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A STUDY OF REACTIVE DYEING AND ENZYMATIC TREATMENT ON SOME PROPERTIES OF COTTON KNITTED FABRIC

C.W. Kan and K.P. Law
The Hong Kong Polytechnic University, Faculty of Applied Science and Textiles, Institute of Textiles and Clothing, Hung Hom, Kowloon, Hong Kong
tccwk@inet.polyu.edu.hk

Abstract: This paper studied the relationship and effect of reactive dyeing and enzymatic treatment, using cellulase as the enzyme, on some properties of cotton knitted fabrics. Two types of cotton knitted fabrics, single jersey and interlock, were used. These fabrics were treated with reactive dyeing) and cellulase treatment. However, the sequence of applying the reactive dyeing and cellulase treatment was varied so as to find out the effect of application on the properties of the fabrics. After applying the dyeing and enzymatic processes, the strength loss, air permeability and dyeability, were evaluated. Experimental results revealed that the cellulase treatment has a more significant effect in the interlock knitted fabric than the single jersey knitted fabric. However, it was interested that the results of the evaluated properties were altered depending on the sequence of applying the reactive dyeing and cellulase treatment. The results were recorded and discussed thoroughly.

1. Introduction

This paper studied the relationship of reactive dyeing and cellulase treatment on some properties of cotton knitted fabrics, i.e. single jersey and interlock. These fabrics will be treated with reactive dyeing and cellulase treatment. However, the sequence of applying the reactive dyeing and cellulase treatment was varied so as to find out the effect of application on the properties of the fabrics [1-6]. After applying the dyeing and enzymatic processes, the strength loss, air permeability and dyeability, were evaluated. Experimental results revealed that the cellulase treatment has a more significant effect in the interlock knitted fabric than the single jersey knitted fabric. The results will be quantitatively discussed.

2. Experimental

2.1. Materials

Two types of scoured and bleached 100% cotton knitted fabrics with different structures were used and their specifications were shown in Table 1.

Table 1: *Specifications of the knitted fabrics used*

Fabric type	Yarn Count, NeC	Loop Length (per inch)	Fabric Count, Wales x Course (per inch)
Single jersey	22/1	0.802	27 x 44
Interlock	22/1	0.606	24 x 30

2.2. Enzymatic treatment

A commercial acid cellulase, with CMC activity of 2035 CMCU/g, was used. The fabric samples were treated with 1% enzyme with liquor-to-goods ratio of 10:1. The pH for the enzymatic treatment was maintained at 5.0 with 0.05M acetic acid/sodium acetate buffering solution and the treatment temperature was kept at 55ºC throughout the treatment time of 50 minutes. After enzymatic treatment, the treatment temperature was increased to 80ºC for 10 minutes for deactivating the enzyme. Afterward, the fabric samples were washed with running deionised water at room temperature for 5 minutes and then completely dried in an oven with temperature of 90ºC. After drying, the fabric samples were conditioned at 20±2ºC with relatively humidity of 65±2% for at least 24 hours prior further treatment.

2.3. Dyeing process

Two reactive dyes were used and their characteristics were shown in Table 2 and the dyeing method was shown in Table 3. After dyeing, the fabric samples were washed with 1% non-ionic detergent to remove the unfixed and hydrolysed reactive dyes. The washed fabric samples were then completely dried in an oven with temperature of 90ºC. After drying, the fabric samples were conditioned at 20±2ºC with relatively humidity of 65±2% for at least 24 hours prior to further use.

***Table 2**: Reactive dyes used*

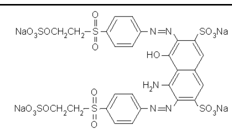
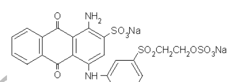
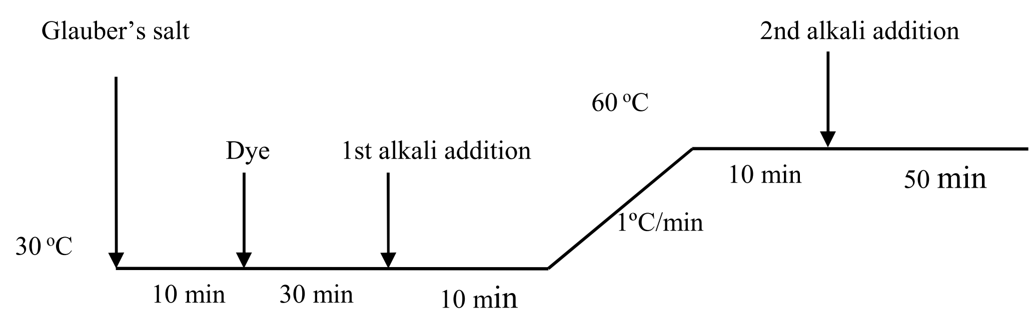
Code	Chemical Structure	Reacting system
CI Reactive Black 5 (RB5)		VS-VS (Bifunctional)
CI Reactive Blue 19 (RB19)		VS (Monofunctional)

***Table 3**: Dyeing parameters*

Liquor-to-goods ratio	10:1	
Dye conc. (% owf)	1.0	3.0
Glauber's salt (g/l)	40	60
Soda ash (g/l)	10	15
1st alkali addition	1/3 amount of soda ash	1/2 amount of soda ash
2nd alkali addition	2/3 amount of soda ash	1/2 amount of soda ash



2.4. Bursting strength and air permeability

The bursting strength was tested by EN ISO 13938 with a diaphragm bursting strength tester. The air permeability reflects comfort of fabric by indicating the breathability of fabric and the air permeability of the denim fabric specimens were evaluated in accordance with ASTM D737 with an air permeability tester.

2.5. Dyeability and colour yield

The dyeability of the fabric samples was measured by a Macbeth Color Eye 7000A Spectrophotometer. A reflectance curve could be obtained by plotting percentage of reflectance (%R) over the visible spectrum (400nm to 700nm). The colour yield of the dyed fabric samples was calculated by $K/S = (1-R)^2/2R$ (where K is the absorption coefficient, S is the scattering coefficient, and R is the reflectance, in %, of dyed fabric samples).

3. Results and Discussion

3.1. Bursting strength

Table 4 shows the bursting strength of the undyed fabric samples before and after enzymatic treatment. The bursting strength of the two types of fabric samples showed a slight but clear reduction in the bursting strength. When the type of fabric was compared, interlock fabric had a larger reduction in the bursting strength than the single jersey fabric. The reason is that the interlock fabric has a looser fabric structure and the enzyme can penetrate into fibre causing enzymatic hydrolysis easily. The hydrolysis will weaken the strength of the fibre resulting in a reduced bursting strength.

Table 4: *Bursting strength of the undyed samples before and after enzyme treatment*

Fabric	Bursting Strength (p.s.i.)	
	without enzymatic treatment	with enzymatic treatment
Single Jersey	105	96 (↓ 8.57%)
Interlock	155	139 (↓ 10.32%)

Table 5 shows the bursting strength of the knitted fabric samples under different treatment conditions. Three conditions were considered for analyzing the relationship between dyeing process and enzymatic treatment which are (i) dyeing without enzymatic treatment, (ii) dyeing followed enzymatic treatment and (iii) enzymatic treatment followed by dyeing. In case (i), after reactive dyeing, there is no reduction in the bursting strength of both types of knitted fabric samples. For the RB5 dyed fabric samples, the bursting strengths were slightly increased when compared with the undyed fabric samples. The bi-functional nature of RB5 would increase the crosslinking between the fibre and hence increased the crystalline region of cotton fibre resulting in increased bursting strength. On the other hand, for the RB19, there is no significant change in the bursting strength. When the dyeing condition was taken into consideration, the dyeing parameters for both RB5 and RB19 were same except the amount of dye added was different, it was observed that the bursting strength was reduced with the increased concentration of dye applied and bifunctional reactive dye has a better bursting strength than monofunctional reactive dye. Therefore, it could conclude that the chemical composition of reactive dye and the amount of dye used could affect the bursting strength of the knitted fabrics. In case (ii), the fabric samples were first dyed with reactive dyes and then followed by the enzymatic treatment. From Table 5, the bursting strength of both types fabric samples were reduced when compared with the undyed fabric samples without enzyme treatment, the bursting strength was improved when compared with the undyed fabric samples with enzyme treatment. This may be due to the pre-existed reactive dye contributes to an inhibitory effect on the enzyme performance and, in addition, the attraction between reactive dye and cellulosic fibre increased the crystalline portion of the fibre resulting in a better bursting strength [7, 8]. When the types of reactive dye were compared, the RB5 has retained a better bursting strength then RB19. This may be due to the bifunctional nature of RB5 which may cause more attractions between dye molecules and fibre causing an improvement in the bursting strength. In case (iii), the fabric samples were first treated with enzyme and then dyed with different reactive dyes. The results in Table 5 show that there is no significant change in the bursting strength when compared with the undyed fabric samples with enzymatic treatment.

Table 5: *Bursting strength(unit: p.s.i) of different fabric samples*

Fabric structure	Dye	Dye concentration (owf)	Bursting Strength (dyeing without enzymatic treatment)	Bursting Strength (dyeing followed by enzymatic treatment)	Bursting Strength (enzymatic treatment followed by dyeing)
Single Jersey	RB5	3%	109	102	97
Single Jersey	RB5	1%	107	100	96
Single Jersey	RB19	3%	106	99	96
Single Jersey	RB19	1%	105	98	95
Interlock	RB5	3%	157	146	139
Interlock	RB5	1%	156	142	138
Interlock	RB19	3%	156	142	138
Interlock	RB19	1%	155	141	137

3.2. Air permeability

As change in the structure of the fabric was believed to be a consequence of the depolymeriztion of the enzyme treatment, the air permeability might have a certain change after the enzyme treatment [7, 8]. To determine this effect, all the samples with various combinations of dyeing and enzyme treatments were subjected to the air permeability test and the results are shown in Table 6. Interesting result was found that the fabric samples with enzyme treatment showed a considerable decrease in the air permeability, especially for the single jersey fabrics, which recorded more than 50% reduction after enzymatic treatment. Regarding to this result, it was suggested that the change of the internal structure of the fabric by the abrasion and other mechanical action occurs during the wet processing such as washing, rinsing, and cleaning should be accountable for this significant change rather than the effect of enzymatic action nor the uptake of addition substance, as the dyed samples without enzyme treatment show a very similar result. The air permeability of other samples treated with various combinations of dyeing and enzyme treatments are also shown in Table 6 and the results were similar to each other and there is no significant tendency or relation could be obtained from these data.

***Table 6**: Air permeability (unit: cc/s/cm² at 100 Pa) of different fabric samples*

Fabric structure	Dye	Dye concentration (owf)	Air Permeability (dyeing without enzymatic treatment)	Air Permeability (dyeing followed by enzymatic treatment)	Air Permeability (enzymatic treatment followed by dyeing)
Single Jersey	RB5	3%	18.1	17.0	17.0
Single Jersey	RB5	1%	18.3	17.5	17.5
Single Jersey	RB19	3%	18.5	18.7	18.6
Single Jersey	RB19	1%	18.7	19.2	19.2
Single Jersey (Undyed): air permeability = 39.8					
Single Jersey (Undyed with enzymatic treatment): air permeability = 19.5					
Interlock	RB5	3%	21.7	25.3	22.3
Interlock	RB5	1%	22.8	25.5	23.8
Interlock	RB19	3%	23.0	24.3	22.1
Interlock	RB19	1%	23.2	23.2	24.3
Interlock (Undyed): air permeability = 30.5					
Interlock (Undyed with enzyme treatment) air permeability = 23.2					

3.3. Color Reflectance

The explanation of the short names used in Figures 1 to 4 was shown in Table 7. Figures 1 and 2 show the reflectance curves of fabric samples dyed with 1% and 3% RB5 respectively with different combinations of dyeing and enzyme treatment. Figures 3 and 4 show the reflectance curves of fabric samples dyed with 1% and 3% RB19 respectively under with different combinations of dyeing and enzyme treatment.

From Figures 1 to 4, all fabric samples showed a very similar reflectance curve, it was suggested that the application of enzymatic treatment before or after the dyeing process did not give any remarkable chromatic change. Some tendencies were observed which are (i) for the fabric samples dyed before enzymatic treatment resulted in a slightly increase in the reflectance value when compared with the untreated dyes samples, and (ii) for the fabric samples dyed after enzymatic treatment, a very small decrease in the reflectance value was observed. During the enzymatic treatment, some cellulose fibres were digested by the cellulase and no room is available for retaining the dye in the fibre. The dye became unfixed and left the fibre. This gives the result in the reduction in dye content and hence increased the reflectance values. The decrease in the reflectance value of the dyed fabric samples indicated that the enzymatic treatment had a certain effect on colour yield of cotton, darker color was resulted. This effect would be further discussed by investigating the K/S values. There is no significant effect on the RB19 in respect to the different knit structures. However, for the RB5 dyed fabric samples, the single jersey was dyed slightly darker than the interlock structure under different concentration of dye.

***Table** 7: Explanation of the samples name in Figures 1 to 4*

Sample	Explanation
RB5-I	Interlock fabric samples dyed with C.I. Reactive Black 5
RB5-DB-I	Interlock fabric samples dyed with C.I. Reactive Black 5 before enzymatic treatment
RB5-DA-I	Interlock fabric samples dyed with C.I. Reactive Black 5 after enzymatic treatment
RB5-S	Single jersey fabric samples dyed with C.I. Reactive Black 5
RB5-DB-S	Single jersey fabric samples dyed with C.I. Reactive Black 5 before enzymatic treatment
RB5-DA-S	Single jersey fabric samples dyed with C.I. Reactive Black 5 after enzymatic treatment
RB19-I	Interlock fabric samples dyed with C.I. Reactive Blue 19
RB19-DB-I	Interlock fabric samples dyed with C.I. Reactive Blue 19 before enzymatic treatment
RB19-DA-I	Interlock fabric samples dyed with C.I. Reactive Blue 19 after enzymatic treatment
RB19-S	Single jersey fabric samples dyed with C.I. Reactive Blue 19
RB19-DB-S	Single jersey fabric samples dyed with C.I. Reactive Blue 19 before enzymatic treatment
RB19-DA-S	Single jersey fabric samples dyed with C.I. Reactive Blue 19 after enzymatic treatment

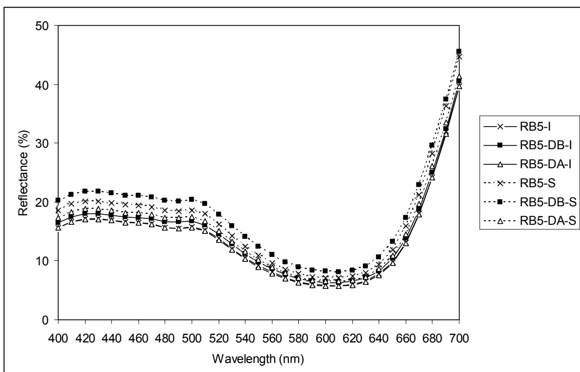


***Figure 1**: Reflectance curves of fabric samples dyed with 1% RB5*

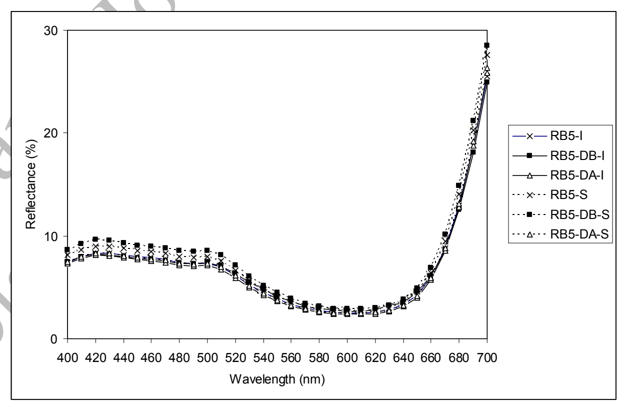


***Figure 2**: Reflectance curves of fabric samples dyed with 3% RB5*

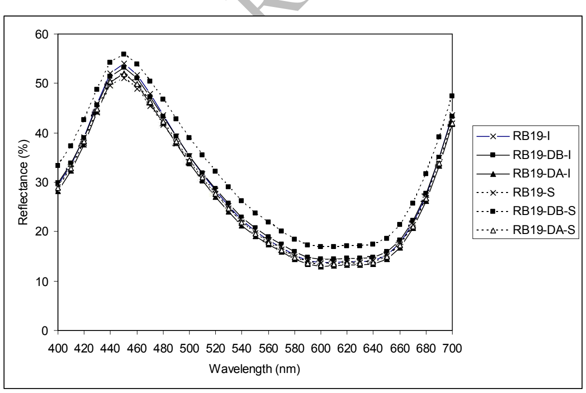


***Figure 3**: Reflectance curves of fabric samples dyed with 1% RB19*

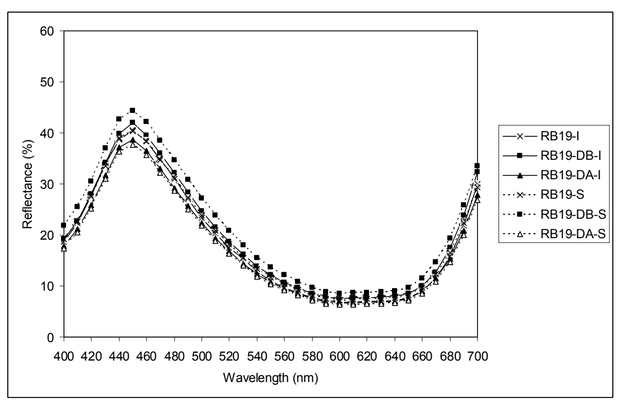


***Figure 4**: Reflectance curves of fabric samples dyed with 3% RB19*

3.4. K/S Values

To better identify the effect of the enzymatic treatment on the colour yield of the cotton fabric. The K/S values were calculated for the fabric samples treated with different combinations of dyeing and enzyme treatment and are shown in Table 8.

***Table 8**: K/S values of different fabric samples*

Fabric structure	Dye	Dye concentration (owf)	K/S value (dyeing without enzymatic treatment)	K/S value (dyeing followed by enzymatic treatment)	K/S value (enzymatic treatment followed by dyeing)
Single Jersey	RB5	3%	264.73	244.74	290.14
Single Jersey	RB5	1%	88.69	76.72	98.12
Single Jersey	RB19	3%	86.34	70.48	100.50
Single Jersey	RB19	1%	41.39	30.93	41.98
Interlock	RB5	3%	285.28	270.68	301.02
Interlock	RB5	1%	111.61	102.78	113.91
Interlock	RB19	3%	91.66	82.34	95.47
Interlock	RB19	1%	40.15	38.46	43.27

All the fabric samples dyed before enzymatic treatment recorded a clear drop in the K/S values compared with the untreated samples. This drop in the colour strength could be explained by the reduction of dye content in the substrate due to the removal of the unfixed and fixed dye after the enzymatic treatment. The fabric samples dyed after enzymatic treatment showed a slight increase in the K/S values. The biopolishing of the fabric surface could be one of the reasons of this phenomenon. The enzymatic pretreatment removed surface hairs and imparted softness to the fabric surface thereby decreasing the scattering coefficient, as a consequence higher K/S values could be obtained [6, 8]. In addition, the development of an additional accessible regain to dye as a direct consequence of the enzymatic attack thereby compensating the region that was readily digested by the enzymatic hydrolysis as well as enhancing the dye-uptake. Although an increase in the K/S values was found in the dyed samples with enzyme pretreatment, the change was minimal. As one previous study reported an increase in K/S values of cellulase treated cotton with increasing weight loss, with this in mind, the minimal weight loss cause by the treatment of the enzyme from both sources could explain this result.

4. Conclusion

It was found that after the enzymatic treatment, as well as the dyeing treatments, a considerable drop in the air permeability of the treated samples was found. The change of internal structure of the fabric by the mechanical action during wet processing was a preferable explanation rather than the effect of enzyme or dye. As indicated by the bursting test, enzymatic treatment had a more significant effect on the interlock knitted fabric than the single jersey. Since the fiber content and yarn count of these two types of fabrics were the same, the longer loop length and smaller fabric count of the interlock may contribute a better accessibility to the enzyme and consequently lead to the better reactivity. In this study, the effect of the pre-existed reactive dyes on the enzymatic reaction was further proved as the pre-dyed samples with enzyme treatment all show a drop on the bursting strength. The result of this project also indicated that, the afterword enzyme treatment of the dyed fabric caused a slight decrease in the color yield. This could be explained by the removal of the unfixed dyed remained on the dyed samples due to the insufficient rinsing after dyeing and the removal of fixed dyed accompanied with the weight loss caused by the enzymatic hydrolysis. The dyed fabrics with pretreatment of enzyme were found to have a slightly better dyeability comparing with the untreated samples, as higher K/S values Lower reflectance values were recorded. It was suggested that the removal of protruding fibers and the improvement in softness of fabric surface caused by the enzyme treatment decreased the scattering coefficient, thus increasing K/S values of cellulose treated samples. In addition, attack on the accessible and amorphous areas as well as crystallite surfaces by the enzymatic action might consequently developed additional accessible regions to dye thereby enhancing the dyeability of the pretreated fabrics.

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