RESEARCH AND DEVELOPMENT

Modelling of the Relationship Between Feeding Sliver Structures and Parameters of Cotton/Linen Blended Yarns

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Abstract
Natural textile raw materials are nowadays undergoing a renaissance. Among natural fibres, flax is characterised by favourable ecological and physiological properties. The human and ecological properties of flax significantly surpass the properties of other fibres. The promotion of using flax fibres in so-called healthy garments in a healthy home and working environment harmonise with modern world-wide ecological trends. New types of bast fibres assigned for the production of fine blended yarns by means of the cotton rotor system have been developed. The relationship between selected bast and cotton fibres, feeding sliver parameters, and the parameters of yarns have been determined. A programmed selection of cotton & flax components will enable the production of high quality rotor yarns.

Key words: *bast fibres, flax, cotton, blended yarn, yarn parameters, sliver parameters, rotor spinning, hybrid neural-analytical model.*

Introduction

Flax fibres have a long and very rich history. Fabric artefacts and paintings presenting tools for flax processing dating from the fourth millennium BC have been discovered. Flax fibres are included in the group of natural bast fibres. Flax is a plant which can be cultivated at very diverse latitudes.

Many investigations have been initiated around the world with the aim of broadening the application of flax in clothing using woven fabrics and knittings [2,9]. The high and uneven linear density of flax yarns, as well as their stiffness - which makes it difficult to process flax with the use of knitting machines - had hitherto been a barrier to the application of flax fibres in underwear products. Investigation results have proved that flax ensures optimal conditions for the proceeding of human physiological processes and stimulates the human's immunity system. These advantages are the reason for making an approach to break the technological barriers which have so far made the application of flax fibres in manufacturing underwear impossible. Conditions responsible for the complex of thermo-hydro-electrostatic phenomena occurring in the area between skin and clothing are the technological barriers in question [1,2,9].

Many Polish [9] and foreign publications have referred to research works aimed at determining the protective properties of textile products against UV radiation acting on skin. Clothing which contains flax or hemp can make a screen against radiation, especially when additional special finish is applied. The degree of this problem increases when we consider the fact that the 'ozone hole' has recently tended to periodically outspreading.

Nowadays, more and more investigations have been carried out into the properties of bast fibres. After a long period of little interest in bast fibres, these fibres have regained the favour of producers as ecological fibres with many profitable features. What is more, modern fashion has awakened the producers' interest, despite the fact that the costs of yarn manufacturing from bast fibres are higher than those of cotton fibre manufacturing. This has forced researchers to search for new low-cost technological solutions in order to decrease the manufacturing costs.

Subsequent investigations have proved that flax fibres have a good influence on the human immune system, and revealed more and more advantages of these fibres. A great percentage of the flax production is destined for summer clothing, as during this period exposure to UV radiation is of crucial importance. Direct investigations engaged in research into the protective properties of flax against UV radiation have demonstrated its excellent usability properties in connection with this problem.

Thanks to the above mentioned properties, flax can be used to manufacture woven

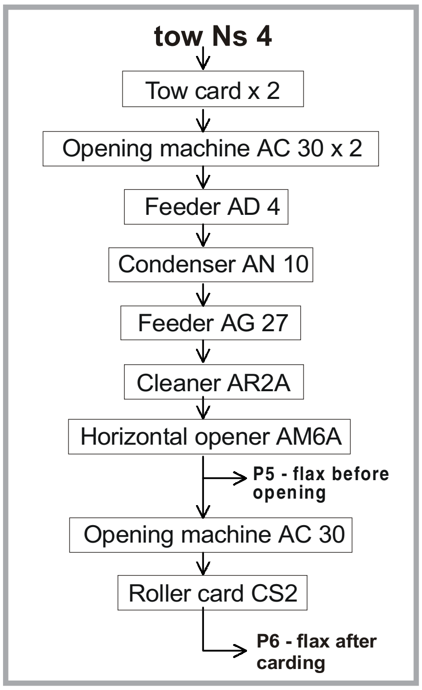

***Figure 1.** Set of machines used for modifying the Ns 4 flax tow.*

Table 1. Characteristic of the variants of modified flax fibres.

Test designation	Variant characteristic of modified flax fibres
P1	cotonine intensively boiled
P2	boiled cotonine intensive and finish increasing friction between fibres (6 g/dm^3)
P3	cotonine intensively boiled and finish increasing friction between fibres (15 g/dm^3)
P4	Cotonine intensively boiled and chlorine bleached
P5	flax before opening (fibres mechanical modified)
P6	flax after carding (fibres mechanical modified)

Table 2. Parameters of the modified flax fibres.

Test designation	Mean fibre length	Mean linear density
	mm	tex
P1	45.4	1.2
P2	44.2	1.3
P3	45.7	1.2
P4	39.1	1.1
P5	48.5	4.5
P6	42.2	3.0

fabrics for summer sports clothing, summer wear, shirts, women's blouses, clothing for children, and working clothes for outdoor use.

The well-known basic advantages of textile products manufactured from bast fibres are as follows:
- anti-allergic properties,
- pleasant, cool handle, especially perceptible at higher temperature,
- low ability of storage electrostatic charges, and
- excellent protection against UV radiation.

The increasing interest in flax fibres has meant that in recent times techniques have been more often adapted which were characterised by fulfilling the basic technological functions required, and by using cotton spinning machines [6,7].

Many investigations have been carried out at the Department of Spinning Technology and Yarn Structure of the Technical University of Łódź into the development of a technology for manufacturing cotton/hemp and cotton/flax blended yarns formed with the use of a BD 200S rotor spinning machine. Research has been conducted into adapting the technology for manufacturing cotton/bast fibre-blended yarns with the use of machines destined for cotton processing. The function of cotton in the blends is to improve the properties of blended yarns and to rationalise the spinning process [5,6,7].

In this paper, we describe the investigations carried out into modifying flax fibres and developing a technology aimed at processing them. On the basis of the test results obtained, model dependencies were elaborated which allowed us to forecast the properties of blended rotor yarns with a flax content on the basis of the properties of the fibre streams which fed the rotor spinning machine.

As the technical flax fibres are constructed from elementary fibres of similar average lengths and linear density to cotton fibres, a idea was formed consisting in splitting the technical flax fibre into thinner fibres and spinning with the use of machines for cotton processing. The flax fibres can be modified by mechanical and chemical methods [2,3,5-8].

The mechanical methods are based on intensive tearing and thinning of the fibres with the use of opening machines, horizontal openers, and cards. The chemical method applied to separate the elementary fibres is based on the use of chemical agents. The irregularity of the elementary fibre length makes the spinning process difficult. The long fibres (if their number is small) are broken by means of the drawing apparatus action, whereas if their number is high, the fibres slide between the rollers, disturbing the process. On the other hand, the fibres which are to short fall out during spinning, yielding large amounts of wastes, additionally disturb the process [3].

The cotonisation of flax fibres is aimed at equalising the fibre lengths. Bast fibres differ from cotton also structurally. The cotton fibre is similar to a twisted band, and this structure ensures appropriate cohesion and elasticity. In contrast, the bast fibres have a stick-like shape without any cohesion, which is the reason flax fibres can not be spun separately. Only the spinning of blends such as cotonine-cotton or cotonine-chemical staple fibres is possible.

With the aim of improving the spinning properties of flax fibres, that is, to decrease their stiffness, the partly modified flax fibres ('flax before opening' as seen in Figure 1) were exposed to additional mechanical and chemical-mechanical processing. The blended fibre streams obtained in the form of slivers (with the content of the previously prepared flax) feeding the spinning machine were characterised by different structural properties than those of flax.

Manufacturing Modified Flax Fibres

Flax cotonine exposed to certain kinds of chemical and mechanical processing was used in our investigations. The aim of chemical processing was to eliminate the natural fibre stiffness and to improve the cohesion between fibres; both these features influence the process of card sliver formation. The characteristics of the flax fibre modification methods used and the designations of the connected tests are presented in Table 1. The mechanical processing for tests P5 and P6 was carried

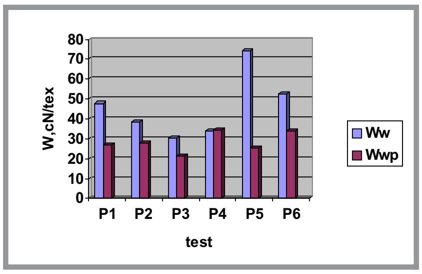

Figure 2. *Strength parameters of flax fibres.*

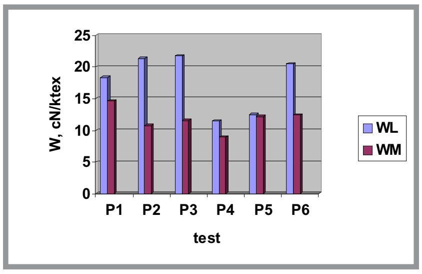

Figure 3. *Specific strength of homogeneous flax slivers (WL) and blended slivers (WM).*

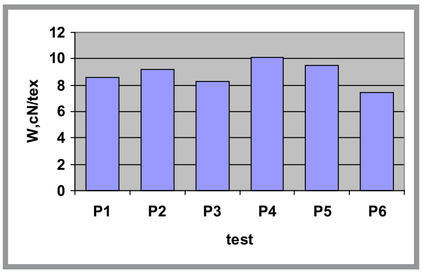

Figure 4. *Tenacity of yarns.*

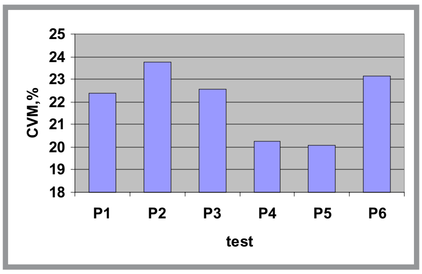

Figure 5. *Mass irregularity of yarn on short length.*

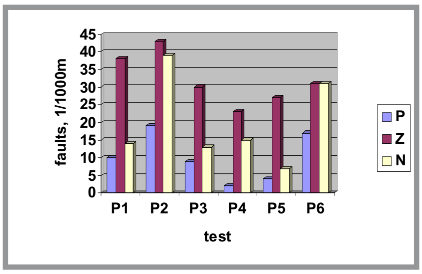

Figure 6. *Number of faults in yarn; P - thin places, Z - thick places, N - neps.*

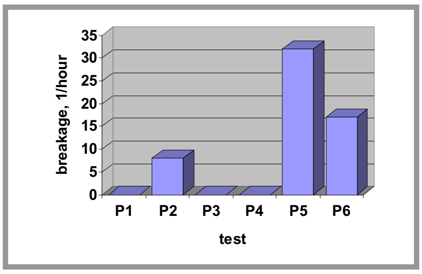

Figure 7. *Number of breaks.*

out with the use of the machines shown in Figure 1. The Ns 4 tow was preliminary raw material.

Fibre parameters

The physico-mechanical parameters of the flax fibres we modified are presented in Table 2 and in Figures 2 and 3. The following flax fibre parameters were determined:

- linear density,
- length,
- tenacity,
- tensile strength in the loop, and
- fibre cohesion (specific strength of flax and blended slivers).

The data presented in Table 2 demonstrates that fibres with small dispersion in linear density and length were obtained as a result of the flax fibre modification. The fibres obtained as the result of mechanical processing are characterised by a significantly higher tenacity of the particular singular fibres than those obtained after chemical treatment. The differences in the tensile strength in loop are considerably smaller.

The tenacity of singular fibres from all the tests carried out is within the range from 36 cN/tex to 74 cN/tex, whereas the tensile strength in loop changes only from 21 cN/tex to 35 cN/tex. The smallest values in both parameters considered were obtained for fibres from the P3 test characterised by intensive boiling of the fibres and applying a finish which increased friction between fibres (15 g/dm^3).

Slivers with a linear density of 3.5 ktex prepared by means of a card were used for the estimation of specific sliver strength . This strength gives us information about the cohesion of fibres exposed to different processing. Homogeneous flax and 50%/50% flax/cotton blended slivers were prepared. The measurements were carried out according to Polish Standard PN-88/P-04771 [32]. The results of specific strength of the homogeneous flax slivers (WL) and the blended slivers (WM) are presented in Figure 3.

The specific strength of all slivers is relatively high, which results from the low paralleling of the fibres in the card sliver. The homogeneous flax slivers are characterised by larger differentiation of the results obtained. The values of their specific strength are higher than those obtained for the blended slivers. Only the blended sliver which contain flax fibres of the P1 test has a highest specific strength near 15 cN/ktex.

Yarn manufacturing

Yarn with a linear density of 30 tex was manufactured with the use of a BD 200S rotor spinning machine from 50%/50% flax/cotton blended slivers at the following machine settings:

- rotor velocity: n_R=50,000 r.p.m.,
- opening roller velocity n_B=7,000 r.p.m., and
- twist coefficient α_m=160.

The number of yarn breaks was recorded during the period of the spinning process. The specific strengths of the yarns from these particular tests are within the range from 7.5 cN/tex to 10.13 cN/tex, as seen in Figure 4. The highest specific strength is shown by yarn samples from the P4, P5, and P2 tests, the lowest by those from the P3 and P6 tests. The effect of chemical processing (intensive boiling and a finish which increases the friction between fibres to 15 g/dm^3) and intensive mechanical processing is a decrease in the tenacity of the yarns obtained.

The yarns' irregularity of mass (linear density) was estimated by means of the Uster Tester 3 apparatus. An analysis of the yarn mass irregularities indicates similar results for yarns exposed to the P4 chemical processing and the P5 mechanical processing (see Figure 5). The CVm values of yarns range between 20.07% and 23.76%.

The number of faults occurring within 1,000 metres yarn length was measured with the use of the Uster Tester 3 apparatus at the same time as the mass irregularity of this yarn. Faults were recorded at the following levels recommended by the Uster company: thin places (-50%), thick places (+50%), and neps (+280%). The results obtained are presented as graphs in Figure 6.

The highest number of faults occurred in the yarn obtained in the P2 test. What is more, this yarn was characterised by the greatest irregularity on short yarn segments (over 23%). The smallest number of faults was noted in the yarn obtained in the P4 test, which was also characterised by the lowest value of CVm. Thus, we may state that a relationship exists between the number of faults and the mass irregularity on short lengths. Yarns obtained as the results of the P5 and P6 tests do not differ significantly in the number of faults from yarns manufactured with the application of fibres exposed to chemical processing.

The number of yarn breaks which occurs during the process of yarn manufacturing with the use of the BD 200S spinning machine (carried out with the use of ten spinning positions) was recorded, and then the number of breaks per hour was calculated. The results are presented as a graph in Figure 7.

The yarn breakage ranges from zero to 32 breaks per hour. The greatest yarn breakage was noted at yarn manufacturing according to the P5 test, where the yarn blend contained flax fibres (as a component with cotton) taken before the opening machine. It should be emphasised that any breakage occurred during one hour of spinning yarns which contained fibres exposed to chemical processing, except in one case, when spinning the yarn which comes from the P2 test. Cotonine intensively boiled was used for obtaining this latter yarn and in addition a finish which increased friction between the fibres (6 g/dm^3).

The analysis of yarn breakage may allow us to state that chemical processing has a great influence on the results obtained. The yarns which were not exposed to chemical processing were characterised by the greatest yarn breakage.

Considering economic aspects connected with the application of chemical modification of flax fibres and the obtention results, which in many cases were similar to those obtained by the mechanical processing of fibres, the following kinds of chemical processing were chosen for further investigations: P6 (with the new designation W1) and P6 (W2).

Yarn manufacturing at the second stage of investigation

Yarns from blended flax/cotton slivers, and for comparison from a 100% cotton sliver, were manufactured with use of the BD 200S rotor spinning machine, and destined for the second stage of our investigations. The specific strength (cohesion) of cotton sliver measured by means of a F 460 apparatus [11] was equal to 50.8 cN/ktex, and considerably higher than the cohesion of the blended slivers.

The cotton sliver and blended slivers from the variant W1 (characterised by the use of flax before opening), as well as slivers from the variant W2 (with flax after carding) fed the rotor-spinning machine. The flax content (U) in the blended slivers was as follows: U=10%, 20%, 30%, 40%, and 50%. The remaining part consisted of middle staple cotton.

Yarns with linear densities of 20, 30, 40, 50, and 60 tex were manufactured with use of the BD 200S rotor-spinning machine at the following parameters:

- rotational velocity of the rotors: 50,000 r.p.m., and
- rotational velocity of the opening rollers: 7,000 r.p.m.

Slivers with a linear density of 3 ktex fed the spinning machine.

Investigation of Properties of the Cotton/Flax Blended Yarns

The objects of our investigations at this stage were cotton/flax blended yarns spun with the BD 200 S rotor spinning machine. The properties of these yarns were compared with the properties of pure cotton yarns. The parameters of cotton/flax blended slivers and their influence on yarn quality were also investigated.

Investigation of the sliver parameters indicated that sliver cohesion *S* decreases exponentially with the increase in the percentage contribution *U* of flax, according to equation (1) as developed by the authors:

$$S = S_{50} + \left(S_0 - S_{50}\right) \cdot e^{-(U/a)} \qquad (1)$$

where:

S_0, S_{50} - cohesion correspondingly of cotton sliver and of 50% flax and 50% cotton blended sliver in cN/ktex;

a - coefficient of exponential function in percent.

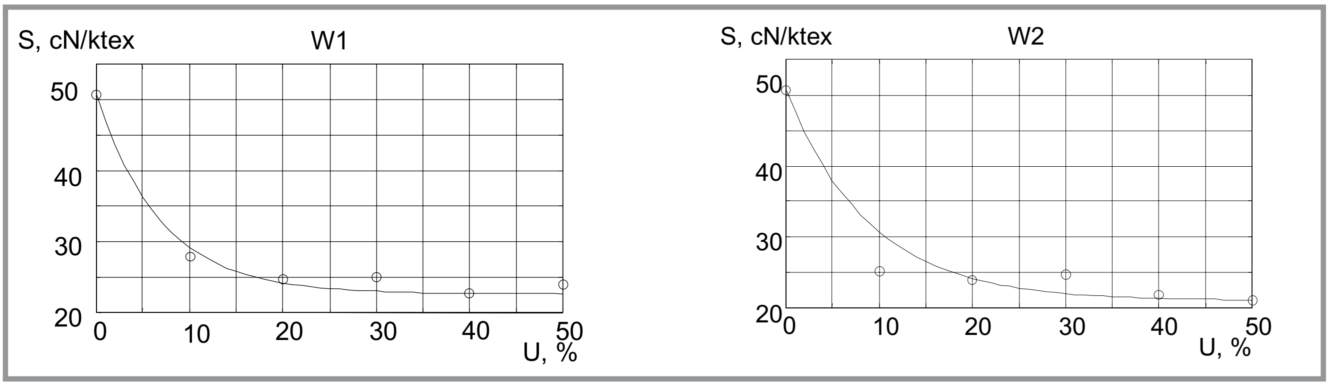

***Figure 8.** Cohesion of slivers versus flax percentage contribution for the cases W1 and W2.*

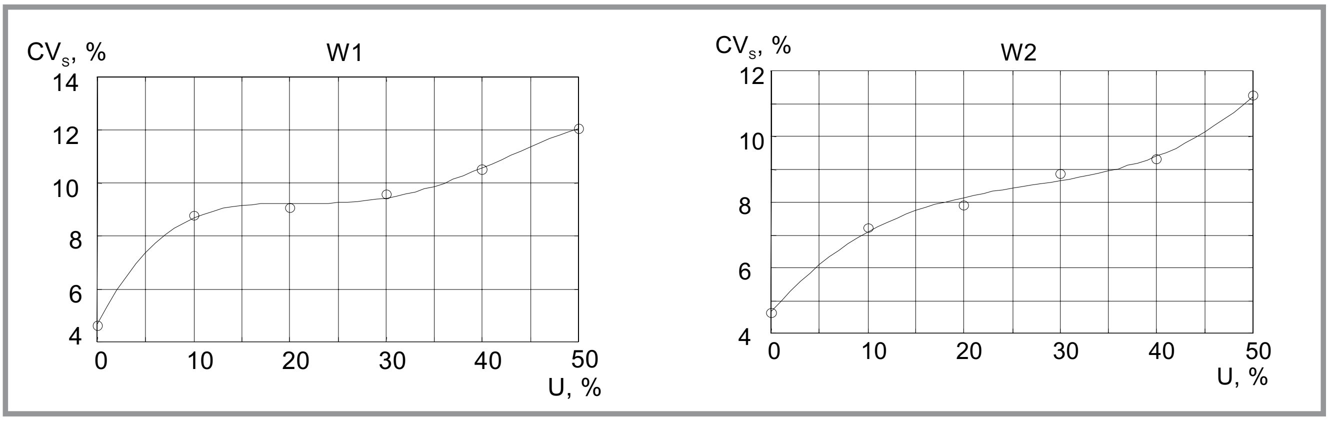

***Figure 9.** Coefficient of the sliver's mass variation, CV$_S$, due to the flax percentage contribution U, for the cases W1 and W2.*

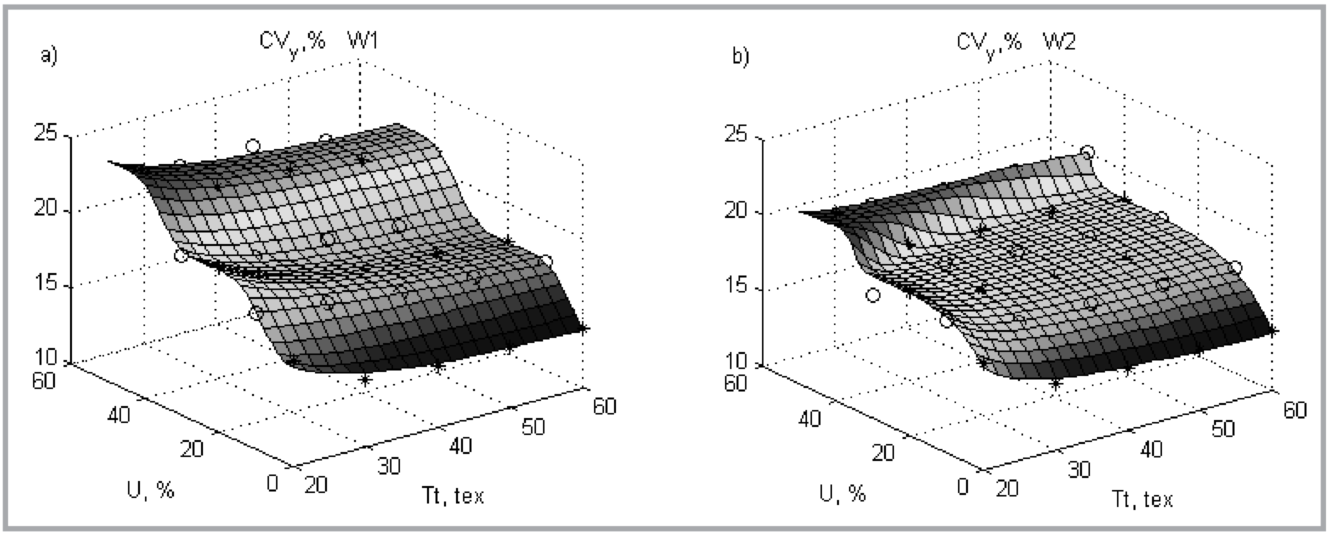

Figure 10. *Coefficient of yarn mass variation CV_y, due to the flax percentage contribution in sliver U, and linear density of yarn Tt_y, for the cases W1 and W2.*

The influence of the flax percentage contribution in sliver on its cohesion is shown in Figure 8a for the case of W1, and in Figure 8b for the case of W2. A numerical algorithm based on the logarithmic method and the least mean square algorithm was applied to estimate the value of the coefficient a. In the case of W1, a=6.9% and in the case of W2, a=8.9%.

The coefficient of sliver mass variation CV_S was another important parameter considered in this research. Its dependence on the percentage of flax contribution is shown in Figure 9a for the case of W1, and in Figure 9b for the case of W2.

The dependence of CV_S on U was assessed by the following polynomial functions of the third degree:

- in the case of W1:

$$CV_S = 0.0001\,U^3 - 0.04\,U^2 + 0.73\,U + 4.64 \quad (2)$$

- in the case of W2:

$$CV_S = 0.0001\,U^3 - 0.01\,U^2 + 0.34\,U + 4.65 \quad (3)$$

The influence of linear density of yarn Tt_y and the flax percentage contribution in the sliver U on the yarn quality was the main aim of our investigation. The BD 200S rotor spinning machine was fed with cotton and blended slivers (of a linear density of 3 ktex), from which yarns of the following linear densities 20, 30, 40, 50 and 60 tex were spun. The tests were carried out at a rotor speed of 50,000 r.p.m. and at a rotational speed of the opening roller of 7,000 r.p.m. The test results are shown in Figure 10.

A hybrid neural-analytical model considering the influence of linear density of yarn and the flax percentage contribution in the sliver on the coefficient of yarn mass variation CV_y is an important result of this research. The theoretical value of the coefficient of yarn mass variation CV_T is computed from the simplified Martindale equation at the first step of the numerical algorithm [8]:

$$CV_T = \frac{K}{\sqrt{\bar{n}}} \quad (4)$$

where:

K - constant, we assumed K=106, as for cotton fibres;
$\bar{n}$ - number of fibres in the yarn cross-section, calculated from the following formula:

$$\bar{n} = Tt_y / Tt_f$$

where:
Tt_y - linear density of yarn,
Tt_f - linear density of fibre.

The percentage contribution U of flax in the sliver and the mass irregularity of sliver CV_T are introduced to the inputs of an artificial neural network (ANN) which determines the real value of the coefficient of yarn mass variation CV_y. A small multi-layer perceptron ANN with one hidden layer was applied using a structure (2-3-1), i.e. two inputs, three processing units with a sigmoidal transfer function in the hidden layer, and one linear unit in the output layer. The networks were trained by means of the back propagation algorithm and the Levenberg-Marquardt optimisation method [4]. The experimental data points which were used for the network training and the results of hybrid neural modelling are shown in Figure 10. The neural networks designed for the cases W1 and W2 have good generalisation properties.

Conclusions

- To improve the spinning ability of flax fibres, the fibres must be exposed to chemical modification which results in obtaining less stiff fibres of higher cohesion.
- Flax fibres obtained as result of mechanical modification are characterised by higher tensile strength than those fibres which were chemically modified.
- The parameters of modified flax fibres influences their spinning ability, and especially the breakage of the blended yarns formed.
- The influence of flax percentage contribution in the sliver on the properties of slivers and yarns has been investigated. The results obtained allow us to state that the assumption accepted was correct, that the flax content has an substantial influence, and that the cohesion and mass irregularity decreases with the increase in the flax content.
- An exponential decrease in the cohesion of slivers with an increase in the flax percentage contribution was stated.
- The coefficient of mass variation CV_S of the slivers depends significantly on the flax percentage contribution. This dependence can be assessed by means

of a polynomial function of the third degree.

- The coefficient of mass variation of slivers and the linear density of yarns have a crucial influence on the coefficient of yarn mass variation.
- Application of a hybrid neural-analytical model, which uses a priori knowledge about the process, allowed us to achieve good modelling results and a simple neural network structure for the problem considered in this work.

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