

Application of Artificial Intelligence in the Dyeing of Denim Blends

Review Article

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Author Details

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Abstract

Denim clothes are the must-have items of clothing around the world. This kind of fabrics is evolving with the increasing consumer demand in order to keep its place as a versatile article. In this context, this paper contributes to the development and dyeing of a new blend fabric made of cotton fibers and bicomponent polyester filaments (PET/PTT). A comparative study between the mechanical and thermal properties of this fabric and conventional fabrics has confirmed the great interest to use bicomponent (PET/PTT) filaments in the manufacture of denim fabrics; these bicomponent filaments allow to give to wearer the desired elasticity and comfort. For dyeing (cotton/bicomponent polyester filaments) blend fabric, three different processes, using reactive and disperse dyes, were tested and analyzed. These dyeing processes are: two-baths/two-phases, one-bath/two-phases, and one-bath/one-phase processes. In addition, in order to obtain uniform shades between cotton fibers dyed with reactive dyes and bicomponent polyester filaments dyed with disperse dyes, an ant colony algorithm was elaborated to predict the optimal dye recipes. By observing obtained results, the developed algorithm is very effective; it allows to find the combination of reactive dyes necessary to achieve the same shade obtained by the disperse dyes with very small color differences between the two components and without having to make corrections mainly for the one-bath/two-phases process. Indeed, dyeing using the two processes (two baths/two phases and one bath/two phases) presents the best values of color yield (K/S) with almost similar results ($\Delta\text{ECMC}(2:1) < 1$). For the one-bath/one-phase process, it presents less significant results; We can observe $\Delta\text{ECMC}(2:1)$ greater than 1 in certain shades. This is due to the strongly pH value (basic pH of 11) of reactive dyeing.

Key words: Artificial intelligence, Bicomponent, Denim, Dyeing, Disperse Dyes, Properties



Introduction

Nowadays, denim production is one of the world's major and constantly evolving textile industry sub-sectors. According to forecasts by the research firm of Prescient & Strategic, the global jeans market expected to post annual growth of 5.8% over the period 2018-2023 [1]. To meet this ever-increasing demand, the denim industries have opted for new alternatives to remain competitive. They have moved towards more sustainable consumption by adopting the 4R strategy (Reduce, Repair, Reuse and Recycle). Elastane is a filament that has very important elastic properties. This filament is widely used in the production of stretch denim articles. Indeed, the good elasticity of the elastane filament allows these garments to be close to the skin, therefore to be very comfortable and pleasant to wear. Thus, these clothing items are currently among the most sought after by the consumer. They represent a potential market for Denim manufacturers [1,2].

However, the presence of elastane in stretch denim articles poses a number of technical problems. Firstly, elastane is difficult filament to use. It must therefore to be covered by other textile materials such as cotton, lyocell, polyester, etc. [2]. In addition, it is highly sensitive to wet treatments such as pre-treatments, dyeing, finishing and heat treatments. In most cases, these treatments cause the degradation and loss of elasticity in stretch items, which is their most sought-after characteristic [3]. Recently, bicomponent filaments (PET/PTT) have been used in the manufacture of various textile fabrics to provide thermal comfort thanks to their elasticity and their elastic recovery [4-13]. These filaments are an excellent alternative for overcoming the technical difficulties associated with the use of elastane filaments [5]. They are composed of two polymers: polyethylene terephthalate (PET) and polytrimethylene terephthalate (PTT). These

two filaments are adjacent, arranged side by side and extruded from the same spinneret.

In previous studies, these bicomponent filaments are characterized in terms of their mechanical, chemical and physical properties [14-21]. Obtained results showed their excellent elastic and recovery elasticity and confirm their ability to replace elastane filaments. A recent study of the stability of bicomponent filaments after heat treatments highlighted the conservation of the desired mechanical properties of these filaments [18]. Consequently, in this work, a new denim item was produced. Warp and weft yarns are composed of 100% cotton fibers and 100% bicomponent (PET/PTT) filaments, respectively. However, a problem arises concerning the dyeing of this cotton/bicomponent polyesters blend fabric. Indeed, 100% cotton warp yarns are dyed with reactive dyes while polyesters filaments are dyed with disperse dyes. The challenge is to formulate and reproduce the same color for warp and weft yarns to have a final article with uniform shade.

In the literature, several studies have focused on color recipes prediction, either using colorimetric and spectrophotometric meth-

ods or using artificial intelligence techniques [22-30]. Recently, Chaouch et al. developed a new genetic algorithm for color recipe prediction of cotton fibers using reactive and direct dyestuffs [31]. The studied parameters of the algorithm were determined using a full factorial experimental design. The evaluation of the efficiency of the algorithm was proven and the obtained recipes showed good colorimetric correspondence with the target colors; all color difference $\Delta E_{CMC}(2:1)$ values are less than 1. The same authors developed a second method based on ant colony algorithm [32,33].

The latter seems to be a promising method for solving the problem of color recipe prediction. Obtained results were very encouraging; theoretical values of $\Delta E_{CMC}(2:1)$ between the target colors and those proposed by the ant colony algorithm do not exceed 0.7. These results reveal the excellent conformity of the predicted concentrations to the desired shades. More recently, a third study focused on comparing these two color prediction algorithms, genetic and ant colony algorithms, in order to determine which best optimizes the color formulation step [34].

Based on this study, the ant colony algorithm seems to be the most efficient algorithm in predicting dyeing recipes of cotton fibers with reactive dyes. Therefore, in this current study, this evolutionary ant colony algorithm was used to determine the appropriate recipes for dyeing our innovative fabric composed of a blend of cotton/bicomponent polyester filaments. First, we presented in the first step the manufacturing parameters of the new (cotton/ bicomponent polyester filaments) blend fabric. Then a comparison study between its mechanical and thermal comfort properties with a conventional denim fabric (100% cotton) and a blend fabric (cotton/ PET filaments) was established. For the dyeing of this new fabric, clean dyeing was performed using different processes: two-baths/two-phases, onebath/two-phases, and one-bath/one-phase. The ant colony algorithm was then applied to predict the appropriate recipes in order to find uniform shades.

Technical Details

The materials used include 100% cotton fabric used as a reference, cotton/PET blend fabric, and cotton/ bicomponent (PET/PTT) filaments blend fabric. Tests for mechanical properties and moisture management of the denim fabrics have been carried out. The blend fabrics have been dyed using reactive and disperse dyes.

The following steps have been followed in dyeing

- a) Two baths/two phases dyeing process
- b) One bath/two phases dyeing process
- c) One bath dyeing process

All colorimetric measurements were performed using a spectrophotometer.

Ant colony algorithm has been used as a technique in artificial algorithm (Figure 1, 2).



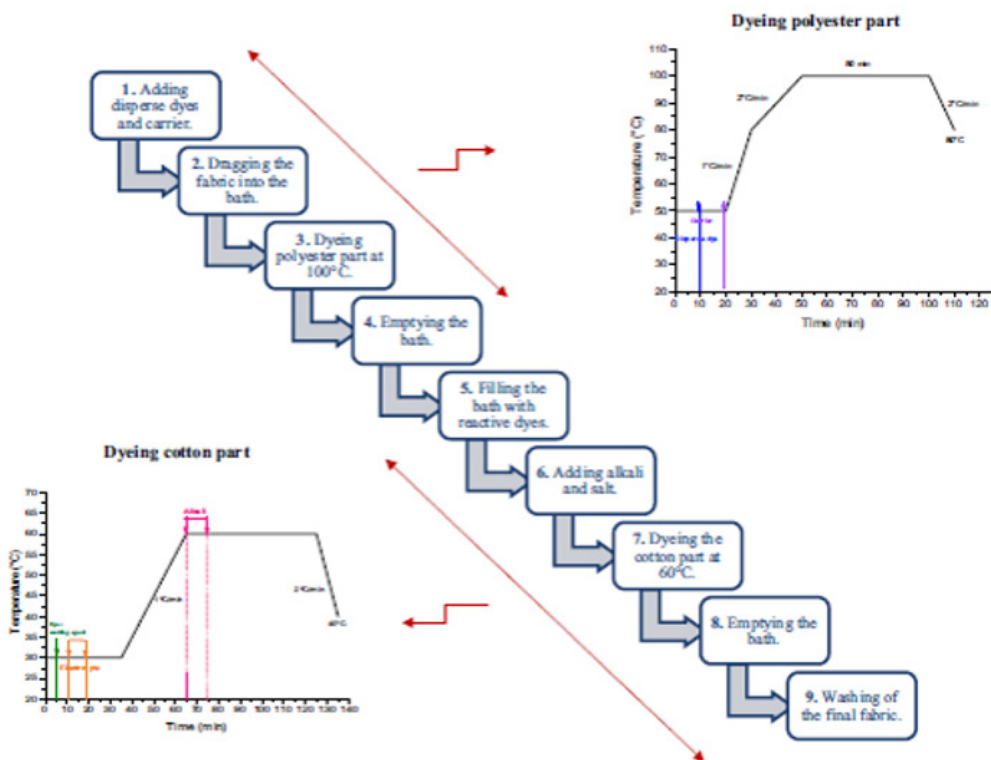


Figure 1: Dyeing (cotton/bicomponent polyesters filaments) fabric using two-baths/two-phases dyeing process.

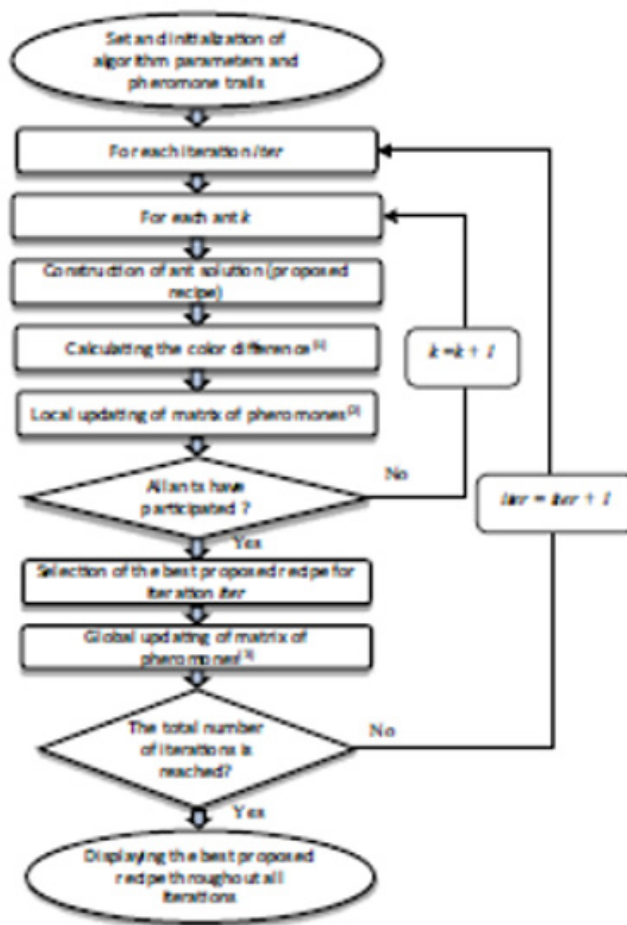


Figure 2: Flow chart of the ant colony algorithm.



1. Theoretical value of color differences $\Delta E_{CMC}(2:1)$ between color
2. obtained using the proposed recipe by ant k and target color;
3. Local updating of pheromone values using equation 3;
4. Global updating of pheromone values using equation 4.

Mechanical Properties of Studied Fabrics

To highlight the excellent mechanical properties of our fabric (F3) made from a blend of bicomponent filaments (cotton / (PET/PTT)), a comparative study was carried out with two conventional fabrics: fabric (F1) made from 100% cotton and fabric (F2) based on a cotton/PET blend. The mechanical properties of these three fabrics have been determined. By observing the obtained results, it can be concluded that the fabric (F1) is much more stiffer than fabrics (F2) and (F3) whose weft yarns are in classic polyester (100% PET) and in bicomponent filaments (60% PET, 40% PTT), respectively. These obtained results are due to the fact that polyester threads are much more resistant than cotton fibers. In addition, the fabric (F3) has an elongation percentage equal to 50.71%. This is a very high value compared to the two others fabrics. These excellent mechanical performances showed that geometry shape of filaments has a great effect on their elastic recovery. The bicomponent filaments have a high value of recovery, thanks to the arrangement side by side of the two polymers PET and PTT. This good elasticity enables the blended fabric (cotton/bicomponent filaments (60% PET, 40% PTT)) to adapt to the wearer's body, to be soft and comfortable.

Thermal Comfort Properties of Studied Fabrics

According to the AATCC TEST METHOD 195 (2011), the ability to evacuate sweat of studied fabrics, in particular the fabric made of a cotton/bicomponent polyester filaments blend, was evaluated. From obtained results, it can be seen that humidification time (sec), absorption rate (%.s), maximum moisture diffusion radius (mm), and moisture diffusion rate (mm/s) values of our fabric are all good. More importantly, the percentage of moisture transport capacity (%) values are excellent and the overall moisture management capability (OMMC) value is also good. It can be concluded that the manufacture of this fabric, on the one hand, remedies all the problems caused by the use of elastane filaments and, on the other, produces a fabric with good, even excellent, thermal comfort properties. This may encourage the use of denim fabrics that offer the user both good elasticity and elastic recovery, as well as good thermal comfort properties.

In addition, a comparative study between the different fabrics developed was carried out. It is found that the fabric containing bicomponent polyester filaments offers the best performance, followed by the 100% cotton fabric and the cotton/PET blended fabric. Indeed, the contact surface is larger than that of conventional fibers with a rounded cross-section; therefore, the moisture will diffuse more easily and more quickly by capillary action. This confirms the great potential for the use of bicomponent (PET/PTT) filaments in various textile articles, in particular denim articles mixed with cotton. The big challenge is to dye these innovative fabrics correctly, and above all to guarantee the same shades for the two materials used: cotton and bicomponent filaments (PET/PTT).

Analysis of Dyeing Performances

In order to obtain the same color on the different components of the fabric, a dye recipe prediction algorithm was developed and ap-

plied. This algorithm, based on ant colony optimization technique, must predict and propose the most appropriate recipe of reactive dyes in order to match the shade obtained by disperse dyes. The shade used for disperse dyes is 1.2% of each one. So, the ant colony algorithm was applied to determine the equivalent recipe to dye the cotton part and obtain the same shade as that of the polyester part. The predicted recipes have been determined. These proposed recipes were used for the three processes (two-bath/two-phase, one-bath/two-phase and one-bath/one-phase) for dyeing the cotton/bicomponent filament blend. The (K/S) values obtained as well as the CIELab colorimetric coordinates of the dyed cotton/bicomponent filament (60% PET, 40% PTT) blend fabrics have been determined.

By observing obtained results, it is clear that (K/S) values and CIELab coordinates of the samples dyed using the three different processes are very close. These results confirm the effectiveness of the developed ant colony algorithm which enables us to find the combination of reactive dyes needed to obtain the same shade as that obtained with the disperse dyes without having to make any corrections. In addition, the use of this algorithm offers the possibility to remedy wastage during the use of dyes and to reduce the quantity of water used during color corrections. It should be noted that dyeing using the first two processes (two baths/two phases and one bath/two phases) presents the best values of color yield (K/S) with almost similar results (color differences $\Delta E_{CMC}(2:1) < 1$). Indeed, if the first involves dyeing the polyester part and then emptying the dye pots before proceeding to dye the cotton, the latter involves keeping the same dye bath after dyeing the polyester part and then incorporating all the products required for reactive dyeing. It can therefore be concluded that the disperse and reactive dyes used in this study are compatible and during their use in both processes, no degradation of either dye was observed. The levelness of dyed fabrics is also good.

For the third dyeing process, one-bath/one-phase, it presents less significant results; We can observe ($\Delta E_{CMC}(2:1)$) color differences greater than 1 in shades 1, 3 and 4. This is due to the strongly pH value (basic pH of 11) of reactive dyeing. Indeed, several previous studies have shown that disperse dyes do not tolerate high values of basic pH, and in such cases, color deviations would be possible [35,36]. Furthermore, we observed that the use of p-vanillin did not cause problems in the dyeing of the reactive part even when using the two processes, one bath/two phases and one bath/one phase, where the dye bath was not emptied or changed during the dyeing of the blend fabric (cotton/bicomponent (PET/PTT) filament) [37-45]. In this way, the bicomponent (PET/PTT) filaments were dyed using a clean and economical process in terms of

temperature (100°C) and the dyeing process for cotton/polyester blend fabrics can also be economical in terms of water consumption by keeping the same dye bath and therefore using a one-bath/two-phases process. These excellent dyeing results could encourage the manufacture of articles containing bicomponent (PET, PTT) filaments and their incorporation into denim fabrics to give the wearer the desired elasticity and comfort. They also allow the use of an economical and ecological dyeing process [46-56].

Conclusion

This paper contributed to the development of a new fabric made of (cotton/ bicomponent polyester filament) blend. A comparative



study between the mechanical and comfort thermal properties of this new fabric and those made of 100% cotton and (cotton/PET) blend has confirmed the interest of the developed fabric. This encourages the manufacture of articles containing bicomponent (PET, PTT) filaments and their incorporation into denim fabrics in order to give the wearer the desired elasticity and the desired comfort. Moreover, this study proposed a suitable process for dyeing this kind of fabrics and evaluated its performance. Faithful to our principles of green chemistry, the one-bath/two-phases process seems to be the most appropriate process for dyeing (cotton/bicomponent (PET, PTT) filament) blend fabric. In addition, the use of the ant colony algorithm, developed in this study, has been very effective in predicting the right dye recipes and in formulating colors without having to make multiple corrections and while minimizing the amount of dyes and water. Obtained results proved that this algorithm is a very powerful tool in the prediction of dye recipes and the formulation of shades for blend fabrics.

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