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Research Article

Coloring Cotton Fabrics by Pigment Printing Method with Reduction of Process Steps: An Innovative Approach

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ABSTRACT

This study focuses on coloring cotton woven fabrics using pigment dyes with a printing technique, without applying the conventional scouring and bleaching processes typically involved in pre-treatment. The aim of the study was to streamline the pre-treatment process by reducing the number of steps, thereby achieving a more efficient process in less time while also reducing the consumption of water, chemicals (both main and auxiliary), and energy. For this purpose, only desizing was applied to the cotton woven fabrics, while the conventional processes of scouring and bleaching were omitted. The fabrics were then directly colored using the rotary screen printing technique with three different formulations. A second batch of cotton fabrics, woven with the same yarn and construction, underwent the full conventional pre-treatment processes (desizing, scouring, and bleaching) before being colored with the same printing technique. The performance characteristics of both sets of fabrics were compared. Fastness properties such as washing fastness, acidic and alkaline perspiration fastness, water fastness, and dry and wet rubbing fastness were evaluated according to relevant standards. Additionally, tests for tear strength, abrasion resistance, pilling, and color spectrum were conducted. The color spectrum analysis revealed that the highest color yield was achieved using the printing formulation containing a polyurethane-based crosslinking agent. As a result, reducing the number of pre-treatment steps led to a decrease in chemical usage and the number of post-washing cycles, thereby lowering water and energy consumption.

Keywords: *Pre-treatment, cotton fabric, pigment dye, printing method, textile finishing*

İşlem Adımları Azaltılarak Pigment Baskı Yöntemiyle Pamuklu Kumaşların Renklendirilmesi: Yenilikçi Bir Yaklaşım

ÖZ

Bu çalışma, pamuklu dokuma kumaşların ön terbiye sürecinde genellikle uygulanan kasar ve ağartma işlemleri olmaksızın, pigment boyarmaddeler ile bir baskı tekniği kullanılarak renklendirilmesine odaklanmaktadır. Çalışmanın amacı, ön terbiye işlemlerindeki adımları azaltarak daha verimli bir süreç elde etmek, aynı zamanda su, kimyasal madde (ana ve yardımcı) ve enerji tüketimini azaltmaktır. Bu amaçla pamuklu dokuma kumaşlara yalnızca haşıl sökme işlemi uygulanmış, geleneksel kasar ve ağartma işlemleri atlanmıştır. Kumaşlar, üç farklı formülasyon kullanılarak rotasyon baskı tekniği ile doğrudan renklendirilmiştir. Aynı iplik ve konstrüksiyon ile dokunan ikinci bir kumaş grubu ise, geleneksel ön terbiye süreçlerinin tamamından (haşıl sökme, kasar ve ağartma) geçirilmiş ve aynı baskı tekniği ile renklendirilmiştir. Her iki grup kumaşın performans özellikleri karşılaştırılmıştır. Yıkama haslığı, asidik ve alkali ter haslığı, su haslığı ile kuru ve yaş sürtme haslıkları gibi özellikler ilgili standartlara göre değerlendirilmiştir. Ayrıca, yırtılma mukavemeti, aşınma direnci, boncuklanma

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(pilling) ve renk spektrumu testleri gerçekleştirilmiştir. Renk spektrumu analizi, en yüksek renk veriminin poliüretan esaslı çapraz bağlayıcı içeren baskı formülasyonu ile elde edildiğini göstermiştir. Sonuç olarak, ön işlem adımlarının sayısının azaltılması, kimyasal kullanımında ve yıkama sonrası döngü sayısında azalmaya yol açarak su ve enerji tüketimini düşürmüştür.

Anahtar Kelimeler: *Ön terbiye, pamuklu kumaş, pigment boyarmadde, baskı yöntemi, tekstil terbiyesi*

I. INTRODUCTION

At the start of textile finishing processes, the procedures performed to remove undesirable foreign substances from both the fibers and the surface, as well as to enhance the overall appearance of the product, are collectively known as pre-finishing treatments. During the weaving process, fabrics are subjected to mechanical stresses such as the movement of the shuttle (hook, pressurized air, or water) or the opening of the heddles. For this reason, warp yarns undergo a sizing process to better bond the fiber ends to the yarn surface, making the fabric more compact and stronger, thus reducing the risk of warp yarn breakage during weaving. However, during dyeing or printing, these sizing agents, which form a film-like layer on the fiber surface, must be removed before coloring to allow the dye to penetrate the fiber. Although various chemical agents are used as de-sizing agents, enzymes are one of the most commonly used chemicals in this process [1-5]. Additionally, cotton fibers contain oils, waxes, pectin, hemicelluloses, and other substances, which, along with foreign materials like leaves, pods, and seed coats, must be removed by treating raw cotton with basic solutions. This process, known as hydrophilization, usually involves treatment with NaOH to remove hydrophobic substances like oils, waxes, and pectin. The removal of these materials is crucial to ensure the subsequent dyeing/printing processes can be effective. Furthermore, cotton fibers naturally contain pigments that give them a light-yellowish color. The process of bleaching, which involves breaking down these pigments to achieve a white appearance, is typically carried out using hydrogen peroxide (H_2O_2), which remains one of the most widely used chemicals in the textile industry today. Traditional hydrogen peroxide bleaching formulations and the hydrophilization steps with caustic soda often involve processing at high temperatures or extended durations to enhance their effects on textile materials. However, these pre-finishing treatments typically involve substantial chemical usage, significantly increasing environmental waste. While the best bleaching results are achieved when hydrogen peroxide and caustic soda are used together in pre-finishing processes, excessive application of these chemicals, along with auxiliary agents, can have numerous adverse environmental impacts. When discharged into wastewater, these chemicals increase its pollutant load. Furthermore, the high levels of hydrogen peroxide commonly used in bleaching processes elevate the chemical oxygen demand (COD) of water, posing toxic risks to aquatic ecosystems. Additionally, these processes often necessitate subsequent washing and drying steps, leading to high consumption of water and thermal energy [6-13].

Pigment colorants are known for their exceptional durability, heat resistance, solvent stability, lightfastness, and resistance to migration. However, they are often challenging to process and typically exhibit lower color vibrancy and intensity [14]. Additionally, unlike reactive dyes, pigments do not chemically bond with the fibers. Instead, they adhere to the fabric's surface through physical interactions [14-17]. Therefore, pigment structured dyestuffs are chemicals that do not have affinity to textile fibres. They can only adhere to the fibre mechanically [16]. Crosslinkers and binders of various bases are used to ensure mechanical adhesion of these dyestuffs to fabrics [16,18]. In order to ensure proper adhesion of pigments to fabrics, binders and crosslinkers are commonly employed in various formulations to help fix the pigments and enhance their mechanical adhesion. Therefore, the application of the dyestuff to the fabrics is achieved by forming a film layer like the coating or pigment printing [19,20]. Crosslinkers and binders of various bases are used to ensure mechanical adhesion of these dyestuffs to fabrics. Since these pigments do not chemically bond, they may exhibit lower colorfastness, particularly to washing, rubbing, and light, unless effective finishing treatments are applied. To improve colorfastness, additional treatments such as fixation agents or overprinting can be utilized [21]. After dyeing or printing, the fabric is generally heated to help the binder dry and "fix" the pigment in place. The fabric is often cured at temperatures between 140-160 C, with the evaporation of water during drying and condensation processes, the crosslinker precipitates on the fibres and forms a film layer [16],ensuring that the binder sets and the pigment adheres more permanently to the fabric's surface. In this study, different printing formulations containing three different crosslinking agents were developed to reduce the steps in the pre-treatment process, and their performance was compared with cotton fabrics that underwent conventional pre-treatment and printing processes. The effects of printing formulations containing pigment dyes on the performance of cotton fabrics were investigated.

II. MATERIAL AND METHOD

A. 1. Material

In this study, fabric woven with 100% cotton Ne 30/1 yarns was used. The 120 g/m² fabrics from Ağaoğlu Tekstil underwent a desizing process with 0.1% amylase enzyme (Genkim, Türkiye) and 0.1% wetting agent (ER-SA, Türkiye). After desizing, the fabrics were thoroughly washed, resulting in desized fabrics that were ready for printing, without any scouring and bleaching treatment. In contrast, fabrics subjected to conventional pre-treatment processes underwent scouring and bleaching with 0.8% combined bleaching agent containing monohydrate 2-(2-butoxy-ethoxy) ethanol (ER-SA, Türkiye), 2.5% NaOH (32 Bé) (Borkim Kimya, Türkiye), and 2.5% H_2O_2 (Tempo Kimya, Türkiye) in a continuous bleaching machine. For the printing process, a red pigment dye and printing paste auxiliaries were used. The detailed composition of the printing paste is provided in Table 1.

Table 1 *Printing Paste Content*

Chemical/Material Used	Chemical/Material Content	Supplier
Ammonia	25% Ammonia solution	İGSAŞ, Türkiye
Foam cutter	Silicone Based	İBER Chemical, Türkiye
Emulsifier	2-[(8-Methylnonyl)oxy]ethanol	İDEA Chemical, Türkiye
Softener	Polysiloxane	MYD Chemical, Türkiye
Thickener	Acrylic Based	MYD Chemical, Türkiye
Urea	46% Nitrogen	İGSAŞ, Türkiye
Binder	Acrylic copolymer dispersion	ER-SA Chemical, Türkiye
Red pigment dyestuff	Diazotisation of 2,4-Dichloroaniline	Dystar Chemical, China

B. 2. Method

B.2.1. Coloring Process with Printing Technique

Cotton fabrics that underwent full conventional pre-treatment processes were printed using a printing paste containing red pigment dye and are labeled as code R0. The conventionally applied printing formulation with pigment dye is detailed in Table 2, while the pre-treatment recipe used for hydrophilization and bleaching of 100% cotton woven fabrics is presented in Table 3. Fabrics that underwent only desizing, without any additional pre-treatment, were printed using formulations developed for the rotary printing technique, labeled as R1, R2, and R3, as shown in Table 4.

In this study, 100% cotton woven fabrics were passed through a desizing bath, rolled onto beams, and remained for 24 hours. After the desizing process, cotton fabrics were prepared for printing without undergoing bleaching or other pre-treatment processes. For each formulation, different crosslinking agents and 40 g/kg red pigment dye were added to the printing paste, and the printing chemicals were prepared accordingly. The printing process was carried out, and the fabrics were then dried and fixed at 150 C-160 C for 4 minutes.

Table 2 *Recipe used in conventional printing tecnique*

Recipe	Substance Content Used	Amount of Material Used (g/kg)	Supplier
R0	Printing paste	960	Agaoglu Textile, Türkiye
	Red Pigment Dyestuff	40	Dystar Chemical, China

Table 3 *Recipe used in pre-treatment process*

Name of Substance/Material Used	Amount of Substance Used (mL/kg)	Supplier
Caustic Soda Solution (32 Bé)	25	Borkim Chemical, Türkiye
Hydrogen Peroxide Solution-	25	Tempo Chemical, Türkiye
Wetting Agent	6	ER-SA Chemical, Türkiye
Stabilizer	6	MYD Chemical, Türkiye
Ion immobilizer	3	MYD Chemical, Türkiye
α-Amylase desizing enzyme	1	Genkim Chemical, Türkiye
Combination Bleaching Agent	8	ER-SA Chemical, Türkiye

Table 4 *Recipes used in rotary printing technique for un-pretreated samples*

Recipe No	Substance Content Used	Amount of Material Used (g/kg)	Supplier
R1	Printing paste	920	Agaoglu Textile, Türkiye
	Aqueous Dispersion of Aliphatic Polyester-Polyurethane	40	Bozetto Chemical, Spain
	Red Pigment Dyestuff	40	Dystar Chemical, China
R2	Printing paste	920	Agaoglu Textile, Türkiye
	Styrene acrylic copolymer emulsion	40	ER-SA Chemical, Türkiye
	Red Pigment Dyestuff	40	Dystar Chemical, China
R3	Printing paste	920	Agaoglu Textile, Türkiye
	Aliphatic blocked polyisocyanate aqueous dispersion	40	Asutex, Spain
	Red Pigment Dyestuff	40	Dystar Chemical, China

B.2.2. Washing Process

After coloring 100% cotton woven fabrics using the printing technique, the washing fastness of the printed samples was investigated. Fabric samples processed with each formulation were washed 20 times. The washing was performed in a household washing machine at 40 C in accordance with the EN

ISO 6330-2012 standard. The fabrics to be tested were conditioned under standard atmospheric conditions (20 C ± 2 and 65% ± 2 relative humidity) for 24 hours.

B.2.3. Color Measurement

A Gretag Macbeth X-Rite Color i7 Benchtop spectrophotometer was used for color measurements. The CIE Lab* values of the printed samples were measured using the spectrophotometer, and their color differences (ΔE) and color yields (K/S) were analyzed.

B.2.4. Fastness and Performance Tests

The fastness and performance tests of the fabrics were carried out in accordance with the relevant standards given in Table 5.

Table 5 *Tests and standards*

Test Type	Related Standard	Devices and Instruments Used
Washing Fastness	TS EN ISO 105-C06	Perspirometer, Etuv
Acidic Sweat Fastness	TS EN ISO 105-E04	Perspirometer, Etuv
Alkali Sweat Fastness	TS EN ISO 105-E04	Perspirometer, Etuv
Water Fastness	TS EN ISO 105-E01	Perspirometer, Etuv
Dry Rubbing Fastness	TS EN ISO 105-X12	Crocmeter
Wet Rubbing Fastness	TS EN ISO 105-X12	Crocmeter
Tear Strength	TS EN ISO 13937-2	James Heal Titan 2
Abrasion Resistance	TS EN ISO 12947-4	James H. Heal-Nu-Martindale 864
Pilling	TS EN ISO 12945–2	James H. Heal-Nu-Martindale 86

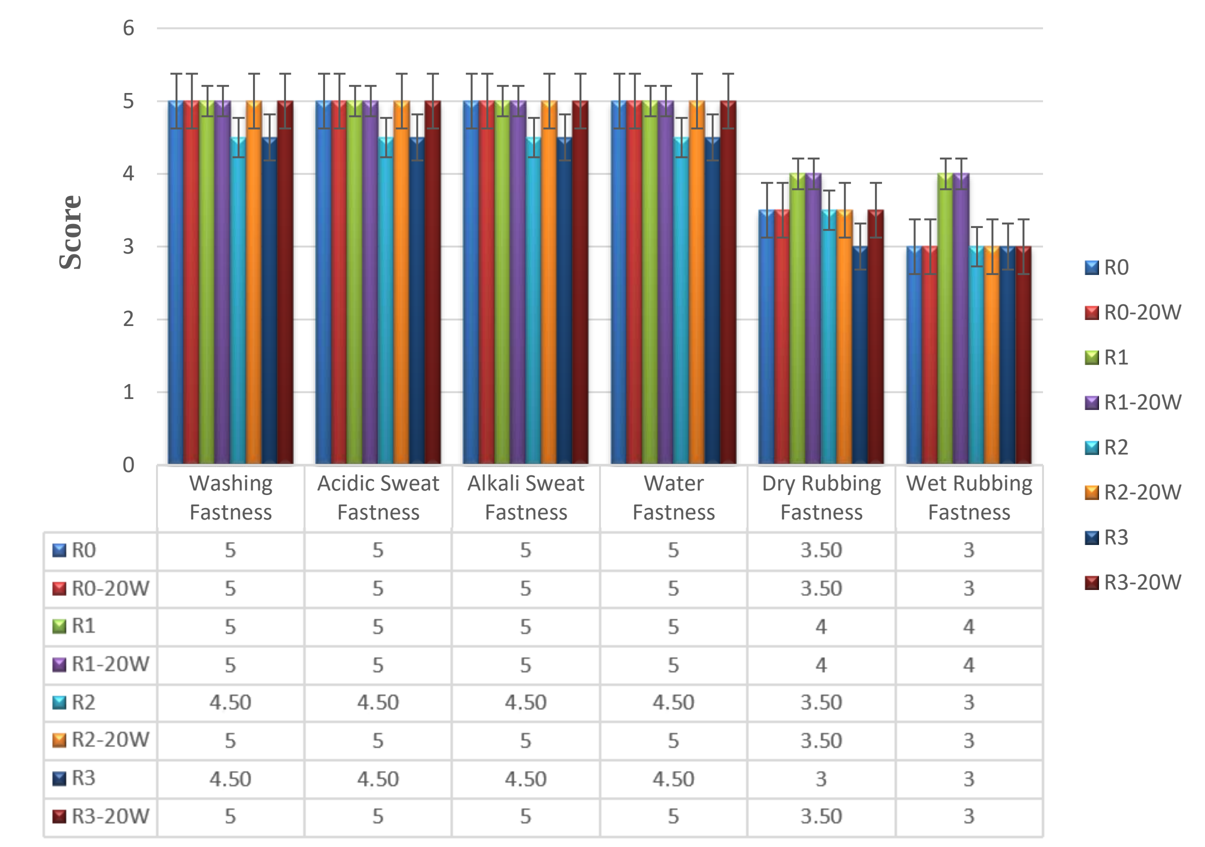
B.2.5. Efficiency Analysis in Process Application

Since 100% cotton woven fabrics need to undergo pre-treatment processes such as desizing, hydrophilization, and bleaching before the conventional pigment printing technique [22-25], all the necessary pre-treatments described above have also been carried out in the control groups As for the experimental group, within the scope of the study, 100% cotton woven fabrics were colored by applying the pigment printing technique without the pre-treatment process. Therefore, the amount of water, energy and chemical consumption has been reduced in this study. The efficiency analysis was carried out with comparing the whole conventional finishing process with new formulations obtained finishing process.

III. CONCLUSION AND DISCUSSION

A.1. Fastness Test Results

All fastness and performance tests for the 100% cotton woven fabrics were conducted at the Ağaoğlu Textile R&D Center Laboratory. The test results, carried out in accordance with the standards provided in Table 5, were evaluated based on the gray scale. The fastness test results for both unwashed and 20-times-washed fabrics are presented graphically in Figure 1.



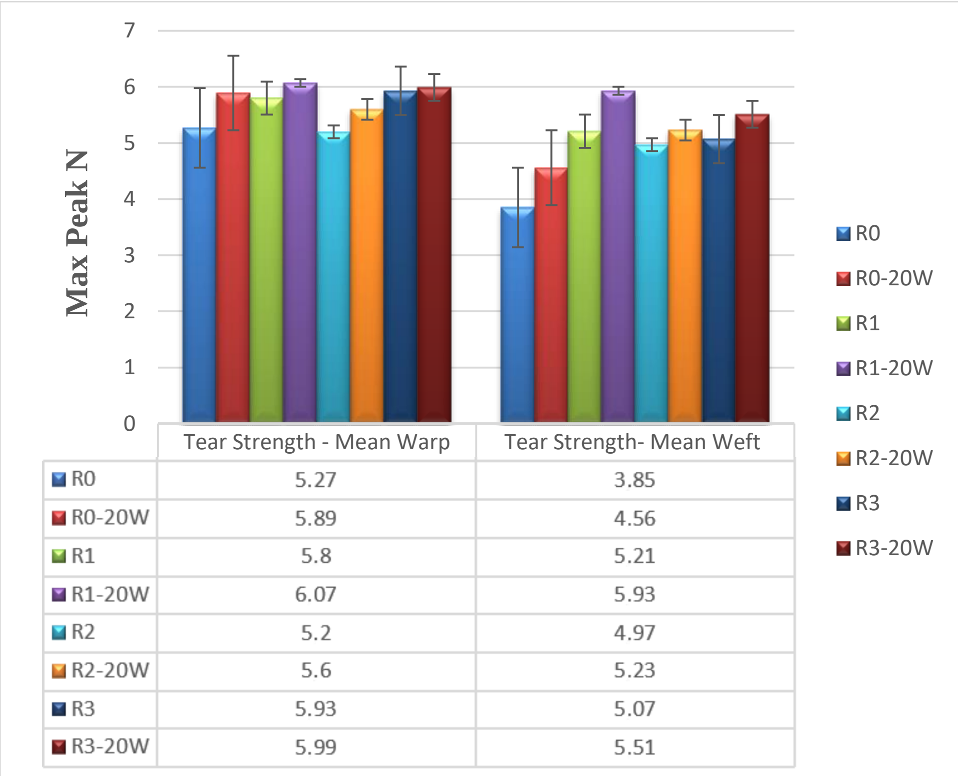
	Washing Fastness	Acidic Sweat Fastness	Alkali Sweat Fastness	Water Fastness	Dry Rubbing Fastness	Wet Rubbing Fastness
R0	5	5	5	5	3.50	3
R0-20W	5	5	5	5	3.50	3
R1	5	5	5	5	4	4
R1-20W	5	5	5	5	4	4
R2	4.50	4.50	4.50	4.50	3.50	3
R2-20W	5	5	5	5	3.50	3
R3	4.50	4.50	4.50	4.50	3	3
R3-20W	5	5	5	5	3.50	3

Figure 1 *Fastness Test Results*

For all samples (R0, R1, R2, R3) and their washed counterparts (R0-20W, R1-20W, R2-20W, R3-20W), washing fastness was observed to be at an excellent level of 5 or 4.5. It is considered that the washing process did not have any negative effect on color fastness. In acidic and alkaline perspiration fastness, all formulations maintained a value of 5 or 4.5 both before and after 20 washes, demonstrating the high perspiration resistance of the recipes. In terms of dry rubbing fastness, values for R0 and R0-20W were measured as 3.5. This indicates that samples prepared with NaOH and bleaching processes showed slightly lower performance in dry rubbing resistance. For R1 formulations, the values were 4 before and after washing processes which indicates that new formulation obtained in printing technique demonstrated better performance than conventional one while R2 and R3 formulations remained same as R0. The lowest values were observed in wet rubbing fastness in R0 and R0-20W: 3 while R1 was 4 and the rest remained same as at the value of 3. Crosslinkers, especially here polyurethane-based ones, were found to improve both dry and wet rubbing resistance when compared to conventional technique. The pigment printing recipe applied after conventional hydrophilization and bleaching treatments showed relatively lower performance in dry and wet rubbing fastness. Polyurethane-based binders are known to bind to the monomolecular chromophore group of the pigment dyestuff, making it difficult for the dyestuff to separate from the fibres and thus improving the fastness properties [26-29]. These findings indicate that printing recipes containing crosslinkers largely maintain their fastness performance even after washing and offer better properties compared to those prepared using conventional methods.

A.2. Performance Test Results

The tear strength test results of fabrics without washing and 20 washing cycles were given graphically in Figure 2. When the tear strength test results were analysed, it was observed that the un-pre-treated and printed with new formulations fabrics had better values than the conventionally pre-treated and printed fabrics. It was considered that cotton fabrics exposed to hydrogen peroxide and other chemicals during the pre-treatment process cause deformation and loss of strength. During hydrogen peroxide (H_2O_2) bleaching of cotton, strength loss occurs primarily due to the oxidative degradation of cellulose fibers. This degradation happens through the cleavage of glycosidic bonds and the oxidation of hydroxyl groups in the cellulose structure. As a result, the degree of polymerization decreases, leading to a reduction in the tensile strength of the fibers. Additionally, the generation of hydroxyl radicals (•OH) during the bleaching process exacerbates fiber damage by further attacking the cellulose chains, causing structural weakening [30-32]. Therefore, the absence of bleaching processes in the pre-tretament application in the study can be linked to the lack of significant mechanical strength losses in the fabrics. This outcome is associated with the fabrics not bleaching processes which contributed to preserving their strength. It was also observed that new formulations in printing process used did not affect the tearing strength of the fabrics negatively. Especially polyurethane based binders, long chain polymers are formed by the chemical reaction of polyol and diisocyanate groups. In addition, when polyurethanes are applied to the fabric surface in emulsion or liquid form, polymer chains are coated on the fabric fibers and long chain structures are formed as a result of drying or reaction. As a result of this polymerization, a thin film layer is formed on the fibers. This film layer increases the durability and flexibility of the fabric [26,33]. Abrasion resistance test results were given in Figure 3 and pilling test results were shown graphically in Figure 4. When the abrasion resistance test results were examined, the same values were obtained in all fabrics, while in pilling test results it was observed that only polyurethane based crosslinking agent formulation had the same value with un-pre-treated and printed with new formulations fabrics. As seen in Figure 4, polyurethane based crosslinking agent formulation showed better effect than other formulations on pilling strength of cotton fabrics. It was considered that polyurethane based binders did not cause a decrease in pilling values like other binders due to their film forming properties [34,35].



	Tear Strength - Mean Warp	Tear Strength- Mean Weft
R0	5.27	3.85
R0-20W	5.89	4.56
R1	5.8	5.21
R1-20W	6.07	5.93
R2	5.2	4.97
R2-20W	5.6	5.23
R3	5.93	5.07
R3-20W	5.99	5.51

Figure 2 *Tear Strength Test Results*

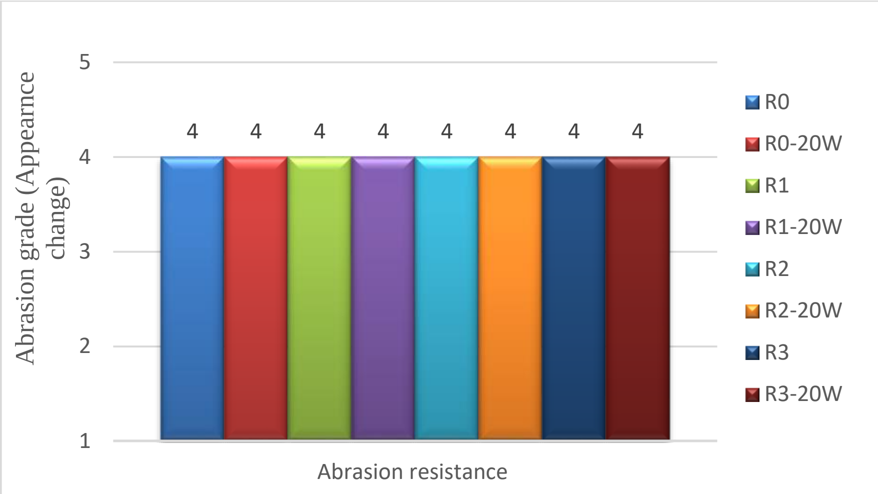


Figure 3 *Abrasion Resistance Test Results*

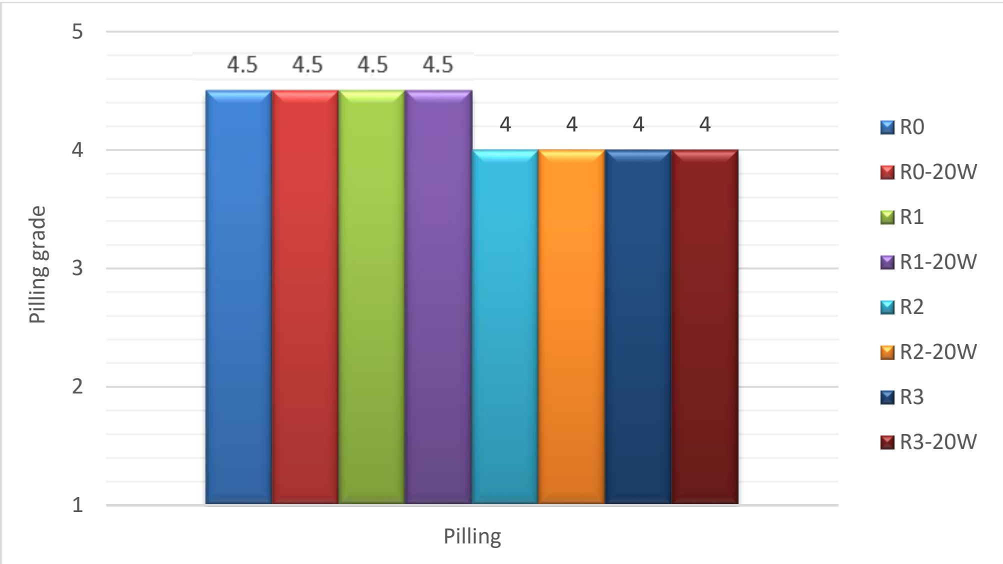


Figure 4 *Pilling Test Results*

A.3. Color Measurement Results

The color measurements of the printed fabrics were examined under D65 daylight at a 10° viewing angle. The CIE Lab* values and K/S color efficiencies of the fabrics after 20 washes were measured with a spectrophotometer. The color properties of the printed fabrics, both unwashed and after 20 washes, are listed in Table 6. The CIELab system is commonly used in spectrophotometric measurements, where the L*, a*, and b* parameters are of importance [36]. When examining the K/S values, the highest color efficiencies were observed in the formulation (R2) containing styrene acrylic copolymer emulsion and polyisocyanate-based formulation (R3). Polyisocyanates not only provide a soft touch as they contain ether, amide and urea groups, but also play an effective role on color depth, fastness and vividness due to their good film forming ability [37]. Styrene-acrylic copolymers enhance color yield in textile dyeing primarily due to their excellent film-forming and binding properties. These copolymers create a uniform and stable layer on the fiber surface, improving pigment fixation and preventing dye migration. Their compatibility with various dyes and fibers allows for better adhesion and distribution of colorants, leading to increased depth and brilliance of color. Additionally, their chemical structure can enhance the interaction between the dye and the fiber, resulting in higher dye uptake and improved color intensity [38,39]. The ΔE value for the fabric samples obtained with polyurethane-based formulation (R1) was measured as 0.74. Even after 20 washes, the color was still preserved, and the color difference was at minimal level. Therefore, it is believed that the polyurethane-based crosslinking agent maintains the color's durability by forming a film layer on the fibers and bonding with a strong mechanical effect. Moreover, it was observed that these formulations did not negatively affect the color values of the fabric samples after washing process washing since the dyestuff was strongly adhered to the fibers in the pigment printing technique.

Table 6 *. Color Measurement Results*

Recipe No	L^*	a^*	b^*	C^*	h°	ΔE	K/S
R0	40.15	57.90	22.54	62.13	21.27	2.82	6.66
R0-20 W	40.85	55.73	20.90	58.08	20.13	2.82	5.33
R1	42.08	56.43	18.91	59.52	18.53	0.74	5.15
R1-20W	42.76	54.81	17.96	57.68	18.15	0.74	4.51
R2	39.50	56.68	22.33	60.92	21.50	2.14	7.20
R2-20W	41.08	52.22	19.06	55.59	20.05	2.14	6.05
R3	39.58	56.64	22.24	60.85	21.43	2.11	7.08
R3-20W	42.08	51.46	17.66	54.41	18.94	2.11	5.69

A.4. Efficiency Analysis Results Obtained in Process Application

The amount of water, energy and chemicals consumed for the preparation of one kilogram of 100% cotton woven fabric for pigment printing technique in conventional method and new formulations used in printing technique are given in Table 7.

Table 7 *Amount of Chemicals Used for One Kilogram Sample*

	Conventional Method	This study
Caustic soda (NaOH)	25 g	-
Hydrogen peroxide (H_2O_2)	25 g	-
Wetting agent	6 g	-
Stabilizer	6 g	-
İon immobilizer	3 g	-
Crosslinkers used in each new formulations	-	40 g

While 68 g/kg of chemicals, mainly caustic soda and hydrogen peroxide, were used additionally for one kg of fabric sample in conventional methods, only 40 g/kg of crosslinker (except printing paste in both methods) was used in this study. In traditional methods, a total of 10 L/kg of water, 0.06 kw/kg of energy and 68g/kg of chemicals were consumed in the processes of hydrophilization and bleaching processes before printing 1 kg of 100% cotton woven fabrics. In the technique applied within the scope of the study, a total of 2 L/kg of water and 0.01 kw/kg of energy was consumed in the process for 1 kg of fabric. In the new formulated-pigment printing technique, 40 g/kg of crosslinker was used to improve the color efficiency and performance tests of the fabrics. Thus, the new method offers a more sustainable and efficient alternative to conventional processes, with reduced resource consumption and improved fabric performance.

IV. CONCLUSION

This study demonstrated that eliminating conventional scouring and bleaching processes in the pre-treatment of cotton woven fabrics and using alternative pigment printing formulations can effectively streamline the textile production process. By applying only desizing prior to rotary screen printing, it was possible to achieve satisfactory fabric coloration and performance properties while significantly reducing the consumption of water, chemicals, and energy. The fastness properties, including washing, perspiration (acidic and alkaline), water, and rubbing fastness (dry and wet), were largely maintained at high levels for all tested formulations. The printing formulation containing a polyurethane-based crosslinking agent exhibited the highest fastness and mechanical properties, indicating its superior performance in enhancing dye fixation. Furthermore, this simplified process contributed to a reduction in the number of post-washing cycles, thereby offering additional savings in water and energy usage. While the alternative approach showed comparable or superior performance characteristics in key areas, it also provided economic advantages with reduced resource consumption, making it a sustainable and efficient solution for textile coloration. In future studies, a wider range of colors can be explored, and cotton-blended fabrics with different compositions can be utilized to observe the effects on various fibers. These approaches aim to expand the scope of research and provide a broader understanding of sustainable textile processing techniques. As a result, the findings of this study are expected to serve as a valuable reference and provide guidance for future research in the field.

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