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〈Research Paper〉

Dyeing Properties of Blanket Fabric of Dyeable Polypropylene

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Abstract— Dyeing and fastness properties of a dyeable PP fiber were examined with four different types of disperse dyes. It was found that the dyed PP fiber could be cleared by soaping without using sodium hydrosulphite, and that the heat setting above 140℃ resulted in the melting of the PP fiber. The rates of dyeing and the extents of exhaustion of three primary E type dyes were different with each other, the apparent color strength did not increase with increasing dye concentration, and color fastness to washing was not satisfactory. In the cases of both high wash fastness and high light fastness dyes, the rates of dyeing were slow and the extents of exhaustion were very low. On the other hand, the dyeing rates of three primary S type dyes were similar and the build-up properties were good with good color fastnesses. It might be concluded that the best disperse dyes for the dyeable PP fiber were S type dyes.

Keywords: *dyeable polypropylene, blanket fabric, disperse dyes, dyeing properties*

1. Introduction

Atactic polypropylene(PP) was synthesized in 1930s and its physical properties were unsatisfactory due to low crystallinity and low melting point. In middle of 1950s, isotactic PP having high crystallinity and good spinnability was synthesized, but it still had some drawbacks of low thermal and light stability[1,2]. The application fields of PP fiber gradually expanded in 1980s with the use of stabilizers which overcame the inherently low thermal and UV stability of the polymer[3]. Nowadays its application fields have expanded as diverse as packagings, pipes, household appliances, textiles and films. The success of PP is attributed to several advantageous properties: easy processability, low specific gravity, almost zero water adsorption, good chemical resistance, good antistatic character, high hygienic property as well as wide availability and low cost.

Although PP is a potential polymer for its excellent physicochemical properties, little has been used in apparel industry because there is no commercial dyeing method for standard unmodified PP fibers. PP fiber cannot be dyed because of its non polarity, high crystallinity and high stereoregularity which limit the accessibility of dye molecules. There have been many researches to overcome this problem by dope pigmentation[4,5], synthesis of new dyes for PP[6~8], modifications of the polymer. Dope pigmentation has advantages of eco-friendliness and excellent color fastness to washing and light. The use of the dope dyed PP is limited to carpet and furniture fabrics as the process is complex and acquired colors are rather limited. The commercial development of new dyes for PP has not been successful, therefore much of current studies are concentrated on the modification of PP itself. The modification can be classified as surface modification[9], bulk modification by attaching dye-receptive monomers or functional groups via copolymerization or grafting[10~12] and blending dye-receptive additives[13~15]. Despite these efforts, no truly commercial dyeable PP is available on the market at present.

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A synthetic fiber company in Korea has developed a dyeable PP fiber by mixing PP resin with an additive which has an affinity for disperse dyes. The company succeed in mass production of dyeable PP fiber by careful control of spinning process, and started to examine feasibility to several textile items including blanket. Compared to PET or nylon, PP fiber is highly suitable for blanket application due to its inherent characteristics; quick dry, high heat insulation, and light weight. In particular, light weight plays an important role in blankets for mountain climbing and military purpose. Its water repellency and stain resistance can help to minimize laundering.

The purpose of the present work was to investigate the dyeing and fastness properties of blanket fabric made of the newly developed dyeable PP fiber. The clearing and heat setting conditions were examined. The rate of dyeing, build-up property and color fastness of four different types of disperse dyes were also measured.

2. Experimental

2.1 Materials

Scoured blanket fabric(weight; 360g/m^2) made of 225d dyeable PP (DTY, 75d/36f, 3ply) was used for the dyeing. Disperse dyes used in this study are listed in Table 1. They are primary colors of the four types: E-type, S-type, high wash fastness(H-W) type and high light fastness (H-L) type. These dyes were commercial samples that were not purified before use. Chemicals including acetic acid, sodium acetate, sodium hydroxide and sodium hydrosulfite, were laboratory grade reagents. CS 940(phosphoric acid ester salt of higher alcohol, Dea Young Chemical) was employed as a soaping agent.

2.2 Dyeing, clearing and heat setting

Dye bath pH was adjusted to 4~4.5 by employing acetic acid/sodium acetate buffer system. Dyeing was carried out in the sealed, stainless steel dye pots with 120 cm^3 capacity of Starlet II (DL-6000, Daelim). Samples were placed at 40℃ in a dye bath of liquor ratio 20:1. Temperature was raised to 130℃, and the dyeing was continued for 60 min. Samples dyed with 2 %owf C. I. Disperse Red 167 were cleared by either soaping or reduction clearing at 60, 70 and 80℃ in order to examine the appropriate clearing process. Dyed fabric was reduction cleared in an aqueous solution containing 2g/L sodium hydroxide and 2g/L sodium hydrosulphite using a liquor ratio 1:40 at a predetermined temperature for 20 min, or soaped in an aqueous solution containing 1g/L CS 940. Effects of heat setting were examined by evaluating K/S value, grade of washing fastness and handle of the samples treated at 130, 140 and 150℃ for 60 sec.

2.3 Evaluation of dyeing properties

The rates of dyeing were determined at 1 %owf depth with Dye-O-Meter (DyeMax-L, Dyetex Engineering). DyeMax-L is a real-time dyeing measuring system which can monitor the extent of exhaustion at predetermined time intervals by assessing the residual dye bath absorbance. The build-up property was examined by comparing K/S values of the samples dyed at the concentration of 0.5, 1, 2 and 4 %owf.

2.4 Measurement of color strength and fastness

K/S values of the dyed samples were calculated from the reflectance curves measured using a spectrophotometer(Color-Eye 3100, Macbeth)

Table 1. Disperse dyes used in the study

type	Dyes (Generic Name/Commercial Name)		
	Yellow/Orange	Red	Blue
E	C. I. Disperse Yellow 54	C. I. Disperse Red 60	C. I. Disperse Blue 56
S	C. I. Disperse Orange 30	C. I. Disperse Red 167	C. I. Disperse Blue 79
H-W	Suncron Yellow S-FW	Suncron Red S-FW	Suncron Blue S-FW
H-L	Foron Yellow AS-3L	Foron Red AS-3L	Foron Blue AS-3L

interfaced with a personal computer. The settings were as follows: specular light included, large area of view, UV included, standard light D65 and 10° standard observer view.

Fastness to washing, light, rubbing and sublimation were measured using ISO 105-C06/A2S, ISO 105-B02, ISO 105-X12, AATCC 117 methods respectively.

3. Results and discussion

3.1 Clearing and heat setting

General coloration process for PET filament fabrics consists of dyeing with disperse dye at 130℃, reduction clearing and heat setting at around 180℃. The chemical and thermal properties of the dyeable PP are so different from those of PET that it is necessary to examine the condition of clearing and heat setting for the new fiber. Fig. 1 shows K/S values of the samples before and after clearing. It can be found that K/S value of the reduction cleared samples decreases as the washing temperature increases, and that K/S value of the sample soaped at 70℃ is the highest among the cleared samples. Table 2 shows wash fastness of the cleared samples, the grade determined by the color change are the same for all samples, but the grades of the soaped samples, determined by the staining on nylon fabric, are better than those of the reduction cleared samples by 0.5 grade.

The thermal stability of the dyeable PP is low and it might melt when exposed to high heat setting temperature used for PET. Hence heat setting temperature was adjusted at 130, 140 and 150℃. K/S values of the samples treated at 130℃ were a little higher than those at 140℃, and K/S values at 150℃ are remarkably high, as shown in Fig. 2. It is also found that K/S value of the samples heat setted at the same temperature decreases as the soaping temperature increases. Table 3 shows effect of heat setting temperature on washing fastness of the samples soaped at different temperatures. The washing fastness of the samples treated at 150℃ are betterby 0.5~1 grade than those at 130 and 140℃.

Although samples heat setted at 150℃ have the highest K/S value and good washing

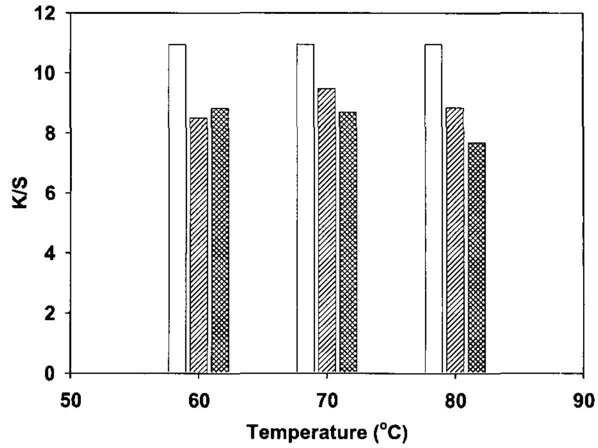

Fig. 1. Effect of clearing process at the various temperatures on K/S values of the sample dyed with 2 %owf C. I. Disperse Red 167 (□; after dyeing, ▨; after soaping, ▩; after R/C).

Table 2. Effect of clearing process on washing fastness of the sample dyed with 2 %owf C. I. Disperse Red 167

Method	Temperature	Staining (Nylon)	Color Change
Soaping	60℃	3	3-4
	70℃	3-4	3-4
	80℃	3-4	3-4
R/C	60℃	2-3	3-4
	70℃	2-3	3-4
	80℃	3	3-4

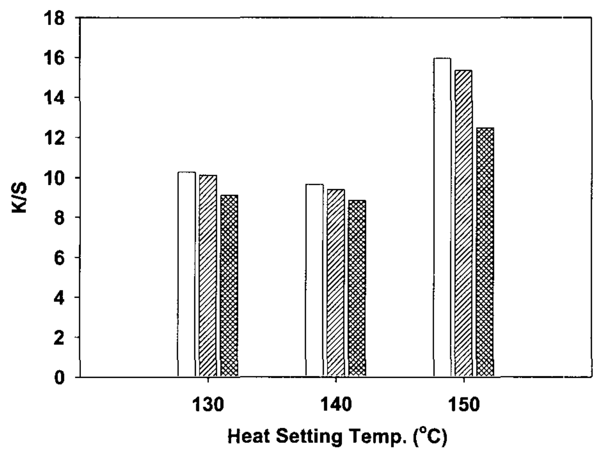

Fig. 2. Effect of heat setting temperature on K/S values of the sample dyed with 2 %owf C. I. Disperse Red 167 (□; soaping at 60℃, ▨; soaping at 70℃, ▩; soaping at 80℃).

Table 3. Effect of heat setting temperature on washing fastness of the sample dyed with 2 %owf C. I. Disperse Red 167

Heat Set Temp.	Soaping Temp.	Staining (Nylon)	Color Change
130℃	60℃	3	3
	70℃	3-4	3
	80℃	4	3-4
140℃	60℃	3	3-4
	70℃	3-4	3-4
	80℃	3-4	3
150℃	60℃	4	3-4
	70℃	4	3-4
	80℃	4	3-4

fastness, they are shrunk, yellowed and stiffened by partial melting of PP. Therefore, heat setting at 150℃ is not practically desirable.

Considering the apparent color strength, washing fastness and softness, the most appropriate conditions for clearing and heat setting are determined as follows; soaping at 70°C and heat setting at 130℃ respectively.

Thus, these clearing and heat setting conditions were applied in the dyeing of the PP fabric throughout the experiments.

3.2 Rate of dyeing

The extents of exhaustion as a function of dyeing time were measured to examine dyeing property of disperse dyes on the dyeable PP as its dyeing behavior was expected to be different from PET. Fig. 3 shows exhaustion curves of E type three primary colors. The extent of exhaustion is extremely low for initial 40 min, and somewhat increases as dyeing proceeds, but final exhaustion is too low. Dyeing rates of the E type dyes show a great difference which implies a low compatibility between them.

Therefore, when dyeing PP blanket fabric with a mixture of the E type three primary colors, color matching might be difficult and subsequently reproducibility would be very poor.

Fig. 4 demonstrates exhaustion curves of S type dyes.

Adsorption starts at the beginning of dyeing process, intensive exhaustion occurs in the period of 60 to 90min(dyeing temperature 100 to 130℃). Even though dyeing rate of Orange 30 is a bit faster and its final exhaustion is about 10 % higher than Red 167 and Blue 79, compatibility of S type dyes is much better than E type dyes.

H-W type dyes are known to have diester group within their structures. The exhaustion curves are shown in Fig. 5. Adsorption of H-W type dyes occurs very slowly until 80min(dyeing temperature 120℃), and their final exhaustions are as low as 13~45%. H-L type dyes are usually used for car seats and their exhaustion curve are shown in Fig. 6.

Their rates of dyeing are very slow from beginning to end of dyeing, and final exhaustions are below 30%. The dyeable PP fiber used for this experiment was manufactured by mixing 6 wt% of polyester copolymer preferentially at the central region of the fiber. The disperse dyes should pass through highly hydrophobic PP component before contacting the dye-receptive sites in the center of the fiber.

In this process, it is assumed that each dye shows abnormal dyeing behavior due to the discorded affinity of disperse dye to the PP component.

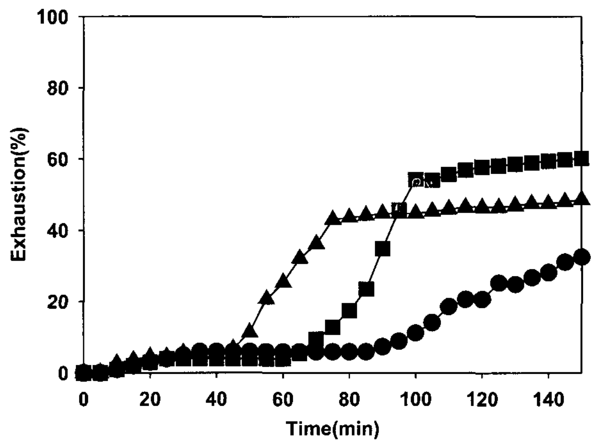

Fig. 3. Exhaustion curves of E type dyes to the dyeable PP (■;Red 60, ▲;Blue 56, ●;Yellow 54).

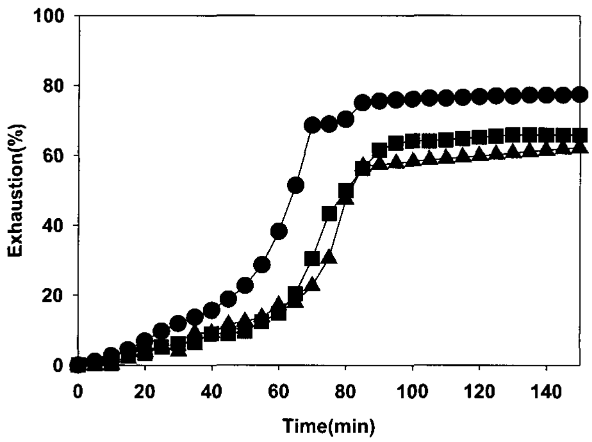

Fig. 4. Exhaustion curves of S type dyes to the dyeable PP (■;Red 167, ▲;Blue 79, ●;Orange 30).

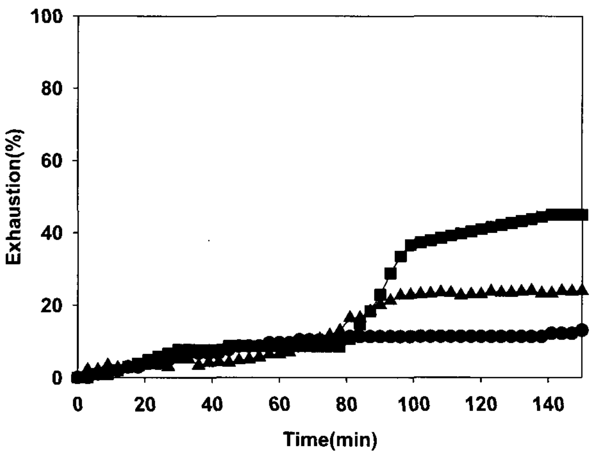

Fig. 5. Exhaustion curves of H-W type dyes to the dyeable PP (■;Red S-FW, ▲;Blue S-FW, ●;Yellow S-FW).

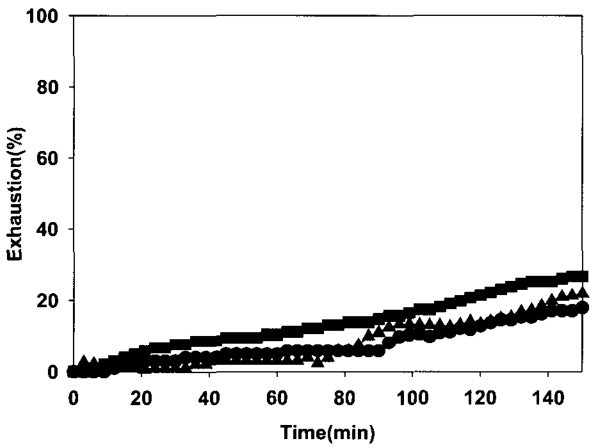

Fig. 6. Exhaustion curves of H-L type dyes to dyeable PP (■;Red AS-3L, ▲;Blue AS-3L, ●;Yellow AS-3L).

Comparing dyeing rate and final exhaustion of four types of disperse dye, it is considered that S type dye is the most appropriate for the dyeable PP blanket fabric.

3.3 Build-up property

K/S values of the samples dyed at 0.5, 1, 2 and 4 %owf were measured to investigate the build-up property of disperse dyes on the dyeable PP blanket fabric. Fig. 7 shows K/S values of the samples dyed with E type dyes. K/S values of Red 60 and Yellow 54 do not increase with increasing dye concentration from 0.5 to 4.0 %owf, which indicates their build-up properties are not good. It was observed that a large amount of dyes came out from dyed sample into clearing liquor during soaping. K/S value of Blue 56 increases almost in proportional to dye concentration and it is as high as 11.8 at 4 %owf after clearing.

K/S values of the samples dyed with S type dyes are demonstrated in Fig. 8. There is an overall tendency that K/S value of the dyed fabric increases as dye concentration increases. It means that build-up properties of S type dyes are better than E type dyes. Considering that increase in K/S value slows down above dye concentration higher than 1 %owf, it can not be thought that build-up property is excellent. Almost maximum exhaustions are achieved at 1~2 %owf, suggesting that the available dye sites has become nearly saturated at 1~2 %owf dyeing because the disperse dye is directly exhausted not to PP fiber, but to the additives. It was observed that the color difference between samples could be clearly distinguished immediately after the dyeing but color difference diminished after soaping.

When the dyeable PP fabric is dyed with H-W type dyes, only Red dye shows slight increase in K/S value, but Yellow and Blue dyes do not show difference in K/S values as shown in Fig. 9. However, it might be worth to consider adopting H-W type dyes for pale depth dyeing because PP fabrics dyed with H-W type dyes are very bright in color. H-L type dyes show a similar tendency with H-W type dyes as shown in Fig. 10: K/S values of Yellow and Red dyes are extremely low and there is almost no change in K/S values as dye concentration increases.

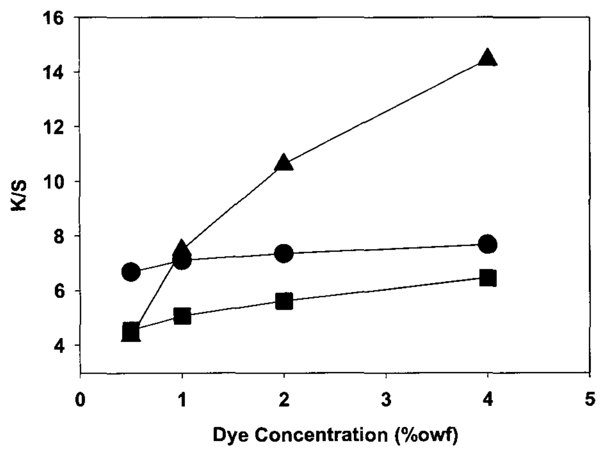

Fig. 7. Build-up properties of E type dyes (■;Red 60, ▲;Blue 56, ●;Yellow 54).

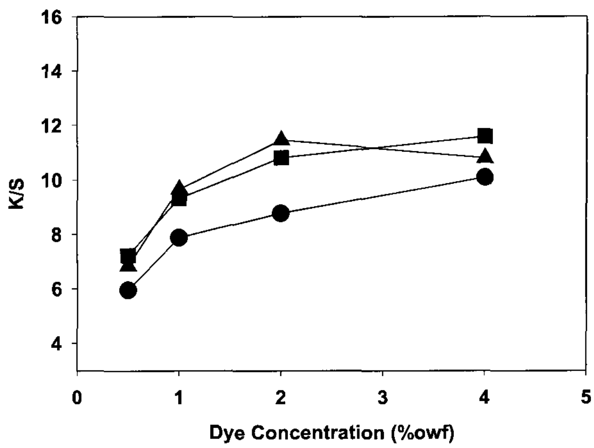

Fig. 8. Build-up properties of S type dyes (■;Red 167, ▲;Blue 79, ●;Orange 30).

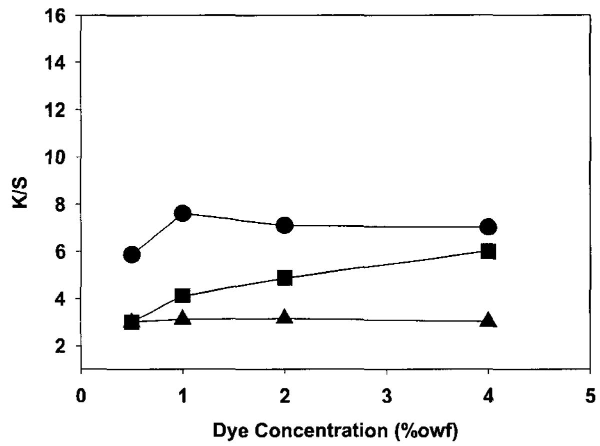

Fig. 9. Build-up properties of H-W type dyes (■;Red S-FW, ▲;Blue S-FW, ●;Yellow S-FW).

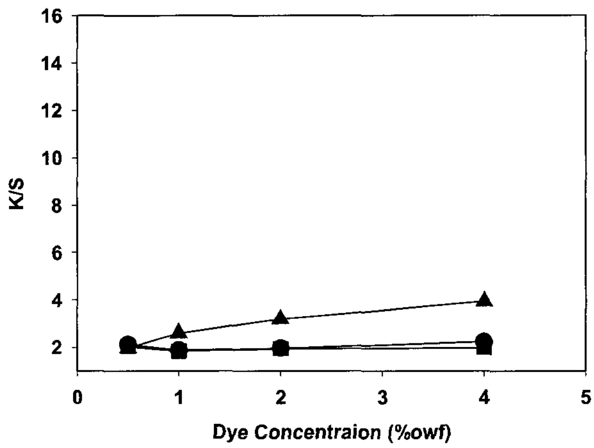

Fig. 10. Build-up properties of H-L type dyes (■;Red AS-3L, ▲;Blue AS-3L, ●;Yellow AS-3L).

3.4 Color fastness

The grades of washing fastness of samples dyed with various types of disperse dyes are listed in Table 4. Although multi-fabrics were used for washing fastness test, the grades evaluated by the staining on PET and nylon are reported here. The grades by the staining on PET are generally so excellent that the grades by the staining on nylon are solely discussed below.

Washing fastness of S type dyes is better than that of E type dyes. In the case of S type dyes the minimum dye concentration to obtain samples whose K/S values are higher than 10, are 2 %owf Orange 30, 1 %owf Red 167 and 1 %owf Blue 79, and the grades of the corresponding sample are 3~4, 4~5 and 4~5 respectively.

Both H-W type dyes and H-L type dyes exhibit excellent washing fastness, but it should be considered that the amount of exhausted dyes in the PP fiber is not much.

The grades of fastness to rubbing, light and sublimation of samples dyed with various types of disperse dyes are listed in Table 5. Fastnesses of E type dyes are generally good, sublimation fastness of S type dyes is excellent, light fastness of H-L type dyes is also very good, but light fastness of H-W type dyes is poor.

4. Conclusions

Dyeing and fastness properties of the newly developed PP fiber dyeable to disperse dyes were studied with four types of disperse dyes. Soaping gave better results in clearing than reduction clearing and heat setting above 140℃ caused PP fiber to melt slightly. The rates of dyeing and

Table 4. Wash fastness of PP fabric dyed with various types of disperse dyes

Color	Concentration (%owf)	E type		S type		H-W type		H-L type	
		Change	Stain	Change	Stain	Change	Stain	Change	Stain
Yellow	0.5	3-4	2-3	4-5	4-5	5	4-5	5	5
	1.0	3-4	2	4-5	4-5	4-5	4-5	5	5
	2.0	3-4	2	3-4	3-4	4-5	4-5	4-5	4-5
	4.0	3-4	2	3	3	4-5	4	4-5	4-5
Red	0.5	4	2-3	5	4-5	5	5	4	4-5
	1.0	3-4	2-3	4-5	4-5	4-5	5	4-5	4-5
	2.0	3-4	2-3	4	3-4	4-5	4-5	4-5	4-5
	4.0	3-4	2	3	2-3	4-5	4	4-5	4-5
Blue	0.5	4-5	3	4	5	5	5	4	4-5
	1.0	3-4	2	4-5	4-5	5	5	4	4-5
	2.0	3-4	2	4	4-5	4-5	5	3-4	4
	4.0	4	1-2	4	4-5	4-5	5	3-4	4

Table 5. Rubbing, light and sublimation fastness of PP fabric dyed with various types of disperse dyes at 1 %owf concentration

Fastness	E type			S type			H-W type			H-L type		
	Yell.	Red	Blue	Yell.	Red	Blue	Yell.	Red	Blue	Yell.	Red	Blue
Rubbing(dry)	3	2-3	3-4	3-4	3	3	3-4	4-5	4-5	2	3-4	4-5
Rubbing(wet)	3	3	3-4	4	3-4	4	4-5	4-5	4-5	3	4	4-5
Light	>4	>4	4	3	2	>4	2	2	2	>4	>4	>4
Sublimation	4	3	3	4-5	4-5	4-5	5	2	2	4-5	4	4

the extents of exhaustion of E type dyes were not similar to each other and the apparent color strength did not increase with increasing dye concentration with insufficient washing fastness.

In the cases of high wash fastness type dyes and high light fastness type dyes, the rates of dyeing were slow and the extents of exhaustion were very low. On the other hand, the dyeing rates of S type dyes were similar, together with good build-up and color fastnesses. It was found that the most appropriate dye for the dyeable PP fiber was S type dyes.

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