Investigation of the Optimum Pretreatment Conditions for the Knitted Fabric Derived from PLA/Cotton Blend

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***Abstract*—** The pretreatment processes prior to dyeing which were the scouring and bleaching, for the knitted fabric of PLA/cotton blend were studied comparing with the 100% cotton and PLA fabrics. These two pretreatment processes were studied in a sequence (scouring followed by H_2O_2 bleaching) and altogether in the one-bath process. The scouring process of the blended fabric was compared when the different scouring agents were employed (NaOH, Na_2CO_3 and pectinase enzyme). The two-bath and one-bath scouring/bleaching processes had a signified effect on the strength of the fabrics because the pretreatment processes typically used for cotton are in the alkaline condition which can deteriorate the PLA fiber. Therefore, the pretreatment conditions for the PLA/cotton blended fabric needed to be optimized to avoid fiber damage. From the research, it was observed that the pretreatments for the blended fabric, which was to enter the pale-shade dyeing, were scoured using 10%owf pectinase (60°C, 60 min) as it enhanced a satisfactory water absorbency to the fabric without causing any adverse effect on the fabric strength. For deep-shade dyeing, the blended fabric should undergo the one-bath scouring/bleaching with 7%owf H_2O_2 (100°C, 60 min) which yielded a water absorbency and whiteness on the fabric to a standard level and the resulting fabric strength was highest and this one-bath pretreatment was the time-saving process.

***Index Terms*—Pretreatment, knitted fabric, scouring, bleaching, PLA/cotton blend**

I. INTRODUCTION

Polyester is a synthetic fiber being increasingly consumed in the textile industry every year. In 2009, its market share was as high as 80% of the synthetic fiber market and China was the chief producer [1]. Polyester fiber is a strong, light-weight fiber with a good dimensional stability and cheap price. However, the starting raw materials used for the polyester manufacturing are the petrochemicals supplied from the petroleum industry. The petroleum price is rising every year because fossil resources are limited. At the same time, the manufacturing process of polyester also produces a high-CO_2 emission and the wastes generated are also difficult to dispose of. Therefore, the researches have focused on an alternative environmental-friendly fiber which has comparable properties and can be used as a substitute of the conventional polyester fiber, poly (ethylene terephthalate) (PET). In 2002, Cargill Dow Polymer LLC, a joint venture between Cargill and Dow Chemical companies opened a production plant to produce a biodegradable polyester fiber, polylactic acid (PLA), with the purpose of replacing the petroleum-based PET fiber. The different structures between PET and PLA are shown in Fig. 1 [2].

PLA fiber has been considered as a new polyester fiber for the textile industry. It possesses several desired properties for use in the production of the textiles highlighting the eco-friendliness and non-petroleum base. As PLA has relatively low thermal stability, its molecule can be degraded by thermal hydrolysis [3], [4]. The PLA fiber used in the textile industry has the melting point of about 170°C [5]. This makes the textiles derived from PLA fiber sensitive to heat. Ironing the PLA woven fabric should be avoided as it may cause a fused fabric surface. In order to tackle this problem, it is recommended to produce the PLA fiber into the form of knitted fabric because the fabric structure is more flexible and better resistant to wrinkles than the woven counterpart, therefore, ironing is not needed or low-temperature ironing can be used. Another solution is to blend the PLA fiber with other fibers with better thermal properties e.g. cotton. Cotton, not only enhances the thermal resistance, but also reduces the cost of the fiber production as PLA fiber is expensive. The blend of PLA and cotton produces a 100% biodegradable fabric. Moreover, a strong and dimensional stable fabric with good moisture absorption can be achieved [6].

Pretreatments of the fabrics prior to the dyeing process are essential processes that help to promote the dyeability of the fabric before passing it to the coloration process. The typical pretreatment processes are singeing, desizing, scouring and bleaching. The pretreatment processes chosen for any particular fabrics vary depending on the extent of impurities present on the fiber or fabric that can affect the efficiency of the subsequent dyeing process [7]. The knitted fabric of PLA/cotton blend requires 2 important pretreatment processes which are the scouring and bleaching processes. Owing to the high content of impurity on cotton, it needs to be scoured to get rid of the natural oils, fats, waxes, and partially remove some proteins and pectin. The cotton fabric which has been through an incomplete scouring will only slightly absorb water. If it is taken to the dyeing process, the shade obtained on the fabric will be unlevel. There are two general scouring processes used in the industry. The first method is the use of alkali to remove fats and oils by means of saponification reaction. The second is the enzymatic

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scouring method in which the impurities on cotton are eliminated via hydrolysis reaction. There are several enzymes employed in the textile industry, e.g. pectinase, lipase, protease and cellulase. Selection of enzymes for scouring depends on the types of impurities to be removed and the process used. The advantage of enzymatic scouring is that the processing temperature can be reduced because most enzymatic scouring is normally performed at lower temperature and pH compared with alkali scouring. Furthermore, enzymes do not deteriorate cellulose structure, hence, the fiber strength is not affected [8].

The current research aimed to study the optimum pretreatment conditions viz. scouring and bleaching, to improve the water absorption capacity and whiteness of the PLA/cotton blended fabric and the effectiveness of the scouring and bleaching processes at different conditions were informed.
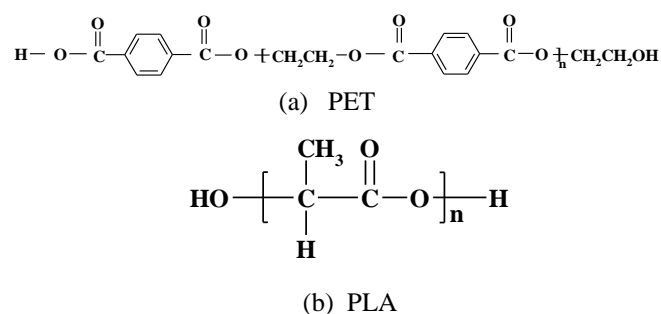

(a) PET

(b) PLA

Fig. 1. Chemical structures of the polyester fibers

II. MATERIALS AND METHOD

A. Materials

The pique-knitted fabrics of the PLA/cotton blend (weight of 227 g/m^2), 100% cotton (weight 239 g/m^2) and 100% PLA (weight 213 g/m^2) were prepared from the PLA and cotton spun yarns. The PLA spun yarn was purchased from Hebei Tianlun Textile Co. Ltd., China and the cotton spun yarn was supplied by Far East Knitting & Spinning Co., Ltd, Thailand. Dypidol 101B (a non-ionic wetting agent) and Scourzyme® L (pectinase enzyme) were supplied by Brenntag Co., Ltd, Thailand. Sodium hydroxide (NaOH), sodium carbonate (Na_2CO_3), sodium silicate (Na_2SiO_3) and 30% hydrogen peroxide (H_2O_2) were laboratory reagents grades.

B. Method

1) Prewash process

The knitted fabrics of PLA/cotton blend, 100% PLA and cotton were boiled in water at 100^oC for 15 minutes in order to remove the water-soluble impurities before taken to the next process.

2) Scouring process

The prewashed fabrics were scoured in the processing conditions employing 3 different chemicals viz. sodium hydroxide, sodium carbonate, pectinase enzyme. The condition of scouring is shown in Table 1. The efficiency of these different scouring processes were compared against the blank condition being the process employed only 1%owf wetting agent at the same temperature and length of the processing time. After scouring, the fabrics were boiled in water at 90^oC for 15 minutes so as to get rid of the alkali traces (NaOH or Na_2CO_3) from the fabrics and to terminate the bioactivity of the pectinase enzyme. The last step was to rinse the fabrics with water and dry at room temperature. The dried fabrics were analyzed their water absorbency using AATCC test method 79-2000 [9].

3) Bleaching processes

The scoured fabrics were bleached with 30% H_2O_2 at the concentrations of 5 and 7%owf. Sodium silicate of 2.5% owf and 0.6%owf NaOH were used. The bleaching process was carried out at 100^oC for 60 minutes, pH 10.5-11.0 and the liquor ratio of 20:1. After bleaching, the fabrics were boiled in water at 90^oC for 15 minutes to eliminate the residual peroxide on the fabrics and later rinsed and dried at room temperature. The whiteness and yellowness of the fabrics were measured according to AATCC Test Method 110-2000 [10].

TABLE I: THE CONDITIONS OF SCOURING

Chemical	Concentration (%owf)	Non-ionic wetting agent (%owf)	Temperature ($^{\circ}$C)	Time (min)
NaOH	3	1	90	60
	5	1	70	90
Na_2CO_3	3	1	90	60
	7	1	70	90
Pectinase*	10	1	60	60
Blank	-	1	90	60
	-	1	70	90

* pectinase scouring carried out at pH 8-9

The prewashed fabrics were scoured and bleached in a one-bath, all-in process using hydrogen peroxide solution. The 7%owf of 30% H_2O_2 was used together with 2.5%owf sodium silicate, 1%owf nonionic wetting agent and 0.6%owf NaOH at pH 10.5-11.0 and the liquor ratio of 20:1. The process was performed at 100^oC for 60 minutes. The fabrics were then boiled in water at 90^oC for 15 minutes to eliminate the residual peroxide and afterwards the fabrics were rinsed and dried at room temperature. The whiteness and yellowness of the fabrics were measured according to AATCC Test Method 110-2000 [10].

C. Bursting Strength

The bursting strength of the fabrics was measured using SDL bursting strength tester Model P1000 followed the JIS L1018 standard method (1999) [11].

III. RESULTS AND DISCUSSION

A. Prewash process

PLA/cotton blended fabric, it was found that water took about 44 seconds to absorb into the fabric as seen in Table 2. By boiling the blended fabrics at 100°C for 15 minutes, the water absorbency properties were slightly improved (water absorption spent about 35 seconds) but still did not pass the standard absorbency (less than 5 seconds is required). The cotton fibers were contaminated with the hydrophobic substances e.g. oils, fats and waxes, which hindered the water absorption into the fabric. The blended fabric exhibited better water absorbency than the 100% cotton fabric as it contained only 50%wt cotton. However, the pretreatment process is still needed for the blend because its water absorbency was still

lower than the standard level. PLA is a synthetic fiber on which the processing lubricants are present as an impurity. Once it was boiled in a 1%owf nonionic wetting agent at 70°C for 15 minutes, the PLA fabric could readily absorb water and the fabric whiteness was higher than 72, so it was ready to enter the dyeing process. Cotton as the most widely used fabric already has its appropriate scouring and bleaching conditions, so this work focused only on the investigation of those conditions for the blended fabric. In addition, the prewash process could improve the fabric strength because of the stress relaxation occurred during washing resulting in the shrinkage of the fabrics.

TABLE II: The properties of the greige and the prewashed PLA/cotton blended fabrics comparing with 100% PLA and cotton fabrics

Fabrics	Process	Absorbency (s)	Whiteness	Strength (KPa)	% Shrinkage [6]
Cotton	Greige	60+	-4.671	859.0 ± 31.1	
	Prewashed	60+	9.937	935.8 ± 25.2	20.50
Blend PLA/Cotton	Greige	44.18 ± 3.74	19.175	649.2 ± 21.6	
	Prewashed	34.76 ± 3.15	28.180	749.4 ± 27.0	15.30
PLA	Greige	60+	76.091	622.0 ± 25.8	
	Prewashed*	adequate	79.570	726.0 ± 30.3	10.22

*PLA was prewashed with 1%owf nonionic wetting agent, L.R. 20:1 at 70°C 15 minutes

B. Scouring Process

When the prewashed PLA/cotton blended fabric was taken to study scouring with NaOH, Na_2CO_3 and pectinase enzyme at various conditions, the water absorbency, the whiteness and the strength of the fabrics were determined in comparison with the prewashed fabrics with wetting agent as shown in Table 3. The chemicals used in the conditions shown in Table 3 were at their minimum amount that could provide a standard water absorbency to the fabric. The fabric prewashed with only wetting agent could not absorb water well due to the lack of alkali to saponify oils and fats on the cotton fiber into water-soluble fatty acid and triglyceride [4]. By scouring with NaOH, Na_2CO_3 and pectinase, the alkalinity was involved in the process, therefore, a better water absorbency of the fabrics was obtained. However, the amount of alkali used should compromise with the strength of the PLA fiber because PLA could be damaged by alkali. From the experiment, it exhibited that using a low-concentration NaOH at an elevated scouring temperature (3%owf NaOH, 90°C, 60 min) could impair the fabric strength even more severely than the scouring at low temperature with high NaOH concentration (5%owf NaOH, 70°C, 90 min). In the mean time, the fabric strength was independent of the scouring temperature in the case of scouring with Na_2CO_3 due to a lower alkalinity, thereby causing less hydrolysis on the PLA structure, as a result, fabric strength reduced to a less extent than the NaOH case. Scouring by pectinase enzyme also improved the water absorbency of the blended fabrics because pectinase eliminated the pectic substance on the cotton fiber resulting in a removal of hydrophobic substances [12]. Furthermore, the use of pectinase did not affect the strength of the blended fabric as it did not destroy the PLA structure.

The whiteness values of the scoured fabrics are shown in Table 3. Not only removing the polar fat compounds, the alkaline solution also eliminated the color matters on the cotton fiber. The alkaline solution and the elevated temperature caused fiber swelling and the impurities were then easily removed, therefore, the scouring with NaOH provided a higher degree of whiteness to the blended fabric than the other scouring agents studied. From the fabric strength in Table 3, the optimum scouring conditions which exhibited the least effect on the fabric strength for 3 different scouring chemicals, was selected. The suitable scouring condition for each scouring agents were 5%owf NaOH (70°C, 90 min), 7%owf Na_2CO_3 (70°C, 90 min) and 10%owf pectinase (60°C, 60 min). The results are depicted in Table 4. These scouring conditions could be used as a pretreatment process for the blended fabrics which will go through deep-shade dyeing, however, if a pale shade is demanded, these scoured fabric is still required bleaching in order to achieve a right shade on the fabrics in the dyeing process.

C. Bleaching process

The majority of the colorants were removed by the H_2O_2 bleaching which was the process to oxidize the molecules of the natural colorants on the cotton fabric into colorless substances. The amount of H_2O_2 used to whiten the fabric in the bleaching process was varied depending on the whiteness of the starting fabrics. In Table 4, scouring with 5%owf NaOH required only 5%owf H_2O_2 in bleaching because such concentration sufficiently provided whiteness to the fabric (standard whiteness is 72). The fabrics scoured with Na_2CO_3 and pectinase and the prewashed ones needed 7%owf H_2O_2 for bleaching in order to achieve a standard whiteness. Besides, the scouring and bleaching could also be done altogether in one step because the obtained blended PLA/cotton fabrics could readily absorb water and the fabric whiteness was in the standard level. The fabric pretreated in the one-bath scouring/bleaching process still maintained the strength level similar to the scouring with pectinase followed by H_2O_2 bleaching and higher than the scouring with the alkaline solution (NaOH and Na_2CO_3) followed by H_2O_2 bleaching.

The results in the strength of the pretreated fabrics compared with the prewashed ones (Fig. 2.) illustrated that the scouring process influenced on the strength of the blended fabrics more than the bleaching process. It can be explained as a result of a stronger alkaline condition of the scouring process directly affected the structure of PLA. The blended fabric then exhibited a significantly lower strength comparing with the other processes. However, pretreatment of the PLA/cotton blended fabric for pale-shade dyeing should be the one-bath scouring/bleaching process with H_2O_2 because the fabric strength was still maintained in a high level and at the same time, it was a time- and chemical-saving process.

TABLE III: PROPERTIES OF THE PLA/COTTON BLENDED FABRIC AFTER BEING SUBJECTED TO DIFFERENT SCOURING CONDITIONS.

Chemical scouring	conditions	Absorbency (s)	Whiteness	Strength (KPa)
NaOH	3%owf, 90°C, 60 min	adequate	41.868	670.8 ±9.96
	5%owf, 70°C, 90 min	adequate	37.863	711.2 ±17.34
Na$_2$CO$_3$	3%owf, 90°C, 60 min	0.88 ±0.16	38.772	730.8 ±11.13
	7%owf, 70°C, 90 min	adequate	33.178	733.4 ±21.6
Pectinase	10%owf, 60°C, 60 min	0.96 ±0.17	28.269	744.4 ±28.18
Wetting agent	1%owf,70°C, 90 min	9.15 ±1.09	-	740.0 ±24.42
	1%owf, 90°C, 60 min	7.98 ±1.14		733.0 ±13.55

TABLE IV: PROPERTIES OF THE PLA/COTTON BLENDED FABRICS AFTER BLEACHING.

Blend PLA/cotton	H$_2$O$_2$	Scoured conditions		Absorbency (s)	Whiteness	Yellowness	Strength (KPa)
		Chemicals	Temp, time				
Greige				44.18	19.175	20.76	649.2 ± 21.6
Prewashed*				34.76	28.180	17.88	749.4 ± 27.0
Two-Step[a]	5% owf	NaOH : 5%owf	70°C, 90 min	adequate	74.665	3.467	693.5 ±16.7
	5% owf	Na$_2$CO$_3$: 7%owf	70°C, 90 min	adequate	67.539	5.769	-
	7%owf				72.087	4.316	720.0 ±21.3
	5% owf	Pectinase : 10%owf	60°C, 60 min	adequate	67.767	5.906	-
	7%owf				72.666	4.517	731.0 ±8.3
One-Step[b]	7% owf	-		adequate	72.469	4.010	728.7 ±8.4

* Prewashed fabric was boiled at 100°C 15 minutes
[a] Initial fabric was scoured fabric, and [b] initial fabric was prewashed fabric.
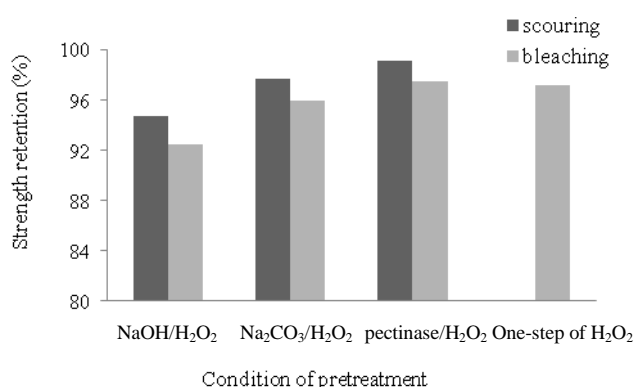

Fig. 2. Effect of the pretreatments on the fabric strength.

IV. CONCLUSION

As the PLA fiber is rather thermally and alkali sensitive, the pretreatment processes used for the PLA/cotton blended fabric should be carefully controlled. In our research, the chemical used had the effect on the PLA structure and the temperature higher than 70°C was not recommended. In order to avoid such problem, pretreating the fabric with enzyme is the most appropriate option. Selection of the right enzyme corresponding to the types of impurities present on the fibers would promote a better scouring efficacy while the fabric strength is maintained. In addition, pretreatment with enzyme is also eco-friendly.

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