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Content

USE OF THREE DIMENSIONAL PRINTING IN THE PRODUCTION OF TEXTILE PRINT FORMS

Andri Petrushevski
State University of Infrastructure and Technologies, Str. Kirilivska 9, Kyiv, 04071, UKRAINE
zmodeller@gmail.com

Abstract: *Since the invention of woven fabric, various types of artistic printing on fabric have been used. One of the most ancient and widespread methods is letterpress and gravure printing. Besides printing, it is also widely used in industrial textile production. The creation of industrial printing plates is a very expensive process today. For this reason, for small editions more economical technologies are used, such as silk-screen printing. However, gravure and letterpress methods have several advantages over screen printing. Reducing the cost of production of printing plates of this type will be an undoubted progress. The relief on the surface of the printing plate is a three-dimensional construction. Therefore, it can be formed in the form of a digital three-dimensional model. Modern methods of three-dimensional printing make it possible to form a printed form based on such a digital model, suitable for use in the textile and printing industries. The introduction of this technology will definitely reduce the cost of manufacturing forms for textile printing. The article describes an experiment that confirms this assumption.*

Keywords: *3D printing, printing plate, photopolymer, letterpress, intaglio printing.*

1 INTRODUCTION

Since the invention of the woven fabric, various types of artistic printing on fabric have been used. Some of the most ancient and widespread methods are letterpress and gravure printing (Figure 1). Besides printing, it is also widely used in industrial textile production. The creation of industrial printing plates is a very expensive process today. However, this is entirely justified due to the mass production. Over time, such costs in the presence of large circulations pay off and generate income. This technique is not available for small-scale production. For this reason, for small editions, more economical technologies are used, such as silk-screen printing. However, gravure and letterpress methods have several advantages over screen printing. Reducing the cost of production of printing plates of this type will be an undoubted progress. There is no consensus regarding the place and time of the appearance of this technique. Most likely it was Egypt, India or China. There are still workshops in India and China that use ancient methods of printing on fabric. The material used for the forms are wood and ceramics.

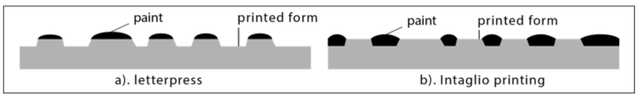

Figure 1 Diagram of letterpress and gravure (intaglio) printing

Similar plaques have been found in Egyptian burials dating back to around 1400 BC. [1, 2]. The ancient historian Pliny the Elder also describes similar printing methods in his writings [3]. The printing form is a plate with a relief on one of the sides. Thick paint is applied to the relief side of the plate. The canvas was then pressed against the painted embossed surface of the printing plate. Thus, the paint was transferred to the canvas. The production of printing plates from polymers and metals is an expensive process, which causes certain difficulties in the textile industry, especially for small enterprises. Despite this, letterpress and gravure printing have a number of advantages over screen printing. The first is the simplicity of the printing process. Secondly, the clarity of the edge and the saturation of the tone. And thirdly, a longer life of the printing plate. The introduction of such methods will reduce the cost of manufacturing unique printing plates for the textile industry and improve quality. The subject of the research is the production of printing plates for letterpress and gravure printing using innovative technologies. The purpose of the study is to study the possibility of creating a printing form with sufficient detail for use in textile production by 3D printing. The study, according to the author, can help expand the possibilities of manufacturing printing plates from traditional materials for printing on fabric. In the modern scientific literature, the author did not find studies on this topic.

Modern methods of production of printing forms

We will deal exclusively with the main areas of production methods relating to letterpress and gravure printing plates. Basically, there are two types of forms: flexographic and typographic. Flexographic forms are photopolymer forms that can be classified according to a number of features: solid and liquid PPC - photopolymer printing composition;

• chemical composition of the layer, depending on the composition of the PPC;

• design (geometric shape) - they can be lamellar and cylindrical (including seamless and sleeve).

Flexographic photopolymer forms also differ in structure (they can be single-layer and multilayer, the type of substrate (polymer or metal), as well as thickness, format, resistance of forms to solvents and other parameters [4, 5]. Printing forms, depending on the nature of the material, are divided into metal and photopolymer. Currently, photopolymer printing plates are mainly used. They are made of solid PPC on polymer or metal substrates, varying in thickness and format. Printing photopolymer plates can have a different structure, which depends on the structure of the used for the manufacturing of the plate material. Most often, the printing elements of the forms consist of a photopolymer, and the space elements are either the substrate, or the base of the form, or the carrier layer with a stabilizing film. The printing elements are made of metal, and a copy layer is located on the surface of the printing elements. The main parameters characterizing the forms of letterpress are the steepness of the profile of the printing element, and the depth of the space elements. The maximum depth of whitespace characterizes the depth of the relief, which in practice is often called the height of the relief. Depending on the size of the printing elements and the distance between them, the blank elements of letterpress forms have different depths [6]. Without going into technical details, modern letterpress and gravure printing plate production methods can be divided into three main groups:

1. Laser engraving
2. Photoelectric method
3. Photochemical method

The author does not set the task of comparing the cost of classical methods of making printing plates. It is known that the cost of each of these methods is significant. This is due to the complexity of the process and the use of highly specialized equipment. The use of the 3D printing method will definitely reduce the cost of production of printing plates through the use of general-purpose technology. This is especially true for forms with a complex structure.

2 3D PRINTING TYPES ANALYSIS

Currently, 3D printing technology is one of the fastest growing industries. This is primarily due to the prospects that these technologies promise us in the future. At this stage of development, unfortunately, technology is in its infancy. Their own technological shortcomings hold back their global spread:

1. Additive FDM - fused deposition modeling printing technology with polymers. At this stage, the following plastics are used: ABS - acrylonitrile butadiene styrene, PLA - polylactic acid and others. The printing method consists in the successive application of layers of molten plastic by an extruder. Of the advantages should be noted the availability of technology. In all other aspects, it requires serious improvement. The disadvantages are the quality of the print itself, the slow speed of model formation, and geometric limitations. Application so far is only in prototyping and prototyping [7, 8, 9].
2. Additive technology SLS – selective laser sintering, SLA – stereolithography photopolymer printing. In this case, the quality of the product is much higher. With professional devices, it reaches the industrial level. The disadvantages are the speed of printing, the relatively high cost of consumables, and geometric limitations. Technology is rapidly evolving and improving. Application: medicine, small-scale production, and particular, jewelry [10].
3. Additive technology for 3D printing with plaster has. Good print quality but the application is very limited and the disadvantages are similar. Application so far is only in prototyping and souvenirs.
4. Additive technology SLM - selective laser melting powder metal printing allows you to get a professional quality product and is already quite widely used for small-scale production in the automotive, aviation and rocket industries. Among the shortcomings, it should be noted the cost and speed of printing, as well as some limitations [11, 12].
5. Additive building technology. This technology is at the very beginning of the journey. A lot of experiments are being carried out in different directions [13, 14].

It should be noted that not all existing 3D printing technologies are listed here, however, they are not related to our subject. For example: printing with biomaterials or food formulations. To solve our problem, two of the listed technologies are suitable for us: photopolymer 3D printing and 3D metal printing. In terms of materials, these two methods are very well combined with traditional printing plate materials.

3 EXPERIMENTAL AND METHODS

The relief on the surface of the printing plate is a three-dimensional construction. Therefore, it can be formed as a digital three-dimensional model. Such a model is necessary for subsequent conversion into a G-code or a sequence of sections, which in turn is an instruction for building a model on a 3D printer. Let's consider the main stages of creating a printed form using 3D printing.

Creation of a vector drawing of a textile décor is shown in Fig. 2.

After the artistic side of the textile decor is solved, the vectorization of the picture is necessary. To generate a 3D model based on a vector image, any general-purpose 3D editor is suitable. You can use for example: Rhinoceros, Autocad, SolidWorks, etc. To obtain a relief, we use the extrusion method. In the case of creating a cylindrical printed block, we use the method of evenly distributing the pattern on the curved Emboss surface. The resulting model is saved in STL. format. To determine the depth of gap areas, we use the following calculations. For industrial typographic forms:

$$h_{min} > A_{k\,r} + \sum \left({}^{\triangle i}_{1} \right) \qquad (1)$$

h_{min} - minimum depth of whitespace elements [nm].

$A_{k\,r}$ - deformation of the knurling rollers [nm].

$\sum^{\Delta i}{}_{1}$ - the sum of metric inaccuracies of the printing apparatus [nm]. In this case, the inequality [15].

The minimum depth of the gap elements is related to the amount of elastic deformation of the deckle:

$$h_{min} > A_{dec} + \sum \left({}^{\triangle i}_{2} \right) \qquad (2)$$

A_{dec} - deckel deformation value [nm].

$\sum^{\Delta i}{}_{2}$ - the sum of inaccuracies, including changes in the size of the plate cylinder [nm]. Must be respected.

When transferring the ink layer from the letterpress form to the fabric, the latter should not come into contact with the blank elements of the form. In the case of the artistic application of the printing plate, as in our case, the depth of the relief comes from the experience of the master and varies between 1 - 3 mm according to the type of printing and the distance between white space elements. The greater the distance, the deeper the relief (Fig. 1, 2).

The digital form model in STL format is imported into the editor for printing preparation. The choice of slicer depends on the brand of 3D printer. For most models, proprietary applications are supplied. To successfully convert to a G-code or section sequence, the mesh of the model must meet certain requirements. Polygons should not overlap, etc.

Figure 2 Vector image from a drawing

Today there are printers that work with different materials. Most often it is plastic, photopolymer resin, gypsum, metal.

Metal, plastic and photopolymer resin are suitable for our task. The FDM additive printing method for ABS plastic is not suitable due to its resolution. Usually it is 0.5 - 0.2 mm This is a low resolution for such a task. But the method of powder printing with metal SLM (20 micrometers) and professional photopolymer technologies SLS, SLA are quite suitable for us. Metal printing is expensive. However, compared to the cost of making a prototype, the traditional method may be preferable. For this reason, it may well replace traditional industrial printing plate production methods in the future. For small volumes, the photopolymer method would seem the obvious choice. Since the resolution of this method ranges from 0.15 - 0.01 mm. which fully meet the requirements of studio printing. Prices for materials and devices become affordable for personal use (Fig. If the size of the printer's desktop is smaller than necessary, we divide the model into several parts so that each of the parts fits in the printer's workspace. We calculate in such a way that the joint falls on the edge of the gap.

Formation of a printing plate on a 3D printer is shown in Fig. 3.

4 RESULTS AND DISCUSSION

For our experiment, the selected model fits completely into the working area of the printer, which greatly simplifies the task (Fig. 2). After obtaining a vector image by vectorization in the graphics editor, it became possible to create a three-dimensional model of a printing plate from the original drawing (Fig. 3). A variant of letterpress imitating the technique of linocut was chosen. In the Fusion 360 system, when trying to project a vector drawing onto the surface of a future 3D model, the system generated an error. Most likely, during the vectorization of the pattern, one or more self-intersections in the form of loops were formed. Breaks in closed areas of the resulting contours can also lead to a similar problem. When trying to project such a line onto the surface of a 3D model, the system may generate an error. This was expected, due to the complexity of the drawing. The search for the cause in such cases can be very time consuming due to the very large number of elements. The complex drawing was not chosen by chance. The task is to check the possibility of printing delicate parts. It is in such places that the shortcomings of the quality of the form appear. It was decided to use an alternative method of building a three dimensional model. The method of extruding a surface through a mask. A digital sculpting system (Fig. 4) was used.

A three-dimensional model of the printing plate was created (Fig. 4). The image was projected in the form of a raster mask onto the high-poly surface of the model in high resolution. After creating the mask, a high relief of 2.5 mm was formed by extrusion method. This method is quite suitable for printing an artistic image. With this method of building a model, the process of image vectorization is not necessary.

After performing the optimization process for the number of polygons, the model was successfully generated and converted to the STL file format. Furthermore, the model was successfully uploaded to the Lychee Slicer system, where the scene for printing was formed and successfully converted into a sequence of sections in pwmx format. This format is designed to be read and executed on Anycubic brand printers. The calculation was made deliberately in the lowest resolution (0.15mm.) to speed up the printing process. Printing was done on an Anycubic mono x photopolymer printer and took 26 hours (Fig. 3). This amount of time is due to the peculiarities of the formation of the model by the photopolymer method.

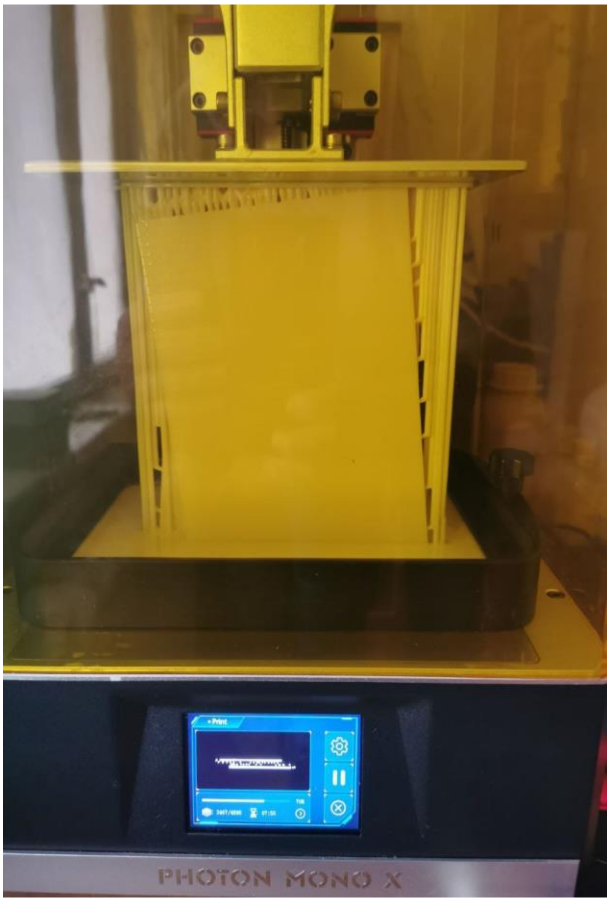

Figure 3 Plate 3D printing process

Figure 4 Three-dimensional model of the plate obtained by extrusion through the mask

Figure 5 The resulting printed plate by 3D printing

Figure 6 Printed plate with applied typographic composition

The model should have the smallest possible contact area with the substrate and, therefore, should be printed vertically along the z-axis. Such an arrangement of the model is due not only to printing features, but also to the dimensions of the plate itself. Only in this position it was possible to place our model in the dimensions of the working area of the printer. The plate material was Wanhao (water washable) brand photopolymer resin in white color. The result was a printing plate measuring 113 x 230 mm with a maximum height of the working area ofthe printing table of 250 mm. Of course, there are professional printer models on the market with a much larger working area. To keep the plate vertical while printing, supports were used in the form of additional reinforcing cylindrical rods supporting the structure a thus giving it additional rigidity. An attempt to print without support failed. In theory, this shouldn't be a problem. The printer only works in one z-axis. But in practice, with a long print time and a large length of the model, the material hardens unevenly and receives minor deviations from the main axis. Due to this process, an undesirable texture is formed on the printed surface of the plate, which will cause artifacts when printed. In a horizontal position, printing is not possible due to the large adhesion area. The first layer will simply not adhere to the print bed and will remain in the material bath. In addition, the distance along the z-axis is always greater.

The resulting surface is suitable for applying paint without prior preparation (Fig 5). Obtain an impression, we used standard printing ink of the CoMax brand of black color, applied to the printed surface using a rubber roller (Fig. 6).The printing method is implemented according to the stamp principle. The printed substrate, in our case a white cotton fabric with a density of 120 g/m², was pressed against the printed surface with black printing ink (korean brand CoMax) under pressure. For the best result, a soft layer is laid between the plate and the printed base. The resulting prints can be considered satisfactory even without the use of a printing press in our case. Despite some unevenness of the colorful printed surface, due to the lack of industrial equipment, all the small details on the fabric were printed perfectly evenly (Fig. 7a). Visually, there is no "liasing" (jagged edge) at all, despite the not the highest resolution of the printing plate. The edges are clearly defined. The fact is the most important thing in this experiment is that it proves the suitability of 3D printing for the production of textile printing plates. In terms of quality, the resulting form is in no way inferior to the traditional one. To prove this, a rather complex pattern was chosen. Thus, the final impression was successfully obtained (Fig. 8). On the final print, you can see several artifacts formed at the attachment points of the supports. For this reason, it is better to place the supports on the back of the slab.

(a) (b)

Figure 7 Detail of the printed form and impression

5 CONCLUSION

1. The experiment proves the effectiveness of the 3D printing method for the production of letterpress and gravure printing plates. On the basis of a specially created high-poly three-dimensional model, a good experimental sample of the printing plate was printed. As a result, a successful impression was obtained, proving the success of the experiment. In the zoomed image, we see well-printed details and the absence of artefacts characteristic of low resolution at the edges of the image. (Fig. 7b, 8). The advantage of this technology is the flexibility of the process and the ability to implement any types and shapes of printed substrates using 3D printing. There is also a simplification and, as a result, an expected reduction in the cost of production of forms for textile printing, which is important for small businesses. Good results can be achieved even with a semi-professional 3D printer, the cost of which is currently affordable for a specific application.
2. A direct relationship has been found between the quality of the print and the quality of the original 3D model of the printing plate, as well as the method of building a sequence of layers and the 3D printing device used. Based on the foregoing, the final quality of the product depends solely on the quality of the 3D model and the quality of the 3D printer itself. The article did not study the economic feasibility of using 3D printing for the production of textile printing plates, however, the constant decrease in the cost of materials and equipment of this technology gives reason for optimism.
3. Based on the accuracy of printing plate reproduction, it seems realistic to use the 3D printing method to produce printing plates.

The method of digital modeling and 3D printing is the best way to create multi-color textile printing plates. Since a separate plate is created for each color and printed separately, registration accuracy is critical to avoid color shifts. For digital technologies, this is not difficult. A properly designed 3D scene will always produce a perfectly predictable result when implemented. The purpose of this study is an attempt to prove the possibility of using 3D printing technology for the manufacture of plates for letterpress and gravure textile printing.

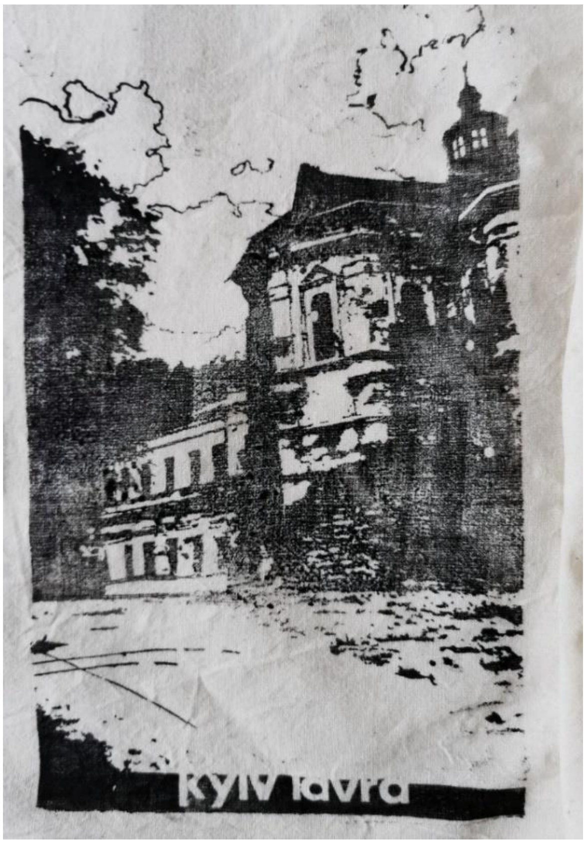

Figure 8 The impression obtained as a result of the experiment

Aspects such as the technical feasibility of introducing this technique into the textile production process and economic opportunity require additional research.

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STUDY OF RIB KNITS COURSEWISE TENSILE PROCESS

Tetiana Yelina[1], Liudmyla Halavska[1], Svitlana Bobrova[1], Nataliya Lytvynenko[2] and Tetiana Dzykovych[1]

[1]Kyiv National University of Technologies and Design, Nemyrovycha-Danchenka St, 2, Kyiv, UKRAINE
[2]Kyiv National University of Culture and Arts, Yevhena Konovaltsia St, 36, Kyiv, UKRAINE
yelina.tv@knutd.com.ua, litvinenko79@knukim.edu.ua

Abstract: *Stretchability of knitwear is one of the most important factors of wearing comfort. Elasticity of knitted structures in course wise direction is usually higher than along wales and often characterized by crosswise shrinkage. Existing methods of knitting program development do not consider the real rate of wale wise shrinkage of rib knitted structure under the course wise extension. During the study experimental research has been carried out to fulfill empirical data on the relationship between samples' length and width under uniaxial course wise elongation. A range of samples of rib 1×1, 2×2, 3×3, 4×4 and 5×5 knits, made of cotton, bamboo, polyacrylonitrile (PAN), wool/acrylic blend and wool yarn, were stretched with a tensile machine WDW-05M. In the process of stretching the width of each specimen was defined in the moments of extension by 50, 100, 150, 200, 250 and 300 per cent. It has been found that linear approximation can be applied to describe the dependence of specimen's width on its relative course wise elongation. It was found that the stitch height/width ratio changes unevenly. In the beginning of the process of course wise stretching of a rib knitted structure, it does exist, such an interval, where an increase of the knit's linear size along the courses occurs without a significant shrinkage in the wale wise direction. It is suggested to name the upper limit of this interval as "unidimensional extension limit" and define it as an extension of a standard (100×50mm) specimen, at which its width decreases by 10%. It was found as well that the value of this index significantly depends on the ribbing variation and much less on the type of raw materials.*

Keywords: *knitting, rib knits, stretching, courswise extension, crosswise shrinking.*

1 INTRODUCTION

Knitted fabrics are widely used for production of underwear, sports apparel, other kinds of clothes, which conform closely to the body shape due to their elasticity. The fit and elasticity belong to the characteristics most influencing the feeling of wearing comfort. Knitted products are subjected to different kinds of deformation during operation. Tight-fitting knitted clothes have a smaller circumference than the corresponding body part's girth. Sometimes an extra extension is also required to provide comfortable taking on and off for such knitted products as socks, sweaters, gloves, balaclavas, mittens, and others. In addition, it is necessary to take into account possible changes in the dimensions in the process of different body movements, as dimensions of some body parts increase during movements. Many researchers emphasize the importance of considering the elasticity in the knitted garment design. Clothes are in contact with the skin in the process of the using. Therefore, the feeling of comfort and discomfort directly depends on the mechanical influence of clothes on the skin [1]. The present study aims to analyze the tensile process of rib knits and to determine the limit of course wise elongation from which the wale wise shrinkage should be taken into consideration for patterning and knitting programming.

In scientific publications the issue of stretchy knitted products made of different types of yarn is being discussed quite widely. Vasconcelos et al. assume the importance of determining the optimal parameters of elasticity for sport clothes produced with a content of elastomeric yarns [2]. The pressure of clothes on the body is one of the important criteria of personal comfort. Spahiu et al. [3] investigate the implementation of new computer design technologies, which provide a parametric regeneration of a virtual mannequin for the assessment of the fitting quality of apparel, which provides an opportunity to assess the comfort of clothing for a given consumer. Guo & Kuzmichev [4] developed a method of assessing the pressure of a women's dress on the body in the important anthropometric points of the female torso that allows to estimate the wearing comfort of the product in the mode of virtual try-on systems. Many scientific papers are aiming to study the elasticity of knitted fabrics and garments, manufactured with the use of elastomeric yarns [5-7], for sports and medical textile garment manufacture. Changing structure parameters of the knit in a deformed state causes a change in its properties. Gupta et al. [8] studied the influence of the deformation state of the pressure garments on the indices of hygienic comfort such as thermal comfort, air, and water vapor permeability. The effect of the tension level on the thermal properties of compression socks is analyzed by Siddique et al. [9]. The change of air permeability in the stretched textiles is investigated in articles [10, 11]. The knit stitch type significantly affects the ability of a knitted product to extend and return to the original size. Manufacturing of complete garments opens wide possibilities for product customization [12]. However, to expand the range and improve the design quality of seamless products, it is necessary to take into consideration the knitwear elasticity.

The fundamentals of the theory of knitted structure's stretching has been laid out in works [13, 14]. Different aspects of knitted textiles' deformation are being discussed in recent research works. Tensile properties of basic weft knitted stitches, such as plain and rib 1×1 stitch, made of cotton yarn and blended cotton yarn with the content of Lycra, are analyzed in paper [15]. Pavlović & Vrljičak [16] considered the mechanical properties of Tensel and modal knitted fabrics. Mechanical properties of knitted fabrics for technical application are studied by Araújo et al. in the works [17, 18]. The means of three-dimensional modeling of knitted structures open new possibilities in analyzing deformation characteristics [19, 20, 21, 22]. At the same time, means of automation are using theoretical calculation methods as mathematical software, which are often based on the empirical data.

Methods of calculation of knitwear structure parameters that consider operational deformations account reduction of the course spacing at the increase of the wale spacing and vice versa [23]. It is known that the yarn in the knitted structure is being redistributed under tensile load [14]. However, at the beginning of tensile process rib knits have a certain interval, where the increase of the specimen's linear size along courses occurs without changing the course spacing value [24]. In rib knitted structures the process of course wise elongation includes such sub processes as reducing the curvature of plain stitch areas, reducing the amount of mutual shifting of adjacent wales belonging to different layers of the fabric, pulling yarn from loops' legs into the head and feet segments, extension the yarn itself [25]. The first two of the above mentioned sub processes take place without yarn redistribution, i.e. without reduction of the loop height as it is shown schematically in Figure. 1.

The value of course wise elongation, at which the process of the yarn redistribution starts, depends on both the number of knit and purl stitches in the repeated unit of the ribbing variation and the yarn's raw material. At present, there is no information about publishing results of research of the rib knits stretching intervals along the course lines, occurring without reduction of linear dimensions in the crosswise direction.

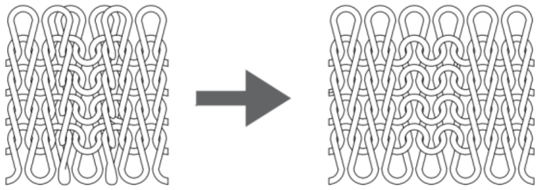


Figure 1 Unfolding process of rib 2x2 under coursewise tensile forces action

At present, there is no information about publishing results of research of the rib knits stretching intervals along the course lines, occurring without reduction of linear dimensions in the crosswise direction. In order to establish the limit value of stretching along one axis without significant shrinkage along the other, a study of geometric characteristics of rib knitted fabrics in the process of course wise stretching was carried out.

2 MATERIALS AND METHODS

Stretchability and elasticity of knitted structures belong to the number of indicators most influencing wearing comfort. Their significance is determined by the purpose and functionality of the knitwear product. The most common method of the study of textile fabrics load/extension properties is so called "strip method". This method is based on stretching a ribbon of textile cloth of a rectangular shape, fixed between two clamps of tensile testing machine.

In this study, a concept of deformation of a section of knit has been used. Under a deformation state we understand a state of a specimen of certain dimensions and the structure's parameters gets under the application of a given load, characterized by both magnitude and direction. The unidimensional extension limit is a deformation condition characterized by such a relative elongation value, until which a specimen of a knitted fabric of standardized size (50×100mm) can be stretched before the crosswise shrinking begins.

2.1 Preparing samples

The most widely used types of yarn, such as cotton, bamboo, polyacrylonitrile (PAN), wool/acrylic (blended) and wool yarn with equal value of operational diameter have been chosen for the experimental study. Theoretical calculation, performed according to [14], gives such a set of yarn types: cotton yarn with linear density of 42 tex, bamboo yarn – 31×2 tex, wool yarn 31 tex ×2, wool/acrylic blend yarn 31×2 tex and polyacrylonitrile 31×2 tex. The test samples of rib 1×1, 2×2, 3×3, 4×4 and 5×5 structures have been produced on a V-bed flat knitting machine PVRK, 10 gauge. After knitting, the samples were kept 24 hours under normal atmospheric conditions (temperature 22±3°C and relative air humidity 62±5 %) to get a dry relaxed state. During relaxation process configuration of the thread and stitches changes, but after 24 hours a knitted fabric laying of on a plane surface doesn't change its size without an external load application. Rectangular specimens with linear dimensions 200±1mm × 50±1mm were cut out for uniaxial stretching in the course wise direction. The characteristics of the samples are given in Table 1.

To know the value of operational deformations relative to the initial circumference of a knitted tubular part, which is measured in a free, undeformed state is also important for the improvement of technological development of complete garment knitwear; as well as for the assessment of wearing comfort. Therefore, the test length for determining deformation characteristics was set at 100 mm, measured in the free state without a prior loading.

2.2 Setting the experiment

To study the deformation properties of knitwear, a tensile testing machine WDW-05M (Fig. 2(a)) has been used. This machine is equipped with one fixed clamp and one clamp, that can move with a constant velocity. A strip-test with automatic recording of load-extension diagrams (Fig. 2(b)) has been carried out. The research was realized in an accredited testing laboratory of analytical research TLAR "Textile-test".

During the tensile testing, a wide-angle camera was set with a tripod in front of the specimen. Each test simultaneously started together with the video recording. To ensure a possibility of the correct scaling, a calibration ruler was placed next to the sample as shown in Fig. 2(a). The use of this equipment allowed to study the nature of crosswise narrowing dynamics.

For accurate calculation the required number of knitting needles and rows of knitting in a certain garment part, it is important to understand how much the product can be stretched in the process of operation without significant crosswise shrinking. In other words, what reduction in the height of the loops will occur under a certain width extension. Wearing comfort relates to the pressure of a textile shell to the body part. In turn, it depends on the difference between the body girth and the knitted shell's circumference in a free state, as well as on the tensile strength of the fabric. Preliminary experiment with chosen structures has shown that in the first stage of coursewise stretching (up to 50%) the elongation occures with little or no loading. The stretching interval has been established for the reason of detectable loading difference (more than 0.05 N). For example, the load-extension diagram represented in Figure 2(b) shows a slow increment of the load value up to the extension of approximately 240%. In the course of the study it has been proposed to assess the values of the width of the specimen in five states of stretching, which will be designated as states T1-T6, corresponding to the relative elongation of the sample on 50, 100, 150, 200, 250 and 300mm respectively.

3 RESULTS AND DISCUSSIONS

In order to determine the crosswise shrinking of the knitted samples during stretching, video recording of each test was processed with the VSDC Free Video Editor. Raster images corresponding to the chosen stretching states were stored. Since the movement of the upper clamping of the tensile tester machine is moving at a constant speed equal to 100 mm/min, evidently, 50, 100, 150, 200, 250 and 300mm elongation of all samples corresponds to 30th, 60th, 90th, 120th, 150th and 180th second of video recording respectively. The received raster images have been imported in the Autodesk AutoCAD environment, scaled and processed to measure the width of the specimens in their narrowest parts.

In Fig. 3 raster images of different ribbing variation from the polyacrylonitrile yarn in the stretching states T1-T6 are shown.

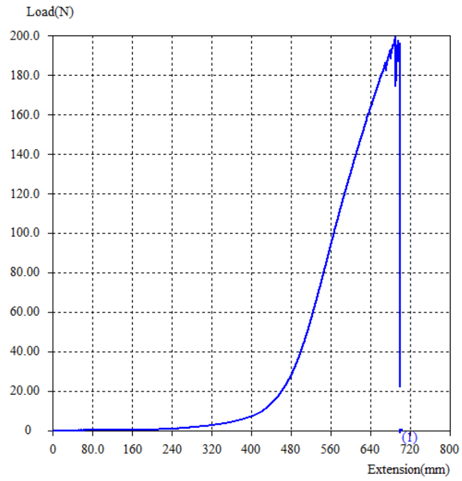
As it can be seen in the photograph, the specimen of 1×1rib knit begins to narrow yet after the extension by 50%, the narrowing of the specimen of 3×3 rib knit occurs at a later stage of tension, between 150 and 200%. The 4×4 rib knit keeps its initial width value by approximately 200% of longwise extension. And the beginning of the width reduction of the specimen of 5×5 rib knit is being observed when the relative elongation value reaches 250%.

Due to the peculiarities of the structure of rib knits, in the beginning of the stretching process, a so-called unfolding is going on. Under the action of tensile force in the structure of rib knits the shifting of purl stitches behind the knit stitches reduces. Therefore, at the initial stage of stretching in the range from 0 to 50% narrowing in the transverse direction is observed only in the structure of rib 1x1 and 2x2 knits. As can be seen from Fig.3, the larger is ribbing pattern, the smaller shrinkage of the test specimen in the transverse direction (along the line of the loop column) occurs in a given deformation state.

Table 1 Characteristics of the experimental samples of knitted fabrics

Ribbing structure type	Code of the sample	Raw material, Linear density	Number of courses in the specimen	Number of wales in the gauge length
Rib 1x1	1.1	Cotton, 42 tex	39±1	100±2
	1.2	Bamboo, 31×2 tex	42±1	110±2
	1.3	Polyacrylonitrile (PAN), 31×2 tex	41±1	102±2
	1.4	Wool/acrylic blend, 31×2 tex	39±1	104±2
	1.5	Wool, 31 tex ×2	38±1	110±2
Rib 2x2	2.1	Cotton, 42 tex	44±1	124±2
	2.2	Bamboo, 31×2 tex	50±1	126±2
	2.3	Polyacrylonitrile (PAN), 31×2 tex	45±1	130±2
	2.4	Wool/acrylic blend, 31×2 tex	46±1	124±2
	2.5	Wool, 31 tex ×2	50±1	133±2
Rib 3x3	3.1	Cotton, 42 tex	54±1	180±2
	3.2	Bamboo, 31×2 tex	59±1	180±2
	3.3	Polyacrylonitrile (PAN), 31×2 tex	50±1	168±2
	3.4	Wool/acrylic blend, 31×2 tex	49±1	168±2
	3.5	Wool, 31 tex ×2	50±1	201±2
Rib 4x4	4.1	Cotton, 42 tex	56±1	192±3
	4.2	Bamboo, 31×2 tex	57±1	192±3
	4.3	Polyacrylonitrile (PAN), 31×2 tex	52±1	180±3
	4.4	Wool/acrylic blend, 31×2 tex	50±1	200±3
	4.5	Wool, 31 tex ×2	50±1	212±3
Rib 5x5	5.1	Cotton, 42 tex	55±1	195±3
	5.2	Bamboo, 31×2 tex	59±1	195±3
	5.3	Polyacrylonitrile (PAN), 31×2 tex	49±1	200±3
	5.4	Wool/acrylic blend, 31×2 tex	48±1	210±3
	5.5	Wool, 31 tex ×2	51±1	210±3

(a)



(b)

Figure 2 Tensile testing of the specimen of rib 5×5 knit from polyacrylonitrile yarn (a) and load – extension diagram, automatically generated during the test (b)

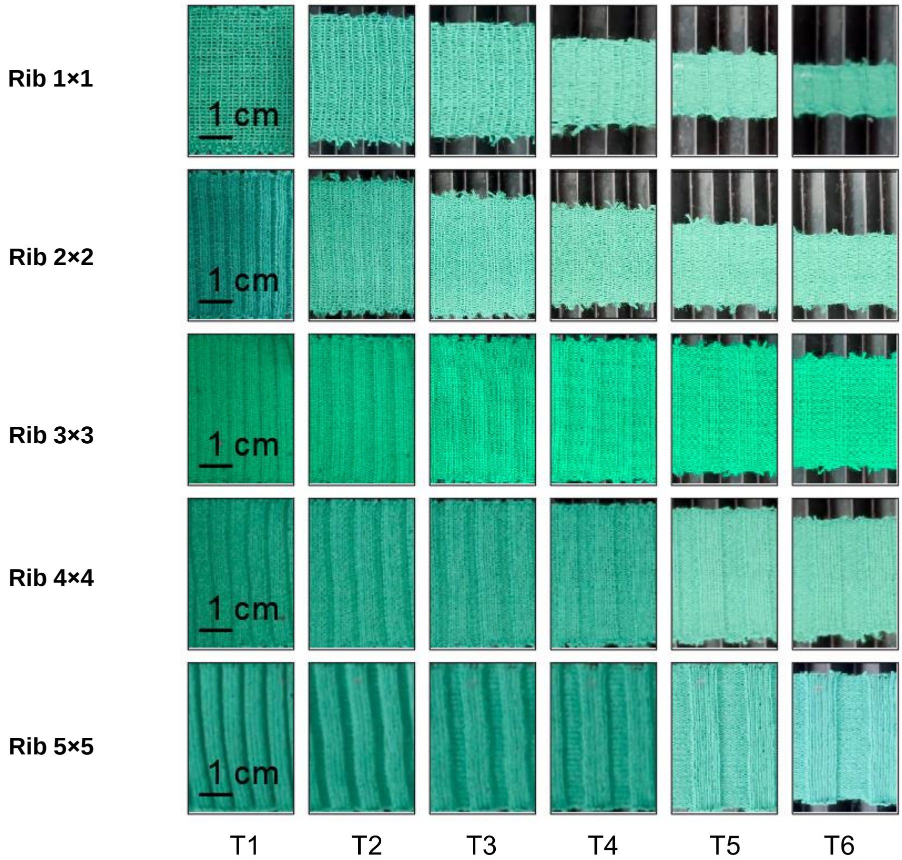


Figure 3 The transformation of surface geometry 1×1, 2×2, 3×3, 4×4, 5×5 rib knits (top-down) from polyacrylonitrile yarn at the relative elongation of 50, 100, 150, 200, 250, and 300% (left-right)

3.1 Unidimensional extension limit

During the study, the character of the size changing has been analyzed. Five specimens of each sample were taken for checking the dispersion homogeneity during the preliminary experiment. In cases of inhomogeneous dispersion, the number of specimens increased. According to the obtained average data for each sample of knitwear, the diagrams of dependence of the absolute specimen width on its relative elongation and the linear approximation graphs are built as shown in Fig. 4. Linear equations for all samples are shown in Table 2. In all samples, regardless the ribbing variation and the raw material composition, the linear nature of the influence of tension along the courses on its narrowing in the transverse direction in the range of 0 ÷ 200% is observed. For rib knits of bamboo and wool yarn after stretching by 200% the dependence becomes polynomial. But because during the wearing use of knitwear products tensile deformation does not reach more than 200%, we admit linear dependence for practical use. Table 2 shows the information about the probability of approximation of the obtained curvilinear dependences.

As it is known, during the knitting process the width of a segment containing a certain number of wales depends on the number of knitting needles in action and out of action, and on the distance between needles. The width of the sample that it had during the knitting process; mm is also shown in Table 2. Based on the results obtained, it is assumed that the rib knit crosswise shrinking over 10%, should be considered during the calculation of the number of rows for manufacturing knitted garment details. The unidimensional extension limit value has been determined for each sample, using the approximation equation having the y value (wale wise size) constant - 10 % of the original length, as shown in Table 2. The value of the unidimensional extension limit as well as the load, necessary to attain this elongation, depends most of all on the ribbing variation. At the same time, samples with the same indicators of unidimensional extension limit, like samples 3.3 and 3.4 are characterized by different tensile forces. It shows that such properties as bending rigidity, roughness, yarn stretchability also influence the stretching process.

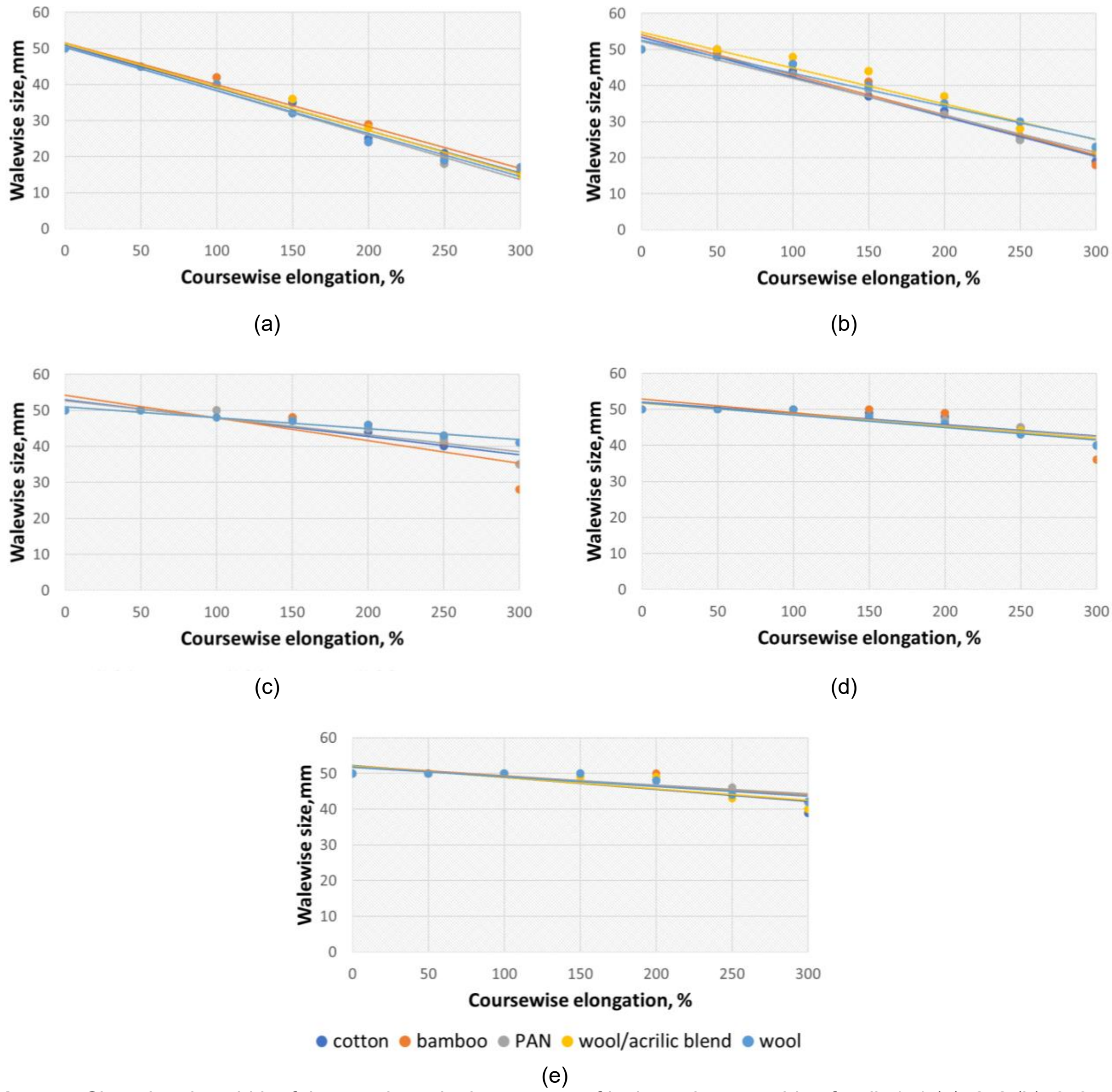


Figure 4 Changing the width of the specimen in the process of its longwise stretching for rib 1x1 (a); 2x2 (b); 3x3 (c); 4x4 (d); 5x5 (e) knitted samples

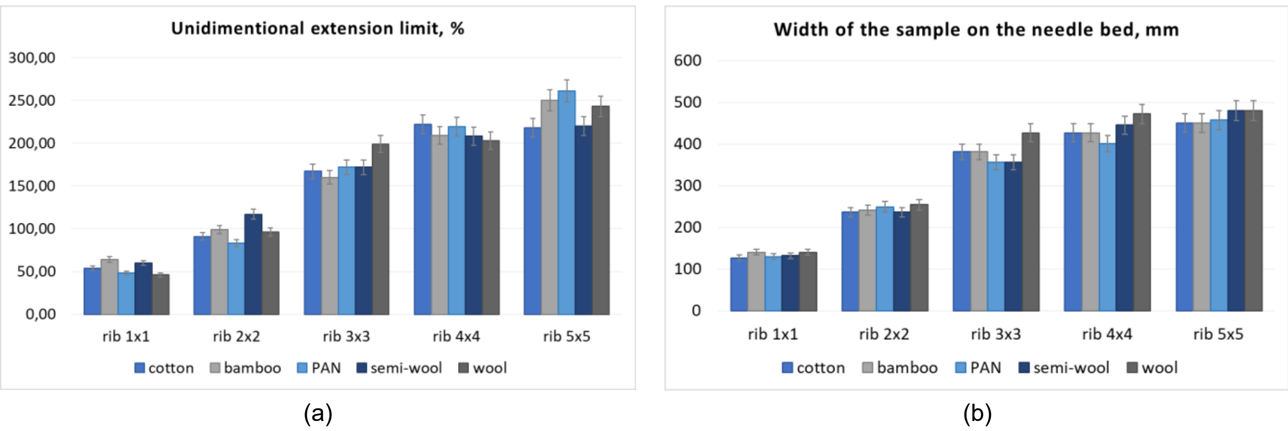


Figure 5 Geometric characteristics of the samples: the value of the unidimensional extension limit (a) and the width of the sample (gauge) in the knitting process (b)

Table 2 Characteristics of the stretching process

Code of the sample	Approximation equation (y- specimen width; x- specimen elongation), probability	Width of the sample on the needle bed, mm	Unidimensional extension limit, %	Load of unidimensional extension limit, N
1.1	$y = -0.1211x + 51.533$, $R^2=0.9858$	127±1	54	0.3
1.2	$y = -0.1217x + 52.8$, $R^2=0.9798$	140±1	64	0.45
1.3	$y = -0.1251x + 51.067$, $R^2=0.9776$	130±1	48	0.55
1.4	$y = -0.1263x + 52.6$, $R^2=0.9834$	132±1	60	0.7
1.5	$y = -0.1206x + 50.6$, $R^2=0.9732$	140±1	46	0.5
2.1	$y = -0.1234x + 56.267$, $R^2=0.9958$	236±1	91	0.5
2.2	$y = -0.128x + 57.733$, $R^2=0.9801$	241±1	99	0.4
2.3	$y = -0.112x + 54.267$, $R^2=0.9918$	249±1	83	0.6
2.4	$y = -0.1183x + 58.867$, $R^2=0.9612$	236±1	117	1.15
2.5	$y = -0.1017x + 54.8$, $R^2=0.984$	254±1	96	0.65
3.1	$y = -0.0623x + 55.4$, $R^2=0.925$	381±1	167	0.25
3.2	$y = -0.0794x + 57.733$, $R^2=0.7735$	381±1	160	0.3
3.3	$y = -0.0577x + 54.933$, $R^2=0.895$	356±1	172	0.8
3.4	$y = -0.0554x + 54.533$, $R^2=0.9411$	356±1	172	1.15
3.5	$y = -0.0349x + 51.933$, $R^2=0.9694$	427±1	199	0.75
4.1	$y = -0.0394x + 53.733$, $R^2=0.8414$	427±1	222	0.5
4.2	$y = -0.0491x + 55.267$, $R^2=0.6802$	427±1	209	0.5
4.3	$y = -0.0377x + 53.267$, $R^2=0.8724$	401±1	219	0.85
4.4	$y = -0.04x + 53.333$, $R^2=0.9292$	445±1	208	0.6
4.5	$y = -0.0417x + 53.467$, $R^2=0.9418$	472±1	203	0.55
5.1	$y = -0.0429x + 54.333$, $R^2=0.7969$	450±1	218	0.35
5.2	$y = -0.0354x + 53.867$, $R^2=0.659$	450±1	250	0.7
5.3	$y = -0.0309x + 53.067$, $R^2=0.8115$	457±1	261	1.2
5.4	$y = -0.0406x + 53.933$, $R^2=0.7928$	480±1	220	0.9
5.5	$y = -0.0343x + 53.333$, $R^2=0.8385$	480±1	243	0.83

In Fig. 5 a bar chart of the value of the unidimensional extension limit for the rib knitted samples is shown. The diagram shows that the type of raw material influences the value of the indicator much less than the ribbing variation. The use of the obtained unidimensional extension limit values in technological calculations contributes to the improvement of the design quality.

4 CONCLUSIONS

Stretchability and elasticity of knitted materials belongs to the number of indicators, most influencing wearing comfort. The structure of the rib knit stitch affects the ability of the knitwear to increase in size and return to the original dimensions. Methods of calculation of knitwear structure parameters taking into account operational deformations, predict reduction of course spacing at increase of wale spacing and vice versa. The value of the extension where the process of the yarn redistribution inside the loop starts, depends on the ribbing variation and the type of raw material. Rib stitches have a certain stretching interval when the course wise elongation occurs without wale wise shrinking. During of the study, it was found that the unidimensional extension limit value much more depends on the ribbing variation than on the type of raw materials. Empirical data and interpolation equations are gathered for use in algorithmic software of computer aided design systems for knitted garments development.

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RESEARCH ON THE ABILITY OF YARNS FOR TEXTILE PROCESSING

Andrew Slizkov[1], Halyna Mykhailova[1] and Inna Borolis[2]
[1]*State University of Trade and Economics, 19, Kyoto str., Kyiv, UKRAINE*
[2]*Kyiv National University of Technologies and Design, 2, Nemyrovych-Danchenko str., Kyiv, UKRAINE*
andrew.slizkov@gmail.com, h.mykcaylova@knute.edu.ua, innaborolis@gmail.com

Abstract: *The article is intended to study the destruction mechanism of yarns of different structures under different types of deformations that occur during their textile processing (weaving, knitting, etc.). Improving the wear resistance of yarns is one of the main ways to determine the causes of their destruction in textile processing with their subsequent elimination. The significance of this problem is determined by the fact that increasing the reliability and endurance of yarns is equivalent to increasing output without additional labor and material resources. The ability of yarns for textile processing is mainly determined by their mechanical characteristics in tension: tensile strength and elongation, endurance, longevity, cyclic elongation, and the like. In the regulatory documents, this ability is mainly assessed only by the indicators of tensile strength and elongation, which does not fully characterize their behavior in textile processing. Therefore, the study of the features of the yarn destruction under different types of mechanical interactions, as well as the impact of their structure on the process of destruction, is relevant for predicting their endurance and developing a new range of textile fabrics.*

Keywords: *textile threads, yarns, textile processing, wear resistance of yarns, breaking force, breaking elongation, breakage, complex method, endurance ratio.*

1 INTRODUCTION

The development of fashion requires the use of textile fabrics with new structures and properties for garment production. To ensure this, new types of threads and yarns with special structures and properties, which strongly influence their processing into textile fabrics, are used [1-9].

In textile processing, threads can withstand different interactions – repeated extensions, bending, abrasion, etc. One of the significant problems is yarn breakage in the textile manufacturing process (knitted and nonwoven fabrics). Knowledge of the ability of yarns for textile processing significantly accelerates the design of a new range of textile fabrics, as well as facilitates the definition of their use [3, 7, 8-12].

A significant amount of research has been devoted to the study of endurance and wear resistance of one of the types of textile threads – yarn [7, 10-14]. In addition, the features of the mechanism of yarn destruction under different types of extensions are understudied, which does not allow to more accurately predict its endurance and wear resistance.

To explain endurance and wear resistance of textile materials, it is advisable to follow S.N. Zhurkov's fluctuation kinetic theory of strength [12, 13] for polymeric materials that include different types of textile threads and yarns. The basic equation of the material endurance according to this theory is as follows:

$$\tau = \tau_0 \, exp \frac{U_0 - \gamma\sigma}{RT}, \qquad (1)$$

where τ_0 – the parameter (corresponds to the extension of one thermal oscillation of atoms (10^{-12} – 10^{-13})) does not depend on the nature and structure of the material; U_0 – the energy of destruction of interatomic bonds of the material; γ – structurally sensitive coefficient; σ – constant load acting on the material during tests; R – absolute gas constant; T – absolute test temperature.

Equation (1) contains a structurally sensitive coefficient γ that characterizes the inhomogeneity of load arising from the extension of the material in its volume and indicates how many times the true local load, under the action of which the failure occurs, exceeds the mean. Thus, all other things being equal, material endurance has a significant dependence on the material structure. Accordingly, knowledge of the structure of textile threads and yarns is essential for predicting their behavior in processing and operation.

The destruction of yarns during single and repeated extensions occurs in different ways [15-18]. Therefore, a comprehensive study of the impact of such types of extensions on the structure of yarns is important for predicting their behavior in the manufacturing of textile fabrics. An important element in determining the endurance and wear resistance of yarns in textile processing is to determine the mechanism of their destruction under different types of extensions.

The number of methods for determining the mechanical characteristics of yarns with different types of deformations is significant, but in most cases, they simulate one type of interaction (extension or bending). Most of the methods will require significant amounts of material and time. Comprehensive methods for determining the wear resistance of yarns, as a model for the main mechanical factors in wear – repeated extensions and bending, which is the most adequate to the real process of yarn wear during their processing. The use of such methods will make it possible to quickly compare yarns of different structures, predicting their operational properties [10, 14, 17, 15-23].

The purpose of the presented work was to study the features of the destruction process of yarns of different structures under different types of extensions and the combined actions of extension and bending as well. This is aimed at providing recommendations to the textile industry with the definition of technological parameters of the equipment, which leads to a reduction in yarn breakage and increases productivity and quality of manufactured products.

2 METHODS AND MATERIALS

All types of yarns mentioned in the research were made of the same raw materials: 50% – wool and 50% – polyester. Also, all of them were obtained by comb (worsted) spinning system and are used in textile production for the manufacturing of worsted suiting.

Yarns for each stage of the study were selected so that the degree of their twist for each stage of the study was the same. The specific values of the yarn structure for each stage of the study are given below. Mathematical processing of test results was carried out according to the standard methods and formulas [12-15].

At the first stage of the study, the relative breakage of a single-thread yarn under single and repeated extensions was compared. At this stage, a single-thread yarn of 19 tex with 750 tpm was studied. Only the places of yarn breakage were analyzed, which allowed determining the peculiarity of its destruction.

Analysis of the areas where yarn breakage occurred during single and repeated extensions was performed using a magnifying glass (20×) and a biological microscope of Biolam C-11 type (50×).

For greater differentiation of the areas of yarn breakage under extension, they were divided into 3 groups. These are the areas without any visible structure changes that are close to the nominal linear density with a stable nominal yarn cross-section, others are with thickenings <20% and sections with thinnings > 20 % of the nominal yarn cross-section. Accordingly, areas of yarn with thickenings < 20 % are 120 %, and with thinnings > 20 – 80 % of the nominal cross section of the yarn.

To determine these areas, 10 bobbins were selected from the batch of yarn. A strand of 100 m long was wound on a reel from each bobbin. Each turn of the yarn on the reel crown was separated from the other, which allowed for making a clear visual observation. Subsequently, the thinnest, thickest, and nominal areas of the yarn were determined with the help of a magnifying glass and marked with a contrasting marker. The number of thin, thick, and nominal areas of the yarn for each strand was 10 each. After that, these areas were cut out and fixed on the cover glass. Each group of areas was formed separately. The areas of the yarn cut in the places marked with a marker were in a free state, which allowed to compare them with the areas of the yarn that broke on the devices RM-3 and PN-5. Then, the cover glass with the areas of the yarn was placed under a microscope that had a micrometer ruler, which allowed to determine the value of the section for each area. After that, the obtained values were averaged. The total number of measurements of each area of yarn was 100. This further allowed to determine the value of the nominal cross-section of the yarn, as well as areas with thickenings < 20 % and areas with thinnings > 20 % of the nominal cross-section.

A single extension of the yarn was performed on an RM-3 tensile-testing machine and repeated extensions – on a PN-5 pulsator. Testing was carried out applying well-known methods [12-15]. The following parameters of the methods were set: the clamping length of the elementary sample on the RM-3 tensile-testing machine was taken equal to 500 mm. The extension speed of the yarn was chosen so that the breakage time was in the range of 10 to 20 s before breakage.

During repeated extensions on the PN-5 pulsator, the clamping length of the elementary samples was 500 mm. Static load on the yarn was determined to be equal to 25 % of the breaking. In textile processing, the yarn does not receive loads exceeding 25% of the breaking one, so this value of the static load on the yarn is optimal for research. The value of the specified cyclic deformation ($E_{s.c}$) was the same and equal to 2.6% of the breaking elongation. This elongation is almost equal to the cyclic deformation of the yarn on the loom. The frequency (speed) of extensions was 200 cycles per minute, which was the approximate frequency of cycles of the loom. At this stage, the study was conducted until the complete destruction of the yarn. The number of yarn tests on each device was 100. The comparison of mean values and determination of the significance of deviations were made using the Student's t-test with a confidence interval of 0.95 (Pd = 0.95).

To study the tips of the yarn fibers after their breakage on the devices RM-3 and PN-5, they were also cut and fixed on the cover glass. First, the tips of the fibers were examined at the breakpoints under a magnifying glass, and then under a microscope.

At the second stage of the study, the relative breakage of single-thread and twisted yarns was compared with repeated extensions on the PN-5 device. The parameters of the methods were similar to the first stage of the research. The single-thread yarn was similar to the yarn of the first stage, and the twisted yarn had a linear density of 19 tex×2 with a twist of 650 tpm. Twisted yarn is obtained from two single-thread yarns 19 tex with a twist of 750 tpm.

At the third stage, the comparison of the endurance of yarns of different production methods to repeated extensions at different values of cyclic deformation was made. At this stage, the yarn of a curtailed production method with the resulting nominal linear density of 44 tex (hereinafter – yarn A) and classic twisted yarn with a linear density of 22 tex×2 (hereinafter – yarn B), obtained by twisting two single-thread yarns (the twist of a single-thread yarn was 750 tpm), were used. The twist for both types of yarns was the same and was equal to 650 tpm. The yarn of a curtailed production method was obtained on a circular spinning machine by twisting two rovings (without the processes of crushing and twisting, which are characteristic of obtaining a classic twisted yarn). This yarn is similar to Sirospun yarn.

The tests were performed on a PN-5 pulsator. The strength of the yarns of both production methods was determined at the initial clamping length of 500 mm, a static load of 25% of the breaking one, and the frequency of extension cycles of 200 cycles per minute. The value of the specified cyclic deformation $E_{s.c}$ ranged from 2.6 to 3.8%. The number of samples at each value of $E_{s.c}$ was 50.

Reliability indicators were also calculated taking into account the correspondence of the distributions to the theoretical law (log-normal) according to the standard method [12].

At the fourth stage, changes in the semi-cycle breaking characteristics of the yarns depending on the number of cycles of their repeated extensions were studied.

The two types of semi-woolen combed twisted yarn mentioned in the third stage were used for the research. Studies of both types of yarns were performed on a pulsator PN-5 under the same conditions with the clamping length: l_0 = 500 mm, the given cyclic deformation - $E_{s.c}$ = 2.6 %, cyclic frequency - n_c = 250 cycles per minute, and static load of 25 % of the breaking one. The parameters of $E_{s.c}$ and n_c were taken close to the production cycle on the loom.

At the beginning of the tests, the samples of both types of yarns were subjected to extensions of 500 cycles, which was taken as conditional zero. Thus, the fibers in the yarn structure were pre-straightened.

Since in the process of weaving the warp yarn withstands about 5 thousand extension cycles before working in the fabric, their maximum number was taken as 5,000. After a given number of extension cycles (500, 1,000, 1,500, 2,000, 2,500, 3,000, 3,500, 4,000, 4,500, 5,000), the yarn (yarn should not be untwisted) was carefully removed from the device PN-5 and subjected to testing on an RM-3 tensile-testing machine with the clamping length of 200 mm. The number of tests for each type of yarn at each value of the specified number of extensions was 100.

At the last stage, devoted to the combined method of determining the ability for textile processing of yarns, the yarns, specified in the third and fourth stages of the study, were studied.

This technique simulates a complex set of simultaneous mechanical actions – repeated extensions, bending, and abrasion, followed by determining the change in the semi-cycle characteristics of the yarn. To do this, the device of Metrimpex company (Hungary) of 5-24-1 type was used [21, 23]. It can be used to simulate the textile processing of threads and yarns as a result of the simultaneous action of a set of mechanical deformations of extension, bending, abrasion, as well as, if necessary, changes in the test temperature. The clamping length of the sample was taken equal to 500 mm.

The degree of action of repeated extensions, bending, and abrasion, as well as the ratio of their modes, are chosen so that they in a relatively short time lead to well-evaluated results and at the same time were not very different from production and operating conditions. The number of cycles of repeated impact on the yarns is chosen according to the practical conditions of textile processing. The static load rate can be adjusted in a wide range, making it possible to bring the test conditions closer to real. The tests were performed at room temperature.

Before the start of multiple tests, the average breaking load P1 of a certain batch of threads on a tensile-testing machine of RM-3 or RM-30 type is determined. After repeated action of the combined types of deformations, the studied samples of yarns are released from the clamps (samples should not be untwisted) and determine their average breaking load P2. The clamping length of the sample was 200 mm. The number of cycles of multiple combined mechanical actions was assumed to be 10,000. The number of samples to assess the endurance (of yarns) by the standard is 5, and in our case to increase the reliability of the results the number of samples for both types of yarns was 10.

3 THE RESULTS OF THE STUDY OF THE DESCTRUCTION OF THREADS (YARNS) IN THE DIFFERENT TYPES OF EXTENSION

An important element in the study of the characteristics of yarn breakage in its textile processing is to find the areas where these breaks occur with different types of deformations. Since the most common type of deformation in the textile processing of yarns is their extension, much attention was paid to the study of the peculiarities of the yarn destruction during its single and repeated extensions in the presented article.

At the first stage of the study, a lot of different types of extension deformations were studied for combed single-thread semi-woolen (worsted) yarns for weaving purposes using the classic technology of spinning. Features of the yarn structure are given in Section 2.

Table 1 shows the results of studies of the relative number of breaks in different parts of the yarn. Single extension of the yarn was performed using an RM-3 tensile-testing machine, and repeated extensions – a PN-5 pulsator. The parameters of the methods are given in Section 2.

The results in Table 1 show that the smallest number of breaks in the yarn under different types of extensions are observed in the areas with thinning, and significantly greater in the areas with thickening. This is because the areas with thickenings have a more heterogeneous structure, so they loosen and break more easily when extended. It is especially true for multi-cycle extensions of a single-thread yarn, where almost half of all breaks are in the areas with thickenings.

It was also found under a microscope and magnifying glass that in the areas with thickenings there is a significant number of unbroken fibers in the places of breakage, which indicates less fiber tightness and stratification of the yarn structure in these areas under different types of extensions.

In the areas of the yarn with thinnings, there is some increase in the degree of fiber twisting compared to other areas. Therefore, in these areas, the degree of fiber bonding increases, and there is a decrease in the yarn breakage compared to the areas where there were thickenings and no damage to the structure. When examining the ends of the fibers under a microscope and a magnifying glass, it was determined that in the areas with thinning at the points of yarn breakage, a larger number of fiber ends are destroyed. The yarn breakage in the areas without any visible destruction of the structure is of mediocre importance under different types of extensions.

Table 1 shows that the number of breaks in thin places of a single-thread yarn is significantly greater under a single extension than under repeated ones. This may be due to the impossibility of rapid redistribution of load on each fiber under a single extension. Under repeated extensions, there is a loosening of the yarn structure and, therefore, redistribution of load on each fiber is more even; accordingly, its breakage in thin places decreases.

Twisted yarns are widely used for the production of textile fabrics in addition to single-thread yarns. In textile processing, yarns are mainly subjected to repeated extensions, so in further studies, attention was paid to this type of deformation.

At the second stage of the study, the peculiarities of the impact of repeated extensions on single-thread and twisted weaving yarns were determined. The features of each type of yarn are listed in Section 2. The study of areas with the yarn breakage was carried out similarly to Stage 1 of the study.

Table 2 shows the results of studies of the breakage of twisted yarns 19×2 tex with repeated extensions on the PN-5 pulsator.

The results given in Table 1 and Table 2 show that in the areas of the yarn with thinning and without any visible damage, the values of relative breaks under repeated extensions are much lower for a single-thread yarn than for a twisted one, and vice versa for the areas with thickening. This is due to the different structures of single-thread and twisted yarns and the peculiarity of their destruction in the process of repeated extensions.

For single-thread yarns, the breakage in different areas is explained by the same reasons as defined above and presented in the explanations in Table 1.

There is a slightly different trend for twisted yarns. The structure of twisted yarns consists of two interconnected (by twisting) single-thread yarns, each of which has its structure. Areas with different deviations (thinning, thickening, and without visible destructions) of each of the components of a twisted yarn are combined in its structure randomly, determining the peculiarity of its breakage under repeated extensions.

Table 1 The value of the relative number of breaks of a single-thread yarn during single and repeated extensions

Areas of yarn monitoring	The relative number of breaks [%]	
	RM-3	PN-5
Thinning (>20 % from the nominal cross-section)	29	13
Thickening (<20 % from the nominal cross-section)	44	51
Without any visible damage to the structure	27	36

Table 2 The value of the relative number of breaks of a semi-woolen combed single and twisted yarn on PN-5

Areas of yarn monitoring	The relative number of breaks [%]	
	19 tex	19×2 tex
Thinning (>20 % from the nominal cross-section)	13	31
Thickening (<20 % from the nominal cross-section)	51	23
Without any visible damage to the structure	36	46

Thus, in contrast to a single-thread yarn, the smallest number of breaks in a twisted yarn is observed in the areas with thickenings. This is mainly because in these areas there is a redistribution of loads between the components of the twisted yarn and the fibers in them, and there is a greater degree of fiber bonding in the structure of the twisted yarn. The number of fibers in the areas with thickenings is significantly greater than in others, enabling redistribution of the load between them.

Given the above, it can be noted that under single and repeated extensions of yarns of different structures, the nature of their breakage is different and depends on the homogeneity in the structure, order, and degree of fiber bonding.

At the third stage of the study, it was important to determine the ability for textile processing of yarns of the same raw material composition, linear density, and purpose, but different spinning methods were used to make a new range of suiting.

To compare the ability of yarns of different production methods and structures for the action of repeated extensions, there were adopted the yarn of a curtailed production method (yarn A) of the resulting nominal linear density of 44 tex and classic combed twisted yarn (yarn B) of similar fibrous composition and the linear density of 22 tex×2. The main characteristics of the yarn are presented in Section 2.

To more fully assess the test results, there was determined the correspondence of empirical distributions to theoretical laws: log-normal, Weibull, Rayleigh, Maxwell, exponential, χ^2 - square, beta, and gamma using the criteria λ and χ^2. It was determined that the log-normal law the most satisfies the empirical distribution of the test results of both types of yarns. The results of statistical processing are given in Table 3.

Table 3 shows that the yarn A endurance in terms of arithmetic mean and median at almost all the values of $E_{s.c}$ exceeds the endurance of yarn B. At $E_{s.c}$ = 3.8 % the mode of distribution of yarn A endurance is smaller because the structure of this yarn is more mobile compared to the classical structure. In addition, yarn B has a greater number of technological transitions in its production and, consequently, a greater number of mechanical effects on the fibers and their greater damage. As the value of $E_{s.c}$ increases, the arithmetic mean, mode, and median of the endurance of each type of yarn converge, which is explained by harder test conditions. The figure 1 shows the graphs of endurance under repeated extensions on the device PN-5.

With increasing $E_{s.c}$, there is a decrease in standard deviation, and the coefficient of variation remains significant. With increasing $E_{s.c}$ the excess and right-hand asymmetry of empirical distributions of the endurance of yarn A increases. For yarn B with increasing $E_{s.c}$ asymmetry and excess of empirical distributions of endurance do not have a clear tendency to change.

Since the twisting intensity of the yarn of the two types is almost the same, the change and differences in statistical indicators are explained by the peculiarities of their structure. With a more mobile structure of yarn A increasing $E_{s.c}$, in addition to tiresome wear, there is also some fiber raveling, confirmed by examining the ends of the yarn under a microscope. Due to the greater mobility of the fibers in the structure of yarn A, there is a better distribution of load in its fibers, which provides it with greater endurance at low $E_{s.c}$ compared to the endurance of yarn B.

Table 3 Indicators of woolen yarn endurance under repeated extensions

Endurance distribution statistics	$E_{s.c}$ [%]							
	2.6		3.0		3.2		3.8	
	Yarn A	Yarn B	Yarn A	Yarn B	Yarn A	Yarn B	Yarn A	Yarn B
Arithmetic mean *X* [cycles]	7409	2336	479	270	206	194	77	40
Standard deviation [cycles]	7180	1976	387	240	191	189	97	21
Asymmetry *A*	0.9	0.8	1.0	1.1	3.3	0.9	2.4	0.8
Kurtosis E_s	-0.4	-0.6	-0.2	0.3	1.0	-1.0	5.3	0.7
Mode M_0 [cycles]	1983	708	110	58	58	44	41	53
Median M_e [cycles]	4705	1570	375	190	150	90	50	40
Coefficient of variation [%]	97	85	81	89	92	97	123	53

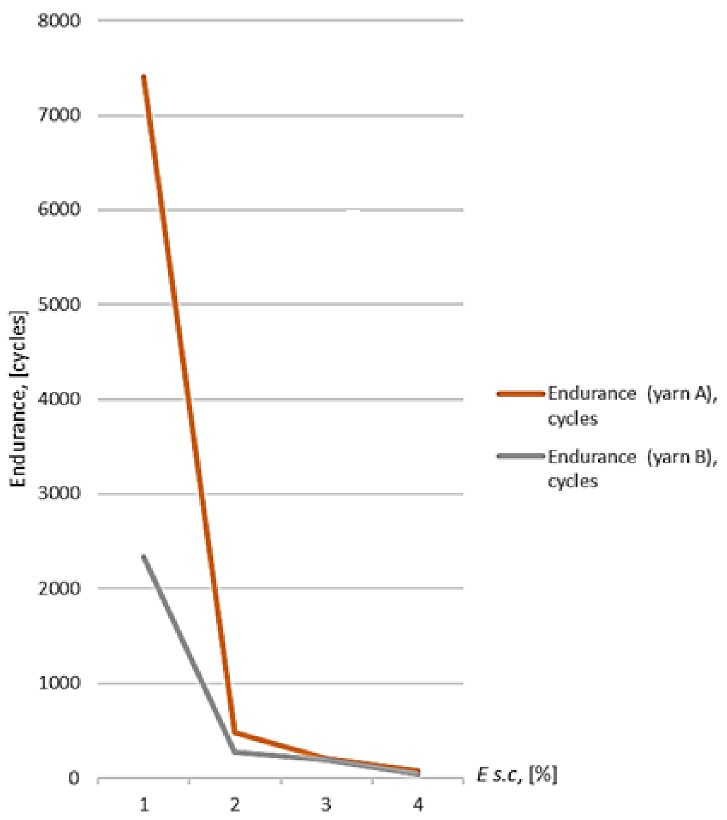

Figure 1 Graphs of yarn endurance under repeated extensions

Table 4 Values of reliability indicators of the yarns with different structures

Given cyclic deformation $E_{s.c}$ [%]	Type of yarn	Failure intensity *X(x)*	Probability of failure-free operation *P(x)*	Operating time to the given probability of failure x_p
2.6	A	4.22×10^{-1}	0.69	580
	B	2.40×10^{-1}	0.38	314
3.0	A	5.02×10^{-3}	0.62	84
	B	2.09×10^{-3}	0.34	34
3.2	A	4.26×10^{-3}	0.44	19
	B	2.90×10^{-3}	0.40	14
3.8	A	3.62×10^{-2}	0.66	9
	B	6.41×10^{-2}	0.58	13

Reliability indicators were also calculated taking into account the correspondence of the distributions to the theoretical law (log-normal) according to the standard method [12].

From the results given in Table 4, it is seen that the failure rate of yarn B is greater, except for the value at $E_{s.c}$ = 3.8 %, because the endurance of yarn B is less compared to yarn A (see Table 3). At all the values of $E_{s.c.}$, except 3.8 %, the density of failure probabilities of yarn A is higher, which affects the increase in failure rate. In yarn B in comparison with yarn A, fibers have a greater degree of bonding, so at significant values of $E_{s.c.}$ = 3.8 %, they are mostly destroyed but do not unravel, which is typical for yarn A. This is also confirmed when studying the fiber ends in the areas of yarn destruction under a microscope.

The probability of failure-free operation of yarn A is higher for all $E_{s.c}$, which is due to its greater endurance. Yarn B is inferior to yarn A by operating time to a given probability of failure, except $E_{s.c}$ = 3.8 %. This can be explained by the greater standard deviation of the endurance of yarn A compared to this indicator of yarn B at the given value of $E_{s.c}$. As the value of the standard deviation of the endurance of both types of yarns increases, the difference in the indicators of the probability of failure-free operation and operating time to a given probability of failure decreases.

Considering the above, it is possible to predict that the yarn with a more mobile structure will be more reliable at low values of $E_{s.c}$, and with a significant increase in $E_{s.c.}$ fiber raveling and a decrease in its reliability can be observed. In real conditions of weaving production in the manufacture of household fabrics on the loom $E_{s.c.}$ does not exceed 3.0 %. Therefore, yarn A with a more mobile structure also has sufficient endurance and reliability at low values of cyclic deformations and can be used to produce a new range of suiting.

At the fourth stage, to more fully determine the ability of yarns for textile processing, changes in their semi-cycle breakage characteristics depending on the number of cycles of repeated extensions were investigated. A one-factor experiment was performed for this purpose. The number of repeated extensions of yarn (X) on the pulsator PN-5 was taken as a variable parameter, the response was: breaking force (Y_1, cN - centinewton) and relative elongation at the time of yarn breakage (Y_2, % - percent).

Subsequently, the functional dependence of the breaking force (Y_1, cN) and elongation (Y_2, %) on the number of cycles of repeated extensions of both types of yarns was determined.

At the beginning of the tests, the samples of both types of yarns were subjected to the extension of 500 cycles, which was taken as conditional zero. Thus, the fibers in the yarn structure were pre-straightened.

The obtained results were processed using statistical information processing programs. As a result of this processing, adequate (P_d = 0.95) linear one-factor mathematical models of the dependence of tensile strain (Y_A, cN) and relative elongation at the moment of breaking (Y_B, %) of both types of the yarns from 500 to 5000 extension cycles were obtained (2-5):

$$Y_{1A} = 18.9 - 2.2 \cdot 10^{-4} \cdot \mathrm{X}, \qquad (2)$$

$$Y_{1B} = 18.4 - 7.6 \cdot 10^{-4} \cdot \mathrm{X}, \qquad (3)$$

$$Y_{2A} = 7.4 - 4.5 \cdot 10^{-4} \cdot \mathrm{X}, \qquad (4)$$

$$Y_{2B} = 6.1 - 4.6 \cdot 10^{-4} \cdot \mathrm{X}, \qquad (5)$$

where Y_{1A} – breaking force of yarn A; Y_{1B} – breaking force of yarn B; Y_{2A} – relative elongation at the time of yarn A breakage; Y_{2B} – relative elongation at the time of yarn B breakage; X – number of extension cycles.

The breaking force of yarn A (Y_{1A}) at 500 cycles of its extension differs slightly from the breaking force of yarn B (Y_{1B}) (P_d = 0.95) when comparing the averages according to Student's *t*-test. Starting with the first 1000 tensile cycles, the strength of yarn A (Y_{1A}) is significantly higher than the strength of yarn B (Y_{1B}). This is explained by the greater mobility of fibers in the structure of yarn A compared to yarn B.

The more mobile structure of yarn A (compared to yarn B) makes it possible to regroup the fibers, and thus redistribute the mechanical load that occurs during repeated extensions at 1000 cycles. In addition, the fibers in yarn B have additional damage, which they receive in the longer technological process of manufacturing this yarn (additional technological transitions of crushing and twisting). The breaking elongation of yarn A (Y_{2A}) is significantly greater (P_d = 0.95) compared to the elongation of yarn B (Y_{2B}) for all variants of tensile cycles. This is also due to the more mobile structure of yarn A.

Thus, the study of changes in the strength of yarns after their repeated extensions more fully reveals the structure of different types of yarns and makes it possible to predict their behavior in textile processing. In addition, it was determined that the correlation dependence of the breaking force on the number of cycles of repeated extensions is not high enough for both types of yarns. Thus, the correlation coefficient for yarn A is 0.51, and for yarn B – 0.49.

4 COMPLEX METHOD OF ASSESING THE ABILITY OF THREADS (YARNS) FOR TEXTILE PROCESSING

A lot of processes of textile production have complex types of mechanical deformations. The use of techniques and devices in the above studies took a lot of material and time. Therefore, further research was related to determining the optimal method for assessing the ability of textile threads and yarns for textile processing, which does not require significant material and time. The features of the method and device are presented in Section 2.

The endurance ratio of one thread K_i is calculated by the following formula (6):

$$K_{\mathrm{i}} = \frac{P_{2\mathrm{i}}}{P_{1\mathrm{i}}}\, 100, [\%] \qquad (6)$$

where i – thread sample number.

The endurance ratio of a production unit K_{un} is calculated by the formula (7):

$$K_{un} = \frac{1}{n}\sum_{i=1}^{n} K_i, [\%] \qquad (7)$$

where n – number of samples from a production unit.

The endurance ratio of yarns K, % for the whole batch is determined by the formula (8):

$$K = \frac{1}{m}\sum_{i=1}^{n} K_{un}, [\%] \qquad (8)$$

where m – the number of production units from one batch.

The ability of the tested batch of yarns for textile processing is evaluated according to the dependence $K \geq [K_d]$, where K_d is the allowable endurance ratio, which is taken as 50 %.

The study identified that the endurance ratio (K, %) for both types of yarns is quite high (yarn A – 94.9 %, yarn B – 94.3 %), which makes it possible to conclude about the possibility of their normal processing in textile production. This is confirmed by the reduction of breaks of certain types of yarns in weaving.

Thus, this complex method should be used to predict the endurance of yarns and other types of textile threads in their textile processing, as well as for comparative analysis of yarns and threads of different structures.

5 CONCLUSIONS

It is advisable to use S.N. Zhurkov's fluctuation kinetic theory of strength to assess the endurance and wear resistance of textile materials. According to the basic equation of textile material endurance, it has been determined that it has a significant dependence on the structure of the material. Knowledge of the structure of textile threads and yarns is essential for predicting their behavior in processing and operation.

The destruction mechanism of combed (worsted) yarns for weaving purposes_of different structures under different types of extensions has been studied. The dependence of the mechanical characteristics of yarns on the peculiarities of their structure and the presence of their significant thickenings and thinnings at different types of deformation of uniaxial tension has been determined. In the case of single and repeated extensions of yarns of various structures, the nature of their breakage is different and depends on the homogeneity in the structure, order, and degree of fiber bonding.

The log-normal law corresponds to the empirical distributions of yarn endurance of different production methods and structures under repeated extensions according to the criteria λ and χ^2. It has been determined that yarns with a more mobile structure will be more reliable at small amounts of a given cyclic deformation due to better load redistribution between fibers. With a significant increase in cyclic deformation of yarns with a more mobile structure, there may be notable fiber loosening and raveling, which reduces their reliability.

One-factor mathematical models of the breaking force and relative elongation at the moment of breaking different types of yarns depending on the number of cycles of their extensions ranging from 500 to 5,000 cycles have been obtained. Starting with the first 1,000 extension cycles, the strength of yarns with a more mobile structure is significantly greater than the strength of yarns with a less mobile structure. The more mobile structure of the yarn makes it possible to regroup the fibers, and thus redistribute the mechanical loads between the fibers during the first 1,000 extension cycles. Breaking elongation of yarns with a mobile structure is significantly greater for all the variants of extension cycles than of yarns with a more fixed structure.

The practicability of determining the ability of yarns for textile processing to predict their reliability and scope of use by applying a comprehensive test method has been substantiated. This method also fairly accurately simulates the real conditions of textile processing of yarns and can significantly reduce the number and time of tests.

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APPLICATION OF JBATIK TECHNOLOGY IN THE DEVELOPMENT OF MOTIF DESIGN FOR TRADITIONAL BATIK CRAFTSMEN

Fajar Ciptandi[1], Morinta Rosandini[2], Muhamad Lukman[3]

[1]School of Creative Industries, Telkom University,
Jl.Telekomunikasi No.1, Terusan Buah Batu, Bandung, 40257, INDONESIA
[2]PT Batik Fractal Indonesia, Jl. Gudang Selatan No.22, Bandung 40113, INDONESIA
fajarciptandi@telkomuniversity.ac.id, morintarosandini@telkomuniversity.ac.id, lukman@batikfractal.com

Abstract: *This participatory action study is aimed at identifying the adaptation level of traditional batik craftsmen in developing batik motif designs using jBatik software technology. The research participants consist of 10 traditional batik craftsmen, three from the innovators group and seven from the adopters group located in Kerek District, Tuban Regency, East Java Province, Indonesia. The application of jBatik technology will be carried out using the Diffusion of Innovation theory which divides the process stages into 5, namely the knowledge stage, persuasion stage, decision stage, implementation stage, and confirmation stage. The results of the theory application resulted in 4 things. First the knowledge about various social system variables and the characteristics of the innovation recipients. Second, the design of the communication model to include knowledge about the innovation of batik motif design as a result of the J-Batik software. Third, the results of the simulation of the application of batik motif designs produced by the jBatik software with craftsmen. Fourth, validation of the simulation results of the application of batik motif design innovations by craftsmen by people who had the ability to measure the level of absorption of innovation, so that the level of adaptation of traditional craftsmen to the technological challenges of the j-batik device could be identified. This study contributes to determining the level of knowledge and basic skills possessed by traditional batik craftsmen to serve as a starting point in deciding innovation strategies to be solutions that can be implemented by them.*

Keywords: *development, motif, batik, jBatik, craftsmen.*

1 INTRODUCTION

The culture of Indonesian people is rich in diversity. One of them is batik. For Indonesian people, batik is not only an ordinary sheet of cloth that has material elements but also contains non-material values. Precisely on October 2, 2009, Indonesian batik received international recognition from the United Nations Educational, Scientific and Cultural Organization (UNESCO) as Masterpieces of the Oral and Intangible Heritage of Humanity [1,2].

Through the process of inheritance carried out continuously to subsequent generations, batik has been able to continue to exist until present time. Although in the process of the inheritance there were also changes in aesthetics, values, and functions because batik is used by the community as one of the solutions to life in order to improve the quality of life without leaving all the characteristics and traditions that it carries [3,4].

In order to survive, basically, any product needs to innovate its design, which actually plays an important role in determining product success by focusing on mastering tools and technology, taking advantage of market opportunities, and also understanding user needs [5,6]. Batik design innovation itself has been carried out by adapting to digital transformation through the use of design software for the development of motif designs [7], product development in accordance with community trends and needs [8], as well as in ways that still maintain traditional ways such as developing variations of natural dyes for textiles using various types of natural materials that have never been explored before [9].

All of these batik innovations are actually the development of batik which was previously a traditional product used for daily needs, and has now become one of the important commodities in the national economy. Batik also contributes to foreign exchange for the country [10]. Based on data released on the official website of the Ministry of Trade of the Republic of Indonesia in 2020, it was known that batik industry had made a significant contribution due to the export performance of batik and batik products in 2019 worth USD 54.36 million.

Meanwhile, in the period of January to July 2020, it was USD 21.54 million. Batik production in Indonesia is dominated by micro, small and medium enterprises, with 88 % of the employees or craftsmen who are local people and home-based craftsmen (Ministry of Trade of the Republic of Indonesia, 2020). One example is the batik industry located in Kerek District, Tuban Regency, East Java Province, Indonesia.

The batik industry in Kerek is one of the representations of other batik industries in Indonesia which is still done at home with traditional processes and relies on local craftsmen. For the people of Kerek, batik has become part of a tradition that is firmly embedded in the pattern of daily life, and has developed into one of the livelihoods of most of the community. Until now, the number of batik industries on the S.M.E. scale in Kerek is around 924 units. Even compared to the handicraft industry and agriculture, batik contributed more as much as 65% [11].

One of the challenges faced by traditional industries, one of which is batik, a representative of other products, in general, is the lack of ability to adapt to change, especially in creating innovations in the appearance of batik. This is due to the mentality of the craftsmen and workers who are still conservative, rigid and difficult to work with various forms of novelty and changes in the environment [12,13]. Especially in Kerek, actually there are no rules in the form of norms and customs that strictly limit the craftsmen to explore batik in order to create novelty. This is more due to the influence of an internal rejection attitude from the craftsmen because they feel safe in their comfort zone, so they decide not to change [11].

While batik craftsmen in Kerek still have problems with mentality, in Indonesia, various trends and technologies are available and can be used to increase the effectiveness and productivity of batik. One of them is the j-Batik software technology which has been developed since 2007 with the aim of assisting batik industry in Indonesia to create variations of traditional motifs development easily and quickly by utilizing shape processing inspired by the shape of the traditional batik motif module [14].

Additionally, as an effort to maintain the existence of batik in this era in which technological intervention is a challenge that must be faced, it is not enough to use conservative methods by keeping batik in its original form. Batik also needs to open itself to the possibility of change and innovation to fit the current conditions. In fact, innovation is considered not only to keep the tradition fresh, alive, and not just static; but also to strengthen the identity so that it can be well maintained [11].

Therefore, the challenge faced by traditional batik craftsmen in Indonesia, especially those selected in this study with batik craftsmen in Kerek as representatives, is how to be able to build the mentality of craftsmen so that they can be open to design innovation in order to present a form of novelty of batik itself.

2 REVIEW OF RELATED LITERATURE

Traditions and Modernity

The term 'tradition' refers to an established knowledge, method, practice, belief, custom, habit, legend, or story that is conveyed and passed on from one generation to another and is deliberately preserved in the present [15]. Additionally, the word tradition is also used to express the state of being 'old' and expired. This is related to the past, pre-industrial, local wisdom, vernacular, and opposite to modernity. Likewise, the term 'traditional object' can mean an object representing all uses of ancient materials, tools, techniques, forms and functions, with a specific place and time [16,17]. The meaning of modernity is something related to the historical period to the present. The word modern refers to the present, contemporary or the last time, something new, as well as trying to create something fresh and not traditional. Furthermore, the definition of modernity also relates to ideas and related to the latest concepts and thoughts [18].

Tradition in its current condition has experienced a narrowing of meaning. There are still some misunderstandings in seeing it. Tradition is considered to be something that is permanent and eternal and its identity is inherited without being able to change, so we cannot change identity and only need to pass it on to future generations. Related to this, identity in tradition should become an opportunity to be analyzed by involving all communities to build new meanings together, so that identity can be negotiated, so that it becomes pluralistic and democratic [19]. Additionally, everything related to tradition is considered good, must be preserved and maintained, so that sustainable local development must respect beliefs, ritual practices, and habits that cannot be changed. Regarding to this matter, possibilities should be opened so that alternative ideas for each individual or group can also appear and develop [20].

Innovations of Traditional Objects

Innovation on a traditional object is basically a process of solving community problems through optimizing the processing of forms, techniques, content, functions and contexts of a traditional object, taking into account the needs, safety, security, health, comfort, and beauty for people [21]. This innovation of traditional objects ends in the form of objects that contain new values taking the main potential source of the tradition itself then combined with modern knowledge and the latest technology [17].

In a traditional object, there are at least four types of methods in the form of mutations to create innovation and novelty [22]. First, primary mutations, i.e traditional objects created by accident. They are caused by a leap in the human imagination. Second, free mutation, that is after the traditional object formed by accident, then changes are made to improve its function. Third, substitution i.e changing or exchanging the material with the same concept. Fourth, cross mutation i.e adapting thoughts or ideas from one traditional object to another. In the beginning, most of the development of a traditional object was obtained through primary mutation and free mutation methods. However, since the amount of knowledge increased and very basic findings became increasingly difficult to obtain, growth and product development began to be dominantly obtained from a cross mutation method.

This innovation with the cross mutation method seems to be enriched by other thoughts, that is in principle every innovation made by taking inspiration from a traditional object needs to first identify 4 main things [23,24], as follows:

1. What is retained? What elements in the tradition must remain and must not be changed. These elements represent the strongest traditional identity, so radical changes to these elements can risk the loss of the entire traditional identity.
2. What was replaced/changed? Which elements in the tradition that can be replaced or changed.
3. What are the new things? What elements can be added to the tradition whichh previously

   non-exsitent, including substitution of materials, techniques, ornamentation, colors, textures, additional tools to help with practicality, to economics.
4. What is omitted? What elements in the tradition that need to be removed / ommitted.

Theory of Innovation Diffusion

An understanding of the theory of innovation diffusion is needed for the application of innovation in the form of ideas and technology to a group of people in a social system, so that the possibility of innovation brought can be accepted by local traditions in certain ways [25].

The theory of innovation diffusion is a communication theory needed to explain how a new idea and technology can be disseminated to a social system of society by being communicated from time to time in a social system. There are at least 4 main elements as the prerequisites for this theory to be carried out successfully, namely: 1) Innovation, 2) Communication media and ways of communicating, 3) limited time, and 5) the social system of society [11][26]. The process of innovation diffusion occurs through five stages of decision making according to Figure 1.

The theory of innovation diffusion is useful as a guide in carrying out experimental steps to see the level of readiness to adopt an innovation [27]. The term “adoption” is used to describe the decision to accept the offered innovation fully and consider it the best course of action. Meanwhile, there is also the term “rejection” which is used to explain the decision not to adopt the offered innovation.

Rogers classified innovation recipients into 2 groups, namely innovators and adopters. Innovators are people who are willing to take risks, have the highest social status, have financial stability, are social and have influence as central figures in society.

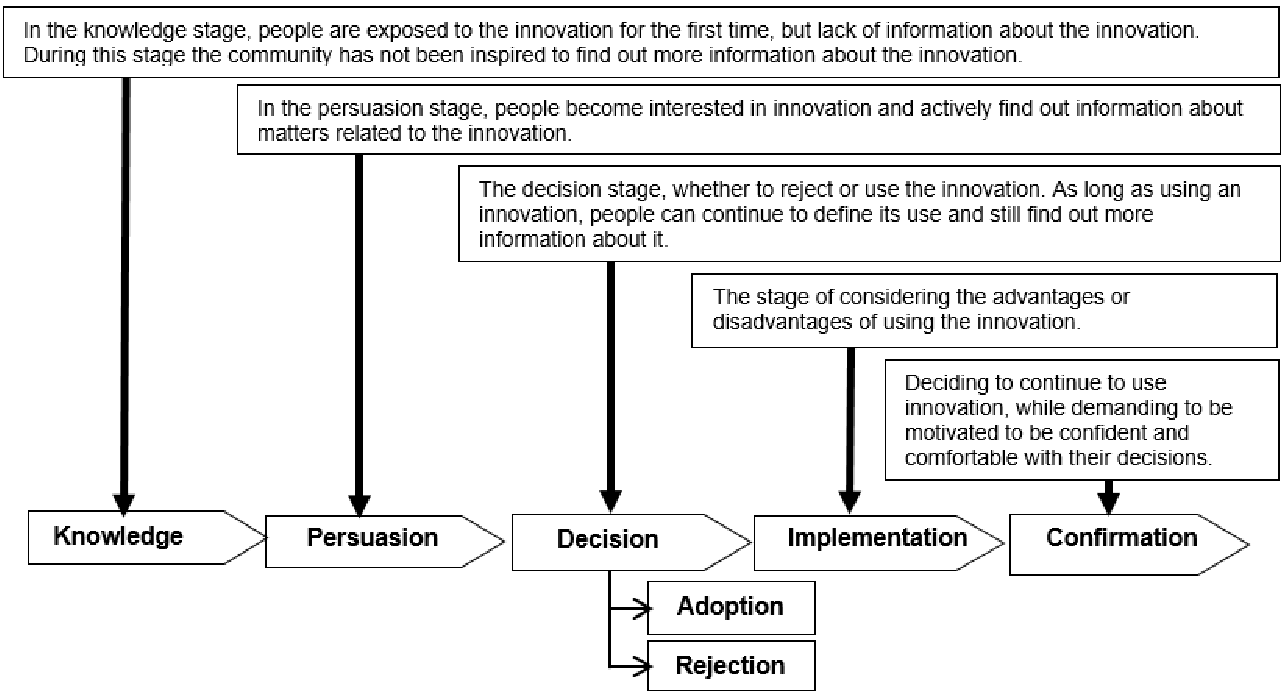


Figure 1 Innovation adaptation process based on innovation diffusion theory

While the adopters are people who receive the influence of the innovators. There are several levels of adopters, ranging from early adopters (i.e. the group of people who first receive influence from the innovators and tend to have no conflict in accepting it) to late adopters (which is the group of people who get the most influence after being influenced by seeing most people who have already done so) [25][26].

Kerek People Batik Tradition

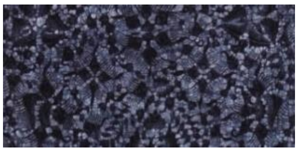
Batik is a cloth made traditionally using 'canting' or copper stamp as a tool for drawing motifs on the cloth and 'wax' as a barrier material during the coloring process. This cloth in traditional contexts is used for traditional purposes and as decorative patterns [28]. A cloth can be called batik if it has at least three main elements, namely: (1) a barrier technique using hot wax as a color barrier, (2) a way of applying wax to the surface of the cloth using a canting and/or stamp and then coloring it by dyeing, and 3) a distinctive and varied pattern on the philosophy of life of the Kerek people [29]. In traditional batik in Kerek these conditions are met.

In particular, what distinguishes Kerek batik from other traditional batiks in Indonesia is its visual appearance, namely motifs and colors that contain certain meanings. In general, the motifs of the Kerek people take inspiration from the forms of objects that are often found in the surrounding environment [30]. Meanwhile, the colors in traditional Kerek batik contain a philosophy of traditional community life [31,32] as explained in

Table 1.

The uniqueness of the traditional batik style of the Kerek people is also found in the details called *coblosan* and *ren-ren* as shown in Figure 2. *Coblosan* is a detail on batik cloth in the form of small fine dots, the effect of which is obtained by piercing the cloth covered with wax with a pointed object resembling a needle. *Ren-ren* is a style of drawing motifs by Kerek people by adding repeated straight lines resembling fine combs placed on the edges of the outline of the main motif [33].

Table 1 The color of traditional batik cloth based on the philosophy of life of the Kerek people

No	Colors	Pictures	Visual and Aestethical Meaning
1	Putihan		A white background with dark blue or black motifs is considered a symbol of purity and holiness. Therefore, *putihan* cloth is usually used to wrap newborn babies, because by the Kerek people this is represented as a symbol of birth
2	Bangrod		It is sed by unmarried women and associated with menstrual blood. It symbolizes fertility and productivity. The word *bangrod* comes from *diabang* (colored red) and *dilorod* (boiled to remove the batik wax).
3	Pipitan		It has a *remekan* basis (effect like cracking) and is commonly used by married women as a symbol of coexistence with their husbands, children, and childbirth. The word *pipitan* means togetherness. In Java, this is interpreted as togetherness and husband and wife as well as children.
4	Biron		This cloth is used as *sesrahan* (gift) of the groom to the bride. This is symbolized as the stage before the woman is finally ready to join as part of the man's extended family.
5	Irengan		It has a dark black motif, a symbol of an end and is usually used to cover corpses because it is considered sacred as a repellent for the salvation of spirits.

Generally, the aesthetics of the traditional batik of the Kerek community represent characteristics that are sociologically influenced by ethnicity describing Javanese values and culture, while psychologically influenced by the environment which is a coastal and agrarian area [34]. The composition is very irregular and is often made on a coarser cotton fabric. Agrarian nature is a source of inspiration, and the variety of decoration symbolizes an unpretentious everyday life. The forms of decorative motifs are often distorted, and the harmony of the design is not taken into account [35].

(a) (b)

Figure 2 *Ren-ren* (a) and *coblosan* (b)

jBatik software

jBatik is a computer software created by the company P.T. Batik Fractal Indonesia, which aims to help craftsmen in Indonesia work efficiently to develop variations of new batik patterns with the help of technology quickly. This creation of jBatik is an effort that the company believes in preserving Batik in Indonesia by collaborating on technology. Information about the jBatik software can be found on the website http://www.jbatik.com/, and for batik products that have been produced, shown on https://batikfractal.com/ website.

jBatik is a special software for creating various alternative new batik motifs by applying the fractal concept, that is the development of shapes based on objects in the form of geometric modules that have 'self similarity'. This means that every small part in the fractal geometry can be seen as part of a small-scale replication of the overall shape [14].

There are several forms of fractals, one of them is the Sierpinski triangle which was discovered by Waclaw Sierpinski by dividing an equilateral triangle which was partitioned into four equal parts. Then it is divided by other, smaller triangles. If the division is continued to infinity, it will get a triangular shape like the overall shape [36], as shown in Figure 3.

The motif design produced by the jBatik software has a shape with fractal properties, so it is called fractal batik. The application of the concept of fractal to batik is actually not something unintentional, but has gone through a series of research processes by calculating the fractal dimension until finally it can be proven that there

Table 2 Research participants from innovators category

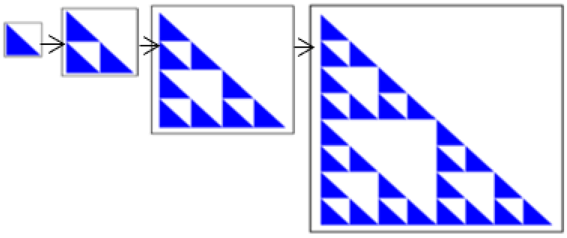


Figure 3 Sierpinski triangle fractal shape

are fractal elements in batik [14]. The existence of fractal properties in batik can be explained by understanding the nature of the fractal itself, namely self-similarity, which means that there is geometric detail on a smaller scale than the motif elements in batik. The concept can be explaind simply as shown in Figure 4 illustrating fractal

properties in the examples of ceplokan batik motifs [11], namely: a) Flower Petals Module with Fractal Properties; b) Flower motifs with Fractal properties from the repetition of the shape of the flower petal module; and c) Composition of *Ceplokan* Motifs Partitioned from Flower Motifs.

(a) (b) (c)

Figure 4 Fractal properties in *Ceplokan* batik motifs

The use of the jBatik software on fractal batik places it as something modern and oriented towards innovation and novelty. This becomes one of efforts to make the batik tradition able to co-exist with technology collaboratively [37].

Fractal batik still collocates the word batik in front of it to show that there are values which are the main principles of batik that are still maintained, that is the process of drawing motifs on cloth using hot wax barriers using tools in the form of canting tulis or canting stamps [11] . On the other hand, fractal batik tries to differentiate itself by involving the role of technology to help create motifs based on the principles of fractal mathematics. The use of this software technology replaces some of the process stages in batik making, especially at the stage of extracting motif ideas and pouring them in the form of drawings / sketches on paper [38].

3 RESEARCH METHODS

The research was conducted following the theory of innovations diffusion involving a group of traditional batik craftsmen in Kerek District, Tuban, East Java to apply jBatik technological innovations to the batik process to produce new batik motifs and the ability

Name	Age [yo]	Working period [year]	Notes
Rukayah	57	34	She was experienced and had opinion leadership among batik craftsmen in Kerek. She also played a role in popularizing Kerek batik until she was awarded *upakarti* by the president.
Uswatun Hasanah	51	31	A Batik entrepreneur who had employed dozens of batik craftsmen. She had received *upakarti* award from the president for her contribution to preserving traditional batik
Sri Lestari	45	26	Batik entrepreneur who had employed dozens of batik craftsmen. Open to various innovations and had won several provincial-level batik motif design competitions.

Table 3 Research participants from adopters category

Names	Age [yo]	Working period [year]	Age Group	Skill Quality
Ningsih	44	24	Middle Aged	Excellent
Sartika	30	12	Young	Excellent
Murti	42	20	Middle Aged	Good
Dewi Srianing	36	15	Middle Aged	Good
Purtini	44	26	Middle Aged	Good
Supiyah	43	21	Middle Aged	Fair
Krusringsih	26	7	Young	Fair

to adapt to innovation. The consideration in involving craftsmen in the design innovation process was to measure the objectivity of the craftsmen's level of readiness to accept innovations in the form of appropriate technology and at the same time so that innovation does not stop and can be continued in a sustainable way [39].

Craftsmen involved in the assignment of experiments were selected by considering several criteria, including: 1) innovators (explained in Table 2) and adopters; 2) the ability to absorb information, motivation, and skills; and 3) age level. This was done to find out whether there is an effect of the absorption rate of a design innovation on the craftsmen group based on these criteria [38].

The adopting craftsmen groups involved as research participants had different levels of absorption of information, motivation, and work skills and are divided into three groups based on the results of observations and identifications carried out directly to the craftsmen in Kerek [11], namely:

1. Excellent quality. Having skills and knowledge of making traditional batik very well from years of experience. Highly motivated (without limiting the reasons for their motivation), quick to receive information, and willing to accept challenges.
2. Good quality. Having the skills and knowledge of making traditional batik well from their years of experience. They did not close themselves to new ideas even though they had doubts about their success.
3. Sufficient Quality. They had the skills to make traditional batik but had not yet produced high quality batik. They did not close themselves to new ideas even though they were doubtful about their success.

At the age level, the grouping was divided into 3, namely: 1) the young group between 18 to 30 years old; 2) the middle-aged group between 35 to 45 years old, and 3) the group over 50 years old. The details of the craftsmen from the adopters category are as shown in Table 3.

Generally, all methods of applying jBatik technological innovations to craftsmen were carried out according to the principles of the theory of innovation diffusion in Figure 5.

Explanation of the numbers in Figure 5 is explained, as follows:

1. Data and information collection regarding social system variables as well as the cumulative personality characteristics of the community and traditional batik craftsmen in Kerek includes: the needs and priorities of the community, environmental conditions in Kerek, prevailing social values and norms, as well as language and ways of communication. The collection of data and information sources was needed by researchers to build a comprehensive understanding.
2. Communication done by researchers both verbally and non-verbally to batik craftsmen (innovators and adopters) in the form of persuasion to offer innovation.
3. Communication in the form of requests for decisions to adopt or reject the innovation
4. Continued communication after the decision to adopt the innovation, then the innovation is implemented.
5. The final decision for the community of traditional batik craftsmen in Kerek relates to its usefulness, whether to continue or discontinue.

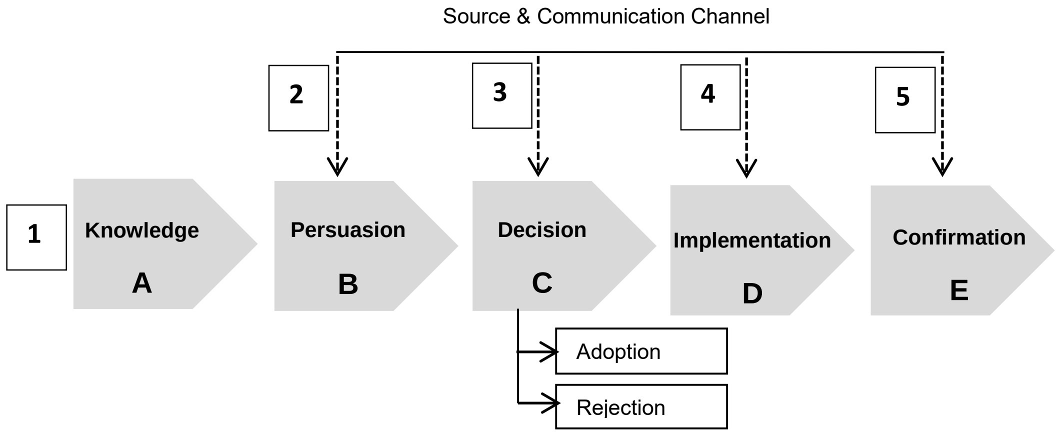


Figure 5 The method of implementing jBatik technological innovations based on the principles of innovation diffusion theory

3.1 Knowledge Stage

The knowledge stage in the application of traditional product innovation was carried out to explore data in order to find out various social system variables and also the characteristics of traditional batik craftsmen in Kerek as recipients of innovation. To be able to build that knowledge. This stage was carried out, as follows:

1. Literature studies from scientific journals, articles, main reference books belonging to Rens Heringa and Judi Knight Acjhadi, as well as visual materials in the form of cloth photos.
2. Observations to see various data and symptoms that occur at the location i.e the batik center area in Tuban, precisely in Kerek District which was spread over 4 hamlets, namely: Kedungrejo, Margorejo, Gaji, and Karanglo. Additionally, observations were made in the form of observing the patterns of interaction occurred among the craftsmen in the batik-making process.
3. Oral tradition to get testimony in the form of narratives of traditional actors who have information from the history of previous generations. This oral testimony was carried out through an in-depth interview process to obtain data and information that were difficult to find in written sources [40]. This process was carried out to several parties, including: 1) entrepreneur and batik craftsmen Uswatun Hasanah and Sri Lestari who were the 3rd generation of the traditional batik family in Kerek, 2) Rukayah community figure who was also one of the main resource persons in Heringa's research in 1994, 3) Santi Puji Rahayu as curator at Kambang Putih Museum in Tuban.

All data obtained were then analyzed to determine the appropriate treatment of innovation for Kerek batik so that the identity and values inherent as tradition are not completely eliminated, including: 1) what was maintained? 2) What was changed/changed? 3) what was added? 4) what was omitted?

In addition, the level of measurement of the readiness of the jBatik technology from the craftsmen involved is also carried out at this stage. This stage is done by giving treatment to several indicators in the use of the jBatik software, including:

1. Ability to operate the jBatik software, i.e., craftsmen have the ability to use the software and operate it to be able to create the development of batik motifs. The indicators are 1) Skills in operating the features of the jBatik software; 2) Knowledge of the features and functions of the jBatik software.
2. The ability to understand the concepts and workings of the jBatik software, even though the crafter is not able to operate the jBatik software himself, they know how a design is created using fractal concepts, from modules to the development stage into motifs and motif composition. The indicators are 1) Understanding how the motif design process occurs in the jBatik software; 2) Understanding how to develop motive ideas.
3. The ability to understand the design results from the jBatik software, namely the craftsmen are not able to operate the jBatik software and do not understand the stages of creating new motifs and motif compositions, but can understand and imagine the final design resulting from the development and then be implemented into batik techniques. The indicators are 1) Understanding how to read batik motif innovations in the form of pictures; 2) the ability to imagine the batik process that must be done to realize the batik motif innovation.

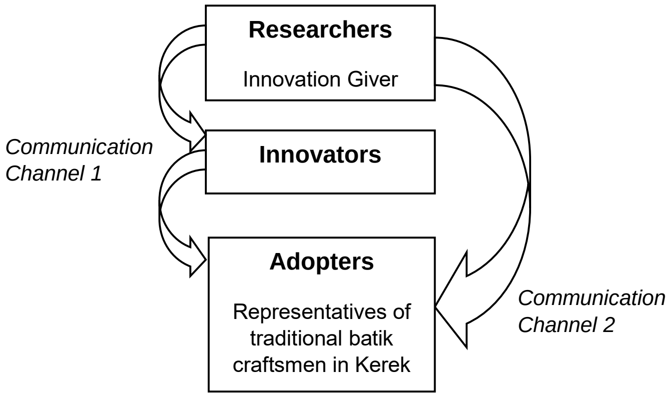


Figure 6 Communication strategy in persuasion stage

3.2 Persuasion and Decision Stage

The persuasion stage is the process of applying the right communication model to traditional batik craftsmen in order to accept innovation [41], which in the condition of the craftsmen in Kerek the innovation was the use of jBatik technology into the process of making batik habits. At this stage, the strategy was carried out according to the illustration in Figure 6 carried out in two directions, namely: 1) the researcher through the intermediary of the innovator as the first recipient of technological information and passed it on to the adopters; and 2) researchers directly to adopters.

Persuasion to craftsmen to accept innovation was done by adjusting the communication patterns that usually occur in the Kerek environment, namely: 1) delivered in a language they understand i.e Javanese; 2) choosing relaxed conditions so that communication is more directed like everyday conversation but has been inserted with an invitation to innovate; 3) persuasion to adopters is carried out by innovators so as not to create distance and craftsmen feel comfortable; and 4) carried out in the form of direct oral communication and minimize the possibility of distance to avoid distraction of messages and information.

The persuasion process was carried out by inviting innovators and adopters to communicate and being asked questions and offers in stages to know their level of motivation, including:

1. Optimistic. Be open to innovation and tend to desire the presence of novelty in the tradition of typical Kerek batik cloth.
   The question given: "Would you like?" and "Are you sure you can?" The answers and attitudes given were able to show a high desire and confidence to accept the offer.
2. Accepting but not motivated. Being open to innovation but not having the initiative to do so, because it is not born from their motivation. The questions at the motivation level are developed if one of the questions at the motivation level number 1 is not met. Additional persuasion needs to be given first to give confidence and then willing and ready: "We will do it together, later we will be guided slowly until we can". If necessary, it can be explained in detail about the stages that will be carried out together. After that the question is asked again at the motivation level number 1, until they will finally give an answer and are willing and ready to accept.
3. Indifferent. Being indifferent and tending to choose the answer to reject, but change to accept the challenge of innovation if given a reward. The craftsmen's motivation to get involved was based on economic motivation.
   Questions at this level of motivation are developed if efforts at levels 1 and 2 are rejected. So, they would be given additional persuasion by rewards offer in the form of fees. The answer that is expected after being given this persuasion is willingness to accept.
4. Rejecting.Being closed to innovation offers and avoiding talking. All forms of efforts that have been given have not succeeded in influencing their willingness to accept.

3.3 Implementation Stage

The implementation stage was the application of the motif design produced by the jBatik software, then transformed into batik sheets by the craftsmen using batik tulis (handmade) technique. This handmade batik technique follows a process that has become a habit for traditional craftsmen in Kerek according to Figure 7. At this stage the craftsmen would be observed in terms of their ability to overcome design problems that they have never made before when implementing it using batik tulis technique.

In the implementation process, the requirements that limit the way of working are determined, including:

1. jBatik makes batik creations according to their characteristics but the inspiration for the motifs is taken from the traditional batik motifs in Kerek. It was decided to choose the Srigunting motif, which is one of the classic motifs and is mastered by most of the craftsmen.
2. The designs produced by jBatik are printed on 1:1 scale paper with the dimensions of the sayut cloth i.e 60 cm x 300 cm.

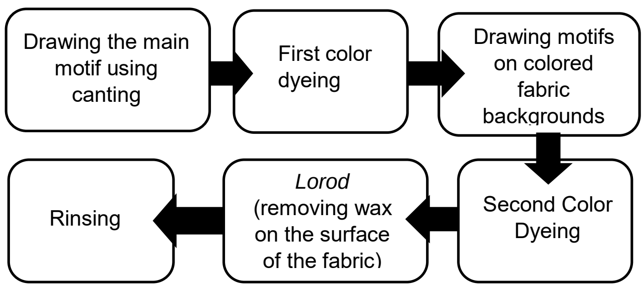


Figure 7 The process of making Batik Tulis (handmade batik) in Kerek

3. Craftsmen responded to designs on paper that have been produced by jBatik as a guide in describing motifs on fabrics through the batik making process. In this process, there was no intervention given to the craftsmen.

3.4 Confirmation Stage

The confirmation stage was carried out to obtain innovation recognition for the benefits of innovation, as well as to validate the simulation results of the implementation of batik motif development using the jBatik software by craftsmen. This assessment process was carried out using a semantic differential approach by determining the factors being assessed and the rating scale [42], as shown in Table 4, as follows:

The assessment on the indicators of the craftsmen's work attitude was carried out by researchers who know the entire series of experimental processes carried out. Meanwhile, the indicators of innovation in the design of batik motifs made by craftsmen, including:

1. Expert and researcher in the field of traditional textiles, Dr. Cut Kamaril Wardani Representative from Cita Tenun Indonesia.
2. Piksel Indonesia as the developer of the jBatik software, Muhamad Lukman.
3. Rukayah, senior traditional batik craftswoman in Kerek, as a representative of craftsmen who know about the development of batik in Kerek.

4 RESULT AND DISSCUSSION

4.1 Knowledge about Factual Condition of Batik Tradition in Kerek

Knowledge about the factual conditions of batik tradition in Kerek was developed from observations, oral traditions as well information searching through literature sources that have been previously carried out. The results obtained were as follows:

1. The characteristics of the Kerek community was previously described as of rural communities such as having a strong relationship with nature so that many rules of life were born with the aim of protecting nature; livelihoods were generally farming, gardening, or making cloth; homogeneity in the form of similarities in social and psychological characteristics, language, beliefs, customs, and behavior was still very strong in society; and social differentiation showed the existence of social stratifications with different social status.

   All of these characteristics now no longer represent the characteristics of the Kerek community, and are starting to be replaced with the characteristics of the suburban community. Nature in the framework of the concept of macrocosm and microcosm is no longer a priority for them, as evidenced by the growth of infrastructure and industrial development that sacrifices the preservation of nature. The people's mindset is more material-oriented than maintaining traditional values that have been considered ancient and unprofitable. This is most clearly seen from the work orientation of the Kerek people who decided to be factory workers. Additionally, a perspective had emerged on the acceptance of innovation in making batik cloth as a response to market trends and demands.

2. Spiritual practices in the form of rituals and traditional ceremonies were less frequenlty carried out by the Kerek community, due to the diminishing level of belief and appreciation of the community towards these matters. Previously the role of traditional cloth was considered important in ritual practices and traditional ceremonies. But now these practices are no longer implemented and are starting to lose their existence.

Table 4 Format for assessing the work attitude of craftsmen and visualizing innovations in batik motif designs

Factors	Rating Scale							Factors
1. Work attitude of craftsmen								
Confused	-3	-2	-1	0	1	2	3	Understanding instruction
Slow								Skillfull
Monotonous								Improvising
Very Slow								Fast
2. Innovation visualization of Batik motif design using jBatik by craftsmen								
Unclear shape	-3	-2	-1	0	1	2	3	Accurate shape
Ordinary								Aesthetics
Old/Ancient								New
Batik Kerek identity unrecognized								Batik Kerek Identity Recognized

Notes for Rating Scale : -3 (very bad); -2 (bad); -1 (not sufficient/minus); 0 (neutral); 1 (sufficient); 2(good); 3 (excellent)

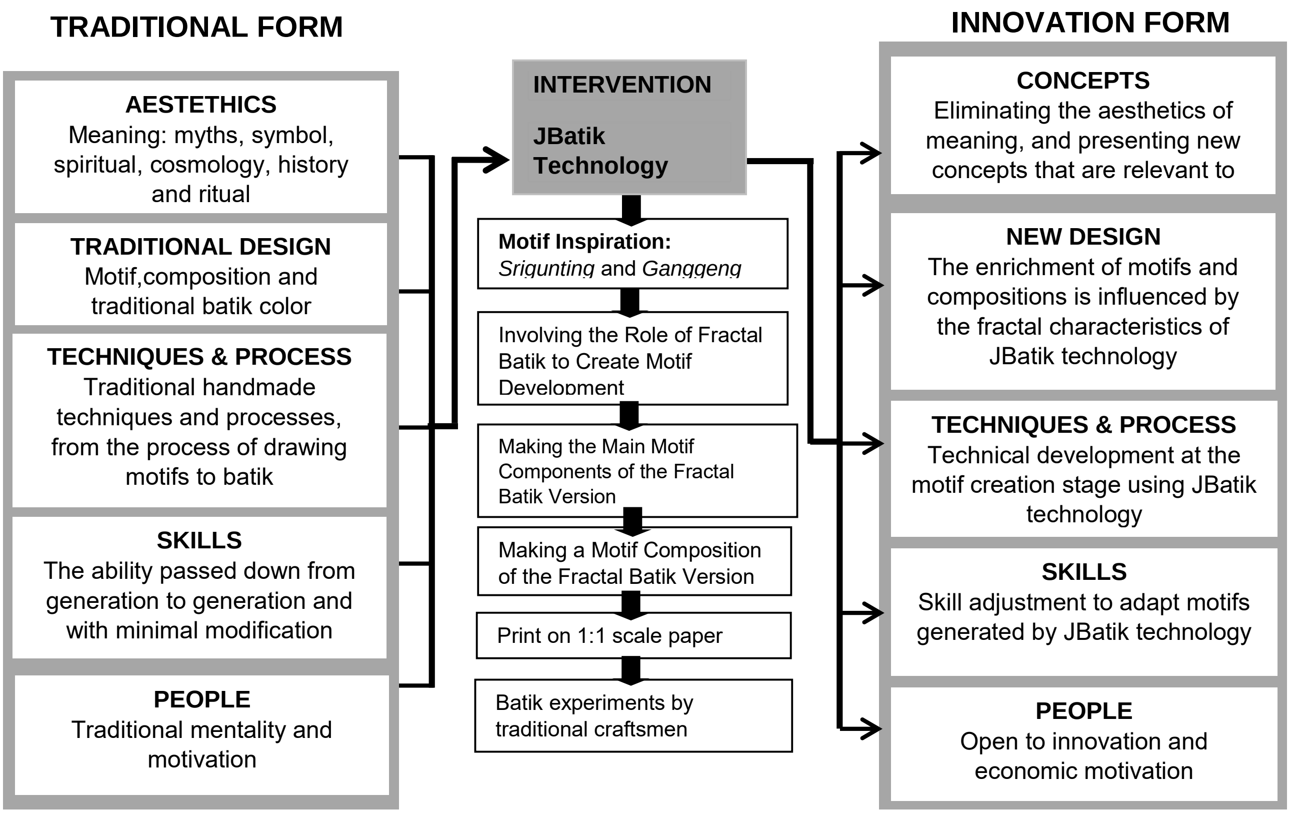


Figure 8 The expected form of innovation through the application of JBatik technology on Kerek batik

3. Environmental conditions in Kerek which are close to industrial areas also have an impact on growth in the infrastructure sector, thus opening up great opportunities to get to know technology and get information flow rapidly. The impact on this also has an impact on the mindset, motivation, and way of making decisions for the Kerek people who are slowly starting to leave things that are rural in nature and prefer the new things offered by the modernity concept.

   Therefore, based on these facts, if you relate this to the act of preserving the existence and vitality of tradition, the most appropriate way is to carry out a transformation strategy, namely developing the tradition of making cloth through innovation by providing a touch of novelty both in terms of technique, function, and aesthetics without completely abandon its traditional values [11]. This needs to be given to the craftsmen so that they can adjust their abilities to create innovative batik.

4.2 Innovation Idea on Batik Kerek

Based on the factual conditions, the strategy implemented was transformation, as described in Figure 8.

Furthermore, transformation through innovation in developing batik motifs using jBatik software needs to measure the readiness of traditional batik craftsmen in Kerek to technology. The following in Table 5 is the result of measuring the readiness of jBatik technology for traditional batik craftsmen in Kerek.

The analysis is the cause of the obstacles for traditional batik craftsmen in Kerek to have a level of readiness at stages 1 and 2, namely, there is a high gap between the basic knowledge and skills possessed by the craftsmen and jBatik itself at this time with the basic criteria that need to be possessed to understand and operate the jBatik software.

Basic criteria are needed for craftsmen to be able to operate the jBatik software; it includes: users have basic skills in understanding computer equipment. The basic requirements are the ability to turn on and off the device, use additional tools such as a mouse and keyboard, and operate the software. The jBatik software requires the user to understand the basics. In addition, early jBatik users are expected to be familiar with the software interface with various window functions and toolboxes. Understanding basic computer literacy is vital to understanding and even mastering how jBatik works. Some of these essential things are not owned by the traditional Kerek batik craftsmen, and none of the seven existing craftsmen know the basics. After mastering the understanding of basic computer literacy, it is also necessary to have basic knowledge of design elements and principles to

Tabel 5 Readiness of jBatik technology Traditional batik craftsmen in Kerek

No	Craftsman Name	Readiness of jBatik technology					
		1. Ability to Operate		2. Ability to understand concepts and how to work		3. Ability to understand design results	
		Ability to operate features on jBatik software	Knowledge of jBatik software features and functions	Understand the motif design process in jBatik software	Understand how ideas are developed	Ability to understand how to read motif innovations in the form of pictures	Ability to imagine the batik process that must be done
1	Ningsih	X	X	V	V	V	V
2	Sartika	X	X	V	V	V	V
3	Murti	X	X	X	X	V	V
4	Dewi Srianing	X	X	X	X	V	V
5	Purtini	X	X	X	X	V	V
6	Supiyah	X	X	X	X	V	V
7	Krusringsih	X	X	X	X	V	V

create various variations of new motifs that are diverse and contain ethical values.

The results of the measurement of readiness for jBatik technology are then used as a basis for consideration of the treatment of traditional batik artisans in Kerek, namely applying motif development innovation starting from the readiness level of stage 3, which has implemented the design of the jBatik software development results to the batik process.

4.3 Persuasion to Traditional Batik Craftsmen in Kerek

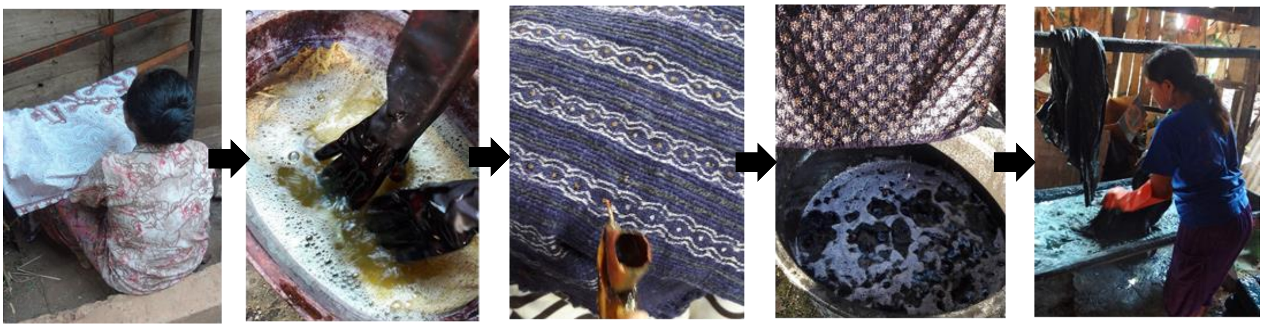
Innovation persuasion was carried out to innovators and adopters in order to accept the offer of innovation ideas given by researchers. After the persuasion process carried out according to the procedure, the innovators and adopters would show their attitude and then made decisions in the form of motivation. These decisions were further grouped based on the level of motivation, as shown in Table 6.

4.4 Implementation Result of jBatik Technology

The implementation of jBatik technology resulted in design development, on the motif module which is processed with design principles, including: repeat, add, change scale, superimpose, and animated as shown in Table 7. The composition was made dynamic and fractal in order to be able to display something different from the composition of the motif which traditionally tend to be static.

The application of the motifs resulting from the development of the jBatik software is then carried out by the craftsmen by following the process of making batik as shown in Figure 9.

The relationship between the motivations shown by craftsmen from the adopter group to the innovation of batik motif designs produced by jBatik technology is shown in Table 8.



(a) (b) (c) (d) (e)

Figure 9 The process of implementing batik motifs resulting from the development of the jBatik software by craftsmen: (a) Drawing motifs with canting; (b) First color dyeing; (c) Draw a motif on a colored cloth background; (d) Second color dyeing; (e) Remove batik wax and rinse

Table 6 Motivation Level of Craftsmen

No	Name	Motivation Level	Notes
1. Innovator Category			
1	Rukayah	1	Had a desire to promote batik in Kerek and believed that outside assistance was needed. Therefore, ideas that come from outside would be fully supported
2	Uswatun Hasanah	2	Reason: Based on her experience of participating in the workshops of batik innovation held by the government. It often does not continue among craftsmen.
3	Sri Lestari	1	Had the desire to promote Kerek batik which was also one of his motivations for making batik so far.
2. Adopter Category			
1	Ningsih	2	Confident as an experienced batik craftswoman and had special skills. However, after seeing the new motif design, she expressed her disbelief.
2	Sartika	2	Confident as an experienced batik craftswoman and had special skills. However, after seeing the new motif design, she expressed her disbelief.
3	Murti	3	Not confident to be able to make it because she was comfortable with the existing pattern so far. The craftsmen have repeatedly said that they were more comfortable making batik as usual because it was easy to make.
4	Dewi Srianing	3	Before engaging in experimental assignments, she had shown high economic motivation. From the beginning, the craftsmen had asked whether they would be given a higher wage than ordinary batik making.
5	Purtini	4	Not willing because she had to go to the fields to harvest in her own field.
6	Supiyah	3	Refusing to get involved because of not confident enough to work it out, but eventually changed her mind after being offered a reward.
7	Krusiningsih	3	Refusing to get involved because of not confident enough to work it out, but eventually changed her mind after being offered a reward. There was even a bargain about the amount of rewards given.

Table 7 Application of Design Techniques in the Development of Typical Kerek Traditional Batik Motifs Using jBatik software

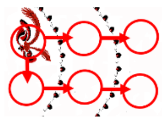
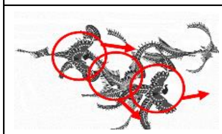
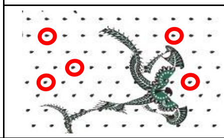
Original Form	Result	Techniques	Developed Motifs
		*Repeat*	
		*Superimpose & animated*	
		*Add*	

Table 8 Development Realization of motifs using jBatik software with hand-made batik techniques by craftsmen

No	Name	Design	Result	Findings
1	Dewi Srianing	Motif 1		There was a change in the batik making process. The craftswoman performed an additional process by firstly making a pattern using a pencil to help determine the shape of the curved line. To make the composition proportional like the example given, the craftswoman made it with the help of a ruler. The process of making batik is twice longer, because the craftswoman drew it carefully.
2	Ningsih	Motif 1		There was a change in the batik making process. The process of making batik is twice longer, as craftsmen often stopped to observe the details of the motifs on the paper and tried to carefully pursue the resemblance when drawing them with canting. There was an additional behavior, craftswoman use more than one canting. Canting with a small hole size was used to make the first outline before overwritten by the larger outline.
3	Krusningsih	Motif 1		There was no change in the batik making process from previous one. New motifs never been created before did not affect the way the craftswoman worked.
4	Supiyah	Motif 2		There was a change in the batik making process. The craftswoman performed an additional process by firstly making a pattern using a pencil to help determine the shape of the curved line so that it looks proportional. The process of making batik was twice longer, because the craftswoman drew it carefully.
5	Sartika	Motif 2		There was no change in the general batik making process from before, although in the process the craftswoman seemed to be more careful so that the completion time was longer than usual.
6	Murti	Motif 2		There was no change in the batik making process from before. New motifs never been created before did not affect the way the craftswoman worked.

Table 9 Validation of innovation indicators: Craftsmen work attitude

Indicators	Variables	Craftsmen	Individual Score	Average Score	Notes (the result of rounding the average value of 0.5 up/down)
Improvements in the work attitude of craftsmen in implementing the motifs of the results developed using the jBatik software	Understanding instruction	Dewi Srianing	2	1.6	Good
		Ningsih	2		
		Krusiningsih	1		
		Supiyah	2		
		Sartika	1		
		Murti	2		
	Skills Improvement	Dewi Srianing	2	1.16	Sufficient
		Ningsih	2		
		Krusiningsih	0		
		Supiyah	2		
		Sartika	0		
		Murti	1		
	Improvisation	Dewi Srianing	3	1.5	Good
		Ningsih	3		
		Krusiningsih	0		
		Supiyah	3		
		Sartika	0		
		Murti	0		
	Fast	Dewi Srianing	-1	0	Neutral
		Ningsih	-1		
		Krusiningsih	2		
		Supiyah	-1		
		Sartika	-1		
		Murti	2		

The results of the development of traditional batik motifs using jBatik software implemented by craftsmen were then analyzed by comparing the characteristics of traditional batik, as follows:

1. The overall motif line of the craftsmen had a character that is not much different from the traditional batik motif line i.e inconsistent and rough. This is because batik was still made using traditional woven fabrics which tend to have a rough and textured surface, making it difficult to make consistent, smooth, and neat line.
2. The shape and composition of the motif inspired by *srigunting* motif was made by applying the principles of fractal mathematics while still paying attention to the characteristics of the original motif so that its identity can still be recognized by changing the composition patterns of traditional motifs by using repeat, add, change scale, superimpose, and animated. This showed a completely different composition from traditional batik and its significance was easy to see.
3. In the developed batik, there were still *ren-ren* (except Krusiningsih) which show similarities to the characteristics of *ren-ren* in traditional batik motifs, although without the *coblosan* effect.
4. Color in traditional batik was one of the fundamental elements which, if removed, would result in the loss of the visual characteristics of the fabric. In the developed batik, it could be seen that the craftsmen were still influenced to maintain traditional colors.
5. *Remekan* was still dominant in some fabrics made based on the initiative of the craftsmen to maintain *remekan* like the traditional batik method.

4.5 Validation of JBatik Technology Motif Development Implementation

Validation was carried out firstly by providing an assessment using a semantic differential approach to measure the presence or absence of innovation content in batik fabrics made by craftsmen as an implementation of design development using jBatik software. The assessment process was carried out on 2 things that were used as indicators of innovation, namely: 1) Improvement in the work attitude of craftsmen in implementing the motifs developed using the jBatik software; and 2) Novelty in the visualization of batik motifs resulted from the implementation of motif development using jBatik software by craftsmen. The validation results are as shown in the following Table 9.

Based on the analysis of the validation results in Table 9, it can be explained that:

1. The variable 'understanding the instructions' was assessed based on the craftsmen's ability to capture every work instruction given by the researcher and execute their understanding in the form of appropriate actions. The results showed the number 1.6 with a description of the score in the form of rounding was 'good'. There were 2 out of 6 craftsmen with a below average score.
2. The variable' improvement of skills' was assessed based on the ability of the craftsmen to improve the basic skills they had previously by being able to do new jobs outside of their habits with the expected results. In this case, the improvement of skills was emphasized on the ability to understand the motifs on the paper before being transferred to the cloth. The results showed the number 1.16 with a description of the score in the form of rounding is 'enough'. There were 3 out of 6 craftsmen with a below average score.
3. The variable 'improvisation' was assessed based on the ability of the craftsmen to optimize their creativity to find various solutions from their limitations in order to be able to produce batik with the expected design. The results showed the number 1.5 with a description of the score in the form of rounding is 'good'. There were 3 out of 6 craftsmen with a score below average, and the rest got a 'excellent' rating.
4. The 'fast' variable was assessed based on the craftsmen's ability to complete their task in a quick time but did not leave the agreed work process. The results showed the number 0 with the description of the score in the form of rounding being 'neutral'. There were 4 out of 6 craftsmen with a minus score which indicated that the work process had taken much longer than the usual working process. As for the others, it had no impact at all. This variable is related to other variables, one of which was variables 1 and 3 where craftsmen improvised so that it increased working time, and some craftsmen needed time to understand the motifs on paper before starting to draw on cloth. In the case of craftsmen whose working time had no impact, even if you look at the previous variables, it showed that there was a relationship between the low level of understanding of instructions or improvisation.

Based on the analysis of the validation results in Table 8, it can be explained that:

1. The 'accurate shape' variable was assessed by the validator based on the clarity of the shape of the motif made by the craftsmen, including: the main motif form, the supporting motif form, and *isen-isen* (details of motif filler) by referring to the motifs generated by the jBatik software. The results showed that the average number of the three validators for all craftsmen was 1.4 with the description of the

score in the form of rounding the number is 'enough'. There were 3 out of 6 craftsmen with below average scores.

2. The 'aesthetics' variable was assessed by the validator based on the final appearance of the batik against its aesthetic content (such as meeting the criteria for elements and visual principles). The results showed the average number of the three validators for all craftsmen was 1.6 with a score statement in the form of rounding was 'good'. There were 3 out of 6 craftsmen with below average scores.
3. The 'new' variable was assessed by the validator based on the final appearance of batik which contained elements of novelty when compared to the appearance of traditional batik. The results showed that the average number of the three validators for all craftsmen was 1.3 with a score statement in the form of rounding was 'enough'. There were 2 out of 6 craftsmen having a below average score.
4. The variable' identity of Kerek batik recognized' 'was assessed by the validator based on how much the impression of traditional Kerek batik could still be felt in developed batik. This could be manifested in the form of styles, details of motifs, and colors. The results showed that the average number of the three validators for all craftsmen is 2.3 with a score statement in the form of rounding is 'good'. The individual score of each craftsmen corresponded to the final average score. This showed that the mentality of the craftsmen was strongly influenced by the mental image of the traditional Kerek batik. Although it must also be considered that this could also be influenced by the decision to develop a motif by taking inspiration from traditional motifs.

5 CONCLUSION

Based on the results and discussions, conclusions can be drawn as follows:

1. This study provides an understanding that strengthens the researcher's assumption that the level of knowledge and basic skills possessed by traditional craftsmen in Kerek is below the standard level to meet the criteria that need to be possessed to be able to operate the jBatik software. So that for traditional batik craftsmen in Kerek, the application of motif innovation cannot be carried out at the level of technological readiness at the operating stage of the jBatik software. This provides support in taking a stance to determine an innovation strategy in order to pay attention to the level of technological readiness of the craftsmen so that they do not offer innovation ideas that go beyond their basic knowledge and skills.
2. The process of implementing new motifs inspired by traditional Kerek decorations using jBatik software for traditional craftsmen could be carried out by going through all stages of the process in innovation diffusion theory. After conducting an assessment of the innovation indicators in the form of the work attitude of the craftsmen as well as the visual appearance of batik with new motifs; then it was known that none of these innovations was on a rating scale below zero. This indicated that the innovation could be accepted by the craftsmen and was successful. In fact, one interesting thing found from the characteristics of traditional craftsmen in Kerek was that in making batik with new motifs, they consciously added *ren-ren*. Therefore, it could be concluded that besides being able to adapt and show creativity in facing the challenges of change, the traditional batik craftsmen in Kerek also had a strong mentality in living every process when drawing batik so far. Additionally, this also proved that the visual of traditional Kerek batik had a strong mental image to keep exuding its own identity.
3. The innovation implementation process needs to refer to the characteristics of the group; as in the innovation diffusion theory, it is important to determine groups of innovators and adopters to improve communication channels so that they can be well received. In addition, in the adopter group, it was also known that age qualification and length of experience as a batik maker were not significant factors. Based on this data, it was known that the length of experience is not always a determinant of the skills quality possessed by the craftswoman. The things that significantly affected the innovation so that it can be done well are the quality of the skills and motivation of the craftsmen. Even though in terms of motivation, it is proven that there was one craftswoman whose motivation was based on economic motivation, but the performance and results of his batik were considered very good. Therefore, motivation was not an absolute thing for some craftsmen, even though it was the majority and dominant.
4. Research has been able to contribute and add value in the form of a precise mapping of the level of technological readiness and the level of basic knowledge and skills possessed by traditional craftsmen. That way, it is beneficial for researchers and designers if they will carry out further developments on the design of the typical Kerek motif so that it can be carried out gradually starting from the position that is the condition of the craftsman at this time. Any innovative ideas and solutions provided will be right on target and can be appropriately implemented in further experience.

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FASTNESS PROPERTIES IMPROVEMENT OF FLUORESCENT PIGMENTS

Md. Khayrul Islam[1], Shekh Md. Mamun Kabir[2], Md. Dulal Hosen[3], Md. Azharul Islam[3]

[1]Department of Textile Engineering, The International University of Scholars, Banani, Dhaka-1213, BANGLADESH
[2]Department of Wet Process Engineering, Bangladesh University of Textiles, Tejgaon-1208, BANGLADESH
[3]Department of Textile Engineering, Mawlana Bhashani Science and Technology University, Santosh, Tangail-1902, BANGLADESH

engr.kislam@ius.edu.bd, mamunkabir.butex@gmail.com, dulalhossainmbstu@gmail.com, azhar.te@mbstu.ac.bd

Abstract: *The resistance of the material to a change of its color characteristics during exposure to sunlight, rubbing and washing as domestic and laundry and other various ways are referred to as color fastness of dyes or pigments. In this research, 100% cotton and blended fabrics were dyed with fluorescent pigments i.e. Shining Flu Pink-F17 and Papillion Orange-FGRN in exhaust dyeing method. The improvement of color fastness properties, i.e. color fastness to washing, rubbing, perspiration and light were observed with the treatment of using antioxidants and UV-absorbers. There were eight samples of dyed fabrics (Four samples of 100% cotton knit fabric and four samples of 60/40 cotton-polyester blended fabrics) treated with 1% (v/v) of antioxidants i.e. Gallic acid, L-Ascorbic acid and UV absorbers i.e. 2-hydroxy-4 methoxy-benzophenone, 4-4 dimethoxy-benzophenone respectively. The treatment of antioxidant L-Ascorbic acid and UV absorber 4-4 dimethoxy-benzophenone provides satisfactory improvement of fastness properties than other antioxidants and UV absorbers. The results were mainly interpreted in terms of color strength, visual assessment of evenness and fastness ratings.*

Keywords: *cotton fabric, fluorescent pigments, color fastness, adsorption, color strength, dyeing blended knit fabric.*

1 INTRODUCTION

The natural grey textile fabric is colored to make it more attractive and comfortable to the wearers by dyeing. So, textile dyeing is one of the most important coloration steps of any textiles materials. Different types of textile fabric i.e. 100% cotton and cotton-polyester blended fabric were dyed by using different types of natural dyes like Turmeric (Curcuma longa L.), Hibiscus (Tea), Avocado etc. and different synthetic dyes [1]. Different scientists and researchers are trying to develop this dyeing process with increasing different properties of the dyed fabric. Besides dissimilar types of pigments are also using in dyeing textile fabric. The pigment dyeing in the exhaust method is generally unpopular due to the unevenness or unlevelled problem. Moreover, many pigment manufacturers standardized the process for exhaust dyeing which are not free from the problem of fastness properties as well [2]. However, pigment has no direct substantivity towards the cotton as pigments contain an anionic dispersing agent and cotton has partially anionic in nature. To create the cationic charge on cotton by using cationizing agents [3], substantivity of cotton and pigments to each other can be developed [4]. Fluorescent pigment is one of them which is now used in dyeing textile fabrics. Fluorescent pigments are such kinds of pigments that can sharpen the fabric's color by emitting more light than the conventional pigments. For producing brighter color, these pigments are chosen by the manufacturer rapidly nowadays. Evenmore, pigments are much more used in synthetic fabric dyeing than cotton due to its poor color fastness as well as light, washing, rubbing, perspiration. On the other side, Antioxidants and UV absorbers are generally applied to dyed fabrics due to resist the fading and bleeding of color [5].

Some textile substrates such as cotton, polyester and nylon fabrics were dyed using fluorescent and non-fluorescent pigments followed by color fastness properties evaluation of the dyed materials [6]. In exhaust methods, cotton, polyester and nylon were dyed with fluorescent and non-fluorescent pigments and found that both dyed fabrics showed poor pigment build-up and levelness [7]. So, fluorescent pigments are used for dyeing the cotton-polyester blended fabric under different conditions [8]. Moreover, Fluorescence dyes involve the absorption of ultraviolet (UV) or visible light and emission of light at higher wavelengths. These dyes are clarified as compounds that both absorb and emit strongly in the visible region, and which have concern with their potential for application to their intense fluorescence properties [9]. Normally, the fastness properties of the fluorescent pigment are not so good. So, the levelness of the fluorescent pigment was improved by the use of cationization by using

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different levelling agents and others supporting auxiliaries.

Moreover, the performance of two conventional UV absorbers, benzophenone and its derivative 2,4 dihydroxybenzophenone was studied in terms of ultraviolet protection factors as well as color fastness, tensile strength, handle etc. [10]. The effects of UV finish with 2,4 dihydroxybenzophenone were found to be more pronounced compared to that with benzophenone. Cotton finished with benzophenone increased the Ultraviolet protection factor (UPF) as well as dyed cotton. Azobenzophenone has excellent UV protection with a lower yellowish effect [11]. The light fastness property of the dyed samples before and after the treatment using UV absorber was tested as per international standards. The results show that for all light, medium and dark shades the dye exhaustion and fixation percentages were very good. Before applying UV absorbers, color fastness to light was poor but after application improved noticeably [12]. Using the antioxidants and UV absorbers for the development of light fastness properties, the cotton fabrics have been dyed with C.I Reactive Yellow-84, C.I Reactive red-22 and C.I Reactive Blue-19 dyes. The antioxidants such as GA, vitamin C and caffeic acid, and the UV absorbers such as 2-hydroxybenzophenone and phenyl salicylate have been applied on reactive dyed cotton fabric by exhaust method. It has been established that the use of UV absorbers or antioxidants improves the light fastness of dyed fabrics. To improve the dyeing fastness properties of the naphthalimide fluorescent dye poly (amidoamine) dendrimer was used [13] and furthermore, fluorescent dye also was selected as a colorant in regenerated cellulose fabric [14] binder-free cotton fabric printing [15-16] and denim dyeing [17].

In the UV-visible spectral analysis, Cibatex UPF has been found to be a suitable agent for rendering adequate UV protection to the cotton/jute fabrics. At present time dyeing and finishing with Cibacron Red FAL and Cibatex UPF provides higher UV protection. The treatment with TiO_2 of Cotton/jute fabrics also provides satisfactory protection against UV rays and radiation [18]. Ultraviolet absorbers are organic/inorganic colorless compounds with strong absorption in the ultraviolet wavelength range of 290 nm-360 nm and block the ultraviolet radiation from reaching the human skin when incorporated in the fabrics [19]. In the case of synthetic fibers, polyester and polyamide fibers have higher absorption in the UV-B region and Acrylic has lower absorption capacity as compared with others. In the bleaching process, some natural UV absorbers reduce the UV absorption capacity of natural fibers [20]. A group of authors studied and proved that the color fastness performance and result of using UV absorbers and antioxidants with different dyes on cotton improved significantly. So, UV absorbers and antioxidants are used to prevent the photo-fading and color bleeding on cotton dyed with fluorescent pigments in exhaust dyeing technique [21]. Few more researchers also worked on the chemistry and reactive species in photo-fading where most attention has been given to singlet oxygen ($^1O_2$) which can be formed due to the demolition of excited states of dyes by the triplet state of oxygen. Singlet oxygen is very reactive toward dyes and pigments which is the reason for fading of color [22].

The main objective of this work was to improve of color fastness properties of the fluorescent pigments by using two UV absorbers (2-H4-MB and 4-4DB) and two Antioxidants (GA and LAA) on 100% cotton and cotton/polyester blended fabric. LAA, GA, 2-H4-MB, 4-4DB were selected as antioxidants and UV absorbers because of its availability in market and it is quite less costly than other staff and same fact works for selecting the fluorescent pigments (SFP-F17 and PO-FGRN) which are used in production widely. To conduct the research, 100% cotton and blended fabrics were dyed with fluorescent pigments (SFP-F17 and PO-FGRN) using exhaust dyeing method for the improvement of color fastness properties, i.e. color fastness to washing, rubbing, perspiration and light with the treatment of using antioxidants and UV-absorbers. There were eight samples of dyed fabrics (Four samples of 100% cotton knit fabric and four samples of 60/40 cotton-polyester blended fabrics) treated with 1% (v/v) of antioxidants (GA and LAA) and UV absorbers (2-H4-MB and 4-4DB) respectively.

2 MATERIALS AND METHODS

2.1 Materials

To complete the study, two categories of well scoured and bleached fabrics were selected i.e., 100% cotton and 60/40 cotton-polyester blended knit fabrics with gram per square meter (GSM)=160, yarn count = 30 Ne and stitch length=2.72mm. The fabric was collected from the local market in Bangladesh. Commercially used direct fluorescent dyes namely Shining Flu Pink-F17 and dispersed fluorescent dyes namely Papillion Orange FGRN were purchased from the manufacturer of Kyung-In Synthetic Corporation (KISCO), Seoul, Korea. The cationizing agent Acramin Prefix K (CAS number: 68131-73-7) was collected from the Netherlands, the wetting agent (Brand name WETEX HD-82, CAS number:160875-66-1) was sourced from Zhuhai Huada Wholewin Advanced Materials company Limited, No.233 Langwan Road, Zhuhai, the sequestering agent (Trade Name: SINQUEST CS 006, CAS number: 2809-21-4) was purchased from Yantai Yuanming Textile Tech Co. Ltd., and the stabilizer (Trade Name: Clarite CBB, CAS Number: 68-04-2) was collected from the Huntsman, Bangladesh.

The antioxidants (GA, LAA) and the UV absorbers (2-H4-MB, 4-4DB) were used for treating the cotton and cotton/polyester blended fabric before checking the color fastness properties. These were collected from commercial sources (Acros organics, Sigma-Aldrich, Germany), and The CAS number of LAA is 50.81.7; GA is 149.91.7; 2-H4-MB is 117-99-7 and for 4-4DB is 90-96-0.

2.2 Methods

2.2.1 Scouring and bleaching pretreatment process of the sample

For the scouring and bleaching process, initially, a recipe was prepared by mixing H_2O_2: 5 g/L, NaOH: 4 g/L, wetting agent: 1 g/L, detergent: 1 g/L, sequestering Agent:1 g/L, stabilizer: 2 g/L and scouring and bleaching were done following Figure 1.

2.2.2 Cationization process

Cationization process is depicted at Figure 2(a) where the cationizing agent (Acramin Prefix-K) was applied at 90 ºC for 10 minutes with the concentration of 5% on-weight-fabric (OWF) while levelling agents (equivalent mixture of oxinol A-24 or oxinol 894 or oxinol LLS) were taken 1 g/L. The effect of the above process on color depth and levelness was gauged by subsequent dyeing with pigments.

2.2.3 Dyeing procedure and sample preparation

The cationized fabrics were dyed with the different pigments; i.e. (SFP-F17) for 100% cotton and (PO-FGRN) for polyester part of 60/40 cotton-polyester blended fabrics by using 1 g/L levelling agents. Both fabrics (100% cotton and 60/40 cotton-polyester blended) were dyed as per the below mentioned recipe. Polyester part was dyed at first according to Figure 2(b) where the sample weight: 10 g, fluorescent pigments (PO-FGRN): 2% OWF, dispersing agents: 1 g/L, temperature:135 ºC, time: 30 minutes, pH: 4.0, molecular and liquor ratio 1:10. Reduction clearing was done as per practically available using methods following that fabrics were cationized by the commercially available cationizer, and dyeing of cotton part was performed as recipe of sample weight: 10 g, fluorescent pigments (SFP-F17): 2% OWF, binder: 5 g/L, levelling agents: 1 g/L, temperature: 80 ºC, time: 45 minutes at molecular and liquor ratio 1:10. The identical recipe was followed to dye the 100% cotton fabric that was used in cotton part dyeing sequence of 60/40 cotton-polyester blended fabric which has been mentioned in Figure 2(c). After dyeing, both fabrics were washed, dried and cured properly following the standard procedure.

2.2.4 Application of UV absorbers and antioxidants

The antioxidants (LAA and GA) and the UV absorbers (2-H4-MB and 4-4 DB) each of 1 g/L concentration were applied to the dyed cotton and blended fabric in a solution at 70 ºC, with 30 minutes stirring that is mentioned in Figure 2(d). The antioxidant LAA dissolves in water but GA and other UV absorbers do not readily dissolve in water.So, methanol was used to dissolve as the recipe of LAA: 1 g/L, GA: 1 g/L (with the mixture of water/methanol at 9/1 v/v), 2-H4-MB: 1 g/L (with the mixture of water/methanol at 9/1 v/v), 4-4DB: 1 g/L (with the mixture of water/methanol at 9/1 v/v) at temperature of 70 ºC for the time of 30 minutes to produce aqueous solution for soaking of fabrics. After treatment, the samples were washed and dried.

2.2.5 Color fastness properties test

Color fastness test properties of all dyed specimens were carried out in accordance with the test methods provided by the ISO Standard where DW (Diacetate-Wool) type multi-fiber fabric was used as it is recommended by ISO. Eventually, the methods were chosen for color fastness to washing ISO 105-C06 B_2S Standard, color fastness to water ISO 105-E01 Standard, color fastness to perspiration ISO 105-E04 Standard, color fastness to rubbing ISO 105-X12 (dry and wet) Standard and color fastness to light ISO 105-B02:2013 Standard.

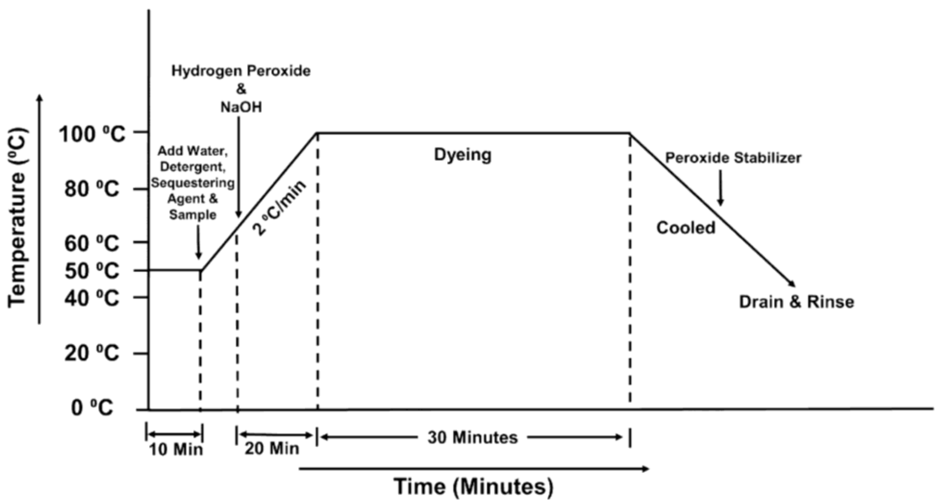


Figure 1 Process curve of scouring and bleaching in same bath

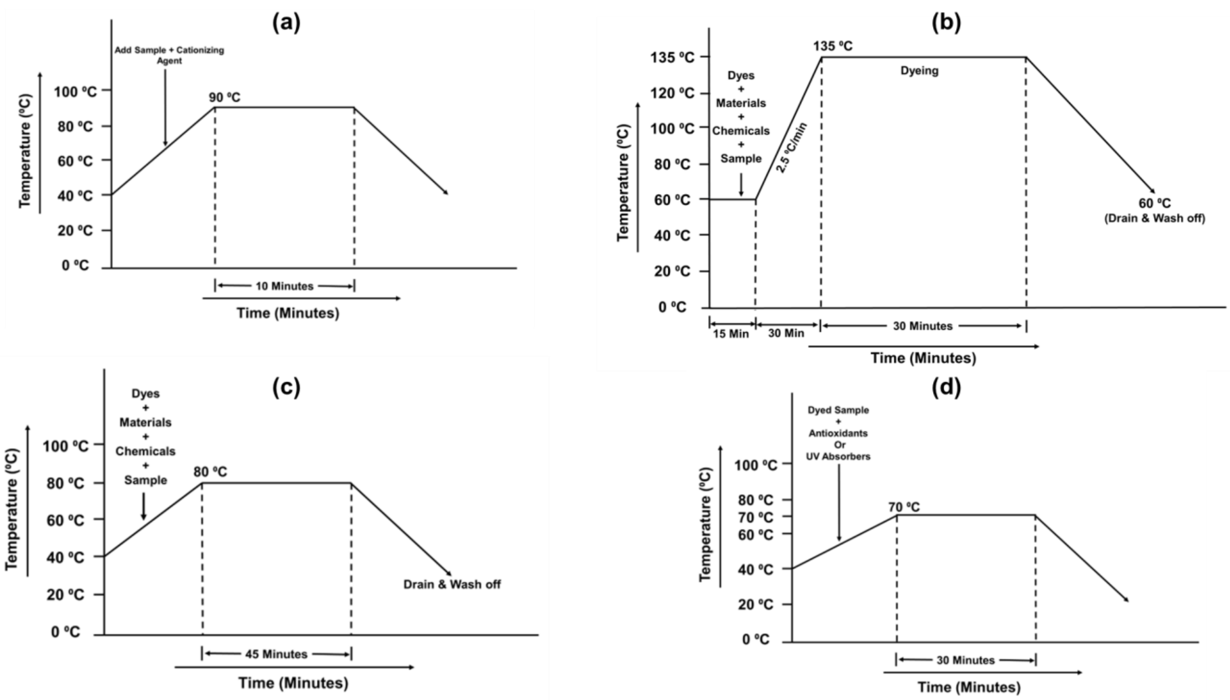


Figure 2 Process Sequences of (a) cationization process (b) polyester dyeing (c) cotton dyeing (d) antioxidants and UV absorbers application

The color strength and the dye absorption of the dyed samples were measured by K/S value by using color measuring instrument (spectrophotometer) which determines the K/S value of a given fabric by using the following formula:

$$\text{Color strength (K/S)} = \frac{(1-R)2}{2R}, \qquad (1)$$

where R = Reflectance percentage, K = Absorption and S = Scattering of dyes.

3 RESULTS AND DISCUSSION

3.1 Color fastness to washing of the 100% cotton fabric and cotton/polyester blended fabric

After washing, the color-changing of 100% cotton (Table 1) without chemical treatment showed the rating 3-4 and 4-4DB showed 4-5 grading (in Greyscale), however LAA, GA and 2-H4-MB treated sample was showing slightly more change of color as grading 4 in greyscale rating. On the other hand, the color staining result of the treated sample was improved significantly than the untreated/ original sample of fabrics. Between the two antioxidants, LAA treated fabric showed comparatively better improvement of color fastness than other antioxidants (GA). And for UV absorbers, both types of treated fabrics showed similar improvement of color fastness as compared with the original sample of fabrics; a similarly improved fastness also was observed by Z. Latif *et.al.* in their research [11].

On the other hand, the color changing of the cotton/polyester blended untreated sample (Table 2) after washing was 4 and same improved fastness (4-5) was found after treatment with all the antioxidants and UV absorbers. In case of the color staining result of the treated sample was improved equally than the untreated/ original sample of fabrics.

Table 1 Color fastness to washing of 100% cotton fabric

	Multi-fiber fabric (DW)	***Results***				
		Before chemical treatment	***After chemical treatment***			
		Original Sample	***LAA***	***GA***	***2-H4-MB***	***4-4 DB***
Color Change	------	3-4	4	4	4	4-5
Color Staining	Acetate	3-4	4-5	4-5	4-5	4-5
	Cotton	4	4-5	4	4-5	4-5
	Nylon	2	4-5	4	4	4
	Polyester	3-4	4-5	4-5	4-5	4-5
	Acrylic	4-5	4-5	4	4	4
	Wool	3	4-5	4-5	4-5	4-5

Table 2 Color fastness to washing of cotton/polyester blended fabric

	Multi-fiber fabric (DW)	***Results***				
		Before chemical treatment	***After chemical treatment***			
		Original Sample	***LAA***	***GA***	***2-H4-MB***	***4-4 DB***
Color Change	------	4	4-5	4-5	4-5	4-5
Color Staining	Acetate	3-4	4-5	4-5	4-5	4-5
	Cotton	4	4-5	4-5	4-5	4-5
	Nylon	3	4-5	4-5	4-5	4-5
	Polyester	3-4	4-5	4-5	4-5	4-5
	Acrylic	4	4-5	4-5	4-5	4-5
	Wool	3	4-5	4-5	4-5	4-5

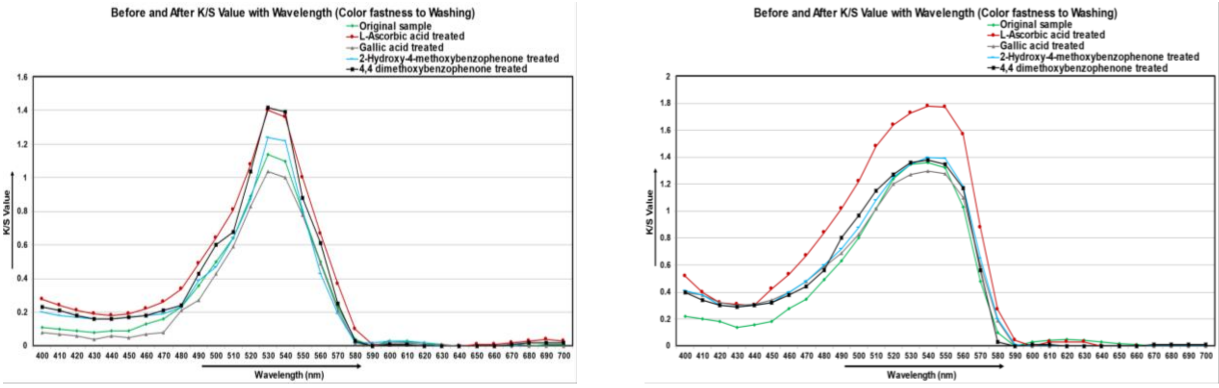


Figure 3 K/S value against wavelength of the color fastness to wash of (a) 100% cotton and (b) cotton-polyester blended fabric

Figure 3(a) explores that after washing process of 100% cotton fabric, the K/S value of treated sample like LAA, 4-4DB and 2-H4-MB was quite better than the original untreated dyed sample where K/S Value of the GA treated sample was a little bit less. On the other part, in cotton/polyester blended fabric (Figure 3(b)), all the treated samples are showed improved color strength than the original sample and among all the antioxidants and UV absorbers, GA's performance was a bit lower and LAA showed better color strength than others.

3.2 Color fastness to water of the 100% cotton fabric and cotton/polyester blended fabric

Table 3 Color fastness to water of 100% cotton fabric

	Multi-fiber fabric (DW)	*Results*				
		Before chemical treatment	*After chemical treatment*			
		Original Sample	*LAA*	*GA*	*2-H4-MB*	*4-4 DB*
Color Change	------	3-4	4-5	4-5	4	4-5
Color Staining	Acetate	3	4	4-5	4-5	4-5
	Cotton	3-4	4-5	4	4-5	4-5
	Nylon	3	4	4	4	4-5
	Polyester	3-4	4-5	4-5	4-5	4-5
	Acrylic	2-3	4-5	4	4	4
	Wool	2-3	4-5	4-5	4-5	4-5

Table 4 Color fastness to water of cotton/polyester blended fabric

	Multi-fiber fabric (DW)	*Results*				
		Before chemical treatment	*After chemical treatment*			
		Original Sample	*LAA*	*GA*	*2-H4-MB*	*4-4 DB*
Color Change	------	4	4	4	4	4-5
Color Staining	Acetate	4-5	4-5	4-5	4	4-5
	Cotton	4-5	4-5	4-5	4	4-5
	Nylon	4	4	4	4	4-5
	Polyester	4-5	4-5	4	4	4-5
	Acrylic	3-4	4	4-5	4-5	4
	Wool	4	4-5	4-5	4-5	4-5

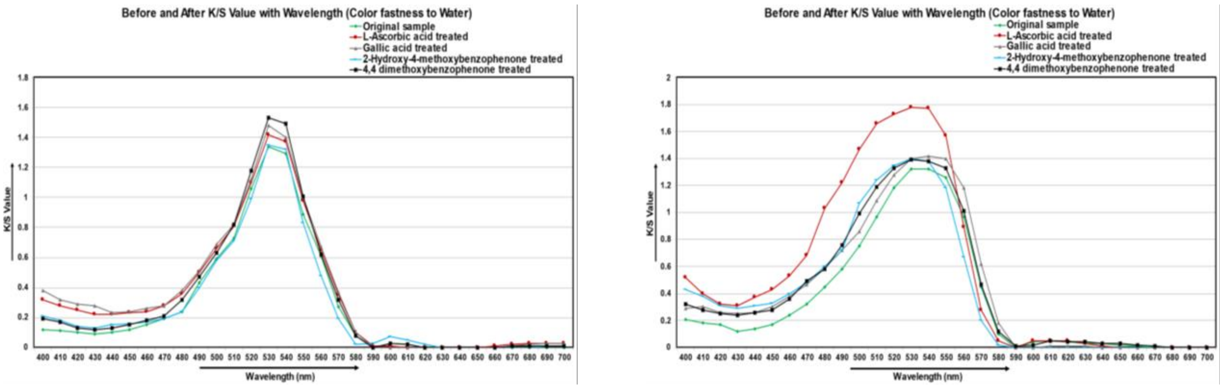
In the case of color fastness to water for 100% cotton (Table 3), changing of without chemical treated sample exhibited rating 3-4, and 4-4DB, LAA and GA treated samples rated similar 4-5 grading in greyscale. But 2-H4-MB treated sample showed a slightly changed color as grade 4. On the contrary, the color staining result was improved significantly than the untreated sample. Between two antioxidants, LAA treated sample had minimal improved color fastness than GA and 4-4DB performed better color fastness to water than 2-H4-MB sample. More or less alike performance of other antioxidants and UV absorbers were observed in P. Thiagarajan and G. Nalankilli's findings [12].

Conversely, color changing tendency in case of color fastness to water of cotton/polyester blend (Table 4) was nearly same (4) for all treated and untreated samples except 4-4DB sample (4-5). The color staining properties were quite similar to the 100% cotton samples. There weas no significant deviation in performance of both antioxidants and UV absorbers.

Color fastness to water test of 100% cotton fabric (Figure 4(a)) revealed the K/S value of treated sample like LAA, 4-4-DB and GA which were enhanced than 2-H4-MB and untreated or original dyed sample. Among the treated samples, the K/S Value of 4, 4-DB treated samples possessed higher than the others samples. Besides, LAA evidenced the highest color strength than other treated samples where 2-H4-MB and GA treated samples' k/s values were moderate to untreated samples in cotton/polyester blended fabrics (Figure 4(b)).

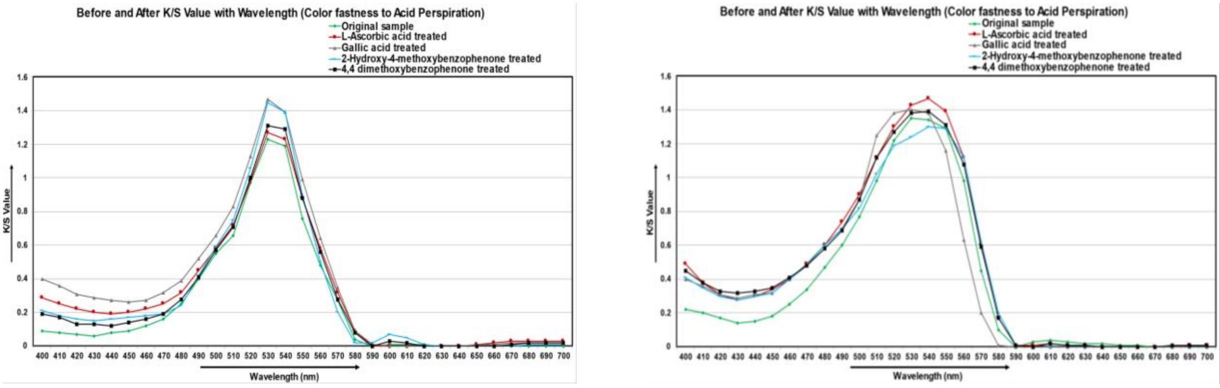
3.3 Color fastness to acid perspiration of the 100% cotton fabric and cotton/polyester blended fabric

In color fastness to acid perspiration of 100% cotton fabric (Table 5), untreated sample color changing value was 3-4 where 4-4DB, LAA showed an improved grading as 4-5 but GA and 2-H4-MB treated samples showed slightly more color change at 4 in greyscale. In case of color staining result, a significant development was found after chemical treatment which is 4-4DB treated sample exhibited the best fastness rating (4-5) of other chemicals.



(a) (b)

Figure 4 K/S value against wavelength of the color fastness to water of (a) 100% cotton and (b) cotton-polyester blended fabric



(a) (b)

Figure 5 K/S value against wavelength of the color fastness to acid perspiration of (a) 100% cotton and (b) cotton-polyester blended fabric

Table 5 Color fastness to acid perspiration of 100% cotton fabric

	Multi-fiber fabric (DW)	***Results***				
		Before chemical treatment	***After chemical treatment***			
		Original Sample	***LAA***	***GA***	***2-H4-MB***	***4-4 DB***
Color Change	------	3-4	4-5	4	4	4-5
Color Staining	Acetate	3	4-5	4-5	4-5	4-5
	Cotton	3-4	4-5	4	4	4-5
	Nylon	2-3	4	3-4	3-4	4-5
	Polyester	3-4	4-5	4	4-5	4-5
	Acrylic	2	4	4	4	4-5
	Wool	2-3	4-5	4-5	4-5	4-5

Table 6 Color fastness to acid perspiration of cotton/polyester fabric

	Multi-fiber fabric (DW)	***Results***				
		Before chemical treatment	***After chemical treatment***			
		Original Sample	***LAA***	***GA***	***2-H4-MsB***	***4-4 DB***
Color Change	------	4	4-5	4-5	4-5	4-5
Color Staining	Acetate	4-5	4-5	4-5	4-5	4-5
	Cotton	4-5	4-5	4-5	4-5	4-5
	Nylon	4	4-5	4-5	4-5	4-5
	Polyester	4-5	4-5	4-5	4	4-5
	Acrylic	4	4	4	4	4
	Wool	4	4-5	4-5	4-5	4-5

But when it came with the cotton/polyester blended fabric (Table 6), untreated sample showed more color change and color staining grading than 100% cotton fabric. Treated samples with antioxidants and UV absorbers were slightly upgraded (4-5) than untreated samples.

Figure 5(a) exposed the color fastness to Acid perspiration of 100% cotton fabric where the K/S value of treated sample like LAA, 4, 4-DB was slightly higher than untreated or original dyed sample and among the treated samples, the K/S Value of 2-H4-MB, GA treated samples were far elevated than the others samples. In the case of cotton/polyester blended samples (Figure 5.b), the K/S value of treated samples of LAA, GA, 4-4DB was exposed to slightly better results than original and 2-H4-MB treated samples.

3.4 Color fastness to alkali perspiration of the 100% cotton fabric and cotton/polyester blended fabric

Color fastness to alkali perspiration of 100% cotton fabric (Table 7) was improved suggestively after treated with antioxidants and UV absorbers. Color changing tendency of LAA, GA, 2-H4-MB was same (grade 4) where 4-4DB was a little higher to 4-5. Best color staining was observed for 4-4DB treated samples, even UV absorbers color staining grade was better than antioxidants.

Table 7 Color fastness to alkali perspiration of 100% cotton fabric

	Multi-fiber fabric (DW)	Results				
		Before chemical treatment	After chemical treatment			
		Original Sample	LAA	GA	2-H4-MB	4-4 DB
Color Change	------	3-4	4	4	4	4-5
Color Staining	Acetate	3-4	4	4	4-5	4-5
	Cotton	3-4	4	3-4	4	4-5
	Nylon	2	4	4	4-5	4-5
	Polyester	3-4	4-5	4	4-5	4-5
	Acrylic	2-3	4	4	4-5	4-5
	Wool	2-3	4-5	4	4-5	4-5

Table 8 Color fastness to alkali perspiration of cotton/polyester blended fabric

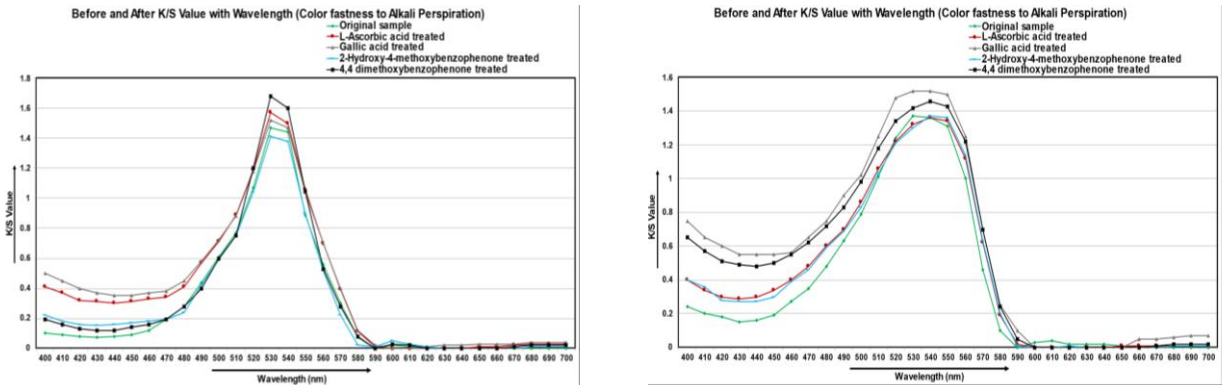
	Multi-fiber fabric (DW)	Results				
		Before chemical treatment	After chemical treatment			
		Original Sample	LAA	GA	2-H4-MB	4-4 DB
Color Change	------	4	4	4-5	4-5	4-5
Color Staining	Acetate	4-5	4-5	4	4	4
	Cotton	4-5	4-5	4	4-5	4
	Nylon	4	4-5	4	4-5	4-5
	Polyester	4-5	4-5	4-5	4-5	4-5
	Acrylic	4-5	4-5	4-5	4-5	4-5
	Wool	4-5	4-5	4-5	4-5	4-5

On the contrary, in cotton/polyester blended fabric (Table 8), no noticeable color changing and color staining variation was observed among treated and untreated samples. Compare to 100% cotton fabric findings, the fastness properties of original, LAA and GA teated samples of cotton/polyester blended fabrics were far better than 100% cotton fabric.

LAA and 4-4DB treated samples exhibited higher K/S value than other treated samples in color fastness to Alkali perspiration of 100% cotton fabric (Figure 6(a)). On the other hand, the color strength of LAA, GA and 4-4DB was improved than 2-H4-MB treated and untreated original sample (Figure 6(b)) of cotton/polyester blended fabrics.

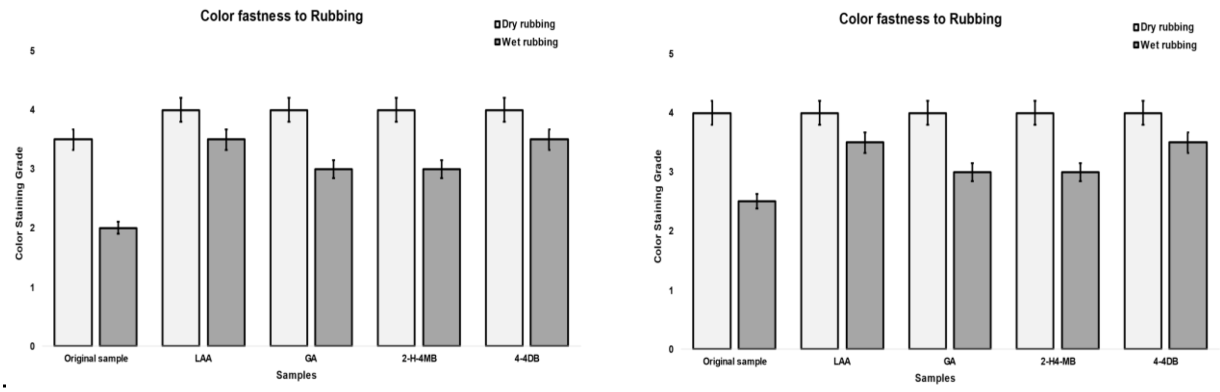
3.5 Color fastness to rubbing of the 100% cotton fabric and cotton/polyester blended fabric

Color fastness to dry and wet rubbing of both 100% cotton and cotton/polyester blended fabric are mostly same except for the 100% cotton original sample (Figure 7(a)) which rubbing grading is a little bit less than cotton/polyester blended fabric (Figure 7(b)). Though the dry rubbing grade (4) is similar for both the fabric types, the wet rubbing of GA and 2-H4-MB (grade 3) are a little poor than LAA and 4-4DB (grade 3-4). Error bars express the confidence level of each grading where error percentage is set at 5% which eventually leads to 95% confidence level.



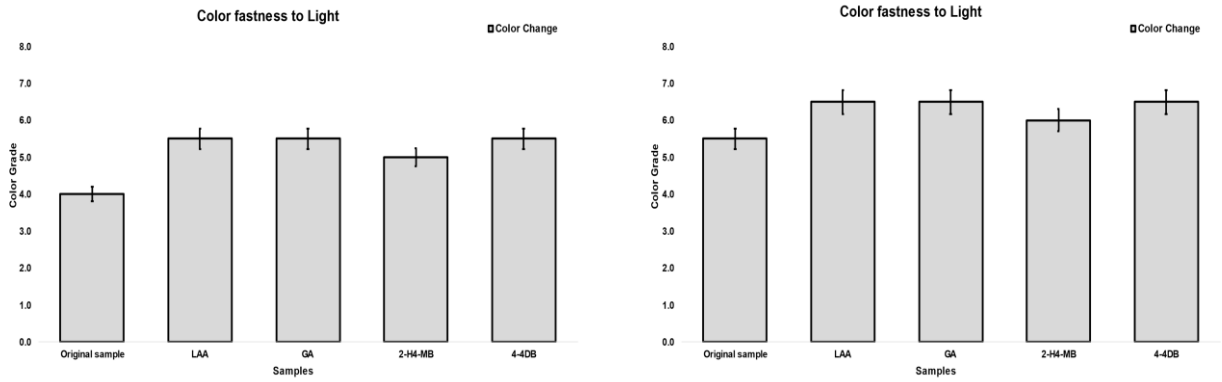
(a) (b)

Figure 6 K/S value against wavelength of the color fastness to alkali perspiration of (a) 100% cotton and (b) cotton-polyester blended fabric



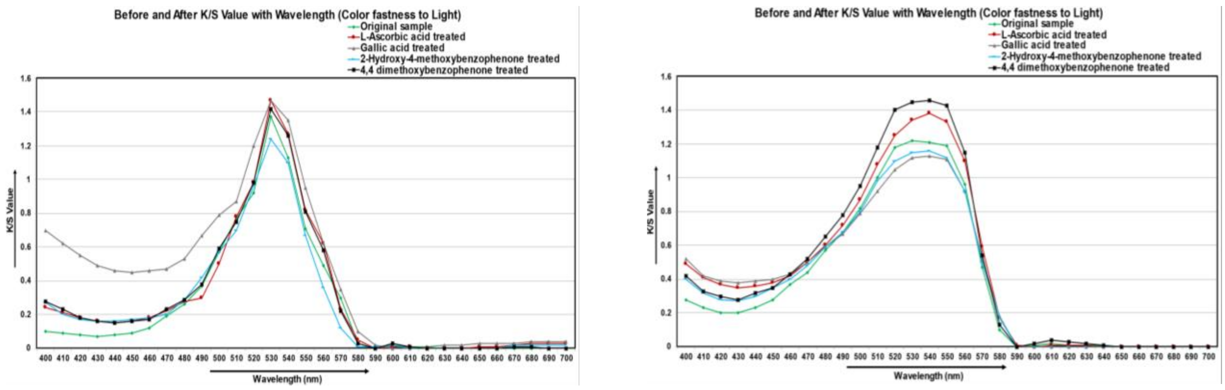
(a) (b)

Figure 7 Color fastness to rubbing of (a) 100% cotton and (b) cotton-polyester blended fabric



(a) (b)

Figure 8 Color fastness to light of (a) 100% cotton and (b) cotton/polyester blended fabric



(a) (b)

Figure 9 K/S value against wavelength of the color fastness to light of (a) 100% cotton and (b) cotton-polyester blended fabric

3.6 Color fastness to light of the 100% cotton fabric and cotton/polyester blended fabric

Color fastness to light for both 100% cotton and cotton/polyester blended fabric was improved after chemical treatment. Advanced fastness grade was observed in cotton/polyester blended fabric than 100% cotton (Figure 8(b)) for both treated and untreated samples. However, 2-H4-MB treated sample experienced a bit less fastness grading than other antioxidants and UV absorbers in both 100% cotton and cotton/polyester blended fabric. Error bar of color fastness to light is plotted within 95% confidence level where the error percentage of each grading is set at a maximum of 5%.

The color strength of 2-H4-MB treated sample was worse than other treated and untreated samples of 100% cotton fabric (Figure 9(a)). Specially GA showed an exceptional improved K/S value from 400-533 nm which also was investigated and proved by another research [23] where non-covalent bond-forming dyes/pigments showed enhanced color fastness to light of 100% cotton fabric.

But the presence of synthetic fiber in blended fabric (cotton/polyester), color strength of GA falls down noticeable for color fastness to light (Figure 9(b)). Not only that, LAA, 4-4DM showed higher K/S values than 2-H4-MB and GA treated samples.

4 CONCLUSION

Finishing of cotton and cotton-polyester blend fabrics with antioxidants and UV absorbers, all the chemicals show a great improvement in the color fastness to light properties as well as others washing, rubbing, water and perspiration properties. The overall K/S of two antioxidants, i.e., LAA and GA are 10% and 6% respectively which concludes that LAA is more preferable and acceptable than GA. At the same time, Between two UV absorbers, overall K/S value of 2-H4-MB and 4-4DB are 7% and 13% respectively. It ensures the performance of 4-4DB was comparatively better than 2-H4-MB. However, All the treated and untreated samples showed a color shifting tendency to red since the pigment color was light pink where presence of red color is higher than green and blue. The combined application with different ratio/percentage of antioxidants and UV absorbers for fluorescent pigment dyed fabrics will be studied in our further research.

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Authorship contribution statement: *Md. Khayrul Islam contributed to the design and implementation of the research, Md. Dulal Hosen carried out the analysis of the results and wrote of the manuscript, Shekh Md. Mamun Kabir generated the concept and co-supervised the project. Md. Azharul Islam supervised the entire research and compiled the final results and discussion.*

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FRAME MODEL OF UNIAXIAL STRETCHING OF 1×1 RIB KNITS

Tetiana Yelina, Liudmyla Halavska, Svitlana Bobrova, Volodymyr Shcherban and Tetiana Dzykovych

Kyiv National University of Technologies and Design, UKRAINE

yelina.tv@knutd.com.ua

***Abstract:** One of the nowadays challenges is the development of scientific sound models of knitwear deformations. The paper is devoted to developing an algorithm for constructing a frame model of rib 1×1 knits stretched in the course or wale direction. In the process of uniaxial stretching, the shape of the sample depends on the tensile force's orientation. A frame model of a deformed knitted structure, and an algorithm of construction of a mesh frame, are developed during the study. The frame model makes it possible to find coordinates of intermeshing points of every stitch. Then yarn characteristic points can be determined that, in turn, serve as input data for the construction of 3D model of rib 1×1 structure under uniaxial tensile deformations at the yarn level of detail. The study provides a graphical tool for formalization of geometric transformation that happen during 2D deformations of knitted structures, characterized by gradual change of the specimen's width crosswise to the loading direction. This model is intended to become a part of a general deformation model of knitted fabrics.*

***Keywords:** knitwear, frame model, deformation modeling, uniaxial stretching, rib 1×1.*

1 INTRODUCTION

Weft knitted structures such as plain and rib knits are the mostly used in knitwear production. One of the current challenges knitwear manufacturers face is the production of materials with predetermined properties, which can be achieved only with computer modeling and simulation. A sample's geometry can be represented in simulation software on different levels of detail, such as macro and meso levels. On a macro level of textile fabric's geometry, a section of a knitted fabric can be represented by its boundary, the surface's configuration, and thickness. Creation of such a model is easy to realize with modern 3D modelling systems. Fabric modeling at the yarn level is more complicated due to an unevenness of knitted structure's deformation. Scientifically-sound algorithms are needed to establish a relationship between the macro-level geometry of a knitted part and the yarn geometry of every stitch inside this part.

Scientific publications of recent years reveal different approaches to modeling knitted structures. S. Vasiliadis et al. address the issues of geometric modeling of the structure of rib 1×1 knits [1] and the application of the finite element method to simulate its mechanical behavior in the process of stretching. A mesomechanical model of knitted fabric, proposed by Chernous et al. [2], determines how the tension in the knitted structure depends on its extension and allows assessment of its mechanical characteristics upon the yarn properties. Different approaches to modeling the structure of basic knits are considered in papers [3-5]. The authors of [6] note that the structural characteristics of the textile reinforcement of polymer composites significantly affect their mechanical properties. Boussu et al. [7] emphasize the importance of the correct choice of textile reinforcement characteristics in analyzing mechanical and physical parameters of textile performs. In [8], Tercan considers the mechanical properties of rib 1×1 knitted fabric composite. Do et al. [9] consider a nonlinear multiscale simulation of the mechanical behavior of functionally graduated knitted structures. Cirio et al. proposed a model of knitwear behavior at a macroscopic scale [10], considering the yarn-yarn contacts as persistent. Kaldor et al. [11] developed a method of transition from the geometry of a polygonal surface, representing the surface of a knitted product to the geometry of the yarn, considering dynamics of deformation. A high-level visual similarity of basic weft-knitted structures, considering the deformation dynamics, was achieved in studies [10] and [11]. Nevertheless, the results obtained in these works cannot be extrapolated to knitwear from different raw materials unless a sufficient experimental base is gathered. Extensive experimental data describing the physical and mechanical characteristics of different fibers and threads is necessary, considering their influence on the behavior of different knitwear structures under various types of deformation and loading methods. The studies of fluid dynamic processes occurring in the structure of knitwear, realized with the use of modern systems of CFD analysis, are considered in [12] and [13].

An in-depth review of recent research in the field of three-dimensional modeling of the knitted structures shows that the problem can be solved

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only with the use of combined approaches, including, on the one hand, computer modeling, and on the other – development of specialized empirical databases.

2 SETTING OBJECTIVES

2.1 Basic definitions

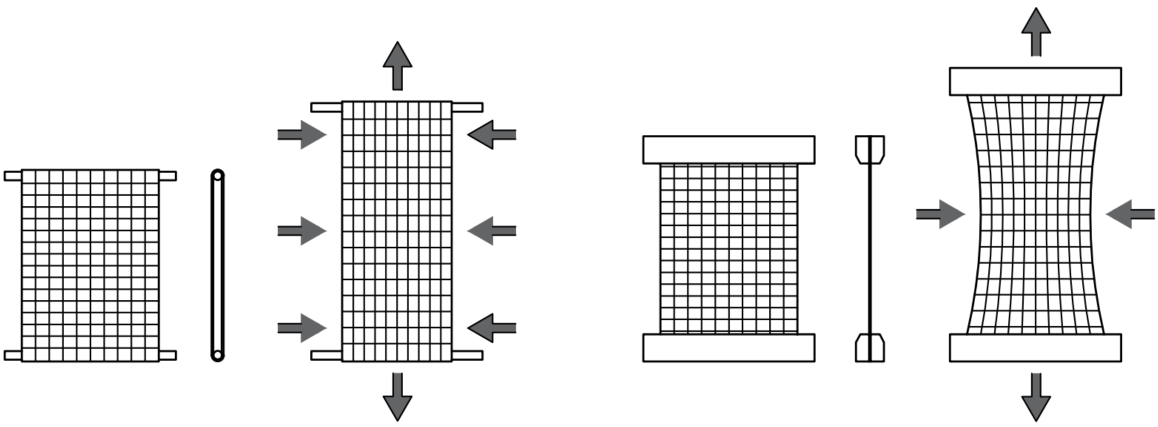
Determination of relative position, shape, and size of every stitch are key points of yarn-level 3D modeling of knitwear structures, considering deformations. A momentary deformation state of a knitted structure should be characterized by peculiarities of its inherent yarn configuration under given loading conditions. Tensile conditions can be different: uniaxial stretching, biaxial stretching, stretching when wrapping a cylinder of a larger diameter, point application of force, deformation on a spherical surface, and others. To create a scientifically-sound model of knitted structure deformation, different types of loading should be analyzed. Usually, a rectangular segment of a knitted fabric can be divided in a certain number of elementary rectangles, corresponding to stitches, and organized in wales and courses. Those elementary sections change during the tensile process, and often their boundary doesn't remain rectangular. Geometry of an elementary section depends on its place in the specimen and on the specimen's contour, and it is changing in the process of deformation. Uniaxial stretching can go along with uniform (Fig. 1(a)) or uneven (Fig 1(b)) transformation of elementary contours. Yarn geometry for uniform transformation has been described in [13]. The present paper aims to describe the case of gradual stitch frame geometry's transformation, as shown in Fig. 1(b).

Rib knitted parts are often submitted to uniaxial deformation. One of the deformation types is uniaxial stretching of a plane part, fixed between two clamps. This study develops a frame model of rib 1×1 knit under uniaxial wale wise and course wise stitching, suitable to imitate the processes of knitted fabric stretching in a tensile testing machine using strip method. In this study we consider mechanisms of transformation of a knitted structure under the action of stretching efforts, which are characteristic for so-called conventionally non-elastic yarns. During the knitting process, they are stretched by no more than 2%. In the process of operation of the products, the stretching of such threads usually does not happen.

Requirements for geometric objects representing the central line of the thread and its cross-sections are formulated by Bobrova et al. [14]. A frame model of knitwear suggested in [15] forms a mathematical description of the transformation of knitwear structural characteristics during the deformation process.

2.2 Variables and designations

Considering the heterogeneity of real knitted fabric geometry, some assumptions should be made from the very beginning. We assume that a knitted sample has a rectangular shape in an undeformed state, when laid out on a plate horizontal surface and consists of $m \times n$ elementary rectangular sections, arranged in wales and courses, corresponding to the knitted stitches. Then m is the number of wales in the specimen (including the wales of both purl and knit stitches) and n is the number of courses. For both wale wise (Fig. 2(a)) and course wise (Fig. 2(b)) stretching we take into consideration only lines of stitches in the operational part of the specimen (between clamp's lines). The length of the sample L, designates its size along the stretching direction. Width, W is the size of the sample in the direction, perpendicular to stretching. We assume also, that during the tensile process the boundary of the specimen stays symmetric relative to its central vertical c_v and horizontal c_h axes (Fig. 2(c)). In Fig. 2c a transformation of 2D boundary of a rectangular specimen of a knitted fabric uniaxial deformation is shown.



(a) (b)

Figure 1 Transformation of knitted specimen's contour with uniform (a) and uneven (b) changing of separate stitchs' boundaries

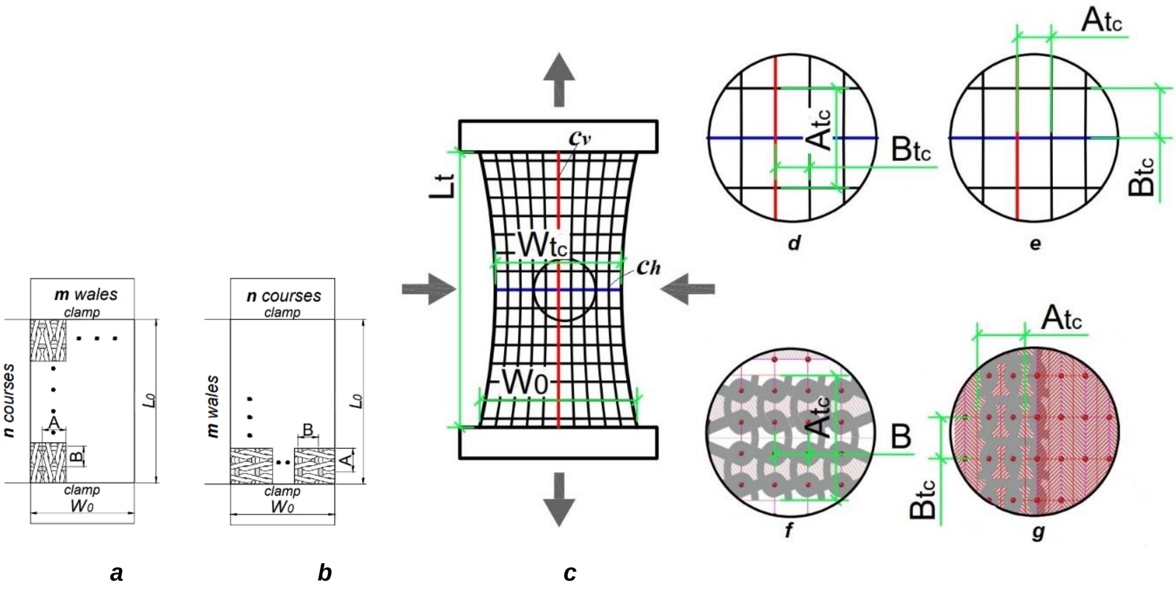


Figure 2 Transformation of 2D shape of a knitted fabric specimen under uniaxial deformation: basic size designation for walewise (a) and coursewise (b) stretching; transformation of the boundary of the rib 1×1 knit specimen (c); operational stitches spacing for corsewise (d, f) and walewise (e, g) stretching

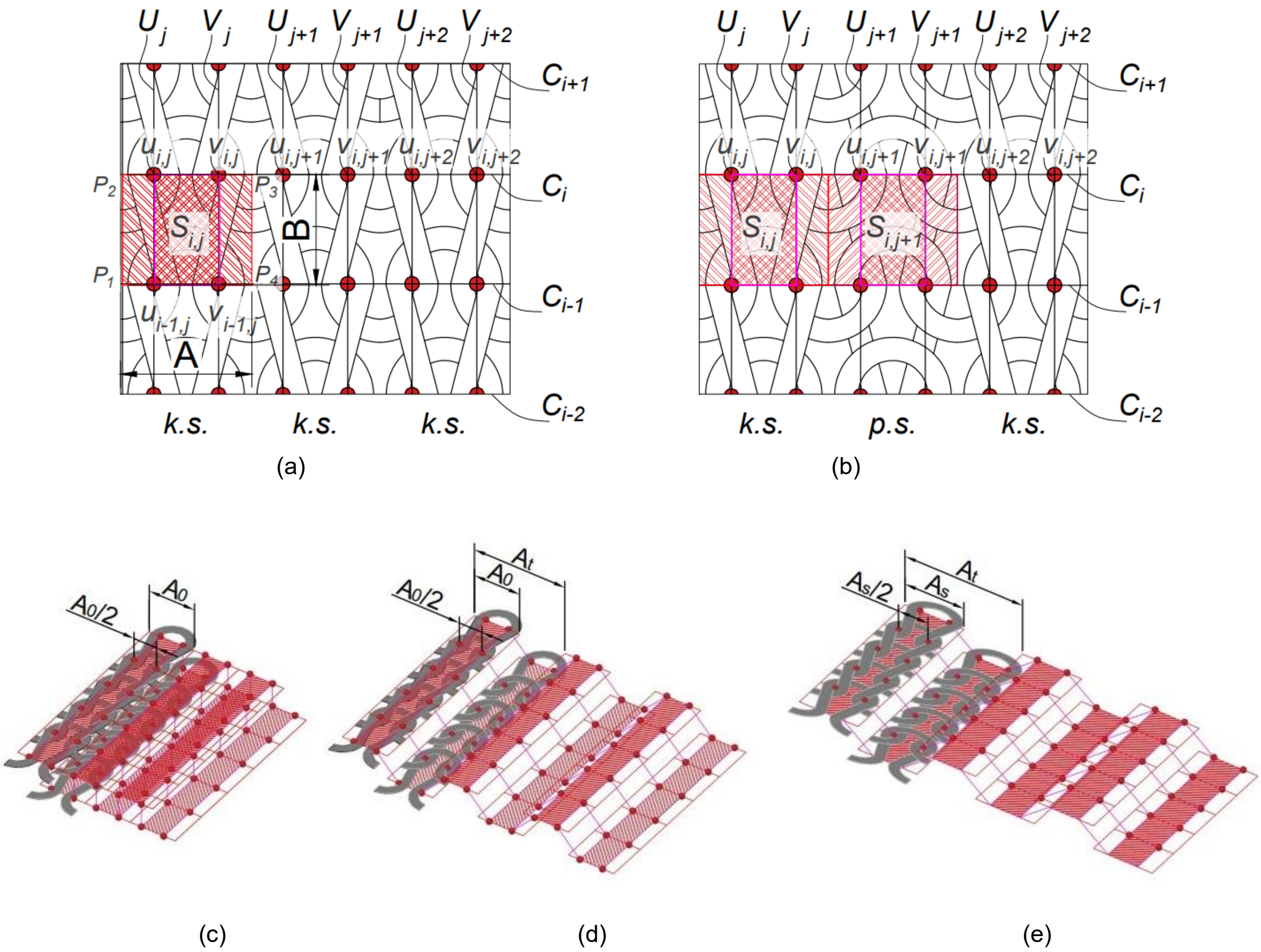


Figure 3 Location of intermeshing points in knitted structures: plain (a) and 1×1 rib knit (b)

Before the application of tensile forces, a specimen's width equals W_0 and its length L_0. In a certain deformation state t the length of the specimen can be designated as L_t. To simulate the transformation that happens during a strip-method tensile test, it should be taken into consideration that the width of the specimen W_t varies along its length. Let Wt_c is the width of a line of stitches, situated at the level of its horizontal central line c_h (Fig. 2(c)). Figure 2(d) and 2(f) show designation of the operational distance between adjacent wales of the same layer of stitches for course wise stretching. Analogously Figure 2(e) and 2(g) show these structure characteristics for the case of wale wise stretching.

In Fig. 3(a) an elementary section of the fabric, bounded by a rectangle with vertices at points P_1, P_2, P_3, and P_4, corresponds to a stitch $S_{i,\ j}$. In the deformation process, the unevenness of stretching explains that the geometry of the boundaries of elementary sections changes and may differ from the rectangular form. It is proposed to use the term *elementary limiting contour* $S_{i,\ j}$ to designate the quadrilateral P_1 P_2 P_3 P_4. For an undeformed plain knitted structure, the *elementary limiting contour* of a loop has the form of a rectangle. Its width equals the wale spacing, A, and its height is the course spacing, B. In the context of modeling the structural characteristics of knitwear, it is possible to use the term *intermeshing points* for the imaginary points, located in the centers of the loop intermeshing zones, where it is connected with the adjacent stitches, and the quadrilateral with vertices at these points – the *elementary inner contour* ($u_{i,j}$ $v_{i,j}$ $u_{i-1,j}$ $v_{i-1,j}$, Fig. 3(a)). Each stitch has four *intermeshing points*. These points are the vertices of its inner elementary contour. Fig. 3(a) shows the location of the structural elements of the plain knit frame model, and Fig. 3(b), respectively, the structural elements of the rib 1×1 frame model. The wales of the technical face are marked as *k.s.* (knit stitch), and the reverse ones as *p.s*. (purl stitch). Rib 1×1 knit structure contains alternating along the course knit and purl stitches as shown in Figure 3 (b,c,d,e). In Fig. 3(b) for convenience, the structure is shown in the deformation state, characterized by the elimination of the mutual overlapping of knit and purl loop wales. In the undeformed state an overlapping of purl stitches by knit stitches occurs and we see usually only stitches of one layer (Fig. 3(c)). During course wise stretching the overlapping slides down as shown in Figure 3(d) and 3(e). The stretching of a rib 1x1 knit, made of a non-elastic yarn, could be divided into 3 main stages: unfolding, yarn redistribution, and yarn elongation before destruction. Operational deformation belongs to the first (unfolding) stage. During course wise stretching distance between the same points of adjacent stitches of the same layer, A_t increases gradually (Fig. 3(d), 3(e)). However, the width of the loop, A_s doesn't grow at the first stage. We assume that in the free, undeformed state A_s=A_t=A_0 (Fig. 3(c)). It can be assumed as well, that the stage of unfolding can be determined by meeting condition (1). And condition (2) holds for both: yarn redistribution and yarn elongation stages.

$$A_t \leq 2A_0 \tag{1}$$
$$A_t > 2A_0 \tag{2}$$

It can be assumed also, that when the condition (2) is met, the width of knit stitches A_s equals to the width of purl stitches and condition (3) is met.

$$A_S = \frac{A_t}{2} \tag{3}$$

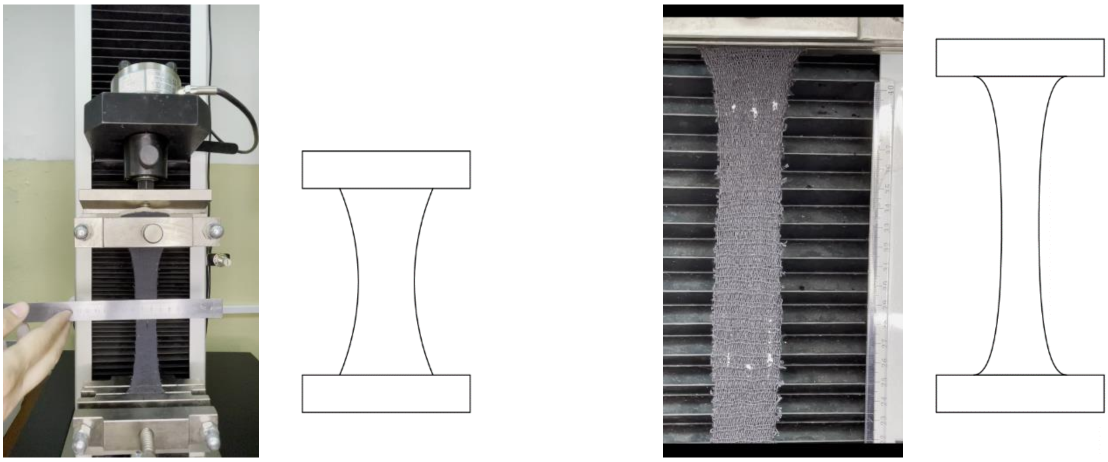
For mathematical description of the co-ordinates of the intermeshing points, the width of the *elementary inner contour* can be found as half *elementary limiting contour* width, as shown in Figure 3(e).

3 RESULTS AND DISCUSSION

A frame model of stretching provides a method to determine coordinates of vertices of elementary limiting and elementary inner contours of particular stitches of the knitwear sample after applying tensile forces. Their construction involves the use of such a set of input data: length of the sample at the moment of modeling, L_t, initial length L_0 and width W_0 of the sample, mm; wale spacing A_0 and course spacing B_0, mm, measured in a free state, number of wales m and courses n in the part of the sample, fixed between the lines of the tensile forces of application, minimal width Wt_c.

The main goal of this study is to provide an appropriate graphical tool for the formalization of the process of 2D deformation for the cases, when stretching in one direction evokes a gradual shrinkage in the crosswise size. In the formalization study the minimal width Wt_c for a certain deformation state t can be assessed experimentally as well as the numbers of stitches in wales and courses of the specimen. For future development of the model it can be calculated as it was suggested in paper [16]. The change in the sample's shape depends on the way the tensile force is applying. Figure 4 shows rib 1×1 knit samples in the process of walewise (Fig. 4(a)) and coursewise (Fig. 4(b)) stretching.

We assume that the coordinate system is located in the geometric center of the sample. Another assumption is taken that the change in size and configuration of the elementary contours occurs symmetrically to the central axes c_h and c_v (Fig. 2(c)). For wale wise stretching equations (4) and (5) can be written down.



(a) (b)

Figure 4 Changing of geometrical parameters of samples of 1×1 rib knits while wale wise (a) and course wise (b) stretching

$$A_{tc} = \frac{2W_{tc}}{m} \quad (4)$$

$$B_{tc} = \frac{L_t}{n} \quad (5)$$

For course wise stretching equivalences (6) and (7) can be used.

$$A_{tc} = \frac{2L_t}{m} \quad (6)$$

$$B_{tc} = \frac{W_{tc}}{n} \quad (7)$$

The fourth step of the algorithm involves determining the length of curves approximating the stretching-oriented sides of the elementary contours. When wale wise stretching, the lines U_j and V_j, oriented in the loading direction, take the form of arcs (Fig. 5(a)). Lines C_i are oriented along the stretching direction in the case of course-wise stretching. They can be described as second-order Bezier curves (Fig. 5(b)). The radii of the arcs U_j and V_j can be found by formula (8).

$$r_{uj} = \frac{(h^*)^2 + \Delta w_{uj}{}^2}{2\Delta w_{uj}}, \quad (8)$$

where h^* is the half length of the deformed sample $h^*=L_t/2$ (Fig. 5(a)); Δw_{uj} is the height of the arc segment U_j (Fig. 5a).

For the arc segments indicated in Fig. 1 and Fig. 3 as V_j in expression (9) the subscript of the variable Δw changes from u to v.

We can write that for each loop wale j the length of the arc L_{uj}

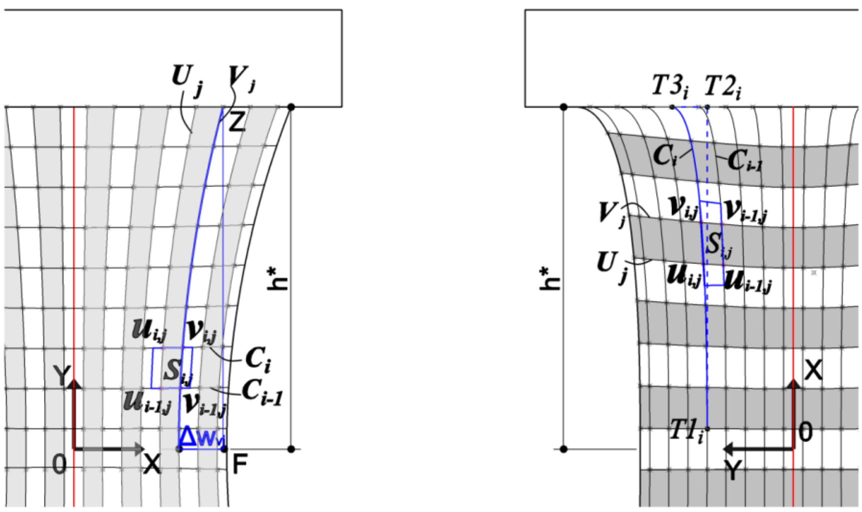
$$L_{uj} = \frac{\pi r_{uj} \alpha_{uj}}{180}, \quad (9)$$

where r_{uj} – radius of the arc U_j and αuj is its central angle.

The equation of the Bezier curve has the form (10).

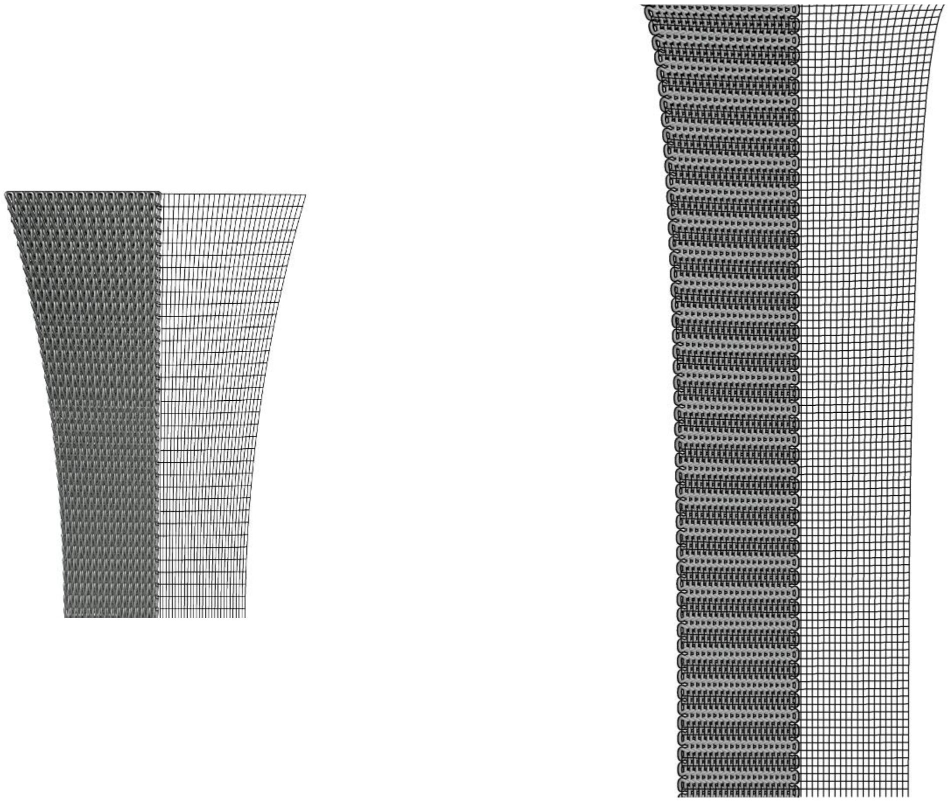
$$P(u) = \sum_{i=0}^{q} \binom{q}{i} u^i (1-u)^{q-i} P_i \quad (10)$$

This provides realistic 3D modeling of knits deformation (Fig 6).



(a) (b)

Figure 5 Mesh frame of the sample stretched along the loop wales (a) and courses (b)



(a) (b)

Figure 6 Mesh frame and 3D model of the specimens of rib 1×1 knit, stretched along the loop wales (a) and courses (b)

In the coordinate system of the sample for each series $i \in [0 \cdots .n / 2]$ there are points $T1_i$ ($x1_i$, $y1_i$), $T2_i$ ($x2_i$, $y2_i$), $T3_i$ ($x3_i$, $y3_i$), which define the curve (Fig. 4(b)), limiting the zones of a particular course. Coordinates of these points can be found using the following mathematical expressions:

$$x1_i = \frac{A_{max}}{2}; y1_i = iW_{el_{2_{min}}} + \frac{W_{el_{2_{min}}}}{2} \quad (11)$$

$$x2_i = h^*; y2_i = iW_{el_{2_{min}}} + \frac{W_{el_{2_{min}}}}{2} \quad (12)$$

$$x3_i = h^*; y3_i = iB + \frac{B}{2} \quad (13)$$

Each curve's C_i, length L_{ci} can be determined using special algorithms embedded in universal computer-aided design systems.

The next, fifth step of the algorithm involves determining the lengths of the elementary curves.

Then, for each intermeshing point lying on the curve, processed at the current step of the algorithm, the transition from its parameters to the coordinates is performed using special functions.

The use of the above algorithm allows considering the peculiarities of transforming the knitted structure in the process of stretching along the wales and courses to implement three-dimensional modeling systems that provide the ability to display the dynamics of deformation of knitwear under tensile forces.

4 CONCLUSIONS

The development and production of materials with predetermined properties is one of the current challenges facing knitwear manufacturers. This task can be resolved only using computer modeling and simulation. Analysis of scientific publications in the field of three-dimensional modeling of knitted structures deformation shows that it can be solved only with the use of combined approaches, including, on the one hand, computer modeling, and on the other - specialized empirical databases. A geometric model providing an algorithmic basis for mathematical description of the yarn topology of stretched specimens has been developed. During the study, an algorithm for constructing a mesh frame of 1×1 rib knits stretched in one of the orthogonal directions is proposed. The frame model rib 1×1 uniaxial stretching and the algorithm of construction of a grid-frame, offered in this paper, form a basis for automated detection of coordinates of characteristic points of every single stitch in a deformed structure. These points are used as input data to construct a three-dimensional model of deformed knitwear at the yarn scale.

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THE INFLUENCE OF CORE – SHELL RATIO ON CHARACTERISTICS OF MICROCAPSULES CONTAINING CINNAMON ESSENTIAL OIL APPLIED TO AROMATHERAPEUTIC TEXTILES

Chu Dieu Huong, Dao Thi Chinh Thuy and Nguyen Thi Tu Trinh
School of Textile-Leather and Fashion, Hanoi University of Science and Technology, Dai Co Viet street 1, Hanoi, VIETNAM
huong.chudieu@hust.edu.vn

Abstract: *Microencapsulation is one of the techniques to prepare the functional textiles. In this paper the essential cinnamon oil loaded microcapsules were prepared by solvent evaporation method. In the microencapsulation process, the core - shell ratio was changed by altering the cinnamon oil content in four levels of 0.15, 0.25, 0.35 and 0.45 g while the other components remained unchanged. The microcapsule characteristics including shape and morphology, size and size distribution, microencapsulation efficiency in dependence on the core-shell ratio were investigated. The antimicrobial capacity and the fragrance durability of interlock knitted fabric coated with the elaborated microcapsules were evaluated. The results showed that cinnamon oil was microencapsulated successfully in the spherical microcapsules. When the cinnamon oil content increased, the microcapsule size decreased and the size distribution became broader, the microcapsules were more porous and more aggregate, the fragrance intensity of the fabric treated with microcapsules increased while the activity against E. coli bacteria decreased. According to the results, the microcapsules elaborated with 0.15 g of cinnamon oil was recommended for the treatment of interlock cotton knitted fabric to apply in aroma and antimicrobial textiles.*

Keywords: *Microencapsulation, solvent evaporation technique, fragrance textile, antimicrobial textile, healthcare textile, interlock knitted fabric.*

1 INTRODUCTION

Today the development of technologies and the rise in environment protection demand orient to the innovation of many new, cleaner, and greener techniques in textile processing. That leads to find the application of microencapsulation in many textile fields such as phase-change materials, fragrance finishes, fire retardants, polychromic and thermo-chromic microcapsules (color - changing technology), antimicrobials, counterfeiting… [1]. The microencapsulation has become a prominently effective technique which enhances the property imparted to the fabric and assures its durability. Microencapsulation is a technique to prepare the tiny particles that contain an active agent in a core and a polymer material surrounded or shell that can limited the liberation of active agent. Microcapsules help to control release of active compounds (sustained, delayed, or targeted release). Besides, they also help to increase the stability of the active agent against oxidation or deactivation by the environment. Other advantages are masking odor, taste, and some side effects of active agents.

Fragrant textile products using the microencapsulation techniques were the subjects of many researches [2-4]. Especially, using microcapsules containing essential oil extracts for healthcare textiles such as antimicrobial and aroma therapeutic ones has been in concern of many studies [2-8].

The satin weave cotton fabrics have been coated with microcapsules containing oil extracted directly from neem leaves and Mexican daisy [5]. The microcapsules were made by simple coacervation method using the oil herbal extracts as active core material and gum acacia as wall material. The antibacterial test was conducted against the *Staphylococcus aureus* and *Escherichia coli*. In case of fabric direct treatment with oil herbal extracts, the antimicrobial efficacy was 100 % and 78.44 % against *Staphylococcus aureus* and *Escherichia coli* respectively. That values for the fabric treated with oil herbal extracts by microcapsules were 93.45 % and 55.21 %. However, the antimicrobial durability test showed the advantage of microcapsules in keeping the antimicrobial efficacy after washing compared to the direct treatment. In case of using neem extract, the bacterial reduction percentage after 15 washing cycles of fabric treated with microcapsules was 78 % and of the fabric directly treated with extract was 41%. For Mexican daisy extract, these values were 67 % and 37 % respectively. Especially, the direct treatment of fabric with oil herbal extracts but without cross linking agent led to the bacterial reduction percentage of 0 % after 15 washing cycles.

Karagönlü S. et al. elaborated the thyme oil loaded microcapsules for antimicrobial textile [6]. The microcapsules were made by complex coacervation method using thyme oil as active agent, gelatin and gum arabic as wall materials. The effect of microencapsulation parameters such as amount of oil and concentration of wall material on the encapsulation yield, particle size distribution and oil loading were investigated. It was reported that microencapsulation yield increased as the amount of oil increased, but the microcapsule shape became more irregular. Moreover, when the amount of wall material in solution increased, the formation of capsules diminished. The antimicrobial capacity of microcapsules and fabrics coated with microcapsules were determined. Antimicrobial activity test demonstrated that both microcapsules and fabrics treated with different microcapsule concentrations showed antimicrobial activity against E. coli, S. aureus and C. albicans microorganisms.

Many papers presented the aroma textile fabrics treated with microcapsules containing natural essential oil which prepared by coacervation and polymerization in situ [7-8]. The durable aroma finish on cotton fabric using microencapsulation technology was conducted by Bhatt L. [7]. In the research, the microcapsule gel was prepared by simple coacervation technique using four kinds of natural essential oil (basil oil, lemongrass oil, orange oil, tea tree oil) as core materials and the gelatin and gum acacia were the membrane of microcapsules. The most efficacy essential oil was considered as lemongrass oil and the research had used it for further works. Cotton fabric was padded with microcapsule gel containing lemongrass oil, the curing temperature and time were optimized at 80°C for 60 seconds. Then the washing durability of fragrance was evaluated by 20 experts through a survey technique using olfactory analysis. According to the research, fabric samples retained aroma for up to 30 wash cycles and the aroma intensity decreased when the number of wash cycles increased. Percentage of fragrance remaining on fabric before washing and after 5, 10, 15, 20, 25, 30 wash cycles were reported as 100 %, 100 %, 100 %, 95 %, 85 %, 75 % and 20 % corresponding. Microencapsulation of fragrance and natural volatile oils for application in cosmetic textile was studied by Tekin R. et al. [8]. The microcapsules with diameters ranging from 10 mm to 80 mm were prepared by interfacial polymerization technique using the fragrance Teddysoft as core material, PVA as surfactant and the polymer wall of microcapsules was the polyurethane. The hand towels were treated with fragrance by two techniques that were microcapsule coating and mixing the fragrance in fabric softener base. These hand towels passed the laundering cycles and were kept for a week to qualitatively evaluate the fragrance by nine perfumers and by headspace-GCMS analysis. Both the evaluations by the perfumers and by headspace-GC analysis showed that the hand towels washed with the fabric softener including more microcapsules smelt stronger after a week and more volatile compounds of the fragrance existed on the hand towels when the fragrance was encapsulated. The results demonstrated the efficacy of microencapsulation technique to maintain the fragrance for textile products.

The method to evaluate qualitatively and quantitatively the fragrance of textile products was mentioned in many researches [8], [9]. The team of experts was considered the best method because of the limitation of electronic devices to a great number of odorants. Stan M. S. et al. developed the textile materials for cosmetic purposes by applying sage melamine microcapsules containing essential oil to woven fabrics from different fiber compositions (100% cotton and 50% cotton/50% polyester) [10]. The authors investigated the influence of the overall finishing processes on the physical-mechanical characteristics such as mass per unit area, maximum force, elongation at maximum force, water vapor permeability and permeability to air. The small and normal influence on fabric physical-mechanical characteristics of the microcapsule treatment by pad-dry-cure method was shown. The test of biological properties indicated good biocompatibility and helped to conclude that the fabric treated by essential oils loaded microcapsules could be used for the cosmetotextile industry, providing certain biological properties, such as antioxidant, anti-inflammatory, antibacterial and flavoring effect.

Microencapsulation by situ polymerization was used for many different textile applications: antimicrobial essential oils of sage, lavender and rosemary for nonwoven textile shoe insoles; smell-based animal repellents for agricultural textiles, textiles for plant protection against damage caused by deer and rabbits; and paraffinic phase change materials (PCMs) for active thermal control garments [11]. In these cases, melamine formaldehyde prepolymer was often used as wall materials. In microencapsulation process, the technical parameters were manipulated to obtain desired characteristics of microcapsules: the microcapsule wall had to be partially permeable in the case of animal repellents in order to slowly release the essential oil in the microcapsule core by diffusion/evaporation and to achieve a prolonged release; but the microcapsule wall had to be impermeable and pressure-sensitive to achieve a targeted release during walking and no release when the shoes were not worn in the case of textile shoe insoles. Moreover, the mechanical resistance of microcapsule wall needed to assure a sufficient mechanical strength to withstand solid-liquid transitions of PCMs microcapsule core without leaking.

Beside the coacervation and polymerization techniques, the solvent evaporation method is used widely to elaborate microcapsules for many textile applications such as cosmetic and fragrant textile, medical textile, thermoregulating textile, antimicrobial and antifungal textile… [12]. Simple process and equipment as well as no use of toxic monomers are the main advantages of solvent evaporation method in comparison to coacervation and polymerization techniques. In the microencapsulation by solvent evaporation method, the mass ratio of active ingredient to polymer was reported to have marked effects on microcapsule morphology, especially the structure of the shell [13 -16]. In the research of Merabedini S. M. et al. [14], the plant oils were encapsulated in ethyl cellulose microcapsules by solvent evaporation method. The mass ratio of active ingredient to polymer varied in three levels of 60:40, 70:30, and 75:25. The results showed that the increase of core - shell ratio made the polymer shell more porous with much tinier holes on the surface. According to the authors, too much of active ingredient might increase the risk of active ingredient leakage due to the limited space inside the microcapsule and the shrinkage of the microcapsule during its solidification, resulting in the more porous polymer shell with an increasing number of holes.

This work aimed to study the ability of microencapsulating cinnamon essential oil by solvent evaporation method. The effect of core - shell ratio in the microencapsulation process on some microcapsule characteristics such as microcapsule shape and morphology, microcapsule size and size distribution, microencapsulation efficiency were investigated. The change in antimicrobial capacity and the fragrance durability of fabric treated with microcapsules according to the core - shell ratio was also in concern.

2 EXPERIMENTAL METHODS

2.1 Materials

Natural cinnamon oil supplied by Vietessence (Vietnam) was used in combination with miglyol 812 from Sasol as the core ingredients of the microcapsules. The Poly(ethyl acrylate-co-methyl methacrylate-co-trimethylammonioethyl methacrylate chloride) (Eudragit RSPO) of Evonik Industry (Germany) was used as the polymer shell of the microcapsules. The solvent of ethyl acetate with purity of 99.9% was supplied by Merk (Germany). Quillaja saponin S4521 from Sigma Aldrich (Germany) with molecular weight of around 1650 Da and contained 20 ÷ 35% of the sapogenin content was the surfactant. All chemical products have been used as providing without any more purification.

The cotton interlock fabric was knitted from cotton yarn with yarn count of Ne40 on circular knitting machine Fukahara (Japan). The knitting gauge was E18. The grey fabric was then scoured, bleached, and fully relaxed to get the dimensional stability. The fabric at fully relaxed state had the loop length of 2.83 mm, the course density of 188 courses/10cm, the wale density of 152 wales/10cm, and the weight of 240 g/m^2.

2.2 Methods

2.2.1 Microencapsulation

The organic phase was 15 ml of ethyl acetate solution containing cinnamon oil (varied with four levels of 0.15, 0.25, 0.35 and 0.45 g, miglyol 812 (0.4 g) and eudragit RSPO (1.25 g). Miglyol 812 was mixed with cinnamon oil in the microcapsule core to slow down the evaporation of essential oil from the microcapsule. That meant the core - shell ratio was changed in an increasing order of 1/2.3; 1/2; 1/1.7; and 1/1.5.

The organic phase was added dropwise to 100 ml aqueous solution of quillaja saponin (0.075 wt%) at stirring rate of 700 rpm for 10 minutes. At the end of the organic phase addition, the evaporation of ethyl acetate was initiated at reduced pressure (300 ÷ 350 Torr) for 5 hours under stirring at 600 rpm. The microcapsules were collected and washed three times by sedimentation and after that were stored as 100ml of suspension in distilled water in the lab fridge.

The microencapsulation efficiency was defined as the weight percentage ratio of the totally dry microcapsules to corresponding original materials. To determine this value, 20 ml of stored microcapsule suspension in water was sedimented to take out the solid microcapsules. After that, the solid microcapsules were dried in the lab fridge (relative air humidity of 20 % and temperature of 8°C) until the weight remained constants. The microencapsulation efficiency E [%] was calculated by (1):

$$E = \frac{M_{mc}}{M_{raw}} 100. \tag{1}$$

In which, M_{mc} was the weight of totally dried microcapsules and M_{raw} was the weight of corresponding original materials.

2.2.2 Microcapsule characterization

The microcapsule morphology was observed by the scanning electron microscope (SEM) JEOL JSM-7600F, USA at working conditions of 5.0 kV; LM mode; WD 8.0 mm. For the original microcapsules, a small drop of stored microcapsule suspension was placed on the sample holder of SEM equipment. For the fabric treated with microcapsules, a small piece of fabric was stick to the sample holder with the fabric surface containing microcapsules faced up. The observation was captured at magnifications of x100, x500 for the overview of whole microcapsule lot and at x10,000 for the details on the microcapsule polymer shell.

The mean diameter and the size distribution of microcapsules were determined by static laser - light scattering on Laser Scattering Particle Size Distribution Analyzer LA - 950 of Horiba. The broadness of the size distribution curve is represented by the span value, which was calculated as below:

$$Span = \frac{d(0.9) - d(0.1)}{d(0.5)} \quad (2)$$

In which $d(0.9)$ meant that 90% of the total particles were smaller than this size, the meaning of $d(0.1)$ and $d(0.5)$ were similar.

2.2.3 Fabric treatment with microcapsules

The circle fabric sample with diameter of 88 mm was placed at the bottom of plastic circle cup with the inner diameter as the same to that of fabric. 20 ml of stored microcapsule suspension in water was diluted with 20 ml of distilled water and then 40 ml of the diluted suspension was poured into the cup. The system was kept in place for the microcapsules to settle on the fabric surface. After 24 hours of sedimentation, the fabric impregnated with microcapsules was gently taken out of the cup and was dried in the lab fridge (relative air humidity of 20 % and temperature of 8°C) until the weight remained constants.

The microcapsule amount loaded by the fabric M [g] was calculated by (3):

$$M = M_2 - M_1 \quad (3)$$

With M_1 and M_2 were the weight in gram of the fabric before and after treatment with microcapsules, respectively.

The microcapsule loading efficiency of fabric MLE [%] was defined as (4) as below:

$$MLE = \frac{M}{M_0} 100\,. \quad (4)$$

In which, M was the microcapsule amount loaded by the fabric and M_o was the microcapsule amount used to treat the fabric, both were in gram. Because 20 ml in the whole of 100 ml of stored microcapsule suspension was used in the fabric treatment, M_o was equal to 1/5 of the total mass of the elaborated microcapsule lot.

2.2.4 Fragrance intensity evaluation

The fragrance intensity of fabric samples treated with microcapsules containing the cinnamon essential oil was evaluated by expert method in combination with the comparison to diluted sample method according to a magnitude scale procedure. The aqueous solution of microcapsule was gradually diluted by distilled water and was kept closing tightly in a small bottle of 10 ml. Eleven bottles were prepared with different ratio of microcapsule volume solution, which were 0 %, 10 %, 20 %, 30 %, 40 %, 50 %, 60 %, 70 %, 80 %, 90 % and 100 %, corresponding to the points of 0, 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100. The bottle of total distilled water was “no odor” and was considered as “blank”. Five experts were trained to participate in the evaluation of the fragrance. The result was the average value given by the five experts.

2.2.5 Antibacterial activity test

The antibacterial activity of microcapsule treated fabric was tested again E. coli Gram - negative gram bacteria according to the testing standard of FTTS-FA-002. A sample of untreated fabric was used as control sample. The result was represented by E. coli bacteria reduction [%] and each test was duplicated.

3 RESULTS AND DISCUSSIONS

3.1 Influence of core - shell ratio on microcapsule characteristics

The core - shell ratio is an important formulation parameter in the microencapsulation process because it has strong impact on the microcapsule characteristics such as shape and morphology, size distribution, microencapsulation efficiency and release behavior of essential oil from the microcapsules.

To investigate the effect of core - shell ratio on the microcapsule characteristics, the mass of cinnamon oil was changed in four levels, while this of the other components in the microencapsulation formulation remained unchanged. The four levels of cinnamon oil content were 0.15; 0.25; 0.35 and 0.45 g corresponding to the total core - shell ratio of 1/2.3; 1/2; 1/1.7; 1/1.5, respectively (the total core mass was the sum of cinnamon oil mass and miglyol 412 mass in the microencapsulation formulation). The microcapsule shape and morphology, the microcapsule size distribution and the microencapsulation efficiency were determined.

3.1.1 Influence of core - shell ratio on microcapsule shape and morphology

The microcapsule shape and morphology were observed by scanning electron microscope (SEM).

SEM images at Fig. 1 showed spherical microcapsules with size ranging from about 1 to 60 µm, which was reported to be suitable for textile applications [2], [3], [5], [15]–[18].

Some broken microcapsules could be seen in all four microcapsule lots M1 - M4 and they were often at large size of about more than 50 µm. That might be the result of very fast diffusion of ethyl acetate from emulsion droplets with bigger size to the aqueous phase during the emulsification and the evaporation steps. The solubility in water of ethyl acetate (90 g/l at 20 °C) is higher than that of halogenated solvents commonly used in the solvent evaporation method such as dichloromethane (20 g/l at 20 °C), so the fast diffusion rate of ethyl acetate from oil droplets to aqueous phase may disturb the emulsification step and induce the formation of broken microcapsules.

Besides, the microcapsule aggregates were shown clearly in the SEM images of all four microcapsule lots. The aggregates contained many small microcapsules adhering to the surface of bigger ones.

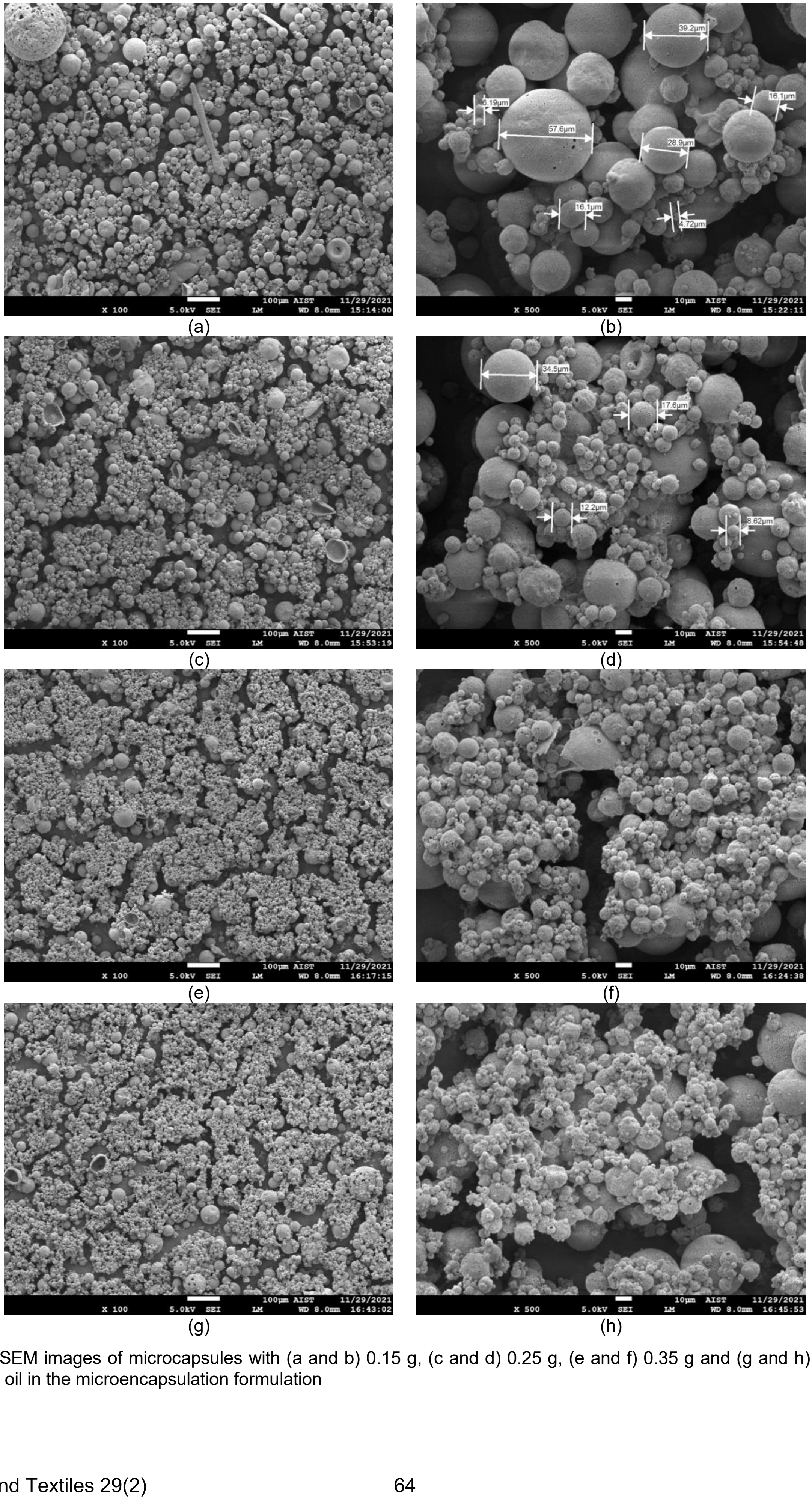

Figure 1 SEM images of microcapsules with (a and b) 0.15 g, (c and d) 0.25 g, (e and f) 0.35 g and (g and h) 0.45 g of cinnamon oil in the microencapsulation formulation

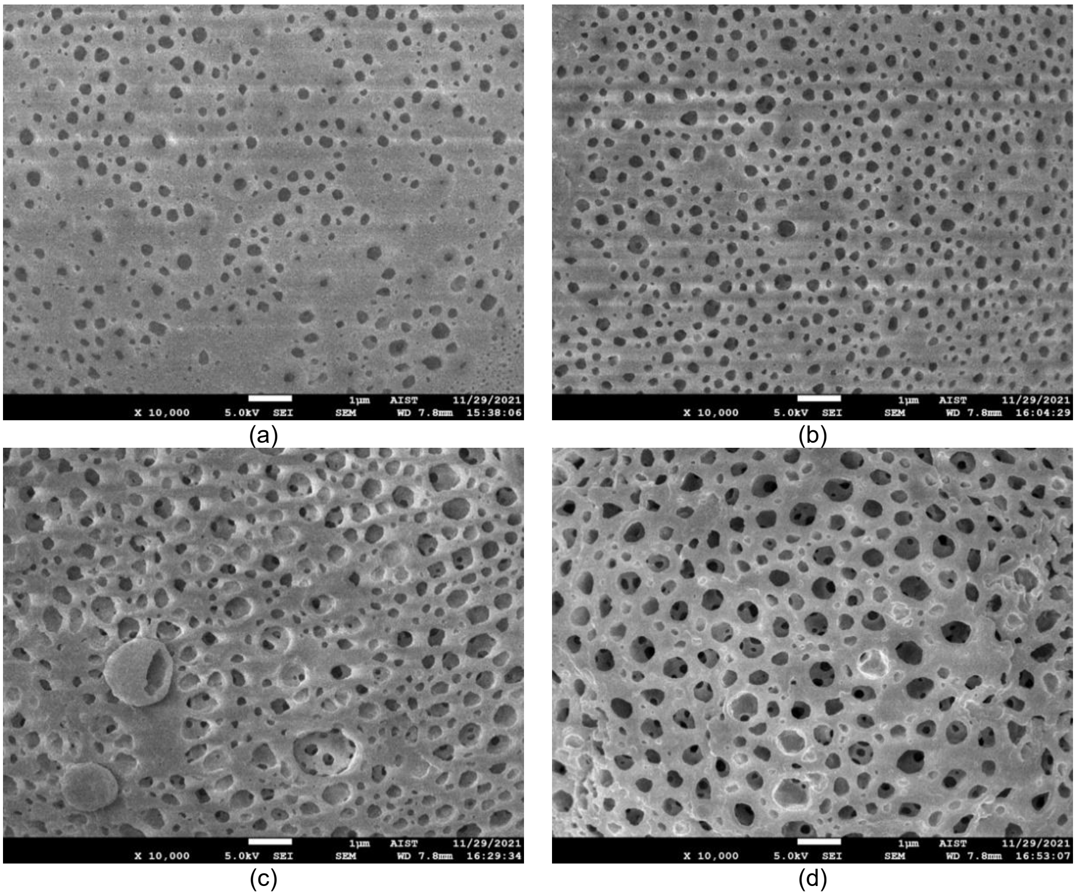

Figure 2 SEM images of the microcapsule polymer shell with (a) 0.15 g, (b) 0.25 g, (c) 0.35 g and (d) 0.45 g of cinnamon oil in the microencapsulation formulation

The aggregation was mentioned as the main feature of microcapsules elaborated by the solvent evaporation technique using ethyl acetate as volatile solvent [14], [19]. Since water solubility in ethyl acetate was 3.3 wt% at 20 ^{o}C, the oil droplets could absorb a considerable amount of water during the microencapsulation processes. Therefore, microcapsules might be soften because of the residual ethyl acetate and water migrating into the microcapsule surface, leading to the aggregation of adjacent microcapsules [19].

The SEM images at Fig. 1 also revealed the decrease in microcapsule size, the more porous microcapsule shell as well as the more deformed microcapsule shape when the cinnamon oil mass in the microencapsulation formulation increased. SEM images at the magnification of x10,000 (Fig. 2) helped to capture the microcapsule shell more detail and then confirmed the more porous polymer shell according to the increase of cinnamon oil mass. The more porous shell of microcapsules with higher amount of core material was also reported in some literatures [14]–[16] and it could be due to the lack of polymer shell to encapsule the high loading of oil. The porous polymer shell played an important role in controlling the release of active ingredient in the microcapsule core because the more porous the polymer shell, the easier and faster release of the essential oil from the microcapsule.

3.1.2 Influence of core - shell ratio on microcapsule size and size distribution

The microcapsule size and size distribution are important characteristics of the microcapsules because they determine the total surface area of microcapsules and therefore affect the release rate of cinnamon oil from the microcapsules.

The results of size and size distribution of microcapsules according to the amount of cinnamon oil were introduced in the Fig. 3 and Table 1.

Table 1 Mean size and span value of microcapsule lots M1 (0.15 g), M2 (0.25 g), M3 (0.35 g) and M4 (0.45 g) of cinnamon oil in the microencapsulation formulation

Lot	Amount of cinnamon oil [g]	Mean diameter [µm]	Span value
M1	0.15	48.69	1.6
M2	0.25	40.25	1.9
M3	0.35	33.52	1.7
M4	0.45	27.37	2.0

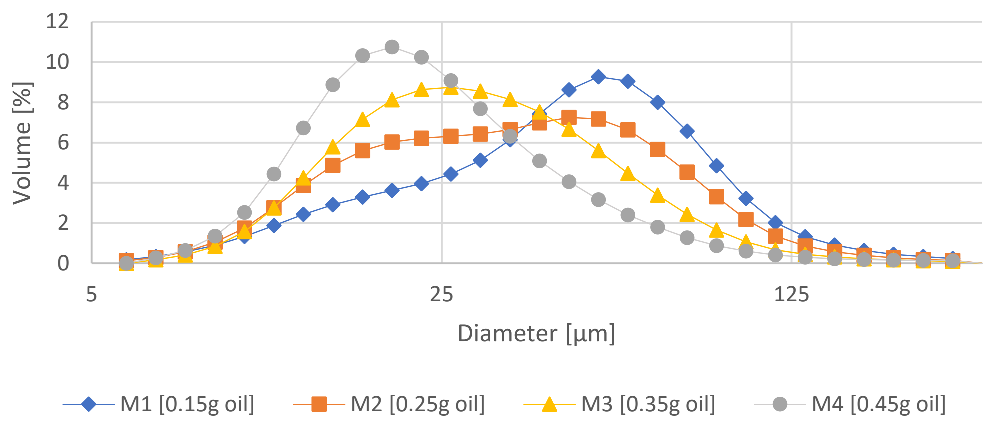

Figure 3 Size distribution of microcapsule lots M1 (0.15 g), M2 (0.25 g), M3 (0.35 g) and M4 (0.45 g) of cinnamon oil in the microencapsulation formulation

The results at Table 1 showed that elaborated microcapsules had the mean diameter of 27 ÷ 48 µm, which confirmed the microcapsule dimension revealed by the SEM images at Fig. 1. The size range of microcapsules containing cinnamon oil in this work was quite popular for textile applications and especially for the fragrant textiles [2], [3], [7], [13], [15], [16].

Moreover, the results at Fig. 3 and Table 1 indicated that when the amount of cinnamon oil increased, the mean size of microcapsules decreased clearly. The mean size of microcapsule lots with the cinnamon oil content of 0.15, 0.25, 0.35 and 0.45 g was 48.69, 40.25, 33.52 and 27.37 µm, respectively. The decrease in microcapsule size according to the increase of cinnamon oil amount also could be seen in the SEM images at Fig. 1. This trend was similar to results reported in another work about the microencapsulation of plant oil using the polymer shell of ethyl cellulose and also by the solvent evaporation technique [14]. The reason for this could be the decrease in the viscosity of dispersed phase when more cinnamon oil was used in the microencapsulation process. Because the rate of stirring blade during the emulsification was not altered (at 700 rpm), it would be easier to disrupt the emulsion droplets into smaller ones when the viscosity of the dispersed phase decreased.

Besides, it was remarkable that the increase of cinnamon oil amount induced the broader size distribution of microcapsules, which was shown by the increase of span value (Table 1) and the size distribution curves at Fig. 3. In general, the span value of four microcapsule lots was in range from 1.6 to 2.0 that was quite high, and the size distribution curves were all in type of bimodal ones as in Fig. 3.

3.1.3 Influence of core - shell ratio on the microencapsulation efficiency

Microencapsulation efficiency is the percentage ratio of the weight of elaborated microcapsules to the total weight of original materials, so it is also an important feature of a microencapsulation process. The microencapsulation efficiency corresponded to different amount of cinnamon oil was presented at Table 2:

Table 2 Microencapsulation efficiency according to the different amount of cinnamon oil in the microencapsulation formulation

Lot	Amount of cinnamon oil [g]	Microencapsulation efficiency [%]
M1	0.15	49.76
M2	0.25	49.15
M3	0.35	43.18
M4	0.45	37.24

The microencapsulation efficiency corresponded to four investigated levels of cinnamon oil content was in range from 37 to 50%. Within the scope of investigation, the microencapsulation efficiency tended to decrease slightly according to the increase in the cinnamon oil content. When cinnamon oil content increased 3 times from 0.15 g to 0.45 g, then the microencapsulation efficiency decreased about 1.4 times from 50% down to 37%. Too much of oil could induce the lack of polymer to make enough strong microcapsule shell, which led to not only the more porous polymer shell as mentioned above (Fig. 1 and 2) but also the lower microencapsulation efficiency.

3.2 Influence of core - shell ratio on the characteristics of the cotton interlock knitted fabric containing microcapsules

As discussed above, the core - shell ratio had effect on the main microcapsule characteristics such as shape and morphology, size, and size distribution. The microcapsule shape and size were important factors that determined the performance of textile containing microcapsules. Therefore, it was necessary to investigate the change in some characteristics of fabric treated with microcapsules when the core - shell ratio altered.

3.2.1 Influence of core - shell ratio on the surface morphology of fabric containing microcapsules

The surface of cotton interlock knitted fabric treated with microcapsules was observed by SEM and the results were shown in Fig 4.

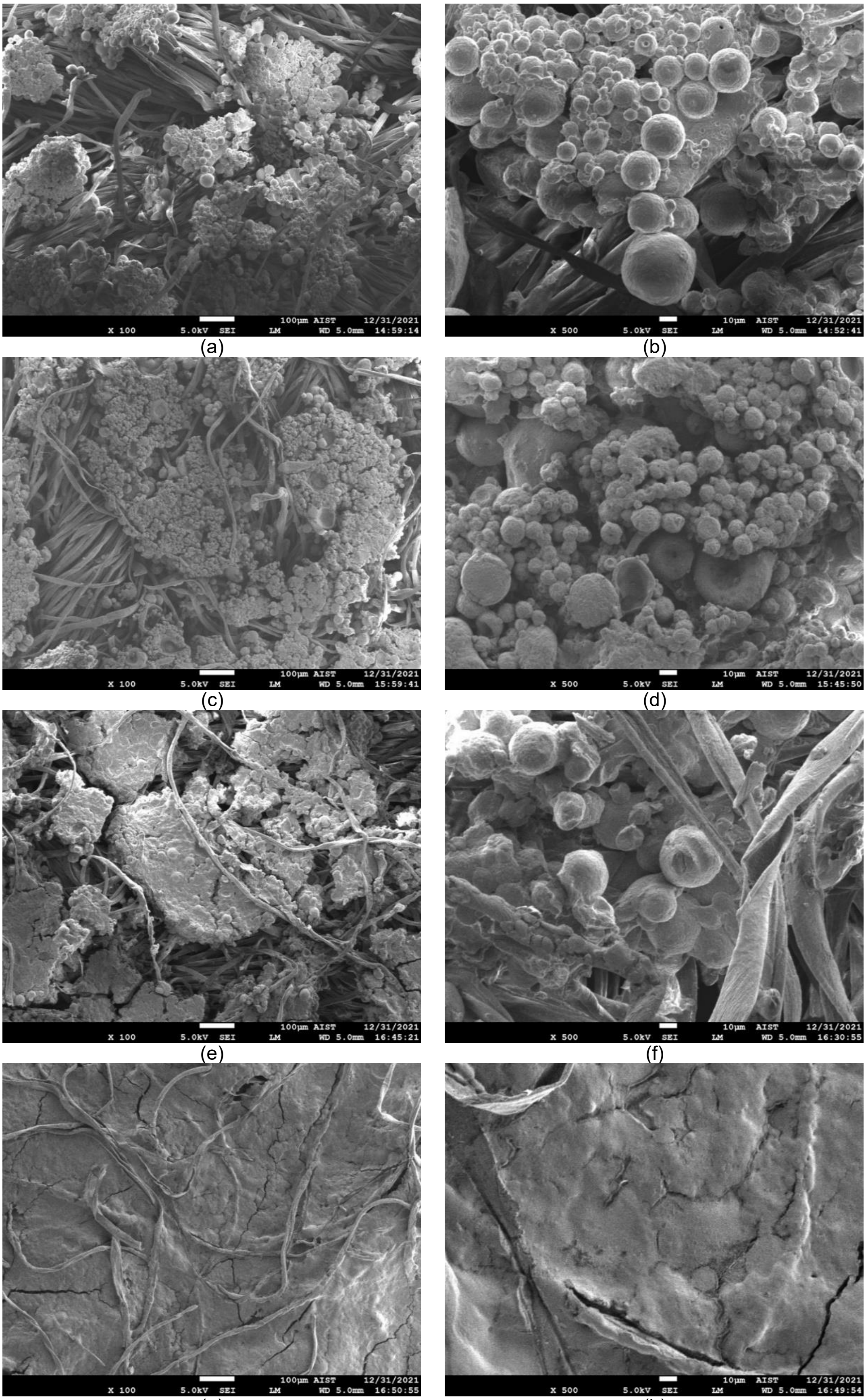

Figure 4 SEM images of cotton interlock fabric treated with microcapsules (a,b) – treated with M1 microcapsules (0.15 g of cinnamon oil); (c,d) – treated with M2 microcapsules (0.25 g of cinnamon oil); (e,f) – treated with M3 microcapsules (0.35 g of cinnamon oil); (g,h) – treated with M4 microcapsules (0.45 g of cinnamon oil)

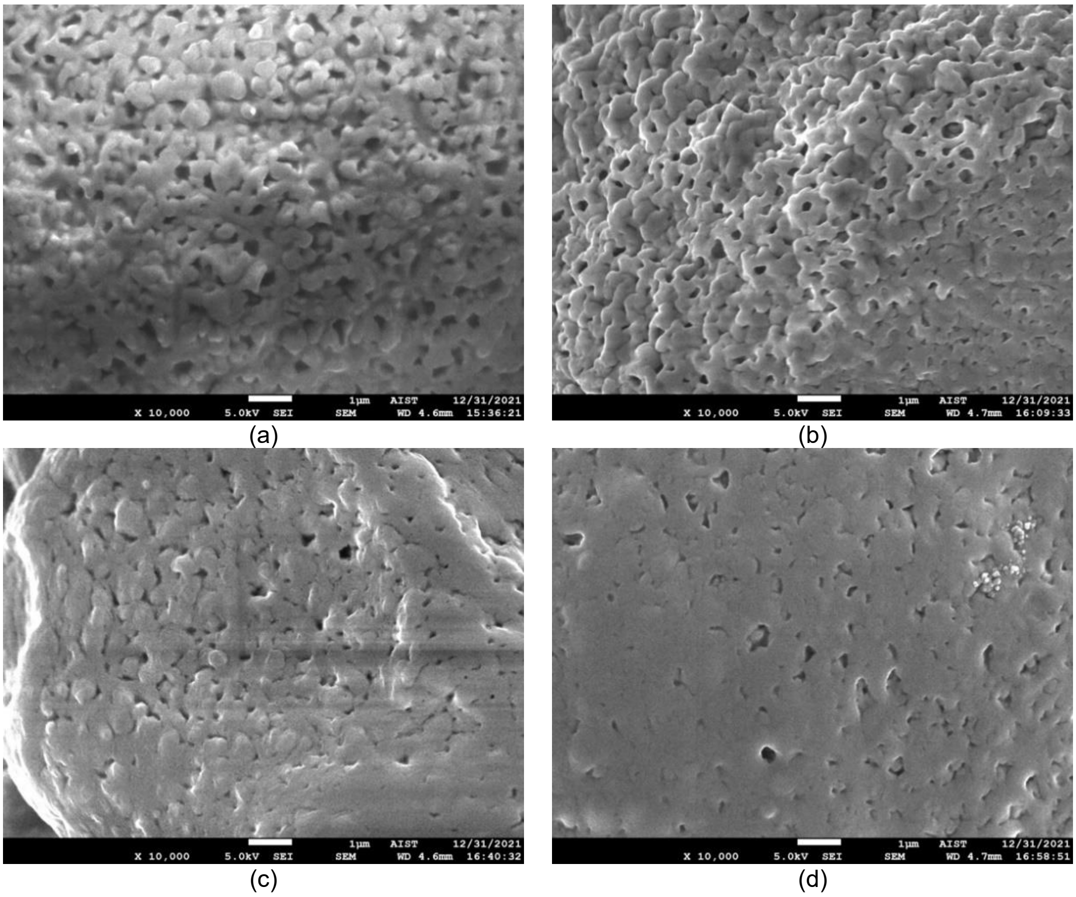

Figure 5 SEM images of the microcapsule polymer shell after the fabric treatment (a) M1 microcapsules (0.15 g of cinnamon oil); (b) M2 microcapsules (0.25 g of cinnamon oil); (c) M3 microcapsules (0.35 g of cinnamon oil); (d) M4 microcapsules (0.45 g of cinnamon oil)

SEM images at Fig. 4 helped to confirm the successful impregnation of microcapsules to the cotton interlock fabric. However, the distribution of microcapsules on the fabric surface was not uniform. Instead, the microcapsules tended to stick together and agglomerate into clumps. Moreover, the microcapsules dried on the cotton fabric surface (Fig. 4) deformed much seriously than being dried in original state (Fig. 1). The fabric surface structure, at the micro scale, was not completely flat but rather bumpy. Besides, as discussed above, the microcapsules elaborated by solvent evaporation technique using ethyl acetate solvent tended to make aggregate by themselves. When the microcapsules were impregnated to the fabric, the bumpy structure of the fabric surface enhanced the ability of the wet microcapsules to stick together and coalesce. During the drying stage, the wet microcapsules that coalesced were dried slower than individual ones, the polymer wall of microcapsules in the coalescence was weaker than that in the individual ones, so they became the deformed aggregate of microcapsules on the fabric surface after drying stage.

SEM images at Fig. 4 also revealed the more serious deformation of microcapsules with more cinnamon oil content in the elaborating formulation. Especially, in the case of M4 lot (with maximum oil content of 0.45 g), the microcapsules on the fabric surface deflated dramatically after the treatment. As described above, higher cinnamon oil amount contributed to the more porous polymer shell of microcapsules, which would be weaker and easier to be deformed during the impregnating and drying stage.

SEM images at Fig. 5 showed the wrinkle microcapsule shell after the fabric treatment with all four investigated microcapsule lots.

That could be the consequence of polymer diffusion during the drying stage in the fabric treatment process. The more oil content of the microcapsules, the weaker of the microcapsule shell, then the more serious diffusion of the polymer as observed by SEM. The diffusion of eudragit RSPO polymer shell also altered the structure of holes on the microcapsule surface. As compared to the SEM images of polymer shell before fabric treatment (Fig. 2), the holes became much smaller. Besides, on the cotton interlock fabric, the polymer shell of microcapsules with higher cinnamon oil content were less porous, which was in contrast with the tendency observed on the microcapsules alone (before the fabric treatment).

3.2.2 Influence of core - shell ratio on the fragrance intensity of fabric containing microcapsules

The cinnamon oil used in the microencapsulation formulation would affect the oil content in the fabric treated with microcapsules and then, would determine the fragrance intensity of the fabric. So, the influence of core - shell ratio on the fragrance intensity of microcapsule treated fabric was studied by varying the cinnamon oil content while the quantity of other materials in the microencapsulation process remained unchanged. The four levels of cinnamon oil content investigated were 0.15, 0.25, 0.35 and 0.45 g, corresponding to the microcapsule lots of M1, M2, M3 and M4.

The fragrance intensity of the fabric treated with microcapsules was determined by expert evaluation after the certain periods of 3, 5, 7, 9, 11, and 13 days. The average evaluation of five experts were represented in the Table 3 and Fig. 6.

As shown in the Table 3 and in the chart at Fig. 6, all four microcapsule lots did help to add the fragrance of cinnamon oil to the cotton interlock fabric. The fragrance intensity in the fabric decreased gradually by times but the odor was still being detected by the experts after 13 days.

It should be noted that the change in cinnamon oil content altered the microencapsulation efficiency. So, with the same volume of stored microcapsule suspension used to treat the fabric (20 ml, equal to 1/5 of the whole microcapsule lot), the microcapsule amount loaded by the fabric would be different. Therefore, the microcapsule amount loaded by the fabric as well as the microcapsule loading efficiency of the fabric were determined and the results was shown in the Table 4.

There was some variance in the microcapsule loading efficiency of fabrics treated with the different microcapsule lot and the dependence of this value on the cinnamon oil content did not follow a clear trend. This will be investigated and discussed more in further research.

Table 3 Fragrance intensity of microcapsule treated fabric after certain periods of time

Microcapsule lot used for fabric treatment	Cinnamon oil content [g] in the microencapsulation formulation	Fragrance intensity					
		After 3 days	After 5 days	After 7 days	After 9 days	After 11 days	After 13 days
M1	0.15	12.0	10.3	9.0	8.0	4.3	3.3
M2	0.25	17.0	11.1	8.8	6.3	3.1	1.8
M3	0.35	21.8	12.2	10.7	9.1	4.8	3.9
M4	0.45	26.3	15.8	13.3	11.3	6.3	4.0

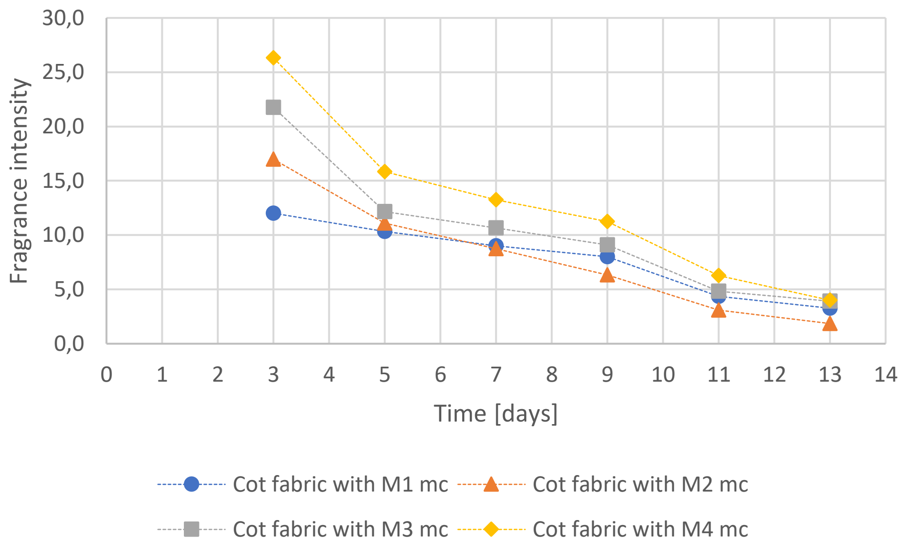

Figure 6 Fragrance intensity of microcapsule treated fabrics after certain periods of time

Table 4 The microcapsule amount loaded by the fabric and the microcapsule loading efficiency of the fabric

Microcapsule lot used for fabric treatment	Cinnamon oil content [g]	Microencapsulation efficiency [%]	Microcapsule amount used to treat the fabric [g]	Microcapsule amount loaded by the fabric [g]	Microcapsule loading efficiency of fabric [%]
M1	0.15	49.76	0.187	0.131	0.70
M2	0.25	49.15	0.194	0.148	0.76
M3	0.35	43.18	0.179	0.126	0.70
M4	0.45	37.24	0.162	0.102	0.63

Table 5 Fragrance intensity per gram of microcapsule loaded to the fabric

Microcapsule lot used for fabric treatment	Cinnamon oil content [g] in the microencapsulation formulation	Fragrance intensity per gram of microcapsule loaded to the fabric					
		After 3 days	After 5 days	After 7 days	After 9 days	After 11 days	After 13 days
M1	0.15	91.6	78.9	68.7	61.1	33.1	24.8
M2	0.25	114.9	74.9	59.1	42.8	20.8	12.4
M3	0.35	172.6	96.6	84.7	72.1	38.4	31.1
M4	0.45	258.2	155.2	129.9	110.3	61.3	39.2

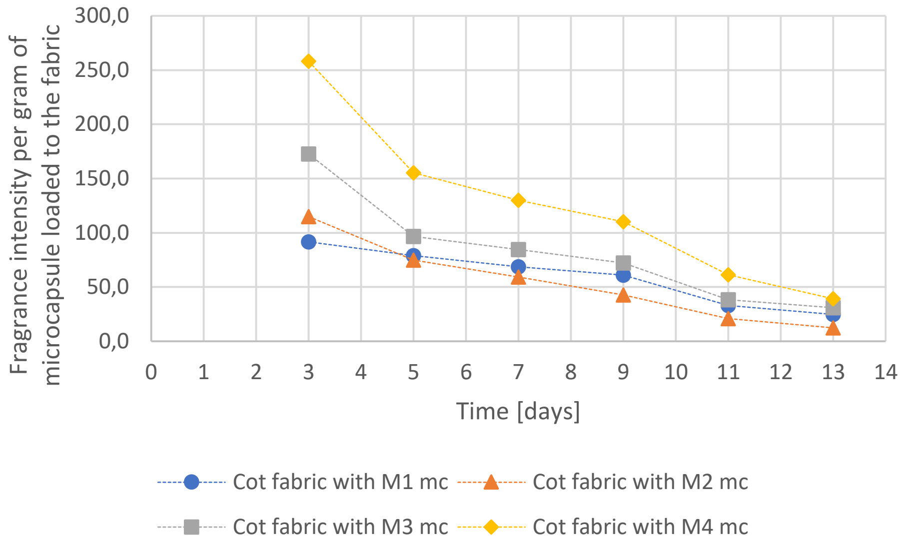

Figure 7 Fragrance intensity per gram of microcapsules loaded the fabric after certain periods of time

The fragrance intensity per gram of microcapsule was deduced from the fragrance intensity reported by experts and the microcapsule amount in gram loaded to the fabric and the results were given in Table 5 and Fig. 7.

The results at Table 5 and Fig. 7 also confirmed the higher efficiency in creating fragrance of microcapsule lot with higher cinnamon oil content used for the microencapsulation. Especially for the case of fabric treated with M4 microcapsules, with the minimum of microcapsule amount on the fabric (0.102 g, as in Table 4), after 3 days of release, the fragrance intensity (26.3, as in Table 3 and Fig. 6) as well as the fragrance intensity per gram of microcapsules loaded to the fabric (258.2, as in Table 5 and Fig. 7) were both the highest among the four microcapsule lots. It could be deduced that more oil content used in the microencapsulation helped to create higher oil loading of the elaborated microcapsules.

However, using less cinnamon oil content helped to prolong the fragrance on the fabric. As presented in Table 5 and Fig. 7, from the day of 3 to the day of 13, the fragrance intensity per gram of M1 microcapsules decreased from 91.6 to 24.8 (3.7 times) while this of M4 microcapsules decreased by 6.6 times (from 258.2 to 39.2).

As mentioned above, with more oil content used in the microencapsulation process, the elaborated microcapsules had smaller diameter with more porous polymer shell. The smaller microcapsules provided larger total surface area for the cinnamon oil to evaporate gradually from the microcapsule core out to the surrounding environment. Besides, the more porous polymer shell with larger holes on the surface (SEM images at Fig. 2) did help the cinnamon oil to release more easily and quickly. Therefore, the increase of cinnamon oil content used in the microencapsulation gave the fabric stronger fragrance intensity but faster decrease of it.

3.2.3 Influence of core - shell ratio on the antibacterial activity of fabric containing microcapsules

The antibacterial property is a major advantage of cinnamon oil for the textile application. Therefore, the change in antibacterial activity of the cotton interlock fabric treated with microcapsules according to the cinnamon oil content in the microencapsulation was necessary to be investigated. The antibacterial capability of the microcapsule treated fabric was expressed by the E. coli bacteria reduction [%] after 24 hours of incubation the fabric with bacterial suspension. The results were given at the Table 6.

The data at Table 6 indicated that untreated fabric had no antimicrobial activity and the treatment with microcapsules did improve the antimicrobial property of the fabric. However, only the fabrics treated with M1 and M2 microcapsules could inhibit the growth of E. coli bacteria while the fabrics treated with M3 and M4 microcapsules could not.

Table 6 Antibacterial property of cotton interlock fabric treated with microcapsules

Sample	E. coli bacteria reduction [%]
Control sample (untreated fabric)	0
Fabric treated with M1 microcapsules	50
Fabric treated with M2 microcapsules	24
Fabric treated with M3 microcapsules	0
Fabric treated with M4 microcapsules	0

The fabric treated with M1 microcapsules (0.15 g) of cinnamon oil used in the microencapsulation) showed the best antimicrobial activity with 50 % of E. coli bacteria reduction. The result of antimicrobial activity could be attributed by the microcapsule morphology on the fabric surface after treatment as shown in Fig. 4. The more oil content used in microencapsulation, the more deflated and aggregated microcapsules on the fabric surface. The aggregation of microcapsules as well as the more wrinkle microcapsule shell with smaller holes limited contact between bacteria suspension and the oil deep in microcapsule core. Especially, in case of fabrics treated with M3 and M4 microcapsules, the strong deformation of microcapsules on the fabric surface (Fig. 4) and too wrinkle microcapsule shell (Fig. 5) was the reason for no antibacterial activity. On the other hand, quicker release of cinnamon oil from M3 and M4 microcapsules as reported in the part 3.2.2 above could be another reason. Moreover, the warm temperature (37 ± 1 °C) in the incubator accelerated the evaporation of cinnamon oil from the microcapsules, resulting in the lack of oil retained on the fabric test sample for enough antimicrobial activity.

4 CONCLUSIONS

The cinnamon oil was successfully encapsulated into eudragit RSPO microcapsules by solvent evaporation method. The microcapsules possessed spherical shape with the size range of 27 ÷ 48 µm. The microcapsules could be loaded to the interlock cotton fabric by impregnating technique with drying conditions at relative air humidity of 20% and temperature of 8 °C. The odor of cinnamon oil and the antimicrobial activity against E. coli strain was added to the fabric after microcapsule treatment.

The core - shell ratio in the microencapsulation process was changed in an increasing order of 1/2.3; 1/2; 1/1.7; and 1/1.5 by changing the cinnamon oil content with four levels of 0.15, 0.25, 0.35, and 0.45 g. The results showed close dependence of some microcapsule characteristics and some fabric properties on the cinnamon oil content.

The increase in cinnamon oil content made the decrease in microcapsule size, the microcapsules became more porous, more deformed, and more aggregate while the microencapsulation efficiency decreased slightly.

The increase in cinnamon oil helped to increase the fragrance intensity of the microcapsule treated fabric. The fragrance was still being felt after 13 days of oil release from the fabric. However, more oil used in the microencapsulation induced stronger deformed of microcapsule shell after the fabric treatment, resulting in the decrease in antimicrobial activity of the fabric. The fabric treated with M1 microcapsules (0.15 g of cinnamon oil was used) exhibited the best antimicrobial ability with E. coli reduction of 50%, while the fabrics treated with M3 and M4 microcapsules did not work.

In conclusion, for the application in fragrant and antimicrobial textile, within the scope of this research, M1 microencapsulation protocol with 0.15 g of cinnamon oil used was recommended due to the microcapsule spherical shape remained after the fabric treatment, the ability of releasing odor gradually until 13 days and the best antimicrobial property against E. coli bacteria.

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STUDY OF THE INFLUENCE OF ANTIMICROBIAL AGENTS ON THE OPERATIONAL AND HYGIENIC PROPERTIES OF CELLULOSE MATERIALS

Olga Paraska[1], Hrystyna Kovtun[2], Lubos Hes[3], Serhiy Horiashchenko[1]
[1] Khmelnytskyi National University, Instytutska Street 11, Khmelnytskyi, UKRAINE
[2] Khmelnytskyi Lyceum of II-III degrees of Khmelnytskyi Regional Council, Ozerna Street 14, Khmelnytskyi, UKRAINE
[3] Technical University of Liberec, Faculty of Textile Engineering, Studentska 1402/2, Liberec, CZECH REPUBLIC
olgaparaska@gmail.com, hrystynak2006@gmail.com, lubos.hes@gmail.com, gsl7@ukr.net

Abstract: *At the present stage of development of society, in pandemic conditions, people are experiencing the growing influence of man-made factors (energy flows of internal and external origin, ionizing radiation, etc.), some drugs, pathogenic microflora (fungi, viruses, bacteria, intracellular parasites). The origination of a critical mass of parasitogens can be prevented by using, in addition to traditional methods of prevention and treatment, textile materials with certain additional properties obtained by antimicrobial treatment. The aim is to study the change in the operational and hygienic properties of cellulosic materials after treatment with antimicrobials. To assess the effect of antimicrobials (biguanide derivatives and quaternary ammonium salts) on the operational and hygienic properties of cellulosic materials (cotton fabric) the following indicators were taken into account: strength, stiffness, wrinkle recovery, capillarity of materials, structural and morphological characteristics. The results of research have confirmed the possibility of using solutions of antimicrobial agents for effective processing of wares, without destructive effects on the structure of cellulosic materials; allowed to introduce a research methodology to provide antimicrobial properties of cellulosic materials of different assortment.*

Keywords: *antimicrobial agents, cellulose, cotton, antimicrobial textiles, biguanide derivatives, quaternary ammonium salts.*

1 INTRODUCTION

Providing consumers with safe goods is one of the urgent scientific and practical problems, as its solution depends on human health, welfare and quality of life. In the ranking of consumer activity, the textile market occupies one of the main places. This is primarily due to the fact that the population is growing and increasing demand for textile products, including cellulosic wares (Figure 1) [1, 2].

One of the most common types of destruction of textiles during operation and under the influence of external factors is microbiological destruction, which occurs due to the amplification of three main types of microorganisms: bacteria, actinomycetales and fungi. On the surface of any textile fiber can be found microflora, which at high relative humidity and optimum temperature for its development is able to eventually absorb the fibers as a nutrient substrate and cause their destruction.

Textiles based on natural fibers, such as cellulosic materials, are most susceptible to microbiological damage. Excessive growth and development of microorganisms on materials leads to deterioration of their operational properties and reduction the term of use of textile products. Therefore, the current problem of the textile industry is the choice and use of biocidal products that would not only destroy unwished microorganisms, but also do not impair the quality characteristics of materials and products.

Currently, the textile industry is actively searching for the most advanced and environmentally friendly substances for the manufacturing of resistant cellulosic materials for various functional purposes.

Many scientific works [3-5] have been devoted to the development of materials with antimicrobial properties, in which it is proved that the creation of such products is possible with the use of antimicrobial biocidal agents that do not reduce their operational and hygienic properties.

There are basic requirements to be satisfied by an antimicrobial agent for its successful application on cellulose materials. The basic requirements of an antimicrobial agent for cellulose materials are summarized below [3, 6, 7]:

- suitable for cellulose materials processing;
- be easy to apply on textile substrates;
- be able to inactivate undesirable microbes while simultaneously not affect desired microbes;
- safe for use on skin or area of application;

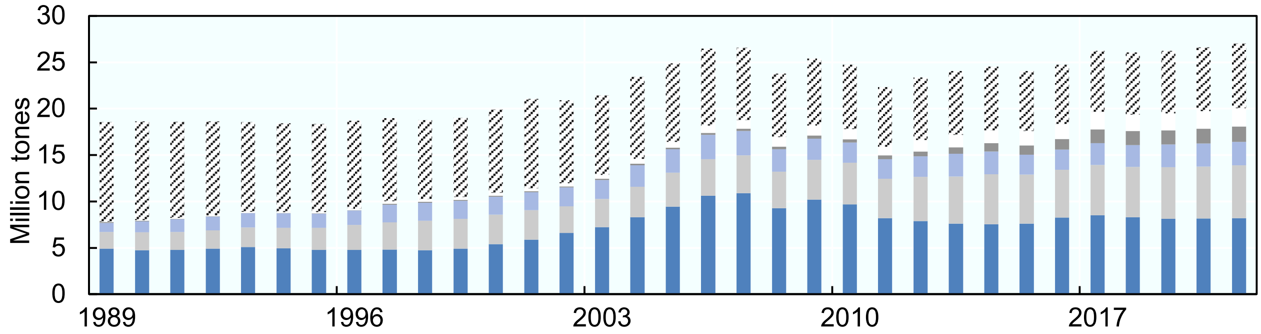


Figure 1 Usage dynamics of cellulosic materials in the world (million tons) in the period from 1989 to 2021: -China; -India; - Pakistan; - Viet Nam; - Bangladesh; - Rest of the World.

- inert to chemicals to which the cellulose materials might be exposed during processing;
- durable to repeated laundering, dry cleaning, ironing and prolonged storage including resistance to detergents used to care for the textiles;
- stable during usage without degrading into hazardous secondary products;
- -conducive to the environment.

These requirements are always counterbalanced by a need for frugality and budgetary constraints.

Most antibacterial agents applied on cellulose materials have been used for many years in food preservatives, disinfectants, and wound dressings. The attachment of these compounds to textile surfaces or their binding with the fiber can reduce their activity largely and limits the antibacterial agents' availability. In addition, the antibacterial agent can gradually be lost during the washing and use of the textile material. The most widely used antimicrobial agents for cellulose materials are based on metal salts, quaternary ammonium compounds, halogenated phenols, polybiguanide, chitosan, and N-halamines [3, 7, 8].

In general, antibacterial agents can either kill the microorganisms (−cidal) or inhibit their growth (−static). Almost all the commercial antimicrobial agents used in cellulose materials, (polyhexamethylene biguanide, quaternary ammonium compounds, and triclosan) are biocides. They can damage the cell wall or disrupt the cell membrane permeability, and inhibit the activity of enzymes or synthesis of lipids [6].

The antibacterial material can be separated in two categories: antimicrobials with controlled release or leaching mechanism and bound or non-leaching type antimicrobials. The mechanism of the leaching type will act upon contact of the cell. On the other hand, the non-leaching types will diffuse a disruptive chemical to the cell. This type is preferred for an environment supporting the diffusion of the chemical, such as water. The non-leaching type antimicrobials (quaternary ammonium compounds, polyhexamethylene biguanide) are chemically bound to the textile substrate. Hence, the antimicrobial can act only on the microbe that are in contact with the treated textile's surface. By virtue of its binding nature, these antimicrobials are not depleted and therefore potentially may have higher durability.

For the purpose of antimicrobial treatment are used traditional biocidal substances, which are not always quite effective and can have toxic effects on consumers and the environment. Therefore, the presented research is devoted to the search for safe for humans and the environment, approachable antimicrobial agents, and the study of their impact on the operational and hygienic properties of cellulosic materials. To assess the effect of antimicrobials (biguanide derivatives and quaternary ammonium salts) on the operational and hygienic properties of cellulosic materials (cotton fabric) the following indicators were taken into account: strength, stiffness, wrinkle recovery, capillarity of materials, structural and morphological characteristics [9-11].

2 EXPERIMENTAL PART

2.1 Materials used

The studies used antimicrobial agents of Ukrainian production, which have high efficacy and a wide range of indications for use - biguanide derivatives and quaternary ammonium salts (Table 1).

Studies of the efficiency of antimicrobial agents were performed on specimens of cotton fiber fabrics, which are presented on the market of Ukraine (Table 2).

2.2 Research methods

The change in mechanical properties of cotton fabrics after treatment with solutions of antimicrobial agents (biguanide derivatives; quaternary ammonium salts) was determined according to standard methods DSTU ISO 13938-1:2007, DSTU ISO 13938-2:2007 [12 – 14].

The assessment of the change in the mechanical properties of cellulosic materials was carried out according to the indicators of bursting strength P_p [N] and bursting distension l_p [mm].

Bursting strength directly reflects the durability index of the fabric when it is deformed and ruptured by external force.

Table 1 Physico-chemical parameters of antimicrobial agents

Parameters of agents	Biguanide derivative	Quaternary ammonium salt
IUPAC name	N,N''''1,6-Hexanediylbis[N′-(4-chlorophenyl)(imidodicarbonimidic diamide)]	10-[dimethyl-[2-(5-methyl-2-propan-2-ylcyclohexyl)oxy-2-oxoethyl] azaniumyl]decyl-dimethyl-[2-(5-methyl-2-propan-2-ylcyclohexyl)oxy-2-oxoethyl]azanium; dichloride
Chemical formula	$C_{22}H_{30}Cl_2N_{10}$	$C_{38}H_{74}Cl_2N_2O_4$
Physical properties	Clear colorless, odorless liquids	
Antimicrobial effect	Has a rapid and distinct effect on gram-positive and gram-negative bacteria, yeast and dermatophytes.	Has a distinct bactericidal effect on Staphylococcus, Streptococcus, Corynebacterium diphtheriae, Pseudomonas aeruginosa, capsular bacteria; fungicidal effect on yeast, yeast-like fungi, pathogens of mycosises; antiseptic effect on Trichomonas, Giardia; virucidal effect on viruses.
Manufacturer	LLC "DKP "Pharmaceutical Factory", PJSC Pharmaceutical Factory "Viola", LLC "MEDLEV", LLC "Pharma Cherkass", LLC "Kilaff"	LLC “Yuriya-Pharm”
Cost, l/USD	3-5,5	12,5-14
Expiration date	3 years	3 years

Table 2 Parametrs of the studied cellulosic materials

The name of the fabric	Composition	Width, [cm]	Weave	Areal density, [g/m^2]	Density		Porosity, [%]	Yarn linear density [tex]	
					Weft [wefts/cm]	Warp [warps/cm]		Weft	Warp
Cotton fabric	Cotton 100 %	150	Plain-weave	180	22	41	68	37	37

Pneumatic method was used for the determination of bursting strength and bursting distension of the samples. The fabric bursting strength and bursting distension was tested using a PT-250 tester machine according to the DSTU ISO 13938-2:2007 (sample size 200x50 mm) testing method. Strain measurement range from 0 to 200 mm. The scale division of the strain gauge is 1 mm. Limits of the permissible value of the error of the measuring device of the movement of the active grip ± 1 mm. The range of task speeds of movement of the active gripper during the working stroke is from 25 to 250 mm/min. The distance between the grips (initial) is adjustable, in 50 mm intervals in the range from 0 to 450 mm, with an error of ±1 mm. The working stroke of the active grip is at least 200 mm. Ten samples were tested from each group and expressed in N. All the tests were performed under standard atmospheric conditions (temperature: 20 ± 2 ºC and relative humidity: 65 ± 2%).

The stiffness of cellulosic materials is determined by the console method (under the effect of the own weight of the distributed load) [15]. A sample of appropriate size is placed on the gear of the device so that on its side faces were placed the ends of the sample length of 7 cm. When lowering the side faces of the device, the ends of the sample, which lost resistance, bend. Using the scale of the device, which is located along the side faces, the absolute deflection of the ends of the sample is measured, the relative deflection is calculated by its value according to the formula:

$$f_0 = f/l, \qquad (1)$$

where: f_0 - relative deflection of the ends of the sample; f - the absolute deflection of the ends of the sample, [cm]; l – the length of the ends, [cm].

$$l = (Z_0 - a)/2, \qquad (2)$$

where: Z_0 - length of the sample, [cm]; a – the length of the fixed part of the surface, a = 2 cm.

The coefficient A of relative deflection of the ends of the sample is determined in the reference book by the value of the relative deflection f_0. The fabric stiffness coefficient EI [μN/cm^2] is calculated by the formula:

$$EI = 42046\, m/A, \qquad (3)$$

where: m – the mass of five samples.

Wrinkling of sample of cellulosic materials is determined by the method of oriented wrinkling according to DSTU 4143-2002/GOST 31101-2003 [9, 16]. The essentiality of this method is that the sample of T-shaped material is bent at an angle of 180°and loaded for 15 minutes. In 5 min after removal of load, the coefficient of wrinkle recovery K_N according to the formula is defined:

$$K_N = \alpha \frac{100}{180}, \quad (4)$$

where: α – the recovery angle of the sample.

To assess the hygienic properties of the studied specimens after treatment with solutions of antimicrobial agents, the capillarity of materials was determined. The capillarity of textile products characterizes the absorption of moisture by the lengthwise capillaries of the material and is estimated by the height h, [mm] of lifting the liquid in the sample, immersed at one end in the liquid for 1 hour. Capillarity is determined in accordance with the requirements of DSTU GOST 3816:2009 [10, 17, 18].

All measurements were repeated 10 times (n = 10) and that mean values together with 95% confidence intervals are shown to enable comparison of sample properties after exposure to the chosen antimicrobial agents.

3 RESULTS AND DISCUSSION

According to the results of the study of the mechanical properties of cotton samples after treatment with solutions of antimicrobial agents (Table 3), it can be observed that after the treatment of biguanide derivatives, the bursting strength was even slightly increased in warp direction and decreased in weft direction. The strength in warp direction was not affected, while it slightly decreased when applying treatment by quaternary salts compared to strength of untreated fabric. The decrease was less than 10 % in both cases compared to the untreated fabric.

After 10 days of exposure in the substrate (substrate simulates soil microflora, contains sand, horse manure and garden soil; substrate humidity 30 ± 5%, pH 6-7.5) the strength of the untreated samples was reduced by half (from 464 N and 430 N to 235 and 205 N) It was expected that usage of antimicrobial agents could reduce this significant degradation of the fabric in the substrate. From tests performed, it is visible that the application of both antimicrobial treatments increases the strength compared to the untreated fabric after placement the fabric in the substrate.

When comparing strength of original fabric and strength of treated fabric after the exposure in the substrate, the decrease of the strength is around 30%. In the case of the biguanide derivatives, the strength in warp direction is reduced only by 23 %. From the perspective of this test, it appears that a higher average bursting strength is achieved by using biguanide derivatives compared to quaternary ammonium salts as antimicrobial agents.

The bursting distension of the weft samples is greater than the warp, due to the fact that the weft threads are more curved than the warp threads. According to Table 4, it can be observed that after the treatment of biguanide derivatives, the bursting distension was increased in warp direction from 10 mm to 14 mm and was not changed in weft direction - 25 mm. The bursting distension was even slightly increased in warp direction from 10 mm to 12 mm, while it slightly decreased - form 25 mm to 24 mm in weft direction when applying treatment by quaternary ammonium salts compared to bursting distension of untreated fabric.

Table 3 Bursting strength (P_p, [N]) of cotton samples (mean values)

The sample of material	Bursting strength, P_p, [N]		Bursting strength, P_p, [N], after 10 days of exposure in the substrate	
	warp	weft	warp	weft
Untreated fabric	464±11.20	430±10.75	235±5.88	205±5.13
Treated with biguanide derivatives	496±12.40	392±9.80	316±7.90	329±8.22
Treated with quaternary ammonium salts	458±11.45	402±10.05	319±7.98	296±7.40

Table 4 Bursting distension (l_p, [mm]) of cotton samples (mean values)

The sample of material	Bursting distension, l_p, [mm]		Bursting distension, l_p, [mm], after 10 days of exposure in the substrate	
	warp	weft	warp	weft
Untreated fabric	10±0.25	25±0.63	17,5±0,44	25±0.63
Treated with biguanide derivatives	14±0.35	25±0.63	16±0.40	19±0.48
Treated with quaternary ammonium salts	12±0.3	24±0.6	15±0.28	26±0.65

Table 5 Stiffness (EI, [μN·cm^2]) and wrinkle recovery (α, K_N, [%]) of cotton samples (mean values)

The sample of material	EI, [μN·cm^2]		α, [%]		K_N, [%]	
	warp	weft	warp	weft	warp	weft
Untreated fabric	5773±144.3	1945±48.6	64±1.6	56±1.4	35,56±0.89	31,11±0.78
Treated with biguanide derivatives	4253±106.3	1752±43.8	66±1.65	54±1.35	36,67±0.91	30,00±0.75
Treated with quaternary ammonium salts	6621±165.5	2124±53.1	62±1.55	59±1.48	34,44±0.86	32,78±0.82

After 10 days of exposure in the substrate (substrate simulates soil microflora, contains sand, horse manure and garden soil; substrate humidity 30 ± 5%, pH 6-7.5) the bursting distension was increased in warp direction for all samples. The bursting distension was decreased in weft direction from 25 mm to 19 mm, when applying treatment by biguanide derivatives. After the treatment of quaternary ammonium salts the bursting distension was slightly increased in weft direction from 24 mm to 26 mm. From tests performed, it shows that a higher average bursting distension is achieved by using quaternary ammonium salts compared to biguanide derivatives as antimicrobial agents after placement the fabric in the substrate.

Analysis of the stiffness (according to equation 3) of cotton samples after treatment with antimicrobial agents (Table 5) shows that treatment with solutions of biguanide derivatives reduces the stiffness of materials from 5773 μN·cm^2 to 4253 μN·cm^2 in the warp direction and from 1945 μN·cm^2 to 1752 μN·cm^2 in the weft direction. When treated with solutions of quaternary ammonium salts, the stiffness of the test samples increases from 5773 μN·cm^2 to 6621 μN·cm^2 in the warp direction, and from 1945 μN·cm^2 to 2124 μN·cm^2 in the weft direction.

The study of the wrinkle recovery of cotton samples showed (Table 5) that the recovery of the warp samples in comparison with the recovery on the weft is faster, due to the elastic deformations of the warp threads. Compared with the untreated samples, changes in the wrinkling of the samples after treatment with antimicrobial agents are insignificant and the coefficient of wrinkle recovery (K_N, [%]) (4) is 30 % - 36.7 %, in accordance.

Thus, antimicrobial treatment with products based on biguanide derivatives is recommended for underwear products, and treatment with quaternary ammonium salts – for form-resistant products (shirts, corporate clothing).

Hygienic properties of cellulosic materials after treatment with antimicrobial agents were determined by the hygroscopicity of fabrics [10]. Table 6 shows the results of capillarity studies of products (h, [mm]), which characterizes the hygroscopicity of cellulosic materials.

As can be seen from Table 6, the untreated fabric has low capillarity, due to the fact that the pores contain residues of concomitant and finishing substances that prevent the penetration of liquid into the textile material.

Table 6 The influence of antimicrobial agents on the capillarity (h, [mm]) of samples of cellulosic materials (mean values)

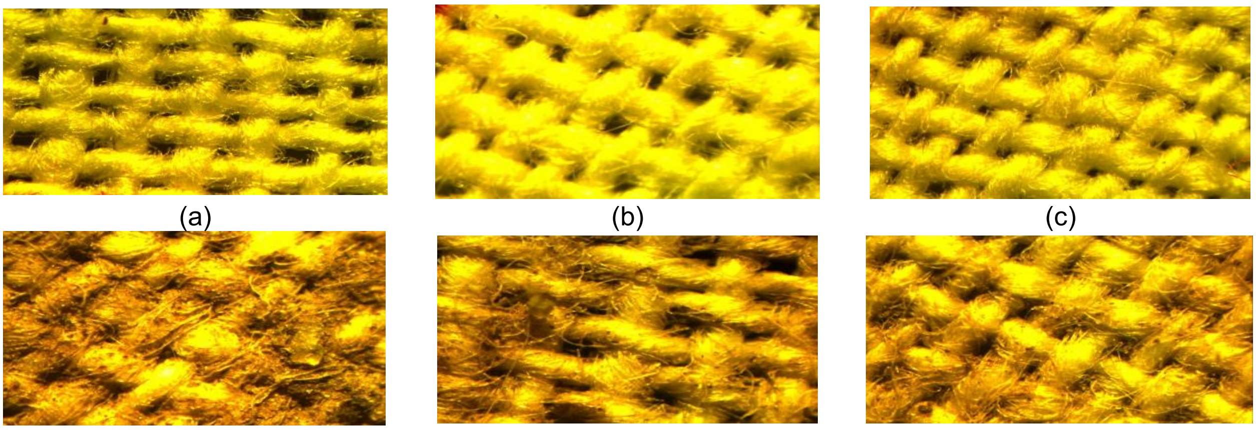
The sample of material	Capillarity, h, [mm]	
	warp	weft
Untreated fabric	16±0.42	14±0.35
Treated with biguanide derivatives	44±1.1	44±1.1
Treated with quaternary ammonium salts	70±1.75	55±1.38

For weft samples were observed less distinct changes in capillarity than for warp samples, which may be due to differences in warp and weft yarn structure. It is established that the use of antimicrobial agents improves the capillarity of cellulosic materials from 44 mm to 70 mm. The capillarity of cellulosic materials treated with quaternary ammonium salts is greater than that of biguanide derivatives, and is 70 mm in the warp sample and 55 mm in the weft sample.

Studies show that antimicrobial agents remove impurities and other substances remaining on the fabric during its exploitation, ie there occurs a cleaning of pores on the surface of cellulosic materials, which improves the hygienic properties of textiles.

Using a microscope Hirox® KH-8700, was observed a relief image (microscope images of samples at ×800 total magnifications) of the surface of cotton fabrics without treatment with antimicrobial agents and treated with solutions of selected antimicrobials (Figure 2). Image analysis shows that the surface of materials after treatment with antimicrobial agents is resistant to damage by microorganisms, due to the adsorption of antimicrobial substances on fabrics [11].

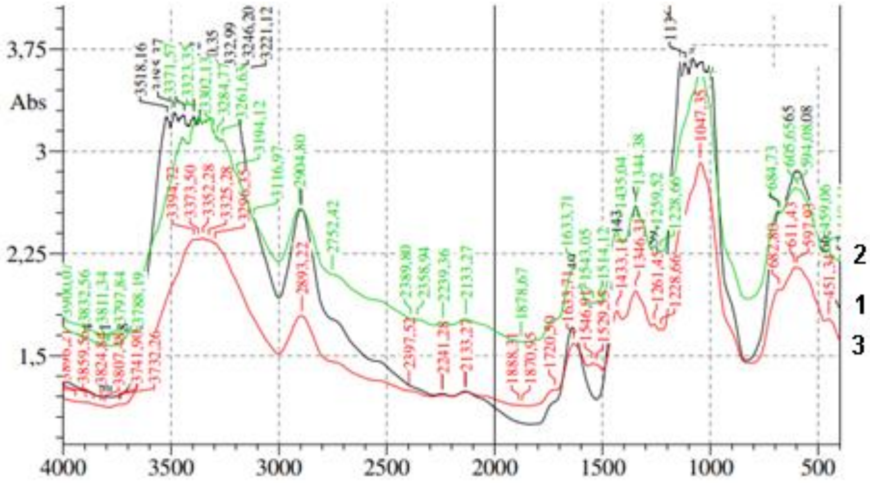
The decrease in the strength of textile materials that have defects in the structure, with increasing degree of crosslinking of macromolecules can be explained by the fact that due to the compaction of the inner layers of the fiber may increase the size of microcracks inside the fiber, leading to loss of the strength. Therefore, the influence of antimicrobial agents on the structure of cellulosic materials was studied using IR spectroscopy. The results of spectral analysis are shown in Figure 3.



(a) (b) (c)

(d) (e) (f)

Figure 2 Image of the surface of cotton materials after treatment with antimicrobial agents (microscope images of samples at ×800 total magnifications): (a) untreated warp sample, (b) sample treated with a solution of biguanide derivative, (c) sample treated with a solution of quaternary ammonium salts, (d) untreated sample after exposure in the substrate, (e) sample treated with a solution of biguanide derivative after exposure in the substrate, (f) sample treated with a solution of quaternary ammonium salts after exposure in the substrate



Wavenumber, cm^{-1}

Figure 3 IR spectra of cotton materials after treatment with antimicrobial agents: 1 - the untreated sample, 2 - treatment with a solution of a biguanide derivative, 3 - treatment with a solution of quaternary ammonium salts

Analysis of the IR spectra of the untreated and treated samples showed that the valence vibrations of the -OH bond of different groups (primary, secondary, tertiary) have maxima of approximately equal intensity: 3329 cm^{-1} - primary -OH and 3284 cm^{-1} - secondary -OH. Valence oscillations of C-O of different groups (C-OH - primary, OH - secondary, C-O-C - cyclic, C-O-C - intercyclic (glycosidic bond), are manifested in the range from 1047 to 1228 cm^{-1} as a complex strip with several maxima corresponding to these connections.

Thus, the analysis showed that the samples contain primary and secondary OH groups, which have the ability to form a hydrogen bond of different strength. Primary groups form such a bond faster, but it is weaker in strength, and secondary groups are slower, but the bond is stronger. This is what provides the ability of antimicrobial agents to be well absorbed and retain on the surface and inside the fiber molecules due to hydrogen bonds.

4 CONCLUSION

Studies confirm the feasibility of using antimicrobial agents – biguanide derivative and quaternary ammonium salts – for antimicrobial treatment of cellulose products, without destructive effects on the structure of textiles.

Analysis of the evaluation of the operational properties of cotton materials after treatment with antimicrobial agents at all levels of the structure of fabrics, allows to propose a methodology for studying the properties of a wide range of textiles, as these factors will affect the extension of the service life of textiles, reducing the amount of textile waste.

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