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INVESTIGATION OF THE EFFECT OF YARN DYEING ON THE PROPERTIES OF 100% POLYESTER WOVEN FABRICS

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ABSTRACT

This research paper investigates the influence of 100% polyester yarn and fabric dyeing on woven fabric properties, including analysis of deviations and other aspects such as that may be affected by dyeing. The study conducts three experiments to evaluate the tensile properties of undyeddyed yarns andwoven fabrics. The first experiment devoted to analyze the tensile properties of dyed and undyed yarns. The second experiment includes dyeing woven fabrics and conducting tensile testing while assessing any deviations. The third experiment was to test the tensile properties of commercially available dyed yarns that were woven into fabric and analyze any other aspects affected by dyeing. The results of each experiment are presented and analyzed and summarized the findings in the conclusion. This study provides valuable insight into the effects of yarn and fabric dyeing on woven fabric properties, including deviations and other factors that may be influenced, and can serve as a useful resource for researchers and industry professionals in the textile sector.

KEYWORDS: Dyeing, Tensile properties, Polyester fabric, Yarn Dyeing, Yarn Properties.

INTRODUCTION

Weaving has been a fundamental method for fabric manufacturing for centuries, and it remains one of the most popular techniques used globally. The demand for woven fabrics is unparalleled in comparison to other manufacturing methods, as these fabrics offer superior quality and durability. With the advancements in weaving technology, sophisticated weaving machines can now produce fabrics with fine variations in the properties of the warp and weft yarn. These variations can significantly impact the final product, including the specifications of the fabric and its appearance. Given the importance of these factors, it is critical to investigate the effects of various yarn properties on the performance and properties of woven fabrics.[1]

Fabric design plays a crucial role in the textile industry, as it influences the aesthetic appeal and functionality of the final product. Three primary methods used for fabric design are fabric printing, fabric dyeing, and interlacing of dyed yarns. Fabric printing involves applying a design or pattern onto the surface of the fabric using various printing techniques, such as screen printing, digital ink-jet printing or usage of thermal transfer processes.[2] On the other hand, fabric dyeing or interlacing of dyed yarns involves weaving the yarns together in a particular pattern to create a design or pattern in the fabric. Both techniques offer distinct advantages and disadvantages, depending on the desired outcome and fabric application. For example, fabric printing is ideal for creating intricate designs and patterns, while interlacing dyed yarns allows for more intricate and detailed designs and offers greater durability.[2] The polyester dyeing process refers to the process of coloring polyester fibers, yarns, or fabrics using synthetic dyes in an industrial setting. Polyester is a synthetic fiber made from petroleum-based chemicals, which makes it challenging to dye due to its low affinity to water. The process involves preparing the fabric, dyeing it using high-temperature dyeing machines, and then finishing it with post-treatment processes such as washing, drying, and pressing. The process requires specialized equipment and expertise to achieve the desired color and quality of the final product. Polyester dyeing involves chemical reactions between synthetic dyes and polyester fibers, where the disperse dyes are used. The dye molecules disperse in water and then penetrate into the fiber.[3]

The polyester dyeing process can affect the properties of the fabric, such as colorfastness, light fastness, and strength. The type and concentration of dye chemicals used, as well as the dyeing temperature and pressure, can affect the depth and shade of the color, as well as the overall quality of the final product. Additionally, the dyeing process can also affect the physical and mechanical properties of the fabric, such as tensile strength, elasticity, and shrinkage. Any variation in the dyeing process can cause color deviations and affect physical properties such as tensile strength and elongation, as well as texture, hand feel, and comfort of the fabric.[4] However, there is a lack of comprehensive research on the relationship between the dyeing process and the fabric or yarn properties, and further studies are needed to investigate this connection.

The quality of dyes and technological parameters are critical factors that can influence the quality of dyed weft yarns and the appearance and quality of woven fabrics. The dyeing process, type of dye used, and other parameters have a direct impact on the properties of polyester woven fabrics, including colorfastness, strength, durability, and texture [4]. Manufacturers must produce high-quality woven fabrics that meet consumer expectations by carefully monitoring the dyeing process and using high-quality materials. To optimize the dyeing process, research is needed to investigate the relationship between the properties of dyed weft yarns and woven fabrics.

The research gap in investigating the relationship between polyester dyeing and fabric properties refers to the lack of comprehensive studies exploring the impact of the dyeing process on the physical and mechanical properties of woven fabric. Understanding this relationship is essential for optimizing the dyeing process and improving product quality. Therefore, further research is needed to bridge this gap and develop a better understanding of the factors that affect the properties of the fabric during the dyeing process.

LITERATURE REVIEW

Dyes can be classified based on their chemical composition and the type of fibers they are used to dye. For example, direct dyes are used to dye natural fibers such as cotton, wool, and silk, while acid dyes are used for wool, silk, and nylon. Reactive dyes are used for cotton, rayon, and other cellulosic fibers, while disperse dyes are used for synthetic fibers such as polyester, nylon, and acetate. There are also specialized dyes such as vat dyes for cotton and indigo dyes for denim. The classification of dyes is essential for selecting the appropriate dye type for specific textile materials, ensuring optimal colorfastness, and preventing damage to the fibers during the dyeing process.[5]

Disperse dyes are used to dye polyester, and they are classified based on their molecular weight and the type of chemical bonds they form with the fibers. In the industrial context, the polyester dyeing process involves several stages, including preparation, dyeing, and finishing. The dyeing cycle typically involves high-temperature and high-pressure conditions, ranging from 120°C to 130°C and 2.5 to 3.5 kg/cm^2, respectively. The temperature and pressure help the disperse dyes to penetrate and bond with the polyester fibers, resulting in a durable and long-lasting color.[6]

Dyeing has a significant impact on the final properties of the yarn and fabric. The exhaustion of dye plays a crucial role in the final properties of the yarn. Dyeing can affect the spun length percentage, short fibre index, tenacity, elongation at break of yarn, evenness, number of naps, and yarn hairiness, which can all influence the final properties of the fabric. A study was conducted to understand the influence of yarn count on the dyeing performance of the exhaust method of reactive dye. They concluded that cotton count, brightness, and color strength are related, and when the cotton count is high, brightness is high, and color strength is less.[7] Disperse dyes are commonly categorized into manazo and athraquinone type structures, with other structures also being used. These dyes are non-ionic, which makes them slightly soluble in water. The most widely used method for disperse dyeing of hydrophobic fibers involves the fiber absorbing dye molecules from the dye bath, which is replenished by a molecule of dye from the dispersion of dye particles in the dye bath. Dispersant agents and surfactants can increase the dyeing rate, while the temperature can also affect solubility and dyeing rate. The nature of attaching dispersed dyes to hydrophobic fibers has been debated, with the solid solution theory being a common explanation.[8]

The solid solution theory suggests that disperse dye molecules dissolve in hydrophobic fibers. The resulting equilibrium absorption isotherms should be linear up to the limit of dye solubility in either the dye bath or the fiber. This linear absorption behavior has been observed with many disperse dyes, supporting the solid solution theory[9].The temperature of dyeing plays an important role in disperse dye intake into hydrophobic fibers. The free volume model explains that disperse dye molecules need a hole to diffuse into the fiber. At low temperatures, the fiber molecules are frozen, and the dyeing rate is slow. However, at higher temperatures, the thermal expansion of the fiber increases the free volume and improves the probability of dye molecules diffusing through. Disperse dyes are categorized into low, medium, and high-energy dyes, and the energy level of these dyes affects the temperature needed for dye diffusion. Disperse dyes can also stain hydrophilic fibers like cotton, which is undesired and can affect the wash fastness of the fabric. Thus, thorough washing of the fabric is required to remove any staining before completing the dye cycle.[8,13]

The selection of dye classes for yarn dyeing is based on the type of fiber used, and adjustments are made to temperature and pH values for optimal dyeing results. Dyeing stages can significantly affect the morphology and physical properties of the fiber, which in turn can affect the physical properties of the yarn after dyeing.[4]

Research carried out by Prasad Shaw.[14] shows that dyeing polyester/cotton blended yarn results in a decrease in tenacity, particularly after dyeing the cotton part of the blend. Conversely, elongation-at-break increases after dyeing, with the highest increase observed after dyeing the polyester part of the blend. The application of a softener leads to a minor increase in elongation-at-break. These findings suggest that the dyeing process has a significant impact on the mechanical properties of polyester/cotton blended yarn, and further investigation is required to determine the underlying mechanisms and develop appropriate solutions.Another studyshows that dyeing polyester/cotton blend yarns with disperse and reactive dyes for polyester and cotton parts, respectively, had a significant impact on the tenacity and elongation-at-break properties of the yarns. The reduction in tenacity after dyeing the polyester part was attributed to the reduction and clearing treatments involved in the dyeing process, while changes in the internal structure of the cellulose polymer were cited as the reason for the higher tenacity drop in the cotton part. In addition, the study found that the choice of dye class also had an impact on the physical properties of the final fabric, with dispersed-dyed polyester showing better performance compared to indigo-dyed polyester. These findings highlight the importance of considering the specific dye classes used in the dyeing process to achieve the desired physical properties in the final fabric.[15] The color index used in reactive dyeing has a significant impact on the physical properties of cotton fabric. Reactive yellow RL and Reactive red 6B showed significant differences. When selecting a dye, it is important to consider the appropriate color index and the dyeing mechanism.[16]

The molecular structure of different color indexes in reactive dyes can have a significant impact on the final properties of cotton fabric. The reactive part of the dye plays a crucial role in the chemical bonding process with cellulose fibers. Coarser yarns have higher build-up properties than finer yarns, which results in lighter color when dyeing with the same color in the same shade percentage under the same conditions. The dye exhaustion rate also affects the final properties of the fabric, and further research is needed to understand this behavior.[17]

Trot man discuss show the yarn construction method, dyeing parameters, fabric structure, porosity, and weave density influence the final properties of the fabric, such as color yield, lightness, and appearance. It also examines the differences in dye exhaustion, mass irregularity, and hairiness between compact and ring spun yarns, and how these impact the quality of the final product.[17]

Dyeing parameters and the type of dye used can have various effects on the final properties of a yarn, and cotton yarn dyeing with reactive dye can have different effects on the yarn depending on the dye color, even when maintaining the same dyeing parameters except the dye.[7]

Understanding this behavior is important to comprehend the influences of the dyeing process on woven fabric properties. The relationship between the dyeing process and the properties of the resulting yarn or woven fabric is an essential area of research that remains relatively unexplored. While polyester dyeing with disperse dyes has been widely studied, the influence of the dyeing process on fabric properties, such as tensile strength, elongation at break, and dimensional stability, has yet to be fully understood. Investigating this relationship is essential for optimizing the dyeing process, enhancing product quality, and developing new materials that meet specific application requirements.

Therefore, this research aims to bridge this gap by investigating the relationship between polyester dyeing with disperse dyes and the physical and mechanical properties of the resulting yarn or woven fabric. By analyzing the influence of various dyeing parameters, such as temperature, pressure, and dye concentration, on the fabric's properties, this research seeks to provide insights into how to optimize the dyeing process and improve product quality. The findings of this study will be of great value to the textile industry, providing a scientific basis for the selection of dyeing parameters and the development of new materials with improved properties.

METHOD AND MATERIAL

To investigate the relationship between the dyeing process and the mechanical properties of the yarn and fabric, three main experiments were conducted.

Experiment 1 involved using commercially available yarns with the same count (80 deniers) and (34) filament count. These yarns were dyed using a laboratory-scale IR dyeing machine, while keeping the dye cycle and parameters constant, except for the dye used. The tensile properties of the yarns were tested both before and after dyeing, using a tensile testing machine, to determine any potential changes in breaking strength and elongation at breakage.The purpose of Experiment 1 was to determine whether the dyeing process affected the tensile properties of polyester yarns. The experiment involved dyeing three different weft yarn samples using three different colors of disperse dye in the form of powder (Danix Red ACE, Danix Yellow ACE, and Danix Blue ACE) using the Infrared laboratory dyeing machine IRD-IV under the highest temperature of 135°C. The experiment maintained the same dye cycle and parameters, except for the dye.Before the dyeing process, the tensile properties of the yarns were tested to establish baseline measurements. The tensile properties tested were average tensile strength (0.94N), and average elongation at breakage (13.76mm). The same properties were measured after the dyeing process to determine if there was any change.To prepare the dyeing liquor, a dye recipe was created for each of the three different color dyes. The recipe included the amount of dye required, the amount of liquid needed, the amount of dispersing agent, acetic acid, and sodium acetate as a buffer. The measurements were carefully taken and recorded to ensure consistency.After the dye recipe was prepared, the water was added to achieve the required M: L (1:40) ratio. The prepared dye recipes of the three different colors were then transferred to separate dyeing pots, and 5g of weft yarn sample was added to each pot with the prepared dyeing liquor. The lid of the dyeing pot was closed tightly to prevent any leakages during the dyeing process.

The dyeing pots were then transferred to the IR dyeing machine, where the temperature was increased by 1°C per minute from the initial temperature of 34°C. Once the maximum temperature of 135°C was reached, the temperature was maintained constantly for 60 minutes for dye absorption. After this time, the temperature was reduced to 70°C with a rate of 3°C per minute. At the end of dyeing, the samples were removed and washed.

The washed samples were then tested according to ASTM D2256 standard to obtain average breaking strength (N) and average elongation at break (mm). Thirty weft specimens from each yarn sample were mounted to an Instron universal tester one by one, and the average breaking strength was calculated.

The results of the experiment were then analyzed to identify any changes that occurred with the color of the yarn. The methodology used in this experiment ensures that the results obtained are reliable and can be replicated.

Experiment 2: Fabrics were woven using the dyed yarns from Experiment 1 as the weft in a rapier weaving machine. The fabrics were tested for breaking strength and elongation at break in the weft direction using a tensile testing machine.In this experiment, the impact of dyeing on the tensile and tearing strength of woven fabrics was investigated. Various dyed yarns were collected and used as the weft while keeping the warp constant. The fabric samples (20-weft direction) were then subjected to tests for tensile strength, elongation at break, and tearing strength in the weft direction, using an Instron universal tester in accordance with ASTM D5034 standards. The fabric was clamped in a 2-inch fabric clamp and the speed was set to 100mm/min. From each specimen, the breaking strength and elongation at break were recorded, and the averages of tensile strength and elongation at break were calculated. This controlled experimental design allowed the isolation of the effect of dyeing on the mechanical properties of the yarns and fabrics and provided insight into the relationship between the dyeing process and fabric performance. The findings can be used to improve the dyeing process and enhance the durability and performance of fabrics.

Experiment 3: 100% polyester fabric was woven in water jet loom using 80 denier warp and weft yarn with 34 filament count at the speed of 450 pieces/min. Three different samples were prepared from the woven fabric sample and dyed separately with Daniel red ACE, Daniel yellow ACE, and Daniel Blue ACE. The fabrics were dyed in different colors in the lab using an IR dyeing machine. The dyed fabrics were tested for their breaking strength and elongation at breakage using a tensile testing machine.

This experiment aimed to investigate the effects of dyeing on the tensile properties of fabrics woven using commercially available yarns with the same count, color, and filament count as those used in Experiment 1. Fabric samples were woven using a rapier loom and subjected to tensile testing to determine their breaking strength and elongation at break. The samples were cut into 20 warp and 20 weft samples each, with dimensions of 11 inches by 2.5 inches, in accordance with ASTM D5034 testing for fabrics.

For the dyeing process, a dye recipe was created to dye a 5-gram fabric sample. The dye solution was prepared by adding 3% dye, which was calculated to be 0.15 grams per sample, to a liquid with an M:L ratio of 1:40. The amount of liquid needed for dyeing a 5-gram fabric sample was 200 milliliters. Acetic acid and sodium acetate were added to the solution in concentrations of 2 grams per liter and 4 grams per liter, respectively, and 1 gram per liter of dispersing agent was also included.

The dye liquor was transferred to a dyeing pot and tightly sealed to prevent dye leakage during dyeing at high temperature and pressure. The pot was then transferred to an IR dyeing machine, where the temperature was increased by 1℃ per minute as in figure 1 from the initial temperature of 34℃. When the maximum temperature of 135℃ was reached, the temperature was maintained for 60 minutes to allow for dye absorption. After this time, the temperature was reduced to 70℃ at a rate of 3℃ per minute. At the end of the dyeing process, the samples were removed and thoroughly washed.

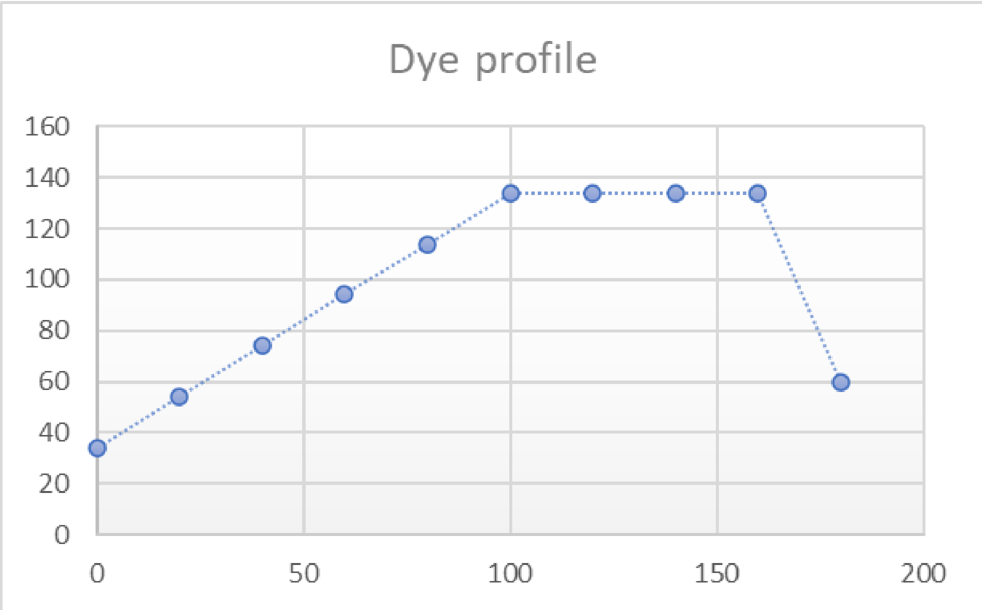


Figure 1: Dye profile for polyester fabric using disperse dye.

The fabric samples were then tested using an Instron universal tester, following the ASTM D5034 standard. Each specimen was clamped in a 2-inch fabric clamp, and the speed was set to 100 millimeters per minute. The breaking strength and elongation at break were recorded for each sample, and the average elongation at break was calculated.

The dyeing process parameters, such as temperature, pressure, and dye concentration, were carefully controlled and monitored throughout the experiments. The data obtained from the experiments were analyzed using statistical methods to determine the relationship between the dyeing process and the mechanical properties of the yarn and fabric.

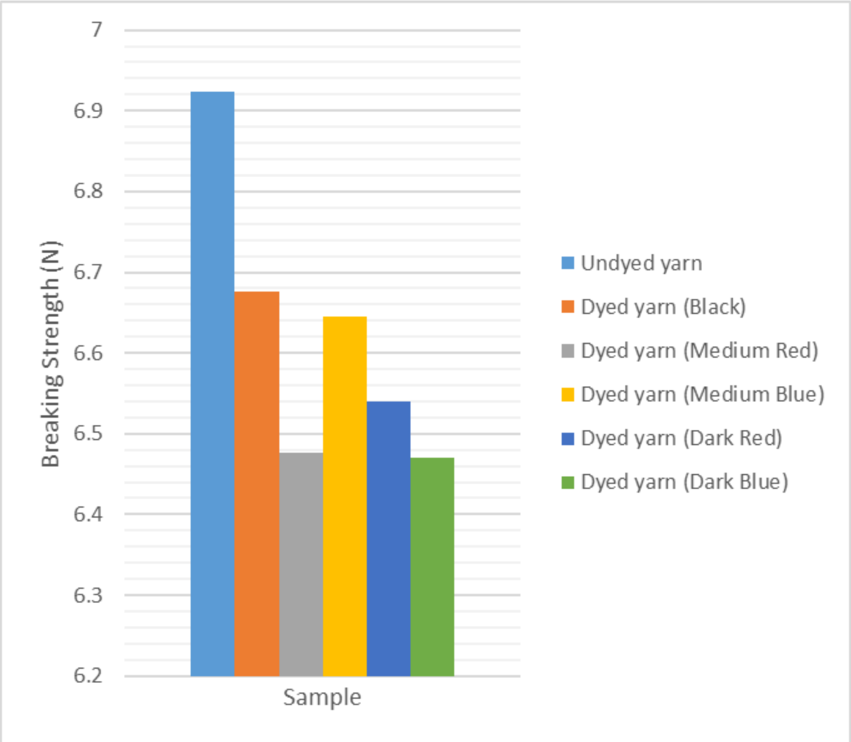
The research method is a controlled experimental design that allows for the isolation of the effect of dyeing on the tensile properties of yarns and fabrics. By maintaining the same parameters in each experiment, except for the dye, the researchers can compare the tensile properties of the dyed and undyed samples and determine the impact of dyeing on fabric performance. This research method provides a comprehensive understanding of the relationship between the dyeing process and the mechanical properties of woven fabrics, which can be used to optimize the dyeing process and improve the durability and performance of fabrics.

RESULTS AND DISCUSSION

Experiment 1

Table 1: Average breaking strength and average elongation at break for different coloured dyed polyester yarn

Yarn samples	Averagebreaking strength(N)	Average Elongation (%)
Undyed yarn	6.9235	21.517
Dyed yarn (Black)	6.6762	28.791
Dyed yarn (Medium Red)	6.4769	27.335
Dyed yarn (Medium Blue)	6.6447	26.554
Dyed yarn (Dark Red)	6.5404	34.609
Dyed yarn (Dark Blue)	6.4705	34.125



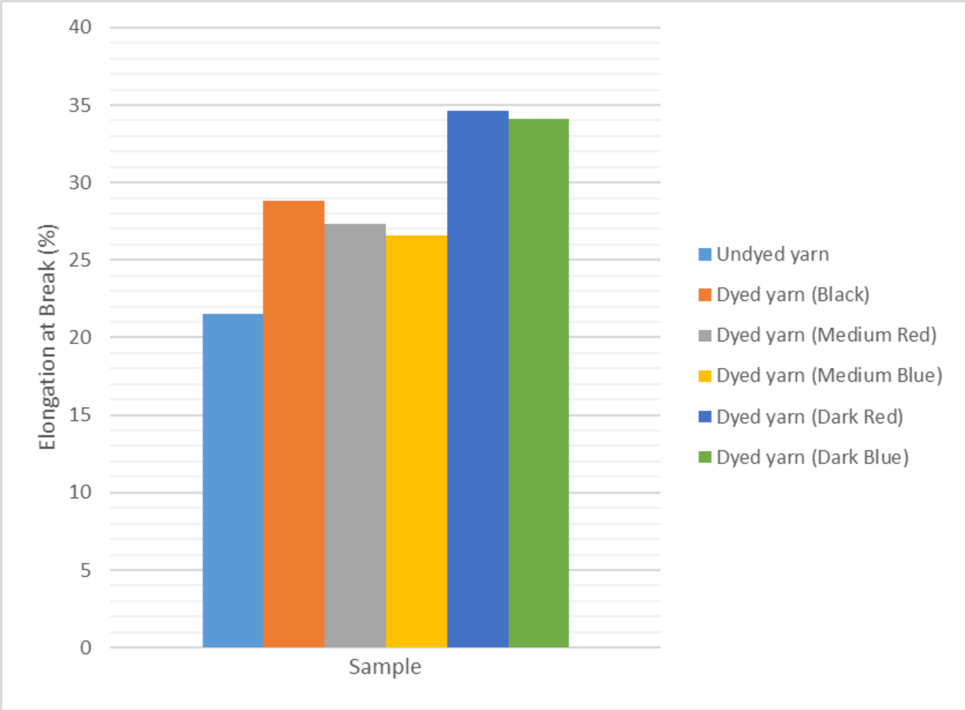


Figure 2: Breakingstrength and average elongation at break for different coloured dyed polyester yarn.

During the testing of dyed yarn samples according to ASTM D2256 standard, it was observed that (figure2 and/or table1) undyed yarn had a higher breaking strength and lower elongation percentage. On the other hand, the dark blue dyed yarn exhibited lower breaking strength, but higher elongation compared to other yarn samples. Overall, all dyed yarns showed a slight reduction in tensile strength and a significant improvement in elongation at breakage.

The behaviour of dyed yarn samples can be attributed to the dye cycle and dyeing temperature. Industrial dyeing practices vary according to the shade (dark, medium), and parameters such as dyeing temperature, dyeing time, dispersing agent, levelling agent, and buffering agents are adjusted accordingly. Dyes can be categorized into two main groups: fluorescent colors and normal colors. To achieve a dark shade, dyeing temperature was raised to 130 °C and maintained for 30 minutes, while for a medium shade, the dyeing temperature was raised to 130 °C and maintained for 20 minutes.

The most widely accepted mechanism for the disperse dyeing of polyester fibers involves the absorption of dye molecules that are dissolved in the dyebath. When a dissolved dye molecule is absorbed, it is replenished by a molecule of dye from the dispersion of dye particles in the dyebath. Thermal expansion occurs as the temperature of the fiber is raised, increasing the specific volume of the fiber. However, molecular motion in the polymer is still restricted by intermolecular forces. When the temperature exceeds a certain point, the extent of segmental motion and free volume continues to increase. The increase in free volume improves the probability of dye molecules encountering a hole large enough to diffuse through. In simple terms, the high pressure and high temperature cause the crystal structure of the polyester polymer to become amorphous, creating holes for the disperse dye to diffuse into the amorphous region. The disperse dye molecules are mechanically bound when the temperature is further reduced.[18,19]

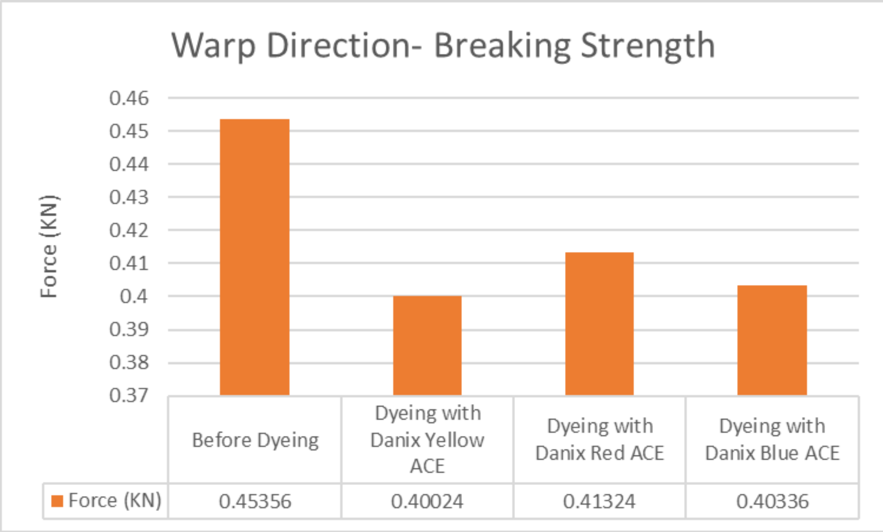
Experiment 2

Table 2: Breakingstrength and average elongation at break of fabrics woven using dyed yarns.

Fabric (weft yarn used)	Average Breaking strength(kN)	Average Elongation at Break (mm)
Undyed	0.7032	46.98
Dark Green	0.6733	50.04
Medium Green	0.6976	57.02
Light Green	0.6807	54.61
Dark Blue	0.731	57.45
Medium Blue	0.7087	58.16
Light Blue	0.6857	54.48
Dark Red	0.6940	52.62
Medium Red	0.6975	53.08
Light Red	0.6981	53.81
Black	0.6414	57.59

Based on the results presented in Table 2, an increase in elongation at breakage of 3 to 12 mm was observed for the dyed yarn samples, while no significant difference was found in tensile strength. However, it should be noted that further analysis may be required to confirm these findings. Overall, a slight drop in tensile strength was observed based on the data presented, but it was not prominent. This suggests that the dyeing process had a greater impact on the elongation at breakage of the yarns rather than their tensile strength.

Experiment 3



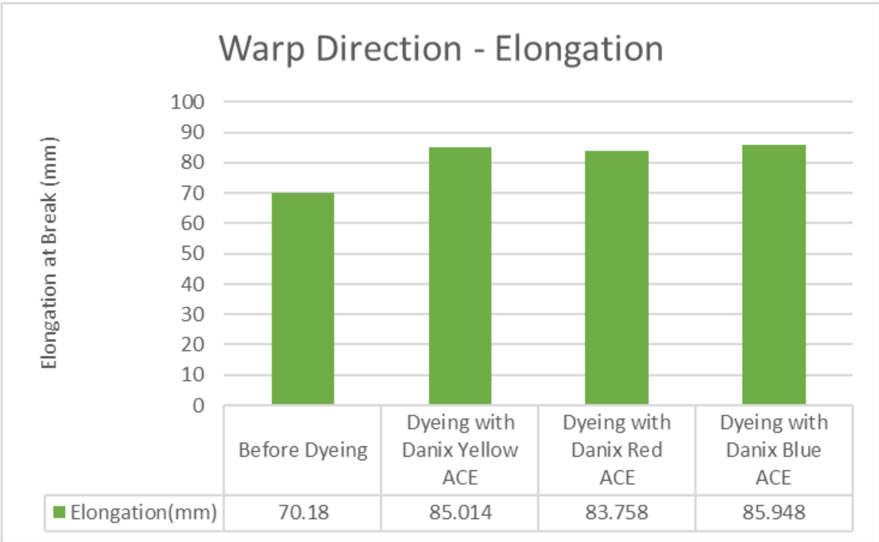
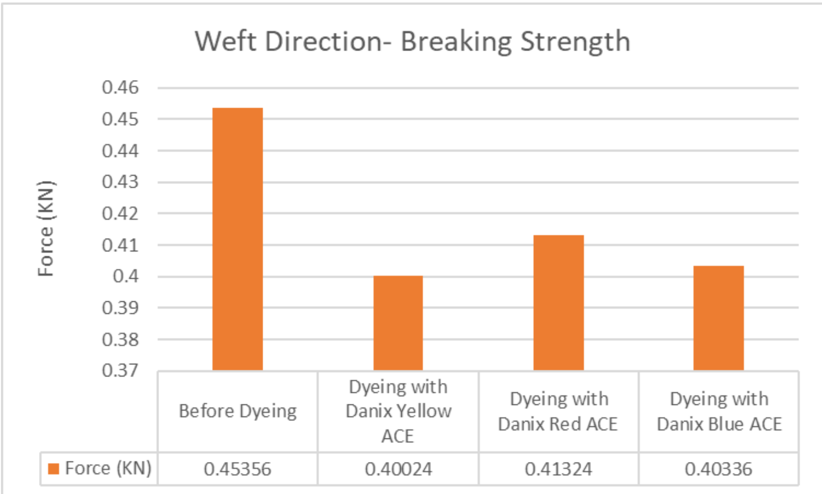


Figure 4: Testing samples breaking strength and elongation at break (Warp Direction)



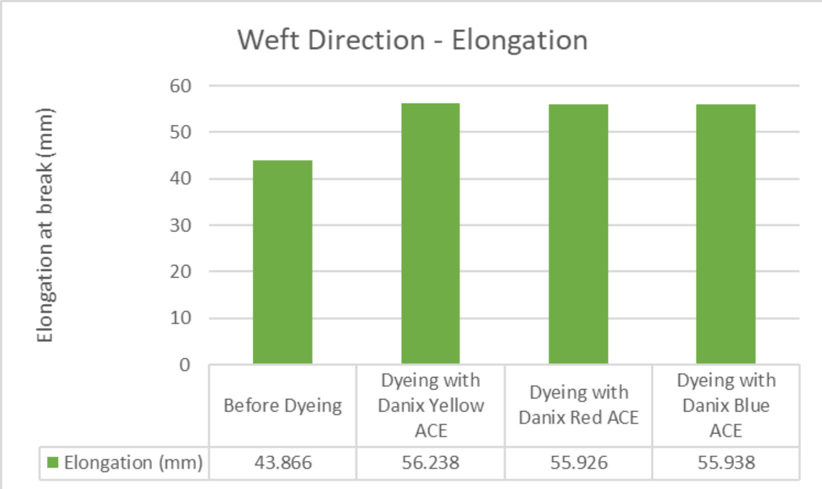


Figure 5: Testing samples breaking strength and elongation at break (Weft Direction).

The presented graph (Figure 4 and 5) displays the breaking strength and elongation at break measurements of four different samples in their weft and warp directions. The first sample was the undyed yarn, and the remaining three samples were dyed using three different dyes: Danix Yellow ACE, Danix Red ACE, and Danix Blue ACE. The data indicates that the undyed yarn had the highest breaking strength in both the weft and warp directions, with values of 0.45356 KN and 0.47836 KN, respectively. In comparison, all three dyed yarn samples had lower breaking strengths, with the lowest value observed for the Danix Yellow ACE sample in the weft direction (0.40024 KN).

The data also reveals that the elongation at break increased for all three dyed yarn samples in both the weft and warp directions, with the largest increase observed for the Danix Yellow ACE sample in the weft direction (56.238 mm). The undyed yarn had the lowest elongation at break values, with 43.866 mm and 70.18 mm for the weft and warp directions, respectively. Overall, the data suggests that dyeing the yarn samples led to a reduction in breaking strength, but an increase in elongation at break. These findings could be explained by the dye cycle and dyeing temperature used, which could affect the mechanical properties of the yarn.

CONCLUSION AND RECOMMENDATIONS

In conclusion, this study showed that the dyeing process can have a significant impact on the elongation at break of a material, as the chemical changes that occur during the process can cause the fibers to swell and lead to an increase in elongation at break. Additionally, it is found that the application of a softener can result in a drop in tenacity and an increase in elongation at break. Further investigations may be required to gain a deeper understanding of the specific mechanisms responsible for these changes. Nevertheless, the findings highlight the importance of carefully considering the dyeing process and softener application when aiming to optimize the physical properties of materials.

The present study investigated the impact of the dyeing process on the physical properties of polyester yarn and woven fabric. The results showed that the dyeing process influenced the properties of the polyester fibers, such as tensile strength and elongation at break. The shade color and dye profile had an impact on the dyeing process, affecting the dye absorption and diffusion rates. However, the change in physical properties of the polyester yarns was not significant with changing color disperse dye or dye profile, except for the effect of dye profile observed in experiments 1 and 2.

It was found that the increase in temperature above the second-order transition temperature resulted in an increase in free volume, which improved the probability of a dye molecule encountering a hole large enough to diffuse through. Disperse dyes were categorized into low, medium, and high-energy dyes, depending on the energy level required for dye diffusion. The study recommends grouping the dark, medium, and light shade categories based on the dye profile and recipe to compare their effects on the fiber properties.

Understanding the influence of dyeing on finer polyester yarns used in woven fabrics is important for optimizing the dyeing process and producing high-quality woven fabrics. The study provides insights into the dyeing process and its impact on polyester fibers and fabrics, which could be useful in the textile industry. Further studies could investigate the effect of other factors on the dyeing process, such as the amount of buffering agent, leveling agent, and dispersing agent.

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