A Multicriteria Decision Approach on Physical Properties of Socks Made from Different Fiber Types

Sena Cimilli Duru*, Cevza Candan and Banu Uygun Nergis

Abstract

The aim of the study is to investigate the physical properties of sock fabrics made from some new regenerated fibers such as modal, micro modal, bamboo, soybean and chitosan. Also, samples from cotton and viscose fibers were produced in the study for comparison reasons. The results obtained seemed that the new regenerated fibers, especially the soybean fiber may still be preferred for socks, as they have high abrasion resistance as well as bursting strength, which is important for a garment’s life time, in addition to their natural antibacterial property. Also, it was shown that TOPSIS can be a beneficial tool for this kind of researches. By using TOPSIS, a single ranking taking into account preferences of the decision-maker and priorities arranged according to the final goal can be obtained. The data obtained showed that fabrics made from soybean fiber were the best alternative from among all.

Keywords
Sock; Comfort; New regenerated fibers; Multicriteria decision making

Introduction

Generally, fabrics having different physical properties were ranked according to properties using different statistical analysis methods. However, better results about the desired end-product properties are obtained if the priorities and preferences of the decision-maker namely the textile engineer is taken into consideration and multicriteria decision making methods (MCDM) are useful means for carrying out such an analysis. There are some studies related to applying MCDM to textile problems. Majumbar et al. [1] developed an algorithm which works by amalgamating TOPSIS and genetic algorithm to determine the quality value of cotton fiber considering two yarn properties namely yarn tenacity and unevenness. In another paper of Majumbar et al. [2], AHP and TOPSIS methods were used to develop software for cotton fiber grading and selection. Also a fuzzy AHP model has been developed to solve the raw material selection problem of the textile spinning industry [3]. Moghassem and Bahramzadeh [4] tested the applicability of the TOPSIS approach in obtaining optimum spinning conditions for rotor spun yarn that is intended to be used in a weft knitting machine. According to the final ranking, the spinning condition in which the sample was spun by using a spiral nozzle, a doffing tube without a torque stop, and a closer setting had the highest closeness coefficient to the ideal solution. Appropriate components of the doffing tube and its adjustment for rotor spun yarn intended to be used for weft knitted fabrics were selected by extended version of the TOPSIS. In order to select the appropriate setting in rotor spinning machine for Ne 30 rotor yarn intended to be used for weft knitted fabric, TOPSIS method was used by Moghassem and Fallahpor [5]. Fuzzy TOPSIS method for group decision making was proposed for the alternatives selection in yarn tension detection and control system by Minna and Yan [6]. In the study conducted by Majumbar et al. [7] selection of navel rotor spinning machine, which influences various quality parameters of the final yarn was investigated by combining TOPSIS and AHP methods. Relative importance of the yarn quality parameters was evaluated by using AHP method, keeping in mind the requirements of denim fabric. The final ranking of nivals was elicited in accordance with the relative closeness value determined by TOPSIS method. Kaplan, Araz, and Goktepe [8] applied ELECTRE outranking method for the selection of rotor navel. Mitra et al. [9] attempted to develop a simple index of handloom fabric quality, which can be used for selecting fabrics for a specified end use. AHP and MAHP multi-criteria decision making (MCDM) were used for ranking 25 handloom cotton fabrics in terms of their overall quality value considering their applicability as summer clothing materials. Under the different conditions of temperature and humidity, moisture absorption, water transmissibility, water retention and moisture liberation of stitch-bonded fabrics with different content of hemp was tested by Hao et al. [10]. According to multiple properties of the moisture absorption and quick drying, the tested performance of five aspects were used to build the evaluation system and TOPSIS method was employed to establish a comprehensive evaluation method. Duru and Candan [11] applied hybrid AHP and TOPSIS methods in order to select best option in terms of wicking and drying characteristics of seamless garments. Hong and Su [12] employed a hybrid of the Taguchi and TOPSIS methods to determine the optimal processing parameter combination for PET/TiO2 UV-resistant fiber melt-spinning using a minimum number of experiments. Dulange et al. [13] identified the critical success factors influencing the performance of power loom textiles, to evaluate their impact on the organizational performance and to find out the effect of these factors on the organizational performance of small and medium-sized enterprises (SMEs) in the Solapur (Maharashtra) industrial sector using AHP. For supply chain selection and organization, there are also some studies to select the best alternative for all among all. Yücel and Güneri [14] developed a new model that complements the weakness and proposes a complete fuzzy multi-objective linear model approach for the supplier selection problem while Yayla et al. [15] used the fuzzy TOPSIS method to select the most appropriate supplier of garment ‘X’ operating in Turkey. Eleren and Yılmaz [16] developed and applied a TOPSIS model that could help managers to select most appropriate supplier within the textile sector in Usak. Tanyas [17] designed the performance evaluation system in a textile global sourcing office using Balanced Scorecard method with the help of AHP within a supply chain perspective.

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During the daily life, owing to the fact that socks are connected with skin and shoes directly, they are subjected to more physical forces than other types of garments. As a result, they need to perform better physical characteristics than the others. With the help of literature survey, it was found that there is no published literature that focuses on physical properties of textile knitted fabrics, using TOPSIS or AHP method of MCDM. For this purpose, in this study, a multicriteria decision making method, TOPSIS and AHP methods, were used in order to select the sock fabric with best physical properties. New regenerated fibers such as modal, micro modal, bamboo, soybean and chitosan were selected for the study. Also, due to the limited number of studies about the performances of these fibers, in an intention to compare their properties with conventional ones, cotton and viscose were also edited to the study.

Material and Method

The details regarding the fiber types and yarns are given in Table 1. For the work, sock fabrics were knitted on a Nagata D210 double cylinder hosiery machine of 176 needles at the same knitting settings (i.e. the loop length for all sock samples was kept constant for each sample).

Unlike ordinary sock fabrics, nylon and elastane were not utilized in the production of the plain jersey socks for the work in an attempt to investigate the effect of fiber type on physical properties of the samples. In addition to that, all sock samples were dyed and finished under the same conditions. Fabric weight, thickness, bursting strength, abrasion resistance, dimensional stability tests were done in accordance with TS 251, BS 2544, TS 393 EN ISO 13938-1, ASTM D4966, ISO 3759-BS4923 standards, respectively. The overall porosity is defined as the ratio of open space to the total volume of the porous material and accordingly it was calculated as calculated from the measured thickness and weight per unit area values using the following equations [18]:

\[
\text{Porosity(%) = } \left(1 - \frac{\text{Density of fabric (g/cm}^3\text{)}}{\text{Density of fiber (g/cm}^3\text{)}}\right) \times 100 \tag{1}
\]

\[
\text{Density of fabric (g/cm}^3\text{)} = \left(1 - \frac{\text{Fabric weight(g/cm}^3\text{)}}{\text{Fabric thickness(cm)}}\right) \tag{2}
\]

A decision making problem is the process of finding the best option from all of the feasible alternatives. Multi-criteria decision making may be considered as a complex and dynamic process that includes one managerial level and one engineering level. TOPSIS is a kind of multi-criteria method to identify solutions from a finite set of alternatives. The basic principle is that the chosen alternative should have the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution [2]. The AHP is a powerful and flexible multi-criteria decision making tool by structuring a complicated decision problem hierarchically at several different levels where both qualitative and quantitative aspects need to be considered [19]. The combination of AHP and TOPSIS can handle the choosing the best fiber type which gives feeling more comfortable. In the case of hybrid AHP-TOPSIS method the pair-wise comparison method of AHP is amalgamated with the other steps of TOPSIS and the procedure of the hybrid AHP-TOPSIS method can be expressed in a series of steps [20-22] given as follows:

**Step 1:** The relevant objective or goal, decision criteria and alternatives of the problem are identified in this step.

**Step 2:** A decision matrix of criteria and alternatives is formulated on the basis of information available regarding the problem. The number of alternatives is M and the number of criteria is N where an element \(a_{ij}\) of the decision matrix \(D_{mn}\) represents the actual value of the ith alternative in terms of jth decision matrix.

**Step 3:** The decision matrix is converted to a normalized decision matrix. The normalized value \(v_{ij}\) is calculated as:

\[
v_{ij} = \frac{a_{ij}}{\sqrt{\sum_{k=1}^{n} (a_{kj})^2}} \tag{3}
\]

**Step 4:** The relative importance of different criterion with respect to the objective of the problem is determined using AHP. To do so, a pair-wise comparison matrix of criteria is constructed using a scale of relative importance. The judgements are entered using the fundamental scale of AHP, which is shown in Tables 2 and 3.

For N criteria, the size of this comparison matrix will be \(N \times N\) and the entry \(c_{ij}\) will denote the comparative importance of criterion 1 with respect to criterion j. In the matrix \(c_{ij}=1\) when \(i=j\) and \(c_{ij}=1/c_{ji}\). The pair-wise comparison matrix (C1) of criteria is shown below:

\[
C_1 = \begin{bmatrix}
1 & \cdots & C_{iN} \\
\vdots & \ddots & \vdots \\
C_{iN} & \cdots & 1
\end{bmatrix}
\]

The normalized weight or importance of the ith criterion (W) is determined by calculating the geometric mean of the ith row (\(GM_i\)) of the above matrix and then normalizing the geometric means of rows as:

\[
W_i = \frac{GM_i}{\sum_{i=1}^{N} GM_i} \tag{4}
\]

To check the consistency in pair-wise comparison judgment, consistency index (CI) and consistency ratio (CR) are calculated

### Table 1: Properties fibers and yarns.

<table>
<thead>
<tr>
<th>Fiber fineness (dtex)</th>
<th>1.5</th>
<th>1.2</th>
<th>1.59</th>
<th>0.82</th>
<th>1.57</th>
<th>0.93</th>
<th>1.91</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fiber length (mm)</td>
<td>28.1</td>
<td>40.8</td>
<td>38.1</td>
<td>35.3</td>
<td>36.2</td>
<td>37.6</td>
<td>41.1</td>
</tr>
<tr>
<td>Yarn Count (Ne)</td>
<td>29.1</td>
<td>28.9</td>
<td>30.2</td>
<td>29.0</td>
<td>29.4</td>
<td>30.4</td>
<td>29.2</td>
</tr>
<tr>
<td>Yarn Twist Coefficient (os)</td>
<td>3.57</td>
<td>3.31</td>
<td>3.54</td>
<td>3.15</td>
<td>3.33</td>
<td>3.54</td>
<td>3.65</td>
</tr>
</tbody>
</table>

*For cotton, modal, viscose, bamboo, chitosan, and soybean photos [18]*
using the following equations where (λ_{max}) is the maximum eigen value.

\[ CI = \frac{2\lambda_{max} - N}{N - 1} \quad \text{and} \quad CR = \frac{CI}{RCI} \tag{6} \]

where RCI is random consistency index and its value can be obtained from Table 4. If the value of CR is 0.1 or less than the judgment is considered to be consistent and therefore acceptable. Otherwise, the decision maker has to be reconsidering the entries of pair wise comparison matrix.

**Step 5:** The weighted normalized value \( v_i \) is calculated as

\[ v_i = W \times r_j = 1, \ldots, \infty, \quad mi = 1, \ldots, n \]

where \( W_i \) is the weight of the \( i \)-th attribute of criterion and \( \sum_{i=1}^{n} W_i = 1 \)

**Step 6:** The positive ideal and negative ideal solution are determined by following formulations:

\[ A^+ = \left[ \begin{array}{c} \nu_1^+ \\ \vdots \\ \nu_n^+ \end{array} \right] = \left( \begin{array}{c} \max_i \nu_{ij} \\ \vdots \\ \max_i \nu_{ij} \end{array} \right) \in J \tag{8} \]

\[ A^- = \left[ \begin{array}{c} \nu_1^- \\ \vdots \\ \nu_n^- \end{array} \right] = \left( \begin{array}{c} \min_i \nu_{ij} \\ \vdots \\ \min_i \nu_{ij} \end{array} \right) \in J \tag{9} \]

where \( J \) is associated with benefit criteria and \( J \) is associated with cost criteria.

**Step 7:** The separation measure using the n-dimensional Euclidean distance is calculated.

\[ d_j^* = \left( \sum_{i=1}^{n} (\nu_{ij} - \nu_{ij}^*)^2 \right)^{1/2} \quad j = 1, \ldots, m \tag{10} \]

**Results**

The tested properties of the fabrics can be seen in Table 5.

For performing the TOPSIS evaluation, weight loss, bursting strength, width wise and lengthwise dimensional stability were taken as a weight. Analytic hierarchy process was used to determine the relative weights of four decision criteria according to their relative importance for fabric performance (Table 6). Here the comparisons were made according to the Saaty’s nine-point scale given in Table 3. The scores given in Table 6 represent the perception of the decision maker about the relative importance of the four fabric parameters. These scores can vary from one decision maker to another and also with the intended use of the fabrics. It can be said from Table 6 that weight loss and bursting strength are more dominant parameters than dimensional stabilities of the fabrics and the relative weights of both parameters were found to be maximum 0.375.

Table 7 shows calculated weights and codes of the four criterias.

For the measurement of consistency of judgment the original matrix is multiplied by the weight vector to get the product. By help of equation 6, \( \lambda_{max} \) was found 4. Therefore, \( CI=0 \) and \( CR<0.1 \). As the value of CR is below 0.1 the comparison matrix remains consistent. Vector normalization was made and weighted normalized matrix was formed and then positive and negative ideal solutions were calculated (Table 8).

After identifying positive (\( A^+ \)) and negative ideal solution (\( A^- \)), the separation of each alternative from the ideal solution was calculated using equations 8 and 9. The relative closeness of the alternatives (\( R_j \)) to the ideal solution (\( A \)) was defined by the equation 12 with respect to \( A^+ \). Based on the closeness of the coefficient to the ideal solution (\( R \), value), ranking of the preference order of all alternatives in descending order is shown in Table 9.

For this study, weight loss and bursting strength parameters are more important than dimensional stability of the fabrics and so their weights are higher. As a result, fabrics made from soybean fiber performed the best alternative from all among others because of its lowest weight loss and highest bursting strength values. On the other hand, although fabrics made from micro modal ones were dimensional stable, its weight loss value was so high which made this very fabric the least preference one.
Conclusion

Weight loss, bursting strength, widthwise and lengthwise properties of the fabrics produced from new fibers such as micro modal, bamboo, soybean, and chitosan were knitted for the experimental work discussed in the paper. In the light of the data obtained, the fiber type seems to markedly affect the physical properties discussed. Moreover, both experimental results and TOPSIS evaluations showed that it was the soybean sock fabrics which performed relatively better than the other fabrics in terms of the mechanical properties where as micro modal fabrics were the worst ones.

References


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