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Blended Yarns with a Content of Biological Active Fibres

Abstract
New raw materials and intermediate & auxiliary products used in clothing textiles may have a beneficial influence on human organisms. Such a user-friendly influence can be achieved by introducing biological active substances into the fibres. Investigations into developing a technology aimed at manufacturing yarns from antimicrobial and antifungal fibres were carried out at the Department of Technology and Structure of Yarns, Technical University of Łódź. A more specific goal of these investigations was to determine the minimum content of Amicor fibres (manufactured by Acordis, Great Britain) in a blend with cotton at which the yarn would still have antimicrobial and antifungal properties. The investigations were finalised by biological tests of knittings manufactured from yarns able to exterminate microbes.

Key words: *yarn blends, cotton, antimicrobial fibres, antifungal fibres, Amicor, yarn properties, biological tests.*

Civilisation's progress in the modern world has created positive as well as negative effects on human beings and their environment. New raw materials and intermediate & auxiliary products used in clothing textiles may have a beneficial influence on human organisms, but may often cause different diseases, in the majority diseases of the skin. An effect which would be beneficial for human beings can be achieved by introducing biologically active substances into the fibres [1-12].

A dynamic development of bioactive fibres has been observed over the last ten years, and is the result of a new perspective on the application of textile products as well as the introduction of high technology into their manufacture. Bio-functional textiles are manufactured from bioactive fibres [13] which meet therapeutic, prophylactic, and after-care needs independent of their general application assignment. Investigations carried out have proved that such textiles could also heal or help cure many skin diseases such as psoriasis, various kinds of mycosis, and inflammations. Experiments with refreshment and mood-altering substances included in the fibres used for textiles were also performed. Good therapeutic effects can be expected considering that textiles cover the human body over many hours throughout the day and night.

Joining active substances with fibres can be performed by different methods. The substances can be introduced during fibre formation, or deposited during finishing processes of yarns or textile fabrics.

The bioactive substances deposited on the surface of textiles may be easily washed out, and may also disturb the fabric's usability and comfort. The bioactive effect of textiles manufactured from fibres with such substances incorporated into their mass or structure lasts much longer.

New methods of inserting and releasing bioactive substances are at present the subject of many investigations carried out as bio-functional textiles create new possibilities of their application.

One typical fibre destined for bio-functional textiles has been developed by Zimmer AG, Frankfurt am Main, Germany [13,14]. It is manufactured from cellulose and seaweed, raw materials which can be regenerated. The active components of this fibre originate from the sea, whereas cellulose is only a carrier, and therefore this new fibre was designated as 'Sea Celi'. Up to now, the majority of bio-functional textiles used for manufacturing underwear and clothing which has direct contact with the human body are produced from Sea Celi fibres.

A cotton with sharp anti-bacterial activity has been developed at the University of California. Bacteria which come into contact with this cotton are killed during a few minutes, which results for example in the elimination of the unpleasant odour of sweat. Moreover, textiles from this cotton exterminate or prevent the growth of saccharomycetes, pathogenic fungi, and even certain kinds of viruses. These fibres are also beneficial for human beings, and cause no irritations or allergies.

Lenzing AG [15] has developed modal viscose fibres called Modal Fresh. These fibres have a durable antifungal preparation, which was achieved by inserting an antibacterial agent into the spinning solution. It should be emphasised that this incorporation does not change the physical-mechanical properties of the yarn. Modal Fresh excellently fulfils its health features, also when it is blended with other yarns from natural and chemical fibres. Such yarn blends have been applied for manufacture of sport clothing, underwear, and textile products for medical applications. Investigations carried out have testified to its good antibacterial properties even after 50 washings.

A yarn with the trade name Salus is manufactured by the Filament Fiber Technology Corp. [1] from ultra-thin filaments. In its mass it contains Microban, a bactericidal agent which prevents the growth of many pathogenic bacteria, saccharomycetes, and spores causing skin mycosis. Salus yarn is mostly applied in the production of 'micro-fibre products' which thanks to their special properties are designated for sport textile applications. The Microban agent included in the fibres not only exterminates micro-organisms but also eliminates the unpleasant odour often connected with intensive sweat.

Nylstar [16] has developed fibres called Skinlife. Its particular feature is its bacteriostatic behaviour; these fibres prevent bacteria from migrating from clothing to human skin.

Rhovyl, France [17] manufacture bacteriostatic fibres with the trade name of Rhovyl AS. These fibres are negatively electrified when rubbed on human skin. Negative ionisation causes the broadening of the blood vessels, which improves blood circulation and has a positive influence on maintaining body temperature; this in turn is especially crucial when treating rheumatic diseases. Additionally, the Rhovyl AS fibres prevent bacteria from depositing and growing on human skin. Rhovyl AS are manufactured as loose fibres and as worsted slivers. Amber-finished yarns and products manufactured in Poland have a similar effect.

Investigations into polyester filaments manufactured at Elana S.A., Toruń have been carried out in Poland [18]. The tests consisted of incorporating a new-generation antibiotic (from the cephalosporin group) into the fibre structure. Tests proved that the agent is powerful against Gram-positive and Gram-negative bacteria (*Staphylococus aureus, Escherichia coli, Pseudomonas aeruginosa*).

Avecia Protection & Hygiene [8] is a company which deals with biocide agents (especially with antimicrobial agents). This company is a world-famous manufacturer and distributor of biocide agents which are used for conservation, disinfection, and protection of industrial and consumer products. The antimicrobial products manufactured by Avecia can be applied not only for processing fibres but also ready-made products. It is possible to finish clothing (especially socks, T-shirts, sport clothing, and normal shirts), materials used in hospitals (e.g. bed linen), and industrial products (e.g. filters) with Avecia products. The antimicrobial agents are in general incorporated into textiles by pressing and absorption, but other methods may also be applied, such as incorporation into the molten polymer mass in melt-spun synthetic fibres.

Acordis [2], Great Britain is a manufacturer of anti-microbe polyacrylonitrile fibres known under the trade mark Amicor. Acordis offers Amicor Standard™ cotton-type antibacterial staple fibres, and Amicor Plus™ antibacterial and antifungal fibres containing Irgasan, an agent which prevents the growth of a broad spectrum of pathogenic bacteria and bacteria responsible for the unpleasant odour of sweat. This fibre is mostly designed for sports clothes, underwear, and socks. For its part, Amicor Plus™ is a blend of the following polyacrylonitrile fibres: the antibacterial Amicor AB fibre, and the antifungal Amicor AF fibre. The Amicor AF fibre includes in its mass a soft antifungal preparation with the trade mark Tolnaftate. This preparation has been developed to prevent the growth of pathogenic fungi, which in turn prevents foot mycosis. All three fibre types presented above retain their properties after washing. They are active even when their content in yarn blends is only 20%.

To summarise, it can be stated that the antimicrobial processing of textiles is aimed at:
- preventing (inhibiting) the progress of micro-organisms,
- improving the hygienic properties resulting from microbe decay, and
- avoiding property losses of fibres degraded after microbe attack.

The anti-microbial agents are:
- deposited on fibres as the result of chemical finishing of fibres and textiles, or
- incorporated during spinning of synthetic fibres by means of agent addition to the spinning solution or spinning melt.

Antimicrobial agents which are deposited on the textiles' surface may be easily washed out, and they may also worsen the user comfort of textiles. Those textiles manufactured from fibres which include antibacterial and antifungal agents inside their structure are active for much longer periods.

The Aim of our Investigation

The investigations aimed at developing a technology of yarn manufacture from antibacterial and antifungal fibres have been carried out at the Department of Technology and Structure of Yarns at the Technical University of Łódź. Preliminary test results into investigation of the 30 tex yarns from Amicor fibres and yarn blends manufactured from Amicor fibres and cotton are described in [19-21]. The aim of the research work presented in this paper was:
- to develop a manufacturing technology for yarns with linear density of 20 tex and with a broadened range (from 12.5% up to 75%) of Amicor Plus™ fibres in the cotton/Amicor blends;
- to determine the minimum Amicor fibre content in yarn blends with cotton which still allows us to obtain yarns with antibacterial and antifungal properties, and
- biological tests of knittings manufactured from yarns which can exterminate microbes.

Test Results

Middle staple cotton together with Amicor Plus™ fibres was used as raw material for the tests. The parameters of Amicor Plus™ fibres are drawn up in Table 1.

The yarns were manufactured by blending the fibre slivers with the use of draw frames. The following machines were used for yarn manufacture: a set of opening and cleaning machines, the CZ 693 carding machine, the Globe 740 draw frame, and the PPM 120 second-generation rotor spinning machine. The spinning plane is listed in Table 2.

The tests were carried out in six stages. The first stage consisted in tests of yarn blends 50%/50% cotton/Amicor Plus™ fibres, manufactured from a sliver twice drawn at a constant velocity of the opening roller of 7000 r.p.m., at α_m=130, and at the following rotor rotational velocities:

Table 1. *Fibre parameters.*

Parameter	Unit	Amicor Plus™	Cotton
Linear density	dtex	1.7	1.3
Mean length	mm	38	25
Coefficient of variation of length	%	13.2	23
Tenacity	cN/tex	38	27
Elongation	%	41	8.2

Table 2. *Spinning plane of the cotton/Amicor Plus™ fibres yarn blend with 20 tex.*

Machines	Type	Ttz, ktex	Number of doublings	Drawing ration	Ttw, ktex
Revolving flat card	CZ 693	400	1		4
Draw frame	Globe 740	4	8	8	4
Draw frame	Globe 740	4	8	8	4
Rotor spinning machine	PPM 120	4	1	200	20 tex

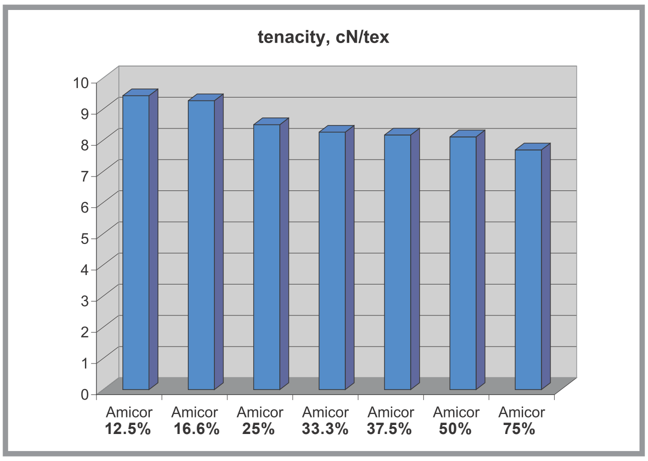

Figure 1. *Dependence of tenacity on the percentage content of Amicor fibres in yarn.*

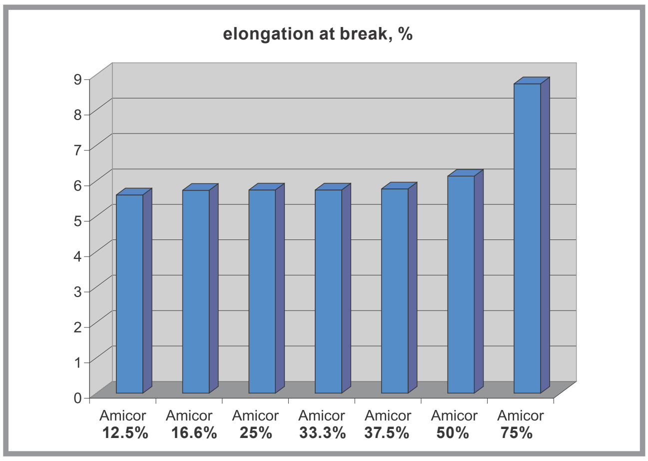

Figure 2. *Dependence of elongation at break on the percentage content of Amicor fibres in yarn.*

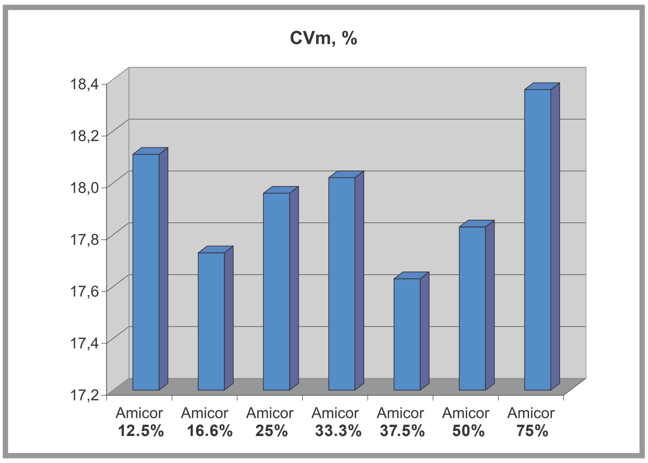

Figure 3. *Dependence of irregularity of linear density (variation coefficient) CVm (%) on the percentage content of Amicor fibres in yarn.*

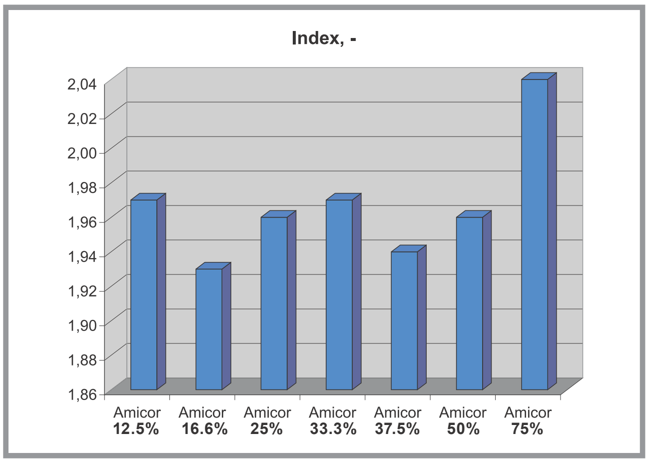

Figure 4. *Dependence of the 'Huberty index' coefficient on the percentage content of Amicor fibres in yarn.*

- 45,000 r.p.m.,
- 40,000 r.p.m., and
- 36,000 r.p.m.

The fibres were blended in slivers with the use of a draw frame.

An analysis of the yarns' quality parameters allows us to state that yarn manufactured at a rotational rotor velocity of 40,000 r.p.m. was characterised (in comparison with yarns manufactured at rotational rotor velocities of 36,000 r.p.m. and 45,000 r.p.m.) by a smaller number of faults, lower irregularity of linear density (coefficient of variation), higher tenacity, and a lower value of the Huberty coefficient. This was why only the rotational rotor velocity of 40,000 r.p.m. was used in further tests.

The second stage was devoted to an analysis of the influence of the opening rollers' rotational velocity on the quality parameters of yarn at constant twist coefficients and at constant sliver which fed the spinning machine. Rotational velocities (of the opening rollers) of 6,000 r.p.m., 7,000 r.p.m., and 8,000 r.p.m. were used in the tests.

The velocity of 7,000 r.p.m. was selected after an analysis of the yarn parameters obtained by tests. Yarn manufactured at this velocity of the opening roller (in comparison with yarn manufactured at both of the other opening roller's velocities) was characterised by lower irregularity of linear density, lower value of the Huberty coefficient, a smaller number of faults in the yarn, and higher tenacity. With an increase in rotational velocity of the opening rollers, the irregularity of linear density measured by the coefficients of variation CV(1 m), CV(3 m), CV(10 m), CV(inert), and CV(1/2-inert) increases, whereas the number of thick places and neps decreases.

The third stage of the tests was devoted to checking the influence of the metric twist coefficient α_m on the yarn quality parameters. After an analysis of the tests results, we could state that the yarn which has the highest twist coefficient, α_m=130, achieved the best quality parameters. It is difficult to state beyond doubt whether an influence of an increase in the metric twist coefficient on the irregularity of linear density and the number of thin and thick places exists. On the other hand, the values of the Huberty coefficient, the hairiness and the coefficient of variation of the hairiness decreases with an increase in the twist coefficient, whereas the decrease in yarn twist causes a decrease in tenacity.

Within the plane of the fourth stage, 7 variants of yarns in the form of cotton/Amicor Plus^{TM} fibre blends with 20 tex were manufactured at optimum machine settings selected within the first, second, and third stages. The variants were differentiated by the following Amicor fibre percentage in the yarn blends:

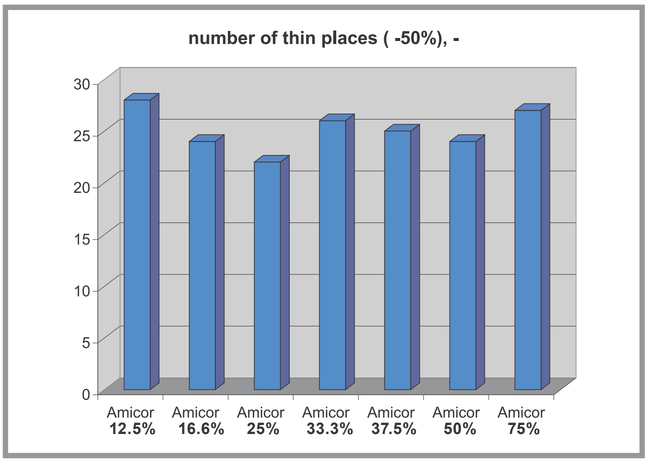

Figure 5. *Dependence of the number of thin places (-50%) on the percentage content of Amicor fibres in yarn.*

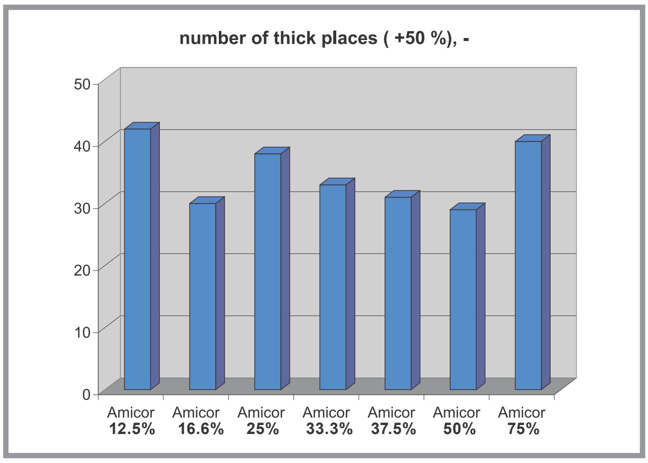

Figure 6. *Dependence of the number of thick places (+50%) on the percentage content of Amicor fibres in yarn.*

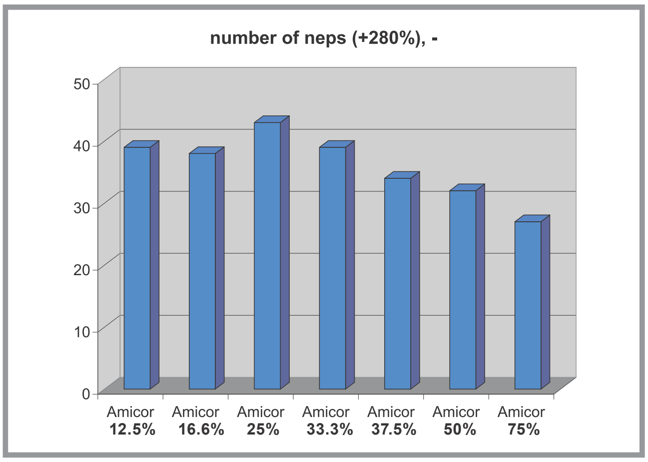

Figure 7. *Dependence of the numbers of neps (+280%) on the percentage content of Amicor fibres in yarn.*

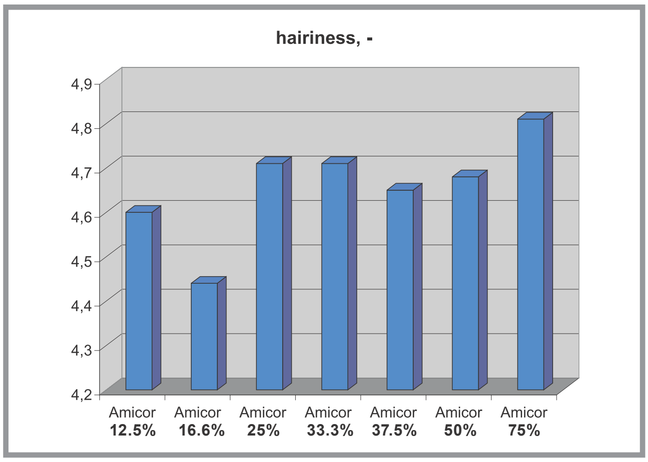

Figure 8. *Dependence of hairiness on the percentage content of Amicor fibres in yarn.*

- Amicor 12.5% (cotton - 87.5%),
- Amicor 16.6% (cotton - 83.5%),
- Amicor 25.0% (cotton - 75.0%),
- Amicor 33.3% (cotton - 66.7%),
- Amicor 37.5% (cotton - 62.5%),
- Amicor 50.0% (cotton - 50.0%),
- Amicor 75.0% (cotton - 25.0%).

The measurement results of the yarn parameters are presented in Figures 1-8. As seen in Figure 1, the yarn tenacity decreases with an increase in the Amicor fibre content in yarn. A statistical estimation by means of one-factor variance analysis proved the essential influence of the Amicor fibre content in blends with cotton on tenacity and on the number of thin and thick places of the yarn blends. With the increase in the Amicor fibre content in yarn, a decrease in the number of thin and thick places as well as in the tenacity were observed. The content of Amicor fibres in blends with cotton has no substantial influence on the irregularity of linear density, the values of the Huberty coefficients, or the yarn hairiness.

A comparison of the results obtained with Uster statistics [22] for cotton yarn, allowed us to state that the particular parameters obtained are at the following levels of total world production:

- irregularity of mass (linear density) CVm: 75-95%,
- thin places: 25%,
- thick places: 5% and below,
- neps: below 50%,
- hairiness: 50%, and
- tenacity: below 95%.

The next stage consisted in estimating the samples obtained in seven knitting tests carried out with the use of a double-cylinder sock automatic knitting machine, and with the yarns manufactured which were previously analysed.

The samples had the structure of 1×1 rib weft-knitted fabrics. The yarns were processed without distortion, and the knittings were characterised by high elasticity, and a soft and pleasant handle. No problems occurred over the yarn processing, but a deviation of the wales from the vertical direction and a twist of the fabric could be observed as the result of a too high a yarn twist.

Results of Microbiological Tests Checking the Knittings' Ability to Exterminate Microorganisms

Tests were carried out with knittings manufactured from yarns with a linear density of 20 tex of the following compositions:

- cotton 100%,
- cotton 87.5%/Amicor 12.5%,
- cotton 83.4%/Amicor 16.6%,
- cotton 75.0%/Amicor 25.0%,
- cotton 66.6%/Amicor 33.3%,
- cotton 62.5%/Amicor 37.5%,

- cotton 50.0%/Amicor 50.0%,
- cotton 25.0%/Amicor 75.0%.

The knittings were tested for the presence of spores of the anaerobic sporogenous micro-organisms, and the total amount (number) of micro-organisms in accordance with standards PN-93/A-86034/12 and PN-A-82055-6. During the test, the standard agar and the agar with glucose were used as the breeding-grounds. The presence of spores of the anaerobic sporogenous micro-organisms was organoleptically estimated in accordance with standard PN-93/A-86034/12. The presence of anaerobic bacteria, which in the conditions prescribed by the standard method create black colonies or cause blackening of the medium, was denoted by the (+) sign, and their absence by the (-) sign. The total number of micro-organisms was determined by the plate method, by observing the number of micro-organisms in one gram of the sample.

The analysis of tests carried out allowed us to make the following statements:

- Knittings manufactured from 100% cotton yarn which were placed (by means of the submersion method) onto the agar with glucose breeding ground were characterised by a greater amount of micro-organisms than the same knittings placed (also by means of the submersion method) on standard agar.
- Knittings of Amicor Plus™ fibres set on the agar with glucose ground:
  - with an Amicor fibre content of 12.5% and 16.6%: no difference in micro-organisms amount is visible;
  - with an Amicor fibre content of 25.0%, 33.3%, and 37.55: a distinct difference in the amount of micro-organisms is visible in comparison with knittings of 12.5% and 16.6% Amicor fibre content;
  - with an Amicor fibre content of 50.0% and 75.0%: a distinct difference in the amount of micro-organisms is also visible in comparison with knittings of 12.5% and 16.6% Amicor fibre content.
- Knittings of Amicor Plus™ fibres set on standard agar (submersion method):
  - a distinct difference in the micro-organisms amount was stated between samples containing 12.5% and 16.6% Amicor fibres and those of 25.0%, 33.3%, 37.5%, 50.0%, and 75.0%.
  - The presence of sporogenous bacteria was not detected in the samples tested.

On the basis of the tests carried out, we can state that, beginning with 25.0% content of Amicor Plus™ fibres in yarn, this fibre causes considerable inhibition in the growth of micro-organisms.

Summary

- On the basis of the investigations carried out, the optimum parameters of the technological manufacturing process of 20 tex yarn (with satisfactory quality parameters) with the use of a rotor spinning machine were elaborated for yarn blends of cotton and Amicor Plus™ fibres.
- The increase in yarn twist has a substantial influence on the improvement of yarn quality parameters and the continuity of the spinning process.
- The content of Amicor fibres in blends with cotton has an essential influence on both the number of thin and thick places and the tenacity of the yarn blends. With the increase in Amicor fibre content in yarn, a decrease in the number of thin and thick places and in tenacity can be observed.
- The content of Amicor fibres in yarn blends has no substantial influence on the irregularity of yarns' linear density, yarn hairiness or the Huberty coefficients.
- Manufacturing knitted textiles in laboratory scale could be performed without disturbances for all variants of the blends used. The knittings were characterised by uniform structure, but a slight twisting of the fabric (caused by too high a yarn twist) could be observed.
- The content of 25.0% Amicor fibres in the yarn blend causes a fundamental inhibition in the growth of micro-organisms and entirely prevents the growth of sporogenous bacteria.

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