Developed woven structures for denim materials

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ABSTRACT – REZUMAT

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Denim is a cotton or cotton-blend twill textile material that is very popular to use for manufacturing different fashionable clothing items, such as jeans, jackets, skirts, shirts, and caps, and it is worn by most people across all age groups. Unfortunately, this material causes damage to the environment and human health through the large quantities of water required to grow the cotton plant, the toxic substances needed to dye the textile, the process of sandblasting to give denim an old, worn look and the large amounts of waste that result from its vast usage.

This research aimed to develop advanced denim materials based on a blend of high-tech fibres, eco-friendly fibres with silver ions (Ag) and cotton fibres. The main purposes of developing these materials were to improve the mechanical potential under the repeated stresses of traction, friction, and tearing and to improve the psychosensory comfort by optimally combining the fabric pattern, the fibrous composition and the component yarn structure. By prolonging the life of these materials so that people can wear them longer, denim textile manufacturers can contribute to the global effort to become more sustainable. The textile structures were designed using the logical design scheme of a woven structure. The preparation of yarns for weaving and the weaving process was performed on equipment from the Experimental Station of the National Research and Development Institute for Textiles and Leather (INCDTP). Finally, the physio-mechanical characteristics of the fabric were examined, and the performances were validated.

***Keywords**: blue jeans/denim, circular economy, innovative textile structures, quality control, improved wearability*

Structuri țesute dezvoltate pentru materiale denim

Denimul este o țesătură cu legătura diagonal din bumbac sau amestec de bumbac, foarte populară pentru fabricarea diferitelor articole vestimentare la modă, cum ar fi blugi, jachete, fuste, cămăși, șepci etc. și este purtat de majoritatea clienților din toate grupele de vârstă. Din păcate, acest material pune mare presiune asupra mediului și sănătății umane prin cantitățile mari de apă necesare creșterii plantei de bumbac, prin substanțele toxice necesare pentru vopsirea acestuia, prin procesul de sablare aplicat pentru a da denimului un aspect vechi, uzat, cât şi prin cantităţile mari de deşeuri rezultate din purtarea sa vastă.

Scopul acestei cercetări a fost de a dezvolta materiale denim avansate, bazate pe un amestec de fibre high-tech, fibre ecologice cu conținut de ioni de argint (Ag) și fibre de bumbac. Principalele scopuri ale dezvoltării acestor materiale au fost îmbunătățirea potențialul mecanic la solicitările repetate de tracțiune, frecare, rupere, dar și îmbunătățirea confortului psihosenzorial prin combinarea optimă a modelului țesăturii, a compoziției fibroase și a structurii firelor componente. Prelungind durata de viață a acestor materiale, astfel încât clienții să le poată purta mai mult timp, producătorii de textile din denim pot contribui la efortul global de a deveni mai durabili. Structurile textile au fost proiectate folosind schema de proiectare logică a unei structuri țesute. Pregătirea firelor pentru țesere și procesul de țesere s-au făcut pe utilajele din Stația experimentală a Institutului Național de Cercetare-Dezvoltare pentru Textile și Pielărie (INCDTP). În final, au fost analizate caracteristicile fizico-mecanice ale țesăturii, iar performanțele au fost validate.

***Cuvinte-cheie:** blugi/denim, economie circulară, structuri textile inovatoare, controlul calității, comportare îmbunătățită la uzură*

INTRODUCTION

Denim is a unique and solid textile material made by using a twill weave and cotton fibre in both warp and weft directions. More recently, cotton yarns blended with other types of yarns, such as polyester, polypropylene, elastane, rayon, and wool, have been used in addition to the cotton fibre during denim production n a core-spun or double-core configuration, used in the weft direction. The blend of these yarns improves the elasticity, smoothness, and abrasion resistance, prevents wrinkles and reduces the weight of the overall fabric [1].

The history of denim fabric as it is recognized today began in the French city of Nimes, where denim was initially used for garments worn by specialists because of its high sturdiness; it was coloured with a blue dye made from the Indigofera tinctoria plant that originated in India [2]. All the developments, until today, were achieved by changes made to the processes of spinning, weaving, finishing, etc.; by improving and varying the visual aspects, the thermal management properties and the moisture management

Table 1

CHARACTERISTICS OF CONVENTIONAL DENIM OR DENIM TYPE FABRICS						
Characteristic	**Ref. 4**	**Ref. 5**	**Ref. 6**	**Ref. 7**	**Ref. 8**	**Ref. 9**
Fibrous composition, warp/weft	100% cotton yarns	100% cotton yarns	100% cotton / double core yarns with elastane, polyester and cotton	100% cotton / core-spun yarns with 94.43% cotton and 5.56% elastane	100% combed cotton yarn / core-spun yarns of 70% cotton and 30% polyester	100% cotton / 100% bamboo yarn
Medium length density of yarns, warp/weft (tex)	7.38/9.22	32.62/ 42.18	73.81/32.80	43.74/36.9	29.52/36.9	29.52 × 2
Average technological sett, warp/weft (yarns/cm)	-	27/33	-/34.4	27.2/20	41/22	-
Specific mass (g/m^2)	225	251	378	-	216.90	256
Tensile strength, warp/weft (N)	-	-	1275/412	791/307	1327/678	560/450
Tearing strength, warp/weft (N)	15.01/12	-	64/58	54/36	46.06/48.54	58/100

properties; and by improving the sustainability of the production process by capitalizing on natural dyes for colouring the fabrics.

The denim fabrics addressed in this research were developed in the context of the circular economy and began from the principles of this internationally spread economic system. The design technique used in this study involves a combination of eco-design and design thinking to prevent waste production related to the LCA of the product category. Such prevention aims to change the goal of the design from the attributes of consumerism (pleasant appearance, low price and 6–10 month maximum use period) to the attributes of non-consumerism by reconsidering the time of use, maintaining the appearance of denim or styling it with minimum variations for weaving structures, or by optimizing the mechanical potential, which is the main vector of the "durability" of the textile material [3].

For the creation of the advanced denim material, the following characteristics of some existing denim fabrics on the market were considered:

- the use in the warp and weft directions of spun yarns of medium cotton fibres, with an average density of 50 tex;
- the use of both twisted and simple yarns in the warp direction, depending on the characteristics of the finished product;
- the specific mass of the grey fabric being, on average, 220–300 g/m^2, which is correlated with the density of the length of the yarns used;
- the technological sets in correlation with the weave must give an average degree of coverage in the grey fabric of 3 units, considering the existence of floats in the two yarn systems, with a jump of 2 units; and
- the representative physio-mechanical characteristics of tensile strength, tensile elongation, tear strength, warp and weft, friction behaviour and mass loss by friction [4–9].

Compared to a classic denim fabric, the advanced denim material has added value from the rational use of high-tech fibres blended (UHMWPE fibres and regenerated cellulose fibres with silver ions) with cotton to improve the mechanical and psychosensory properties and sustainable design to increase the lifecycle of the final products.

The technology required to make the advanced denim-type material is related to the processes of preparing the materials for weaving and weaving control to obtain the grey fabric. The developed woven denim-type structure can be made on any weaving machine, conventional or unconventional, as long as it allows the use of at least 8 (eight) heald shafts [10].

From a visual point of view, the woven structure retained the same look as denim products; however, in terms of functionality, the structure met specific and personalized requirements for some well-defined target groups, including fabric needed for professional activities (PPE, clothing for high-performance sports activities) and for the daily activities of people with special needs, such as people disabilities or elderly individuals [11].

The physio-mechanical characteristics of the conventional denim and denim-type fabrics, as identified from the literature and discovered using the aforementioned techniques, are presented in table 1.

MATERIALS AND METHODS

Raw materials

The following types of yarns were used in the two weave systems (weft and warp) to make the textile material:

- Yarns used in the warp system:
  - spun yarns 25×2 tex; 100% carded cotton (Fu1)

Table 2

THE PHYSIO-MECHANICAL CHARACTERISTICS OF THE YARNS USED FOR WARP AND WEFT			
Yarn code	**FU_1**	**FU_2**	**FB**
Length density (tex)	25×2	20×2	30×1
Fibrous composition	100% carded cotton	80% cotton 18% regenerated cellulose 2% Ag ions	98% carded cotton 2% UHMWPE
Coefficient of variation, CV (%)	10.21	5.79	7.23
Tensile strength (N/tex)	6.67	5.61	5.98
CV (%)	10.21	5.79	5.61
Elongation at break (%)	6.56	5.76	7.65
CV (%)	10.42	7.23	5.45
Torsion (torsions/m)	831	864	700
CV (%)	3.82	2.85	2.20
Twist (twists/m)	490	469	-
CV (%)	4.36	3.43	-

– spun yarns 20×2 tex; 80% carded cotton, 18% regenerated cellulose, 2% Ag ions (Fu2).

• Yarns used in the weft system:

– spun yarns 30×1 tex, 98% carded cotton, 2% UHMWPE (Dyneema) (Fb).

The preparation of the yarns for weaving conventional denim and weaving the variants of woven structures was done using the equipment from the Experimental Station of INCDTP.

The characteristics of the yarns used in the warp (Fu1, Fu2) and weft (Fb) directions for making the denim-type fabric are presented in table 2.

Fabric design

For the weaving of the advanced textile material, a logical programming scheme was used (figure 1), which contains the technological information necessary to make a fabric in the form of drawings. In the programming logic scheme, the position of the drawing was determined by the technological characteristics specific to the weaving machine.

In principle, the programming scheme had three main drawings and two auxiliary drawings.

The main drawings were as follows:

– weave drawing, **DL**;

– the drawing of the warp reed denting in the shafts, **DN**; and

– order drawing, **DC**.

The auxiliary drawings were as follows:

– the drawing of the warp reed denting in the reed joints, **DS**; and

– the drawing of the binding of shafts to the forming mechanism of the shed, **LP**.

For processing, a conventional technological flow was used (figure 2), specific to the preparation of spun yarns for weaving (fabric preparation) and for weaving the final product. The processing operations in the technological flow (figure 2) were correlated with the logical programming scheme of the weave (figure 1), the type of yarns used and the existing

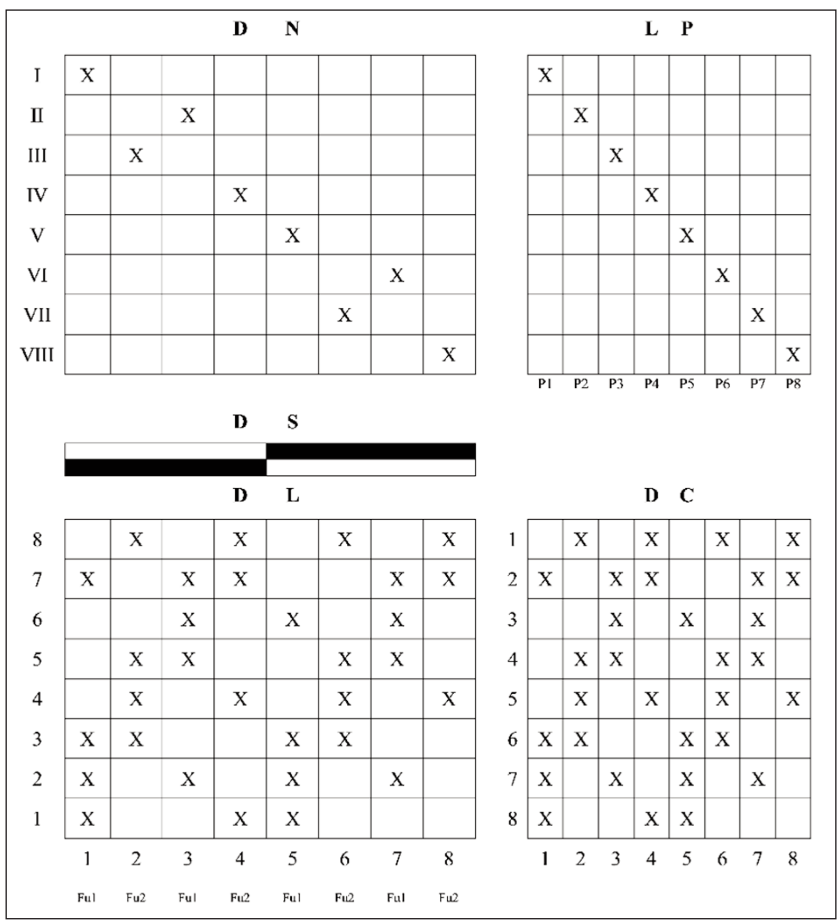

Fig. 1. Logical programming diagram of the weave

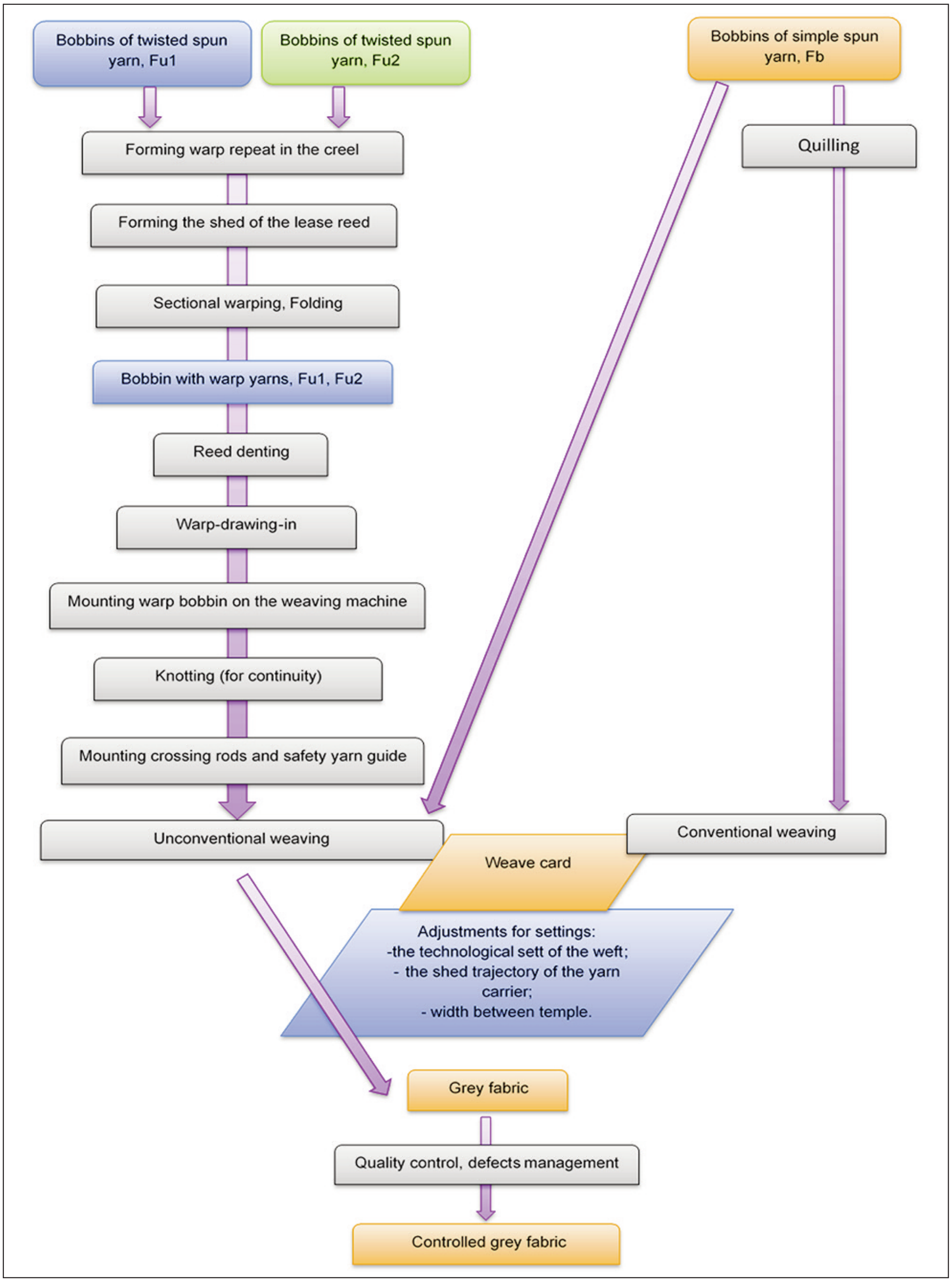

Fig. 2. Technological flow

endowment in the Experimental Station of INCDTP. The following machines were used to process the yarns and obtain the woven structure: sectional warping machine, quilling machine, folding machine, winding machine, shuttle or gripper weaving machine, control table and meter.

The processing of these yarns, even if they incorporated high-tech elements (2% Ag ions or 2% UHMWPE) to ensure performance and psychosensory comfort, did not require the use of accessories, special consumables or special adjustments of the machines.

In the processing, the yarns used behaved similarly to 100% cellulosic yarns, with the observation that the incidence of stops due to the breaking of weft yarns (those containing 2% UHMWPE) was zero.

The technological flow of manufacturing (figure 2) was valid both for weaving on the weaving machine with the shuttle and on the one with the grippers.
There were two main categories of settings:
– correlation adjustments to the operating diagram of the weaving machine; and
– adjustments adapted to the yarns in the two yarn systems and to the weave programming scheme.
An unusual component of processing was the use of 8–10 heald shafts, allowing for 2 additional heald shafts to reach the edge. Also, dyed or undyed yarns could be used. Environmentally friendly dyes could be used, including natural dyes. The chemical finishing of the fabrics was conventional and in compliance with environmental protection regulations.

RESULTS

Physio-mechanical characteristics of the fabric

The structure and mechanical potential characteristics were evaluated in the RENAR-accredited laboratories of INCDTP (figure 3).
The physio-mechanical characteristics of the grey fabric are presented in table 3.
The mechanical potential, in response to the repeated stresses of traction, friction, tearing, and repeated bending, was a result of two vectors: a) the weave of the structure that gave the surface effect of the fabric presented above; and b) the fibrous composition of the yarns used, which incorporated a percentage of max 10% high modulus synthetic fibre in the fibrous mass from the high-tech polyethylene class (UHMWPE), makes the dispersion of the characteristics that contribute to the mechanical potential, to be significantly minimized, at values of the coefficient of variation not specific to the spun yarns, but specific to the multifilament yarns.

Table 3

PHYSIO-MECHANICAL CHARACTERISTICS OF THE GREY FABRIC

Characteristic	Value
Specific mass (g/m^2)	200 +/– 5%
Technological sett, in the warp (yarns/cm)	28
Technological sett, in the weft (yarns/cm)	22
Tensile strength, in the warp (N)	960 – 1000
Tensile strength, in the weft (N)	980 – 1200
Elongation at break, in the warp (%)	9.8 – 12.2
Elongation at break, in the weft (%)	8.7 – 10.5
Tearing strength, in the warp (N)	46 – 52
Tearing strength, in the weft (N)	56 – 64
Received grade after testing after 20000 friction cycles, 9 kPa	4 – 5/5
Relative specific mass loss after friction (%)	4.8

Fig. 3. The structure of: *a* – conventional denim fabric; *b* – prepared denim-type fabric

The fabric obtained had a specific mass comparable to a fabric composed of 100% cellulosic fibres (a specific mass usually obtained in denim fabrics), but with a mechanical tensile, abrasion and tear strength that was increased, on average, by 20% compared to a conventional denim-type fabric composed of 100% cellulosic yarn with a length density of 30 or 50 tex.
An excellent friction resistance was obtained for the fabric. The very low coefficient of friction of the high-tech fibre was conducive to obtaining and maintaining proper frictional behaviour, a minimised risk of fibre breakage, a minimised appearance of fibre ends on the side surface of the yarns, a pleasant touch (psychosensory comfort) and a pleasant appearance during the cycles of wearing, washing, and ironing the fabric.

Quality aspects and performance validation

Quality control of the fabric was done in accordance with the regulations in force or according to the particular requirements of the client/beneficiary. The types of defects (minor and major) in the grey fabric were found to be in accordance with the standard SR ISO 8498-96: Woven fabrics – Description of defects. If the fabric had a higher number of defects than permitted by the standard, it was delivered only with the consent of the beneficiary.
The performances of the created advanced denim material were validated by the following attributes that were specific to the requirements of the consumer and the manufacturer:
A. Requirements specific to the final consumer:
- preserving the surface appearance of the denim fabric, both on the front and on the back;
- maintaining the specific mass of denim-type fabrics;
- maintaining a composition of over 75–80% cotton; and
- ensuring safety and protection.

B. Requirements specific to the manufacturer:
- workability by conventional and unconventional technologies, without involving special accessories, adjustments, maintenance techniques or preparations;
- grey fabrics with 2% UHMWPE exhibiting behaviour caused by the frictional demands on the surface, similar to conventional denim fabrics; and
- 2–10% UHMWPE fabrics having a psychosensory feel similar to 100% cotton fabrics regardless of the

weave used, so the high-tech fibre will exhibit its high performance in wear/use as well as the eco-regenerated cellulose fibre with a content of silver ions.

When considering the manufacturing specifications and the characteristics of conventional denim fabric, it was estimated that the advanced material made of high-tech fibres met the customer requirements (end consumers and manufacturers).

CONCLUSIONS

The denim-type woven structure developed in this study preserved the types of yarns generally associated with these fabrics.

The advantages of this developed innovative denim-type structure are as follows:

- advantageous price-to-time ratio for the use of the final product;
- increases the amplitudes per sequence in LCA about both the textile fibres used and the products made from the textile;
- increases the use time while maintaining the comfort, safety and protection requirements, despite the decline in denim-type surface appearance;
- eliminates the need for finishing processes that improve the appearance but cause irreversible damage to the woven structure (e.g., prewashed or ripped jeans);
- minimises the vectors of consumerism and maximises the vectors of nonconsumerism, such as maintaining the mechanical potential and increasing/optimising the use time, thus redefining the concept of quality in the field of denim fabrics and denim-type fabrics;
- creates the possibility of making clothing products, including personal protective equipment (PPE), modified according to the requirements of use; and
- ensures a change in the aims of textile production from consumerism to sustainability and alignment to a circular economy.

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