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# Investigation of an Innovative “Cotton Hollow” Yarn

## Abstract

Cotton is a basic raw material processed in the textile industry all over the world. Some new cotton products have been developed thanks to the inventions and efforts of scientists and engineers dealing with cotton. One of the innovative cotton products is SPINAIR yarn by Kurabo (Japan). It is so called “hollow” yarn made of cotton and PVA fibres. PVA fibres are introduced into the yarn during the spinning process. Next they are dissolved and removed in fabric finishing, thanks to which in the final product the yarn is composed only of cotton fibres. The yarn has been developed to improve the thermal insulation of cotton fabrics. Due to the dissolving of PVA fibres, the structure of yarn and fabrics made of it is loose and porous. The air trapped inside the yarn between the cotton fibres increases the thermal resistance of fabrics. Within the framework of the work presented composite “hollow” yarn 42 tex made of cotton (80%) and modified PVA (Polyvinyl alcohol) fibres (20%) was investigated within the range of its structural, mechanical and technological parameters. Woven fabric was then manufactured with the application of the 42 tex CO80/PVA20 yarn in the weft direction. Investigation of the manufactured woven fabric with Alambeta confirmed that fabric with weft yarn 42 tex CO80/PVA20 is characterised by a higher thermal resistance and warmer sensation while touching than that made of 42 tex cotton rotor yarn in the weft.

**Key words:** “hollow” yarn, cotton, woven fabrics, thermal resistance, thermal comfort.

## Introduction

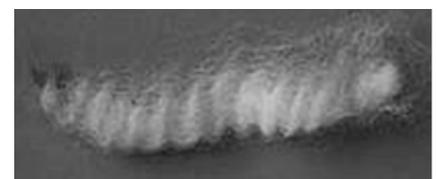
Cotton is a basic raw material processed in the textile industry all over the world. It is used in different types of textiles for a wide range of applications. Due to the excellent natural hygienic properties of cotton fibres, textile products made of cotton have an ability to ensure physiological comfort. Cotton is commonly applied in textiles in contact with human skin such as clothing, most notably in shirts, T-shirts jeans, coats, jackets, underwear but also in sheets, pillowcases, towels and washcloths. The rapid and intensive development of chemical fibres has significantly limited the application of cotton, especially in the area of technical textiles. Nevertheless it is still possible to create new innovative cotton-based textile products which can compete successfully with textiles from man-made fibres [1 – 4].

Some new cotton products have been developed thanks to the inventions and efforts of scientists and engineers dealing with cotton. Lunafa yarn by Kurabo (Japan), “storm cotton” or “wicking windows” technology of cotton fabric finishing developed at Cotton Incorporated (USA) can be examples of innovative cotton solutions. One of the innovative cotton products is so called “hollow” yarn made of cotton and modified PVA fibres. The yarn is manufactured using technology developed by Kurabo (Japan). Due to the unique structure and properties of the yarn, textile products

made of it are characterised by thermal resistance higher than that of standard cotton fabrics.

Thermal resistance is one of the most important comfort-related properties of textile materials [5 - 9]. The higher the thermal resistance the better the protection of the human organism against cold. There are different methods of improving the thermal insulation of textile materials. The thermal resistance of textile materials can be increased by increasing the material thickness. Nevertheless increasing the fabric thickness leads to the utility discomfort of clothing due to the limitation of freedom of movement.

An appropriate choice of fibres is another way of increasing the thermal resistance of textile materials. Usually in fabrics and clothing protecting against cold, wool fibres are applied due to the excellent thermal insulation properties of wool. The high resilience and crimp of wool fibres (*Figure 1*) cause that fabrics made of them are fluffy and porous. They also contain a big amount of air trapped inside their structure, which gives them high thermal resistance. Nevertheless wool



*Figure 1.* Bundle of wool fibres.

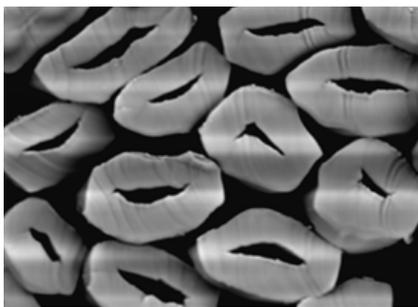


Figure 2. Microscopic picture of cross-sections of synthetic hollow fibres [14].

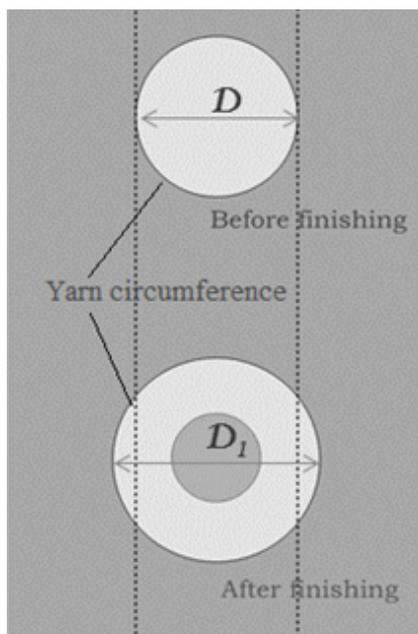


Figure 3. Schematic drawing of "cotton hollow" yarn before and after finishing [15]

fibres are coarse and can cause irritation and even allergy of the skin. Due to this fact wearing wool textiles is problematic, especially in the case of babies and people with sensitive or oversensitive skin, owing to the different skin diseases it can cause [10 – 12].

Hollow fibres (Figure 2) are also an innovative solution in the area of fibres of high thermal resistance [13]. They imitate fibres of the polar bear and ensure high thermal resistance due to air in the internal channel. Synthetic hollow fibres are usually made of polyester or polyamide.

Air trapped inside a small space is a good thermal insulator. Porous textile structures with a big amount of air inside the structure – between fibres and yarns – are an excellent thermal insulator and additionally they are significantly lighter than fabrics made of conventional fibres.

The idea was applied to the yarn investigated, which was a "hollow" yarn made of cotton and polymer Kuralon K-II (modified PVA), using the "focus method" of spinning developed by KURABO (Japan). Modified PVA dissolves in water much better and at a lower temperature (below 90 °C) than ordinary PVA. When the Kuralon K-II, which creates the core at the center of the yarn, dissolves, the center then becomes hollow (Figure 3), making the yarn light, soft and fluffy [15].

According to the declaration of the yarn manufacturer, fabrics made of "hollow" yarn are lighter, more porous and pleasant to the touch in comparison to those made of conventional cotton yarns [15].

The aim of work presented was to investigate the structural, mechanical and technological properties of "cotton hollow" yarn as well as the basic structural and thermal-insulation properties of woven fabrics made thereof.

## Experimental

### Material and methods

"Cotton hollow" yarn 42 tex CO 80%/PVA (Kuralon K – II) 20% (Japan) was the object of the investigation. The range of the investigation included:

- microscopic observations of the yarn cross-sections,
- laboratory measurement of the basic physical and mechanical properties of the yarn,
- manufacturing woven fabric containing "cotton hollow" yarn in the weft,
- measurement of selected properties of the woven fabric prepared.

Woven fabric was manufactured in plain weave on the basis of warp yarn 25 tex CO and warp density 180/dm. "Cotton hollow" yarn was introduced in the weft direction with a density of 210/dm. For comparison an identical woven fabric was prepared with cotton rotor yarn 42 tex in the weft. The woven fabrics were finished according to the procedure described by the "cotton hollow" yarn manufacturer.

Microscopic observations were performed using an electro-scanning microscope - VEGA3 (TESCAN, Czech Republic). Measurements of the basic parameters of the yarn and fabrics were performed with standardised methods commonly applied to the measurement

of yarns and woven fabrics. Additionally for measurement of the thermal properties of the woven fabrics an Alambeta (Sensora, Czech Republic) device was used [16 - 19]. It is a computer-controlled instrument for measurement of the basic static and dynamic thermal characteristics of textiles. This method belongs to the so-called 'doubled plate methods', the working principle of which involves recorded uni-directional heat flow through the sample from the hotter upper plate to the colder bottom plate adjoined to it [16].

With the Alambeta the following thermal insulation and thermal contact properties of fabrics can be determined: thermal conductivity, thermal diffusivity, thermal absorptivity, thermal resistance, ratio of the maximal and steady heat flow, stationary heat flow density and fabric thickness. The instrument directly measures the transient and steady state heat flow density passing through the plates, the temperature difference between the upper and bottom fabric surface, and the fabric thickness. Other thermal parameters such as the thermal conductivity, thermal absorptivity and thermal diffusivity are calculated by means of special software from the directly measured parameters.

According to the standard [17], for each fabric variant measurement of 10 laboratory samples were made with the Alambeta.

## Results and discussion

Microscopic pictures of cross-sections of the 42 tex "cotton hollow" yarn CO80/PVA20 are presented in Figure 4.

In the cross-section of the 42 tex CO80/PVA20 yarn we can see two kinds of fibres:

- cotton fibres of irregular shape with inner lumen arising during fibre maturation [20],
- round PVA fibres.

On the basis of the microscopic observations of yarn cross-sections it was stated that the real structure of the yarn investigated significantly differs from the structure presented by the yarn producer (Figure 3). PVA fibres are inside the yarn but do not create the core in the yarn center. We can see that PVA fibres are located

inside the yarn randomly between cotton fibres.

Results of laboratory measurement of the 42 tex CO80/PVA20 yarn are presented in **Table 1**.

Mechanical properties of the yarn investigated are very good in the relation to conventional cotton yarns. The tenacity of the yarn is high – 18.8 cN/tex, comparable with that of cotton combed yarns, and it was achieved at a twist level typical for cotton carded yarns.

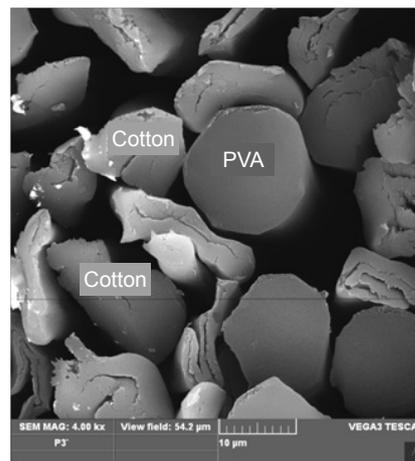
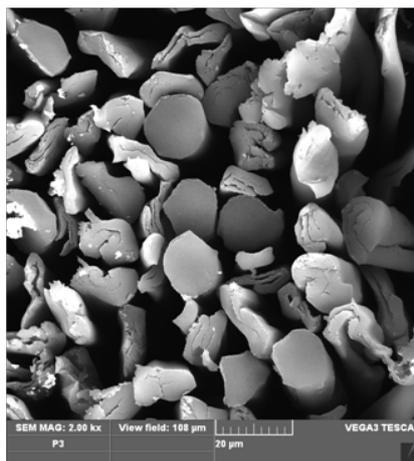
The yarn investigated is innovative and unique in the aspect of its structure and composition, due to which there is a lack of criteria for quality assessment of the yarn on the basis of measurement results. In order to discuss the results the values of particular parameters of the yarn investigated were compared with statistical data according to Uster® Statistics version 2013. Uster® Statistics have been applied in the textile industry since 1957 and have been updated many times according to changes in the global textile industry. The yarn quality reference values established worldwide aid yarn producers, yarn users and machine manufacturers in comparing their results measured with global benchmarks, and they have become the common quality language for the global textile industry [21].

The results for the 42 tex CO 80/PVA20 yarn were compared with data for cotton ring yarn for weaving, because in the Uster Statistics there are not any data concerning unconventional yarns. For comparison cotton ring yarns were taken because it was assumed that the yarn investigated should be considered as an alternative to that kind of yarn in cotton products.

Interpretation of the results is as follows:

- 5% means the best 5% of yarns of a given assortment manufactured all over the world,
- 50% means the mean quality in reference to the global quality of yarns manufactured in a given assortment,
- 95% and more – the worst quality in comparison to that of yarn of a given assortment manufactured in world spinning mills.

The quality level of the yarn investigated in the range of particular properties is presented in **Table 2**.



**Figure 4.** Microscopic pictures of cross-sections of 42 tex CO80/PVA20 yarn.

Summing up the quality assessment according to Uster® Statistics it was stated that the quality of the yarn investigated corresponds to the best quality of cotton ring yarns manufactured in spinning mills all over the world. The results allow to assume that the yarn investigated can be successfully applied in further processing in weaving or knitting processes.

In order to check the behavior of the yarn in the weaving process, technological trials were carried out in industrial conditions. In these trials 42 tex CO 80/PVA 20 yarn was applied in the weft direction. It was stated that the weaving process runs without any disturbances caused by the yarn investigated. Grey fabric was finished with a process similar to the finishing of standard cotton fabrics. Neverthe-

less in order to dissolve the PVA fibres, the initial temperature of the finishing bath was 50 °C, subsequently increased gradually to 90 °C.

Next microscopic pictures of cross-sections of the weft yarns established from the finished fabric were prepared (**Figure 5**, see page 36) in order to check the dissolving of the PVA fibres.

Microscopic observations confirmed that the PVA fibres were successfully dissolved in the process of fabric finishing. We can see that there is a lack of PVA fibres in the weft yarn cross-section. Moreover the yarn is characterised by a loose structure with visible spaces between cotton fibres, which also confirmed by the results of the gray and finished fab-

**Table 1.** Results of measurement of 42 tex CO 80/PVA 20) yarn.

Parameter	Unit	Value
Linear density	tex	42.46
Breaking force	cN	798
Coefficient of variation of breaking force	%	7.33
Tenacity	cN tex <sup>-1</sup>	18.8
Elongation at break	%	7.09
Coefficient of variation of percentage elongation at break	%	6.29
Twist	t.p.m	577
Metric twist coefficient	–	119
Coefficient of variation of twist	%	3.4
Coefficient of variation of mass, CV <sub>m</sub>	%	10.85
Thin places per 1000 m	–	1
Thick places per 1000 m	–	1.6
Neps per 1000 m	–	1.6

**Table 2.** Quality level of the yarn investigated according to Uster® Statistics.

Parameter	Level acc. to Uster® Statistics	Quality
Coefficient of variation of mass CV <sub>m</sub>	5%	Excellent
Thin places (- 40%) per 1000 m	11%	Very god
Thick places (+ 35%) per 1000 m	5%	Excellent
Neps (+200%) per 1000 m	5%	Excellent

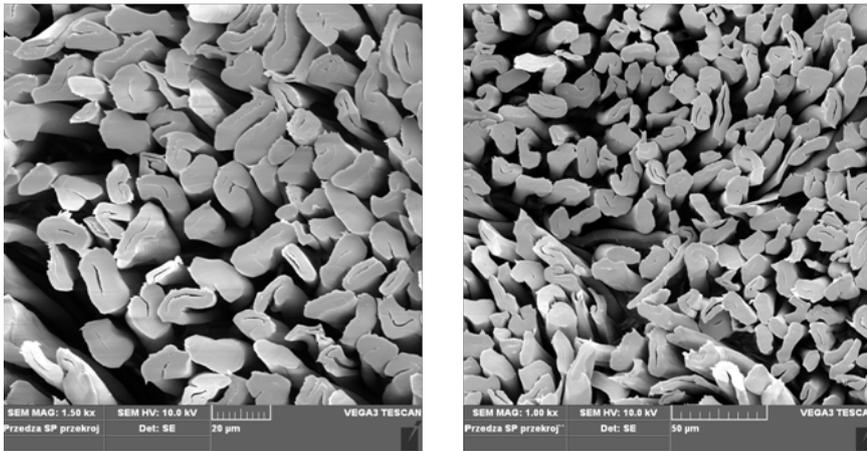


Figure 5. Examples of microscopic pictures of the cross-section of weft yarns established from the finished fabric.

Table 3. Basic parameters of the woven fabrics.

Kind of weft yarn		Mass per square meter, gm <sup>-2</sup>	Weft linear density, tex	Warp density, cm <sup>-1</sup>	Weft density, cm <sup>-1</sup>
42 tex CO80/PVA20	gray	140	42.0	19	18
	finished	125	36.5	21	19
42 tex CO OE	gray	140	42.0	19	18
	finished	150	43.0	21	20

Table 4. Thermal-insulation properties of the woven fabrics investigated.

Kind of weft yarn		Thermal conductivity, Wm <sup>-1</sup> K <sup>-1</sup>	Thermal absorptivity, Wm <sup>2</sup> s <sup>1/2</sup> K <sup>-1</sup>	Thermal resistance, W <sup>-1</sup> K m <sup>2</sup>	Thickness, mm
42 tex CO80/PVA20	gray	0.0441 (0.00062)	151.56 (5.928)	0.0136 (0.00069)	0.60 (0.025)
	finished	0.0523 (0.00181)	163.81 (12.034)	0.0106 (0.00047)	0.55 (0.012)
42 tex CO OE	gray	0.0441 (0.00063)	153.57 (2.911)	0.0142 (0.00067)	0.63 (0.030)
	finished	0.0555 (0.00242)	186.22 (12.922)	0.0099 (0.00069)	0.55 (0.022)

ric measurement in the range of mass per square meter and linear density of weft yarn (Table 3).

Both gray fabrics are characterised by the same mass per square meter – 140 g/m<sup>2</sup>

and the same linear density of the weft yarn – 42 tex. In the case of fabric with weft yarn 42 tex CO80/PVA20 a significant reduction in the mass per square meter and linear density of the weft yarn is observed after finishing, caused by dis-

solving the PVA fibres. In the case of the fabric with 42 tex cotton rotor yarn in the weft, opposite changes are observed – both the mass per square meter and linear density of the weft yarn are higher after fabric finishing than before. The increase in the mass per square meter is caused by the rise in the density of warp and weft after finishing.

Table 4 presents values of the thermal-insulation properties of the woven fabrics investigated. The brackets present values of the standard deviation of the results.

The thermal resistance of gray fabrics is significantly higher than that of the finished fabrics (Figure 6.a), caused by the looser structure of gray fabrics in comparison to the finished ones. Gray fabrics contain a bigger amount of air trapped inside the structure between threads than the finished fabrics. Moreover gray fabrics are thicker than finished ones, implying higher thermal resistance.

When analysing the finished fabrics, the thermal resistance of the fabric with weft yarn 42 tex CO80/PVA20 is higher than that of the fabric with 42 tex cotton rotor yarn, which is according to expectations because weft yarn 42 tex CO80/PVA20 after fabric finishing has a looser structure and bigger spaces between cotton fibres due to the dissolving of PVA fibres. The air trapped between threads and fibres is a good thermal insulator and provides higher thermal resistance of the fabric with weft 42 tex CO80/PVA20 in comparison with that with the weft made of cotton rotor yarn 42 tex.

Admittedly we expected a more significant increase in the thermal resistance of the woven fabric by the application of

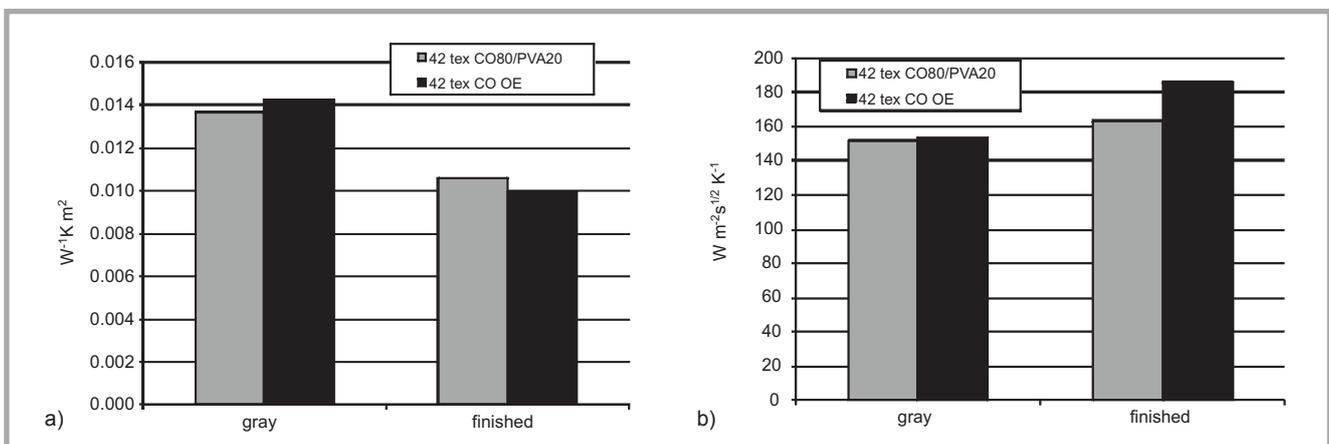


Figure 6. Thermal resistance (a) and absorptivity (b) of woven fabrics.

42 tex CO80/PVA20 yarn due to its “hollow” structure. Nevertheless it should be noted that 42 tex CO80/PVA20 was applied only in the weft direction, meaning that the share of 42 tex CO80/PVA20 yarn in the total mass of the fabric manufactured is ca. 50%. Hence it must be assumed that the application of the yarn in both directions: warp and weft allows to achieve a much bigger effect of the thermal resistance increment.

What is more the higher thermal resistance of the fabric with weft yarn 42 tex CO 80/PVA 20 than that with the weft made of 42 tex rotor yarn was achieved at a lower mass per square meter of the woven fabric (**Table 3**), which can be considered as an advantage from the point of view of utility comfort.

The thermal absorptivity of the fabrics investigated is presented in **Figure 6.b**. This parameter characterises fabrics from the point of view of the warm or cool sensation at the moment of contact with human skin. The higher the thermal absorptivity the cooler the sensation [15, 20].

Results showed that the finished fabric made of weft yarn 42 tex CO80/PVA20 gives a significantly warmer sensation than that made of 42 tex cotton rotor yarn in the weft. Taking into consideration that 42 tex CO80PVA20 yarn was developed especially to improve thermal comfort, the warmer touch should be considered as an advantage.

## ■ Summary

Yarn made of cotton and modified PVA fibres manufactured using patented spinning technology allows to obtain a hollow-like structure of yarn, which ensures higher thermal insulation of fabrics in comparison to those made of conventional cotton yarns.

The yarn investigated is innovative and unknown till now in the world textile industry. Due to this fact it was necessary to check its basic structural, mechanical and technological parameters.

The investigations carried out showed that “hollow” yarn 42 tex CO80/PVA20 is characterised by high quality corresponding to the best quality of cotton carded yarns manufactured in cotton spinning mills all over the world and it

can be processed on looms without any problems.

The investigations of yarn 42 tex CO80/PVA20 presented confirmed its loose hollow-like structure. However, the structure is different from that declared by the yarn producer. Microscopic observations showed that the PVA fibres do not create a core at the center of the yarn. They are placed randomly between the cotton fibres. After dissolving the PVA fibres there are empty spaces between the cotton fibres.

Measurement of the woven fabrics by Alambeta confirmed the ability of 42 tex CO 80/PVA 20 yarn to increase the thermal insulation of fabric made of it. Finished fabric with yarn 42 tex CO 80/PVA 20 in the weft is characterised by higher thermal resistance than finished fabric with 42 tex cotton rotor yarn in the weft. However, the thermal resistance increment due to the application of the yarn investigated was lower than expected.

The application of yarn 42 tex CO80/PVA 20 in both directions: warp and weft should allow to achieve a much bigger effect of the thermal resistance increment. A significant advantage of the application of yarn 42 tex CO 80/PVA 20 in fabric is the warmer touch in comparison with fabric without it.

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