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EVALUATION OF THE EFFECT OF WEAVE STRUCTURE ON THE DYEING OF FABRICS WITH REACTIVE DYES

Khudaiberdieva Dilfuza, Akhmedova Mukaddam
Tashkent Institute of Textile and Light Industry, Tashkent, Uzbekistan
akhmedovamukaddam90@gmail.com

Annotation: The article covers the effects of weave structural properties of cotton fabrics dyed with reactive dyes on their coloristic properties. Samples of varying yarn structures and thicknesses in twill, satin, and Plain weave were used for the research. Dye intensity was measured using an x-Rite spectrophotometer, and dye fixation was measured using a UV – 5100 UV/VIS spectrophotometer. It was established that changes in warp and weft thread density, as well as surface porosity, do not affect dye intensity. Among all weave types, Plain weave exhibits the highest dye fixation due to its high surface porosity and square and regular pores. The results showed that in twill weave, decreasing surface porosity increases dye fixation.

Keywords: cotton fabric, weave, Plain, twill, satin, surface porosity, volumetric filling, reactive dye, color intensity, fixation.

INTRODUCTION

A fabric is produced through the weaving process, in which two systems of yarns, i.e., the warp, oriented in the longitudinal direction, and the weft, arranged transversely, are interlaced to form a coherent structure. Weaving plays a key role in shaping fabric structure, which is the second factor (after the raw material) determining its performance properties. The structure of a fabric is primarily determined by the type and fineness of the yarns used, the characteristics of their interlacing pattern, and the density, expressed as the number of threads per unit area of the fabric. The intersection of the warp and weft is called the overlap. The length and offset of the overlap influence the properties of the fabric. Weaves are divided into four classes: Simple (main), fine-patterned, coarse-patterned (jacquard), and complex. Simple (main) weaves include plain, twill, and satin. Twill is recognized by experts as one of the most durable and abrasion-resistant weaves. It can be visually distinguished by the diagonal rib it forms. They are produced by interlacing threads with an asymmetrical shift of 2-3. The resulting fabric exhibits a relatively rough and coarse texture, which, however, does not hinder its suitability for the production of duvet covers and pillowcases. Among the most commonly produced materials utilizing this technique is fine twill fabric. Satin weave is characterized by elongated overlaps. In satin weave, single warp or weft overlaps are evenly spaced throughout the entire pattern. The thread system that emerges on the surface of the fabric has a high density. Fabrics of these weaves are characterized by increased abrasion resistance, high strength, and a low coefficient of friction, meaning they glide well and have a smooth, even surface. Plain weave is the simplest and therefore most popular weave. In this structure, the yarns are interlaced in a checkerboard pattern, with every alternate thread crossing over and under, resulting in a slightly open, mesh-like texture. At the same time, fabrics such as poplin, calico, and several others produced by this method are characterized by high wear resistance and durability. [1].

The quality of finished fabrics is determined not only by their physical and mechanical properties, but also by their coloristic properties. Fabric dyeing requires not only the correct recipe and settings, but also knowledge of fabric parameters, such as thread thickness and twist, weave coefficients and fabric structure, surface and volumetric fiber content, and the geometric parameters of the yarn bending values in the fabric, which significantly affect the shade of light. Numerous studies have addressed the influence of weave structure on the physical and mechanical properties of fabrics [2-5]. However, as an analysis of studies and publications [6, 7] has shown, to date there is very little research on a clear analytical relationship between fabric structure and the efficiency of the dyeing process. As a rule, in production conditions, dyeing processes are the same for fabrics of all types of weaves, and recipe features correlate only with the raw fiber composition. In each particular case, the problem of optimizing the dyeing process and determining the color characteristics of fabric dyeing is solved using empirical data [8].

Literature data show that weave structure, fabric density, thread count, and even yarn twist affects dye penetration, as dye solution can flow more easily and quickly in fabrics with low thread counts than in fabrics with high thread counts [9, 10]. Scientists [11] analyzed the effect of varying the warp and weft counts of cotton fabrics during reactive dyeing. Variations in warp and weft densities, as well as fabric porosity, exerted a significant influence on dye utilization. It was established that higher dye uptake occurs in fabrics with finer yarn counts and greater porosity.

As is known, fabric coverage and porosity improve the physical properties and comfort of textile materials [12]. Furthermore, these parameters are crucial for assessing dye penetration into the pores between yarns and into the pores within the yarn [13]. This means that porosity can be used as a factor in determining color consistency [14]. Given these observations, it is clear that fabric density and porosity directly affect color yield and should be considered when addressing color reproducibility issues.

The smaller the pores in a fabric, the more difficult it is for dye to penetrate the fabric, especially during continuous dyeing processes due to the short dyeing time. When a tightly woven cotton fabric absorbs water or a dye solution, it swells, increases its density, and creates a virtually impermeable barrier to liquid or water penetration.

However, a change in pore size also leads to a change in color intensity [15]. Scientists have shown that with increasing fiber content, the color intensity of primary weave fabrics decreases. [16]. It has been established that for fabrics of various structures, dyeing formulas must be regulated based on the volumetric fill factor of the fabric, which will improve the efficiency of the fabric dyeing process under industrial conditions.

In this context, it is essential to evaluate the influence of physical fabric parameters, such as weave type, porosity, and related structural characteristics on color appearance. This research focuses on assessing the effect of fabric structure on color matching

Methods

Dyeing with reactive dyes. Dyeing was carried out using Denovo Red Y2BL reactive dye supplied by Nichem. The process was conducted on an IR Dyeing Machine model DL-6000 (Korea)

Determination of the amount of dye absorbed by the fiber using a residual bath. Measuring the amount of dye absorbed by the fiber using a residual bath. This method determines the amount of dye absorbed by the fiber by comparing the concentration of the dye solution before and after dyeing. Measurements were performed using a colorimetric method.

The amount of dye transferred to the fibers is determined after colorimetry, strictly accounting for dilution and based on the initial and final concentrations of the dye bath. Residual and concentrated dye solutions were measured using a UV – 5100 UV/VIS spectrophotometer

Colorimetry. The color of each dyed fabric was determined using a x-Rite Color iMatch (Korea) Colorimeter. The instrument was first calibrated using a standard white tile as specified by the manufacturer. The relative color strength (K/S) of each dyed fabric was measured from the reflectance value at the wavelength of the maxi mum absorbance (k_{max}) of the dye. For each sample, K/S was measured randomly at 3 different locations along the front side of the length of the fabric and at three different locations along the back side of the length of the fabric. The 6 measurements were then averaged to obtain a single value for each sample. K/S values were determined using the Kubelka–Munk equation [17]:

$$K/S=(1-R)^2/2R$$

Where, R – is the reflectance at k_{max}

RESULTS AND DISCUSSION

12 cotton fabric samples of basic weave structures, varying in weave pattern and yarn fineness, were examined in this study. Samples of twill, satin, and plain weaves were woven on an MZX3-60 knitting machine at the Tashkent Institute of Textile and Light Industry.

In order to analyze the influence of not only weave but also yarn thickness on dyeing quality, the samples were produced using the following parameters: Twill (No. 1-3) and Plain (No. 9-12) of the same weave, but with different warp and weft yarn thicknesses; Twill (No. 3-5) and Satin (No. 6-8) of different weaves, but with the same warp and weft yarn thicknesses. All samples were bleached before dyeing using the same batch process. The technical characteristics of the bleached samples are given in Table 1.

Table 1.

Technical characteristics of bleached cotton fabrics

No	Weave	Linear thread density, T, tack	Surface density, g/m^2	Number of threads per 10x10 cm	Whiteness, %	Capillarity, mm/min	Surface filling ES, %	Surface porosity Rs, %
1	Twill 3/1	50/35	232	450/180	84.0	210	91.4	8.6
2	Twill 3/1	22/20	174	540/270	82.0	195	98.49	1.51
3	Twill 3/1	25x2/25x2	209	290/150	82.4	250	89.09	10.91
4	Twill 2/4	25x2/25x2	216	280/140	83.3	240	86.87	13.13
5	Twill 3/3	25x2/25x2	212	270/130	82.1	235	84.48	15.52
6	Satin 12/5	25x2/25x2	235	290/170	83.36	217	89.95	9.85
7	Satin 6	25x2/25x2	244	320/160	85.13	218	90.15	10.05
8	Satin 4	25x2/25x2	241	250/180	84.19	213	85.12	14.88
9	Plain	25x2/25x2	201	250/110	80.0	230	77.52	22.48
10	Plain	25x2/34	205	250/140	82.28	195	81.76	20.79
11	Plain	25x2/20	182	255/17	80.34	205	85.02	20.34

				0				
12	Plain	22/20	145	420/270	81.3	200	86.8	13.20

According to the table data, surface density increases linearly with increasing thread thickness in all weave types. Of all weave types, twill weaves have the highest surface fill.

Comparing samples of the same 3/1 twill weave, sample No.2, which has the smallest thread thickness, has the lowest porosity. This suggests that the thread thickness increases the number of threads per 10 cm, creating a denser distance between the threads, which correspondingly reduces surface porosity.

In twill samples of different weaves with identical warp and weft threads, the 3/3 weave has the highest porosity. This is explained by the fact that porosity increases as the yarn intersection point decreases.

In Plain weave, volumetric porosity decreases correspondingly as the warp and weft thread thickness increases. However, in twill weave, due to the difference in weave structure, this bonding is not noticeable. Although samples No.2 and No.12 have warp and weft threads of the same thickness, the porosity differs by almost ten times. This is explained by the fact that Plain weave has square or rectangular pores, while twill weave has straight, open pores due to the diagonal pattern. In satin weave, pores are fewer than in Plain weave due to the float of the threads (four or five threads per yarn cross at the top and bottom).

Table 2.

Quality indicators of dyed samples

Sample No.	Dye content in fiber, g/kg		Reflectance factor, R	Color Strength, K/S	System CIE L*a*b*		
	Exhaused	Fixed			L*	a*	b*
1	14.2	12.8	3.50	13.30	43.23	59.19	-0.40
2	14.8	13.5	3.55	13.10	42.22	59.17	0.23
3	14.3	12.9	3.54	13.14	42.30	58.90	0.00
4	14.3	12.8	3.11	15.14	41.83	59.21	0.48
5	13.9	12.3	2.86	16.50	41.67	58.75	0.59
6	16.2	14.6	3.88	11.87	42.08	59.26	-0.41
7	16.0	14.0	3.23	14.45	43.26	59.10	-0.81
8	15.6	13.5	3.27	14.26	43.71	58.72	-0.79
9	15.7	14.2	3.62	12.98	42.45	58.50	-0.98
10	15.6	14.3	3.41	13.68	41.73	58.79	-0.23
11	16.0	14.7	3.44	13.55	42.84	59.04	-1.17
12	15.9	14.6	3.67	12.72	42.27	57.40	-0.76

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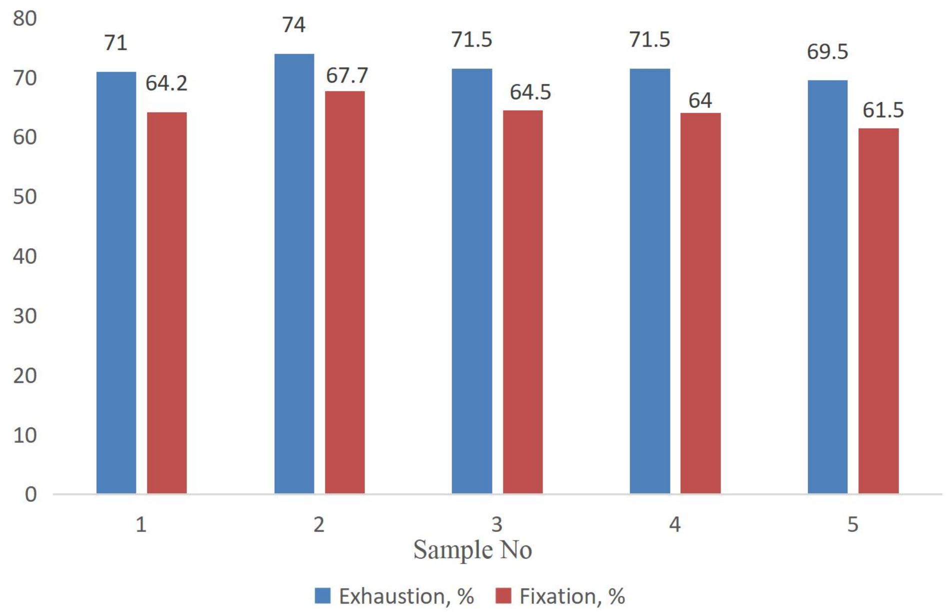

Fig. 1. The degree of exhausted and fixed dye in the fiber for 3/1 Twill weaves with different thicknesses of warp and weft threads

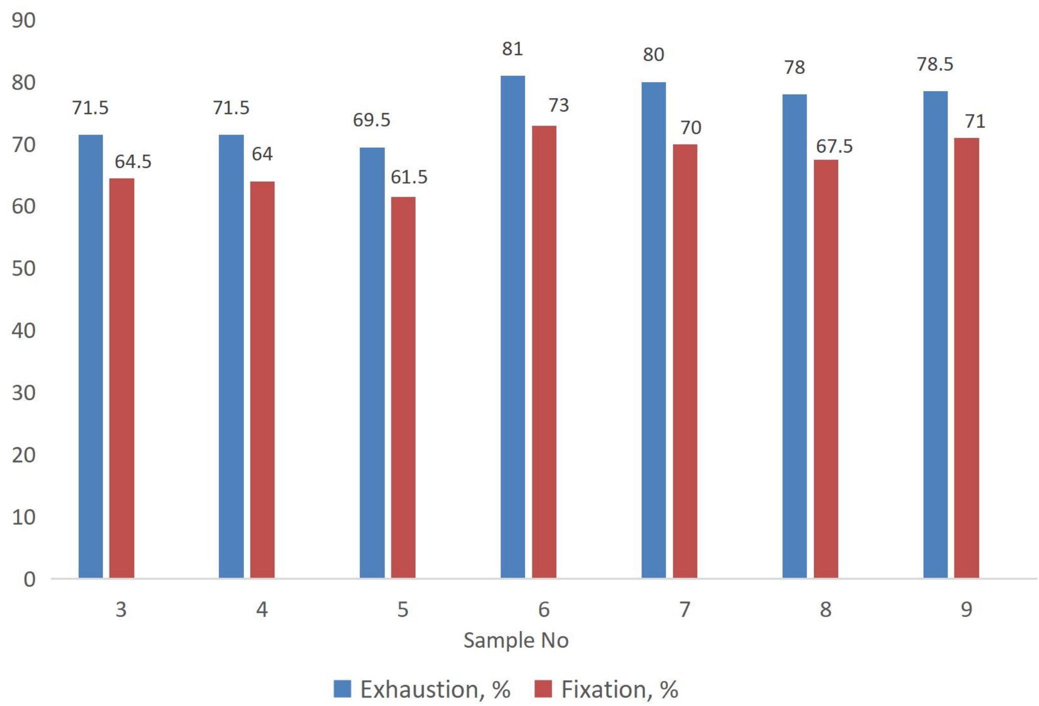

Fig. 2. The degree of exhausted and fixed dye in the fiber for different weaves with the same thickness of warp and weft threads

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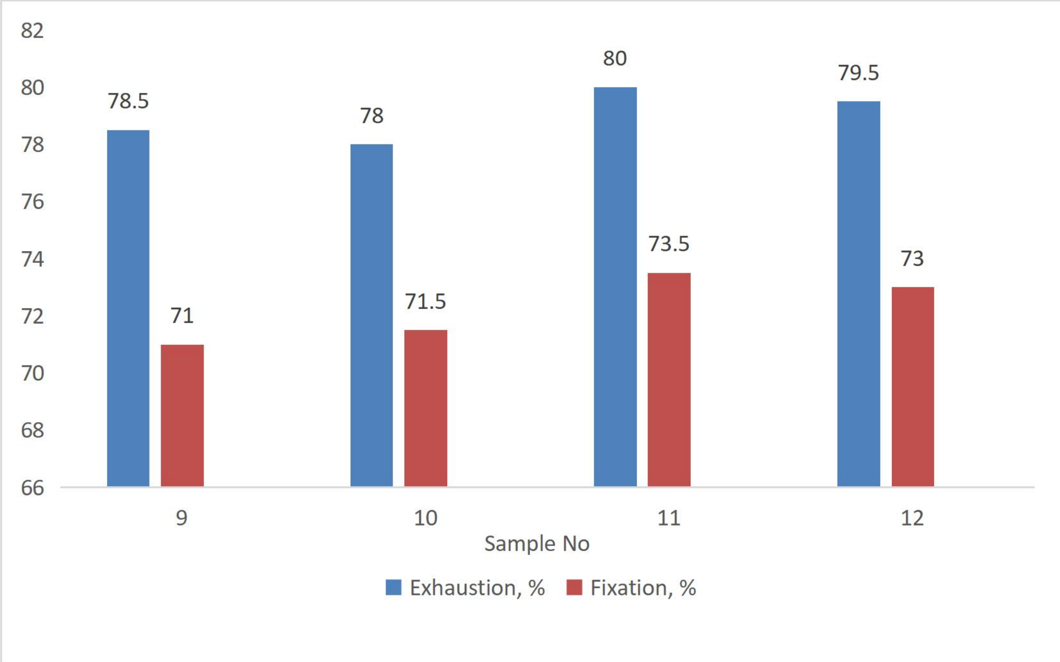

Fig. 3. The degree of exhausted and fixed dye in the fiber for weaving fabrics with different thicknesses of warp and weft threads

According to the table results, within the group of twill weaves, Sample No. 5 with the highest porosity percentage demonstrated the highest level of color intensity. All 3/1 twill samples have very similar color intensity indices, but vary significantly with weave type. This suggests that changes in warp and weft thread density, as well as porosity, do not affect color shades. Sample No.2, which has the lowest porosity, has a high degree of dye fixation, which is 6.2% less than Sample No.5. The L* values of the samples increase with increasing warp and weft thread density. Compared to other weaves, twill has, on average, the highest color intensity (13.1–16.5), but at the same time the lowest degree of dye fixation (61.5–67.7%). This is explained by the fact that in twill weave, each weft thread crosses a certain number of warp threads, so that one thread crosses over two or three warp threads in the fabric in a perpendicular direction. Increasing the distance between the threads correspondingly reduces the speed of dye flow. At the same time, the floating threads in twill weave fabrics promote a uniform distribution of dye molecules, which contributes to high color intensity.

When comparing different weave types with the same warp and weft thread thickness, it was found that the highest dye absorption rate (73%) is observed in sample No. 6, a satin weave. This is because in satin weave, the weft threads form long floats that overlap the single warp threads in the fabric, resulting in a smoother surface. This factor promotes uniform and rapid dye penetration into the yarn and fiber, and the flat surface of the fabric also provides regular light reflection, which increases the color intensity.

In plain weave, dye fixation decreases with increasing thread thickness. Samples No.11 and No.12, which have the lowest porosity and surface density, demonstrated high dye fixation. Overall, Plain weave fabrics exhibited the highest dye fixation among all weave types. This can be attributed, firstly, to their relatively low surface density, which facilitates more effective dye absorption during the dyeing process. Secondly, the characteristic ‘one-up, one-down’ interlacing pattern forms uniform, square-shaped pores and a smooth surface, resulting in regular light reflection.

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Conclusion.

Cotton fabrics differing in weave structure, warp and weft densities, and porosity were dyed with reactive dyes, and their color characteristics were subsequently evaluated using a spectrophotometer. The density and porosity of the warp and weft threads had no apparent effect on color shade, although a significant change in color yield was observed. The research revealed that the weave structure, particularly the degree of interlacing and float length of yarns, has a more pronounced effect on dye intensity than yarn thickness. Dye fixation was observed to increase with decreasing fabric porosity, indicating that excessive porosity hinders the interaction of dye molecules with the fiber. Moreover, excessively large and irregular pore sizes negatively influence not only the dyeing uniformity of fabrics but also that of yarns.

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