature of 150^{o}C) respectively, with optimum values of tetraethyl-orthosilicate and nano-titanium-dioxide. The optimum baking temperature and time for maximum tensile strength of the treated fabric were 150^{o}C and 5 min respectively.

TABLE 1. EFFECTIVNESS OF TETRAETHYL-ORTHOSILICATE AND NANO-TITANIUM-DIOXIDE QUANTITIES

Amount of Tetraethyl-Orthosilicate (mL)	Concentration of Nano-Titanium-Dioxide (%)	Breaking Force (cN)	Elongation (%)
Untreated Fabric		21440	58.36
05	1	30000	49.13
	2	27350	48.60
	3	23080	53.37
	4	24570	50.92
	5	27440	48.06
10	1	33370	50.58
	2	31900	48.89
	3	27740	51.63
	4	31880	47.29
	5	31780	48.43
15	1	30190	45.59
	2	29140	40.72
	3	28410	41.77
	4	29260	33.20
	5	26310	36.45

3.2 Effectiveness of Sol-Gel Coating on Bamboo Knitted Fabric

The breaking force, elongation, absorbency, air-permeability and wrinkle recovery results of the untreated fabric and the sol-gel coated fabric are given in Table 4. This table reveals the overall effectiveness of the sol-gel coating with respect to the aim of this work. The table shows that the tensile strength of the fabric is improved by sol-gel coating with negligible effect on the absorbency and air-permeability. This means sol-gel coating does not affect the inherent comfort of the bamboo fabric. This may be attributed to the porous networking of the tetraethyl-orthosilicate and too small (nano-level) size of the titanium-dioxide to fill the fibre pores [18]. Interestingly, wrinkle recovery of the fabric also improved, because of the decrease in the fabric elongation. As cellulose based substrates have the problem of wrinkle formation at higher extent, therefore, such improvement increases the significance of the sol-gel coating of bamboo fabric.

TABLE 2. EFFECTIVENESS OF BAKING TEMPERATURE

Baking Temperature (°C)	Breaking Force (cN)	Elongation (%)
130	33250	50.28
140	33350	50.49
150	33370	50.58
160	30290	50.58
170	31640	49.84

TABLE 3. EFFECTIVENESS OF BAKING TIME

Baking Time (min)	Breaking Force (cN)	Elongation (%)
2.5	33350	50.49
5	33370	50.58
7.5	32832	50.05
10	30670	50.54

3.3. Effect of Washing of the Sol-Gel Treated Fabric on Durability of the Coating

The durability of the coating was assessed in terms of the effect of washing treatment on breaking force, elongation, absorbency, air-permeability, wrinkle recovery and the shrinkage. The results are given in Table 5. The table shows that there was a negligible effect of washing on the breaking force, elongation, wrinkle recovery and absorbency. This reveals that the sol-gel coating is durable for five industrial washings. However, the air-permeability is slightly reduced after washing. This is due to 7% fabric shrinkage after washing. This shrinkage may have occurred due to contraction of the porosity in the bamboo fibre as well as in the gel-network on the substrate.

TABLE 4. EFFECTIVENESS OF THE SOL-GEL COATED FABRIC

No.	Property	Untreated Fabric	Treated Fabric
1.	Breaking Force (cN)	21440	33370
2.	Elongation (%)	58.36	50.58
3.	Absorbency (sec)	<1 sec	4 sec
4.	Air-Permeability (ml(cm^2/sec))	22.74	20.39
5.	Wrinkle Recovery (o, degree angle)	<1	60

TABLE 5. EFFECT OF WASHING OF SOL-GEL COATED FABRIC

No.	Property	Unwashed Treated Fabric	Washed Treated Fabric
1.	Breaking Force (cN)	33370	33420
2.	Elongation (%)	50.58	49.95
3.	Absorbency (sec)	4 sec	4 sec
4.	Air-Permeability (ml(cm^2/sec))	20.39	17.74
5.	Wrinkle Recovery (o, degree angle)	60	58
6.	Shrinkage After Washing (%)	-	7

4. CONCLUSIONS

This study concludes that the tensile strength of the bamboo fabric can be increased without affecting its inherent comfort property by sol-gel coating using tetraethyl-orthosilicate and nano-titanium-dioxide. Specifically, sol-gel coating of the bamboo fabric increases the breaking strength with negligible effect on the fabric absorbency and air-permeability. It was revealed that sol-gel coating not only improves the breaking strength but also the wrinkle recovery of a cellulosic substrate such as bamboo fabric. The coating was found to be durable for five industrial washings.

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