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A Comparative Analysis of Polyester Fabric Properties between Dyed with Indigo and with Disperse Dyes

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Abstract

A study was carried out to compare several colorimetric, physical and comfort properties of polyester fabric dyed with indigo type vat dye and traditionally used disperse dye. It was observed that in terms of colorfastness properties the results were found similar for both the dyes, however in some cases indigo showed slightly better performances. While comparing physical properties, though pilling resistance was found similar, abrasion resistance and bursting strength were found better for disperse dyed fabric. The lower drape co-efficient, bending length and flexural rigidity exhibited the improvement of limpness of the indigo dyed sample. The comfort property was also found improved attributed by the enhanced air permeability of the indigo dyed polyester fabric.

Keywords

Comparison, Polyester, Indigo, Disperse, Colorimetric, Physical, Comfort Properties

1. Introduction

Polyesters are one of the most used poly-condensation polymers belonging the class containing ester functional group on polymeric main chain. They are derived from dicarboxylic acids and diols and are usually denoted as PET (polyethylene terephthalate). Polyesters are used in various forms, e.g., fibers, filament, fabric, composites, resins, dendrimers, films, sheets, and membranes in different fields, such as textile, automotive, medical, electronic, and construction applications, etc. They are also popular in use for packaging materials, such as bottles/containers, etc. [1]. It is the most important synthetic fiber worldwide in terms of production volume and applications [2]. The main reason for its extensity is being the cheap and easily available raw material along with desirable properties [3]. High tenacity, low creep, good resistance to strain and deformation, high glass transition temperature, and good resistance to acids and oxidizing agents are the desirable properties. All these physical, mechanical and chemical properties make it appropriate not only for apparel and textile products but also for industrial and composite applications. Polyester fibres are versatile in apparel because of their receptivity to heat treatments and their ease of blending with other fibres [4] [5].

Disperse dyes permit dyeing of hydrophobic thermoplastic fibers including nylon, polyester, acrylic, and other synthetics [6] [7]. They are colorants with low water solubility that, in their dispersed colloidal form [8]. As their name implies, these dyes are present in the dyebath as a fine aqueous suspension in the presence of a dispersing agent [9].

Although polyester fibers have been dyed dominantly using disperse dyes, little attention has focused on the application of vat dyes on polyester fibers. In terms of fastness properties, especially to the washing, the satisfactory levels of wash fastness are not present in the results from disperse dyeing due to the dye reduction and migration behavior. In this context, vat dyeing leaves a potential possibility and is an alternative method to overcome the disadvantage in use [10].

Indigo, a natural dye has been in use for the coloration of textiles for ages [11]. It is a form of vat dye, has an affinity for cotton, wool, and silk fabrics in its leuco form, but has a low affinity for synthetic fabrics such as polyester [12]. Indigo is normally insoluble in water, alkaline, or acid solutions and the oxidized form has no affinity for the cotton fabrics. Sodium hydrosulfite while reducing indigo produces three different forms of reduced indigo by carefully controlling the dye-bath pH. Each from exhibits a different degree of substantivity to fibre (**Figure 1**).

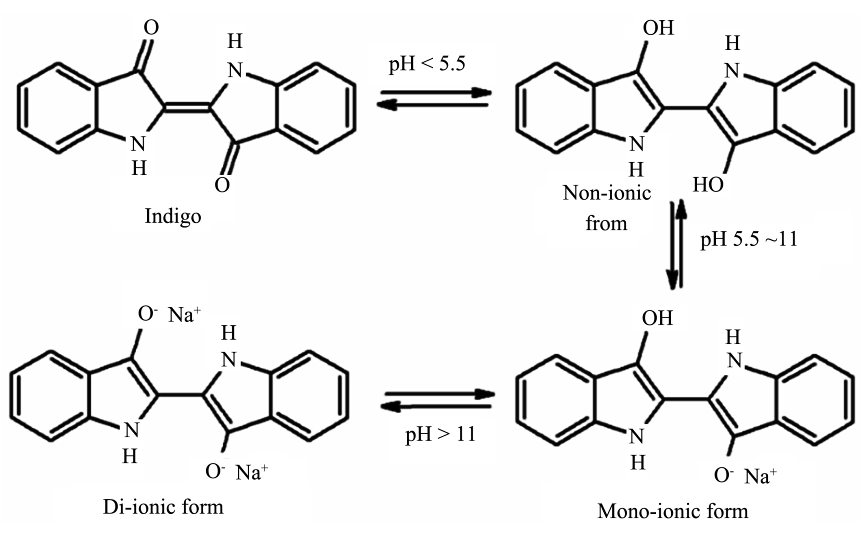


Figure 1. Structures of reduced indigo in different pH [4].

With the increase of alkali concentration the ratio of leuco vat acid to mono-sodium phenolate form decreases. When sodium hydroxide exists, the di-sodium arylenolate form (di-ionic form) and the mono-sodium arylenolate form (mono-ionic form), which are water-soluble, are present in the dyebath. The nonsodium arylenolate form (non-ionic form) is present in the low pH dyebath. The ionic forms, which are more hydrophilic than the non-ionic form, have a high affinity for cellulose fabrics such as cotton. However, the ionic forms have a low affinity for polyester fabrics, which are more hydrophobic than cellulose fabrics. The hydrophilic cotton fabrics could be dyed with indigo dissolved in an aqueous solution including a small amount of sodium hydrosulfite and sodium hydroxide. The polyester fabrics could not be dyed well with the ionic forms. The non-ionic form should have a higher affinity for polyester fabrics than the ionic forms, so the polyester fabrics were dyed with indigo using the aqueous solution including the excess amount of sodium hydrosulfite and the smaller amount of sodium hydroxide [13] [14].

Some work has been carried out in the dyeing of polyesters, particularly, PET fibres with indigo blue. A literature survey showed that little work has been carried out in the application of vat dyes on synthetic fibres other than polyesters [3] [15]. Some of the work has been published about the application of vat colorants on synthetic fibres mainly PET [4]. Excellent shade depth with good washing and rubbing fastness properties have been obtained. Although there are poor light and sublimation fastness properties, this poor fastness has been taken advantage of in obtaining faded-look effects such as conventional denim on all-polyester as well as PC blended fabrics [3]. In general, dyeing produced with vat dyes imparts overall higher wash fastness properties than results obtained by other classes of dyes. An insoluble characteristic of vat dyes is attributed to this superior wash fastness result [10]. In the present work, polyester fabric was dyed with both indigo vat dye and traditionally used disperse dye. The surface morphology was assessed via scanning electron microscope photograph. Colorimetric properties were compared by color strength and visual appearance of the dyed samples. Color fastness tests including fastness to wash, water, perspiration, rubbing, dry heat etc. were carried out to compare the fastness properties of the dyed samples. In terms of physical properties of the dyed fabric, pilling resistance, abrasion resistance, bursting strength were assessed. Other physical properties such as bending length, flexural rigidity and drape co-efficient were tested to compare the comfort properties of the dyed samples which was further complemented by the air permeability tests.

2. Materials and Methods

2.1. Materials

2.1.1. Fabrics

100% polyester fabric was used for this research work. The specification of the sample was plain weave, areal density 50 gram per square meter (GSM), warp count 82 den, weft count 72 den, ends per inch (EPI) 102 and picks per inch (PPI) 62.

2.1.2. Dyes and Chemicals/Auxiliaries

Novasol Blue-CL MD as Indigo vat dye and Terasil Blue BGE as disperse dye, both in granular form, were collected from Swiss Colours Bangladesh Limited. Sodium dithionite/Sodium hydrosulphite ($Na_2S_2O_4$) (in powder form) and Sodium hydroxide (NaOH) (in flakes form), collected from Merck, Germany, were used for reduction of vat dyes. For reduction clearing, Sodium carbonate (Na_2CO_3) (in powder form) from the same source was used. For several characterization of the dyed samples, chemicals and auxiliaries were used as per standard testing methods.

2.2. Methodology

2.2.1. Fabric Pre-Treatment

Since synthetic fibres contain a very few amount of impurities in the bulk of the material and there may present some added impurities [16], a mild combined scouring bleaching treatment was carried out. The treatment bath contained 1 g/L Caustic Soda (36˚ Be), 4 g/L H_2O_2 (35%), 2 g/L Soda ash, 1 g/L Peroxide stabilizer, 1 g/L wetting agent and 1 g/L detergent. Pre-treatment was carried out at a temperature of 100˚C for 45 minutes at a pH of 10.5 with material to liquor ratio of 1:10.

2.2.2. Vat Dyeing

Vatting of indigo was started in sealed, stainless steel dye pots of 250 cm^3 capacity in a laboratory scale dyeing machine (AHIBA IR) with 3% o.w.f. indigo dyes, 10 g/L sodium dithionite and 1 g/L caustic soda at a temperature of 70˚C, for 30 minutes. The bath pH was 7.5 - 8. Vatting was confirmed by the color change of the solution (lemonish-yellow). Polyester samples were then added and further dyeing continued at 130˚C, for 60 minutes. At the end of dyeing, the dyed samples were removed, rinsed thoroughly in water. Oxidation was carried out to convert the indigo dye to its original insoluble form with 2 g/L H_2O_2 at a temperature of 70˚C for 20 minutes. Reduction clearing to remove the loosely fixed dye on the surface of dyed fabric was carried out with 1 g/L detergent, 1 g/L sodium dithionite and 1 g/L caustic soda at a temperature of 70˚C for 20 minutes.

2.2.3. Disperse Dyeing

Polyester fabric was dyed with 3% disperse dye in same laboratory scale dyeing machine. The chemicals and auxiliaries required in the dyeing bath were 2 g/L acetic acid, 1 g/L dispersing agent, 1 g/L sequestering agent and 1 g/L leveling agent. The dyeing was carried out at 130˚C for 60 minutes with a material to liquor ratio of 1:55. The dye-bath pH was maintained 4.5. At the end of dyeing, the samples were removed and rinsed thoroughly in tap water. Reduction clearing was then carried out to remove the loosely fixed dye on the surface of dyed fabric with 1 g/L detergent, 1 g/L sodium dithionite and 1 g/L caustic soda at a temperature of 70˚C for 20 minutes.

2.2.4. Characterization of Differently Dyed Samples

1) Morphology of the Dyed Sample

The Scanning Electronic Microscope focuses on a beam of high-energy electrons to generate a variety of signals at the surface of solid specimens. The signals that derive from electron—sample interactions reveal information about the sample's surface topography (the surface features of an object or "how it looks", its texture), morphology (the shape, size and arrangement of the particles making up the object that is lying on the surface of the sample) composition, and other properties such as electrical conductivity [17].

2) Color Strength

Color strength values (K/S) of the dyed samples were calculated using Datacolor 650 (Dual-beam spectrophotometer) under the following condition: Pulsed Xenon filtered to approximate D65 illumination and 8˚ viewing measurement geometry, measurement wavelength range from 400 nm to 700 nm in which 650 nm was used as a maximum wavelength to measure the color strength of the dyed samples. The Kubelka-Munk equation was used with the help of relevant software, where, K is the coefficient of absorption; S is the coefficient of scattering and R is the reflectance value of the sample at a particular wavelength, on which maximum absorption occurs for a particular dye/color component [18].

$$\frac{K}{S} = \frac{(1-R)^2}{2R}$$

3) Colorfastness tests

The resistance of color of textiles to fade or bleed against different agencies such as wash, water, perspiration, rubbing, acid, alkali, hot pressing, bleaching, etc. is called color fastness. The ISO test methods followed for the assessment of fastness properties of dyed polyesters against several agencies are listed in **Table 1** and the interpretation of fastness rating is shown in **Table 2**.

4) Bursting Strength

Bursting strength is the force uniformly distributed over a given area, needed to break the fabric when applied at right angles to the fabric [28]. The method

Table 1. Different methods for colorfastness tests.

Name of the test	Test method	Ref.
Color fastness to wash	ISO 105 C06 (C2S)	[19]
Color Fastness to Perspiration	ISO 105 E04	[20]
Color Fastness to Water (Cold)	ISO 105 E01	[21]
Color Fastness to Sea Water	ISO 105 E02	[22]
Color Fastness to Hot Water	ISO 105 E08	[23]
Fastness to Dry Heat	ISO 105 P01	[24]
Color Fastness to Rubbing	ISO 105-X12	[25]

Table 2. Ratings for colour change and staining [26] [27].

Fastness Grades	Shade change	Comments	Staining
Grade-5	No change	Excellent	No staining
Grade-4	Slight loss in depth	Good	Very slight staining
Grade-3	Appreciable loss	Fair	Moderate staining
Grade-2	Significant loss	Poor	Significant staining
Grade-1	Great loss in depth	Very poor	Deep staining

for assessment was ISO 13938-1:1999 [29]. Strength loss% was measured by following formula:

$$\text{Strength loss }\% = \frac{\text{Before strength} - \text{After strength}}{\text{Before strength}} \times 100\%$$

5) Pilling Resistance

Pilling is a fabric surface fault characterized by little pills of entangled fibres clinging to the cloth surface and giving the garments an unsightly appearance. Pilling resistance is the resistance of a fabric to the formation of pills which may form during wear and washing by the entanglement of loose fibres. The test Method was ASTM D 4970-02. The observed resistance to pilling was reported using an arbitrary rating scale after 125, 500, and 2000 revolutions [30]. The ratings for the pilling resistance test are given in **Table 3**.

6) Abrasion Resistance

Abrasion resistance may be defined as the ability of a surface to resist being worn away or to maintain its original appearance when rubbed with another object. The Test Method followed was ISO 12947-3:1999 (mass loss). The mass loss of the test specimen was measured after 1000 revolutions [31].

7) Bending Length and Flexural Rigidity

The length of a rectangular strip of material that bends under its own weight to a specified angle is called its bending length. The method followed for the test was BS 3356:1990 in Shirley stiffness tester. The flexural rigidity was obtained from the bending length and the mass per unit area of the fabric [32]. If M is the areal density of the fabric in GSM and C is the bending length in mm,

$$\text{Flexural Rigidity} = M \times C^3 \times 9.8076 \times 10^{-6}\ \mu\text{N} \cdot \text{m}$$

8) Drape Co-efficient

Drape is the ability of a fabric to assume a graceful appearance in use. The results are mainly dependent, however, on the stiffness of the fabric. The Test Method followed was BS 5058 [33].

9) Air Permeability

The air permeability of fabric is a measure of how well it allows the passage of air through it. It is a representation of the comfort properties of the fabric. Air permeability is defined as the volume of air in millilitres which is passed in one second through 100 mm^2 of the fabric at a pressure difference of 10 mm head of water. The Test Method followed was ASTM D 737 [34].

Table 3. Rating of pilling test assessment [28].

Pilling Rating	Rating
5	No pilling
4	Slight pilling
3	Moderate pilling
2	Severe pilling
1	Very Severe pilling

3. Results and Discussions

3.1. Surface Morphology of the Dyed Sample

The scanning electron microscopic (SEM) images (**Figure 2**) of the two differently dyed polyester samples exhibit no significant changes. It can thus be assumed that though the dyes exist in different forms however the dyeing mechanism is more or less similar for both the dyes. The presence of dye particle is uniform, thus a successful even shade could be obtained.

3.2. Colorimetric Properties

3.2.1. Color Strength

The color strength (K/S) values for 3% shaded indigo dyed polyester and disperse dyed polyester were found almost similar, for indigo 20.48 and for disperse dyed polyester the value was 19.86. Since, this is not an absolute value, rather dependent on different dye chromophores as well as different brands; any such conclusion of color yield could not be made. Yet, both the dye under experiment was found almost identical. The visual appearance is shown in **Figure 3**.

3.2.2. Colorfastness Properties

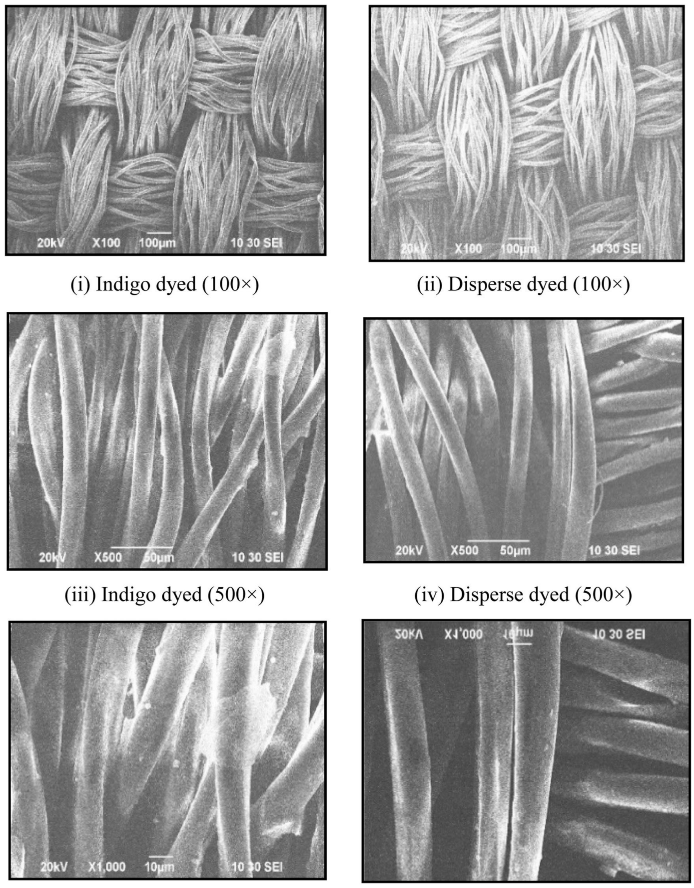
The colorfastness properties of differently dyed polyesters are tabulated in **Tables 4-6**.

Overall, it was seen that, colorfastness properties were almost similar. In terms of wash fastness test, indigo dyed polyester showed similar or a bit better result from disperse dyed sample. In case of fastness to perspiration (both acidic and alkaline), cold water and sea water, the treatment condition were too mild to bleed any color from both the indigo and disperse dyed sample. The fastness grades were thus excellent in all the cases. In the case of rubbing, disperse dyed samples showed poor results in comparison with indigo. The indigo dyes, after oxidation, get converted into original insoluble form, thus making the dye more durable in the interior of the fibre. The colorfastness to hot water and color fastness to dry heat also showed the same trend. For disperse dyed polyester fabric, sublimation fastness is always a matter of concern. Using indigo dyes this problem could be omitted.

3.3. Physical Properties

3.3.1. Pilling Resistance

The results of pilling resistance test at several cycles are presented graphically in



(i) Indigo dyed (100×) (ii) Disperse dyed (100×)

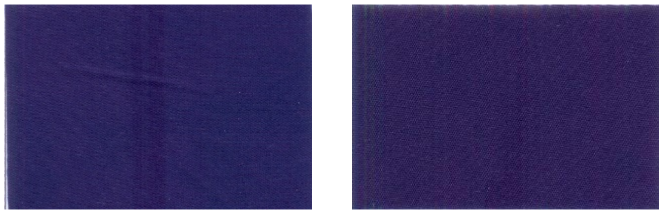
(iii) Indigo dyed (500×) (iv) Disperse dyed (500×)

(v) Indigo dyed (1000×) (vi) Disperse dyed (1000×)

Figure 2. SEM photograph of indigo and dispersed dyed polyester samples.

Table 4. Colorfastness to wash, perspiration, cold, sea, hot water.

Colorfastness to	Polyester dyed with	Color change	Staining					
			Diacetate	Bleached cotton	Polyamide	Polyester	Acrylic	Wool
Wash	Indigo	4/5	4/5	4/5	4/5	4	5	4
	Disperse	4	4	4	4/5	4	4	4
Perspiration (Acidic)	Indigo	5	5	5	5	5	5	5
	Disperse	5	5	5	5	5	5	5
Perspiration (Alkaline)	Indigo	5	5	5	5	5	5	5
	Disperse	5	5	5	5	5	5	5
Cold Water	Indigo	5	5	5	5	5	5	5
	Disperse	5	5	5	5	5	5	5
Sea Water	Indigo	5	5	5	5	5	5	5
	Disperse	5	5	5	5	5	5	5
Hot Water	Indigo	4/5	4	4/5	4	4	4/5	4/5
	Disperse	3/4	4	4/5	4	3/4	4	4/5



(a) (b)

Figure 3. Visual appearance of indigo and disperse dyed polyester fabric. (a) Indigo Dyed; (b) Disperse Dyed.

Table 5. Colorfastness to dry heat.

Polyester type	Color change	Staining
Indigo dyed	5	4
Disperse dyed	4	4

Table 6. Colorfastness to rubbing.

Polyester type	Warp Direction		Weft Direction	
	Dry	Wet	Dry	Wet
Indigo dyed	5	4/5	5	4/5
Disperse dyed	4/5	4	4	3/4

Figure 4. Pilling grades were found similar for both the indigo dyed and disperse dyed polyester fabric.

In shorter pilling cycles (that is 125 and 500 cycles), pilling grades were 5 for all the samples representing there were no pilling. In the 2000 cycle, pilling grade was found one grade lower (*i.e.* 4 to 5) for both indigo and disperse dyed samples representing slight to no pilling. The mild rubbing action was not sufficient enough to create significant pills in any of the samples.

3.3.2. Abrasion Resistance

Abrasion resistances of the indigo and dispersed dyed samples were determined in terms of mass loss% after 1000 cycle and are presented in Figure 5.

It was found that indigo dyed polyester had a greater loss in mass (7.1%) than from disperse dyed polyester (5.81%). The reason behind this could be attributed by the application medium. Since polyester was dyed with indigo in slightly alkaline medium and polyester is sensitive to alkali, a slight degradation might occur that reduced the strength of fibre during abrasion cycles. This might cause a slight more mass loss than disperse dyed polyester.

3.3.3. Bursting Strength

Figure 6 represents the bursting strengths of the grey and dyed samples. It is seen that, bursting strength was found higher (887 KPa) in the case of disperse dyed polyester than indigo dyed polyester (840 KPa). Indigo was applied in polyester in slightly alkaline medium and as polyester is hydrolysed in alkaline

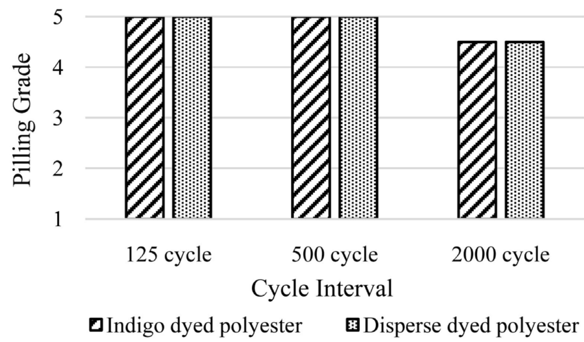


Figure 4. Pilling resistance of polyester samples.

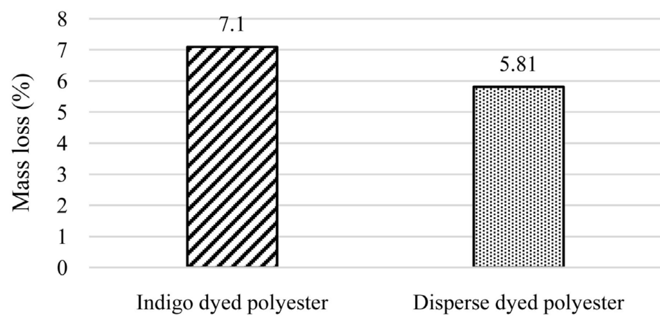


Figure 5. Abrasion resistance of polyester samples.

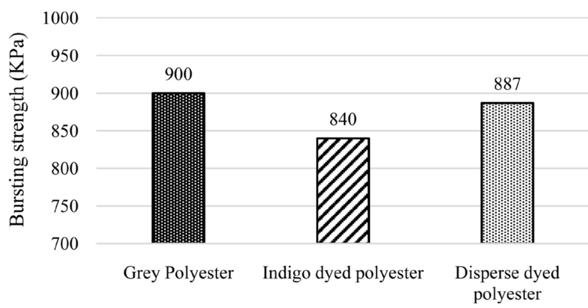


Figure 6. Bursting strength of polyester samples.

medium, a degradation might occur that reduces the strength. Since the raw polyester strength was found 900 KPa, the strength loss was 6.67% and 1.44% for indigo dyed and disperse dyed polyesters respectively.

3.3.4. Drape Co-Efficient

While comparing the drape co-efficient between indigo dyed and disperse dyed polyester fabric, it was observed that the values were almost closer, yet disperse dyed polyester fabric was a bit stiffer (co-efficient 0.814) than indigo dyed polyester (0.748). The slight degradation of polyester during alkaline treatment in case of indigo dyeing might be the cause of such limpness of indigo dyed fabric. The data are shown in **Figure 7**.

3.3.5. Bending Length and Flexural Rigidity

Bending length (**Figure 8**) and flexural rigidity (**Figure 9**) are another way of

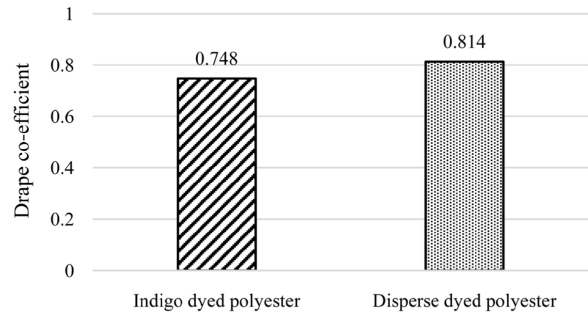


Figure 7. Drape co-efficient of polyester samples.

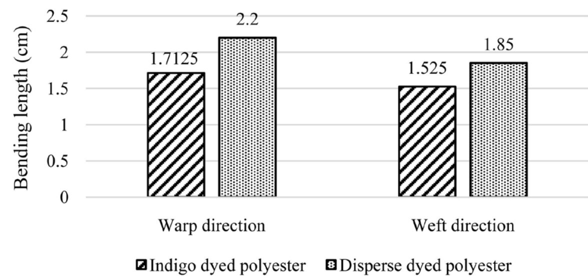


Figure 8. Bending length of polyester samples.

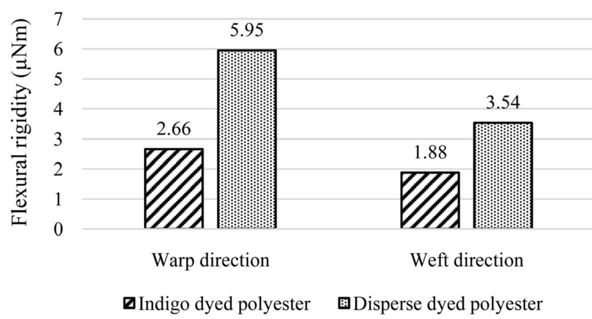


Figure 9. Flexural rigidity of polyester samples.

representation of fabric stiffness or limpness. In warp way direction the bending length was found higher (2.2 cm) for disperse dyed sample than indigo dyed sample (1.7125 cm). In weft way the trend was found similar, for disperse dyed sample it was 1.85 cm and for indigo dyed sample 1.525 cm. Flexural rigidity values, obtained from bending length, represented the stiffness in µNm. The indigo dyed samples were found limper (warp way 2.66 weft way 1.88) than disperse dyed samples (warp way 5.95 and weft way 3.54). As mentioned previously, the alkaline treatment condition during indigo dyeing of polyester might be the reason of molecular weight degradation. As a consequence, the fabric became limp and the bending length was found smaller than disperse dyed polyester fabric.

3.3.6. Air Permeability

As a representation of the comfort properties, air permeability was assessed and is shown in Figure 10. It was found that after dyeing the air permeability reduced

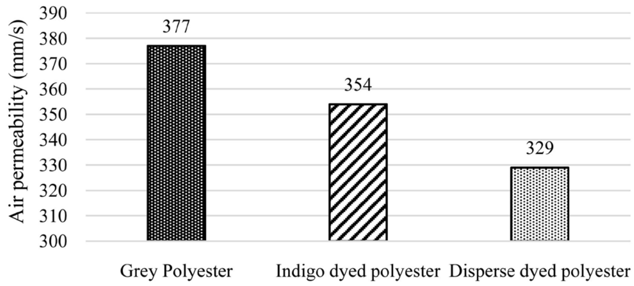


Figure 10. Air permeability of polyester samples.

for both the indigo and disperse dyed samples than the grey state. For grey state, air permeability was found 377 mm/s and while comparing both the dye types, it was observed that indigo dyed fabric had a greater permeability (354 mm/s) than disperse dyed polyester (329 mm/s). The reason could be correlated with the treatment medium during dyeing. Polyester fabric is sensitive to alkaline condition. In the case of indigo dyeing, the treatment was in slightly alkaline medium. A slight degradation in alkaline medium might loosen some compactness of fabric, which in result increased accessibility. The air permeability was thus found greater than in the case of disperse dyed polyester fabric.

4. Conclusion

It can be summarized that, while comparing identical indigo dyed and disperse dyed polyester, the color strengths were found similar. Though this is not independent of various chromosphere groups as well as manufacturers, however, it revealed that similar shades are achievable even in the case of indigo dyes. The fastness properties were almost similar, though indigo dyes showed better results at some tests, especially for the dry heat fastness test. In terms of physical properties, though the mass loss % was higher in case of indigo dye, drape co-efficient, bending length and flexural rigidity proved the indigo dyed fabric to be limper than disperse dyed fabric. It also exhibited better air permeability resulting in higher comfortability than traditionally dyed polyester. Indigo thus can be a comparable alternative to disperse dye in case of polyester dyeing. Further research may focus on revealing an alternate route of existing blend dyeing technique through simultaneous single stage dyeing of both polyester and cotton parts leading to minimize the processing time, energy, water, and inventing a cost-saving dyeing of blend textiles.

Conflicts of Interest

The authors declare that there is no conflict of interest in publishing articles.

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