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Measurement of Cotton Fineness and Maturity by Different Methods

Abstract
Different measurement principles are used in measurement systems. There are some new systems which are not commonly used in cotton fiber assessment, like Siromat and CottonScan by CSIRO or ITRU UAK-1+. The method of cotton fineness assessment by CottonScan is based on a direct method of measuring the total length of a known mass of fiber snippets to directly calculate the mass per unit length (fineness). The SiroMat™ instrument determines a fiber's maturity based on fiber colors when viewed under a polarised light microscope. The relationship between the interference colours assumed by fibers under the crossed polarised light beams and fiber maturity is based upon the orientation of cellulose chains in the fiber wall, which affect the path length of light through the wall. This method (not automated) has been used for many years by GOST (now an Uzbeck standard) and ASTM. The ITRU Fiber Tester UAK-1+ operates on the basis of the computer image analysis principle. To determine fiber parameters, only two tests are needed: a test of the fiber beard, and an image analysis of the fiber or fabric surface. This study presents a comparison of fineness and maturity results obtained by traditional measurement systems (HVI & AFIS, according to GOST) and by new ones. The method of ITRU UAK-1+ surface Micronaire measurement is also presented, as well as results for the same parameter from Y-section Microscope analysis performed on single fibers.

Introduction

The Maturity Ratio is a cotton maturity parameter which, according to ASTM D-13, determines the degree of wall thickening. To define the degree of wall thickening, the coefficient of fibre circularity was introduced, which is defined as the ratio of the wall cell area and the area of a circle of the same perimeter as the fibre cross-section:

$$\theta = \frac{4\pi A}{P^2} \qquad (1)$$

where:
P – perimeter of a given fibre cross-section,
A – area of the cross-section of the secondary fibre wall defined by equation 2,

$$A = T(P - \pi T) = \pi R^2 [1 - (r/R)^2] \qquad (2)$$

where:
T – thickness of the secondary fibre wall,
R – maximum fibre radius,
r – lumen radius.

The circularity coefficient is equal to 1 when the fibre cross-section is a circle without a lumen. The IFC (Immature Fibre Content) is defined as a percentage of fibres of the circularity coefficient less than 0.25. MR (Maturity Ratio); according to Lord and Heap [8], it is defined as:

$$MR = 0.70 + (N - D)/200 \qquad (3)$$

where:

N and D are, successively, the percentages of mature fibres of a circularity coefficient $\theta > 0.5$ and dead fibres ($\theta < 0.25$). Fibres of a MR < 0.7 are not met in practice. Fibres of aMR in the interval 0.7÷0.8 are immature: fibres of a MR in the interval 0.8÷1 – are mature, and fibres of a MR > 1 have been very rarely met; such fibres are too mature and can cause problems in the spinning process.

The commonly used Micronaire determines both the fibre fineness and maturity, whose values are in the interval 3÷6. Lord proposed an empirical relationship combining the maturity, fineness and Micronaire:

$$(MR)^2 Tt = 3.86(IM)^2 + 18.16(IM) + 13 \qquad (4)$$

where: IM – Micronaire,
Tt – fibre fineness,
MR – maturity ratio.

Equation 1 can be converted to give the fibre maturity as follows:

$$MR = \theta/0.577 = 4\pi A/(0.577\, P^2) \qquad (5)$$

Cotton fibre fineness is given by the relationship:

$$Tt = \rho A \qquad (6)$$

where: ρ = 1.52 g/cm^3 – cell density of the cellulose wall.

Also known is the GOST method, elaborated by Fiodorow, which relies on a comparison with cotton fibre patterns (***Figure 1***). This method was adapted by Polish Standard PN-88/P-04675. According to Standard UzRST 604-93 (also based on the old GOST method, later named GOST for short), cotton maturity is determined by the interference colour of fibres in polarised light. According to this method, fibres are classified in four colour classes, as follows:

- mature fibres – orange, golden yellow and yellow-green,
- light mature – green-yellow with blue parts, green, blue,
- not mature – blue and blue-violet,
- dead – violet-purple or transparent.

The mean degree of maturity is calculated on the basis of the fibre percentage in particular classes according to equation:

$$\mathbf{z} = \sum_{i=1}^{n} a_i p_i / 100 \qquad (7)$$

where:
z – degree of maturity,
$a_{i\,n}$ – coefficient characteristic for a given cotton class depending on the cotton origin set in tables,
p_i – fibre percentage in a given class of maturity.

The relationship between the circularity coefficient θ and the degree of maturity **z** according to GOST is presented below [11]:

$$\theta = 1 - (0{,}95 - 0{,}15\mathbf{z})^2 = 0{,}0975 + 0{,}285\mathbf{z} - 0{,}0225\mathbf{z}^2 \quad (8)$$

where: **z** – degree of maturity.

Description of the systems invented by CSIRO

CSIRO together with the Australian Cotton Industry developed two new devices for measuring fibre fineness (CottonScan™) and maturity (SiroMat™) quickly, directly and accurately. Each device is based on an existing standard technique, which has been automated. In the case of fibre fineness (CottonScan™), the standard method involves the cutting and weighing of cotton fibres, whereas in the case of cotton maturity (SiroMat™), the standard method is the observation of fibre colour by polarised light microscopy [1, 3].

The CottonScan™ Instrument

This approach to measuring fibre fineness on a Cottonscan™ instrument is based on the direct method of measuring the total length of a known mass of fibre snippets to directly calculate the mass per unit length [2, 4-5].

The fibre snippets prepared and weighed are suspended in an aqueous medium within the instrument before introducing them into the measurement cell. The suspended snippets are then imaged, and image analysis is used to determine the total snippet length within the image. It is more reliable to measure the suspension of the sub-sample than the total volume in order to determine the length of fibre snippets within the sample. The average fibre fineness (linear density), Tt, of the cotton sample is calculated by an equation considering the device constants:

$$Tt = M^*(v/V)/l \quad (9)$$

A technical requirement for the snippet preparation device is its ability to deliver snippets that can be mixed into a uniform suspension within the CottonScan™ instrument. The CottonScan™ instrument with the snippet preparation device should be both easy to operate and 'user-friendly'.

A significant breakthrough in the technology in question was the development of an easy to operate module for preparing snippets from lint samples [6]. A sample (approximately 10 g) of lint is manually inserted into the chamber. The movement of the piston at a fixed pressure compresses the lint sample, and then in the second action cylindrical cutters (each approximately 2 mm in diameter) extend from the face of the piston to collect a core of snippets from the cotton lint sample. A set of 8 cylindrical cutters are arranged in the piston assembly so that the total mass of snippets collected from one cycle of the preparer is approximately 80-100 mg i.e. adequate for the CottonScan™ instrument. The snippet preparation module is driven by an external compressed air supply.

One additional feature of the CottonScan™ instrument is that if the Micronaire value of a cotton sample is known and inputted into the instrument with the sample details, the software automatically calculates the maturity of the sample on the basis of the fibre fineness and Micronaire values measured (using the relationship developed by Lord).

The SiroMat™ Instrument

The SiroMat™ instrument was also developed at CSIRO [4, 7]. The instrument determines cotton fibre maturity on the basis of fibre colours, which can be seen under a polarised light microscope.

The relationship between the interference colours assumed by fibres under the crossed polarised light beams and the fibre maturity is based upon the orientation of cellulose chains in the fibre wall, which affect the path length of light through the wall. Previously, classifying cotton fibres on the basis of their colours by an operator was subjective, and the manual counting of fibres was too slow. However, the development of the colour digital camera and the increased power of computers make this method faster.

Previously it was suspected that the method was biased towards fibre fineness [8] or the implication of the path length of light through the fibre. A survey of interference colours assumed by different types of cotton showed that there was no difference in the colour caused by the genetic origin or intrinsic fineness.

Colour digital cameras, image analysis software and high power computers allow to shorten the test time to two minutes per sample. Moreover, a sample taken from raw or processed cotton does not require conditioning before testing. The SiroMat™ method determines fibre maturity based on the colours of fibres under a polarised light microscope set up according to the ASTM standard. Cotton fibres are automatically scanned and analysed so that a selection of fibres or fibre sections and the interpretation of their colour is no longer subject to operator interpretation. Additionally, the method is also able to measure the distribution of mature and immature fibres in the sample.

The SiroMat™ instrument is calibrated in terms of the maturity ratio. The current calibration equation is a two term multiple linear regression with the independent variables being the areas of yellow and green colour measured in the fibre snippet images. These colour area percentages are correlated with the maturity ratio data measured by a 'Shirley' Fineness and Maturity Tester (FMT) for a calibration set of Australian Upland cottons.

Specimens are prepared by blending them through one passage of a 'Shirley' Analyser. Then specimen preparation involves guillotining a fibre beard prepared using a 'Fibrosampler' to obtain 2 to 3 mg of 1 mm snippets from two cuts near the aligned end of the beard. The snippets are collected and then spread in an annular pattern on a 5 cm x 7 cm glass slide using a fibre spreader. A clean 5 cm x 7 cm slide is used to cover the specimen. Castor oil (refractive index = 1.477÷1. 481) is used as the mounting medium to enhance the contrast of the fibre snippets to their background.

Preparing the SiroMat™ instrument involves adjusting the digital camera settings and the microscope lamp intensity to match the background colour in terms of red, green and blue ratios. Background colours are checked at regular intervals during testing to minimise the drift in instrument readings. For each sample four replicates are measured. There is also the possibility of using the SiroMat™ maturity ratio to calculate cotton fibre fineness.

The new instruments for measuring cotton fibre fineness and maturity developed by CSIRO (both the Cottonscan and SiroMat) give reliable results and are capable of providing valuable additional information to the cotton industry.

Table 1. Fineness and Micronaire; standard deviations are given in brackets.

Symbols	HVI	GOST	CottonScan		AFIS
	Micro-naire	Fineness, mtex	Micro-naire	Fineness, mtex	Fineness, mtex
A – Azer.289-001	**5.1** (0.41)	**196** (6)	**5.30**	**236** (2.3)	**181** (5)
B – Tadz.224-051	**3.9** (0.28)	**164** (4)	**3.71**	**191** (6.4)	**161** (3)
C – Tadz. 235-075	**4.5** (0.35)	**174** (5)	**3.68**	**203** (3.1)	**167** (4)
D – Tadz. 239-070	**4.9** (0.38)	**185** (6)	**4.79**	**223** (5.7)	**176** (3)
E – Tadz.239-081	**4.8** (0.37)	**178** (5)	**4.75**	**224** (3.2)	**177** (4)
F – Uzb.079-550	**4.3** (0.33)	**170** (5)	**4.04**	**212** (2.1)	**167** (3)
G – Uzb.153-081	**4.3** (0.35)	**165** (3)	**3.43**	**201** (13.3)	**167** (3)
H – Kaz.356-504	**4.7** (0.37)	**186** (5)	**4.75**	**221** (6.1)	**180** (5)
I – Kaz.999-059	**4.3** (0.32)	**176** (6)	**4.12**	**205** (5.5)	**169** (7)
J – Kirg.258-018	**4.1** (0.32)	**150** (4)	**3.83**	**193** (4.0)	**161** (5)
H – Kaz.253-105	**4.2** (0.31)	**179** (5)	**4.61**	**208** (1.5)	

Table 2. Fiber maturity and IFC; standard deviations are given in brackets.

Symbols	SiroMat	GOST		AFIS	
	MR	Maturity z	MR (eq.8 and 5)	MR	IFC
A – Azer.289-001	**0.922** (0.170)	**1.9** (0.07)	**0.97**	**0.95** (0.02)	**5.0** (0.5)
B – Tadz.224-051	**0.700** (0.168)	**1.9** (0.06)	**0.97**	**0.89** (0.01)	**8.2** (1.0)
C – Tadz. 235-075	**0.650** (0.164)	**1.9** (0.05)	**0.97**	**0.94** (0.02)	**5.9** (0.8)
D – Tadz. 239-070	**0.847** (0.155)	**2.1** (0.08)	**1.03**	**0.96** (0.01)	**5.3** (0.5)
E – Tadz.239-081	**0.842** (0.177)	**2.0** (0.07)	**1.00**	**0.98** (0.02)	**4.8** (0.8)
F – Uzb.079-550	**0.880** (0.175)	**1.9** (0.06)	**0.97**	**0.88** (0.02)	**8.0** (1.0)
G – Uzb.153-081	**0.600** (0.168)	**1.9** (0.06)	**0.97**	**0.94** (0.01)	**6.6** (0.7)
H – Kaz.356-504	**0.843** (0.176)	**2.0** (0.08)	**1.00**	**0.94** (0.03)	**5.7** (0.9)
I – Kaz.999-059	**0.746** (0.175)	**1.9** (0.06)	**0.97**	**0.92** (0.03)	**7.0** (1.5)
J – Kirg.258-018	**0.720** (0.168)	**1.7** (0.05)	**0.91**	**0.91** (0.01)	**7.9** (0.9)
K – Kaz.253-105	**0.861** (0.162)	**1.9** (0.05)	**0.97**		

Description of the UAK-1+ system, invented by the ITRU Group

The ITRU Fibre Tester UAK-1 is an automated Turkish system for measuring the properties of cotton raw material, sliver and yarn as well as chemical fibres and their blends. It enables the determination of 88 parameters [9] and is based on new ideas, terms and definitions [10]. It consists of the following components:

- totally atomised measurement systems (mechanical, electronic and pneumatic) and a computer image analysis system,
- fibre testing software,
- computer with an operating system – MS-Windows,
- monitor and printer.

The system works based on the computer image analysis principle. To determine fibre parameters, only two tests are needed:

a) test of the fibre beard,

b) image analysis of the fibre or fabric surface.

The ITRU Group has developed a new system to measure the fineness and maturity of a single cotton fibre and their distribution. There are many known computer programs available to determine the fineness and maturity values of cotton fibres from cross-section analyses. In the UAK-1 system, longitudinal images have also been used to determine fineness and maturity parameters.

The development of UAK-1+ is based on microscopic image analyses of the cross-section and longitudinal y-section of cotton fibres and the correlation between them. The system converts the measurement of longitudinal images to fineness and maturity values for each single fibre in the image via sophisticated algorithms developed by the ITRU Group. In short the input is an image of the longitudinal view of cotton fibre, and the output is created by the following parameters, named by ITRU as follows:

Theta (θ) – circularity coefficient of cotton fibre,
P2 – cotton fibre perimeter in micrometers,
AW – area of wall,
FM3 – maturity ratio – H/HS,
H – fibre fineness in mtex,
HS – standard fibre fineness,
FM1 – causticare maturity in %,
IFC – immature fibre content,
DF – degree of fibre flatness,
U – micronaire microgram/inch of cotton fibre.

There is a high correlation between the fineness and the Micronaire calculated in most cases. The ITRU UAK-1 tester can be used for single cotton fibre analyses mainly for research purposes. According to the producer, the advantages of longitudinal analyses over cross-section analyses can be summarised as follows:

- more precise measurement of the diameter of cotton fibre,
- the system is fast.

The longitudinal view of mature and immature fibre is different (***Figure 1***). Mature fibre is more circular and has no convolutions, whereas immature fibre is more convolved and less circular. Therefore, microscopic digital images of each single fibre are used to determine the fineness in mtex and the Maturity Ratio.

Experimental results

Using different measurement instruments, the maturity, Micronaire and

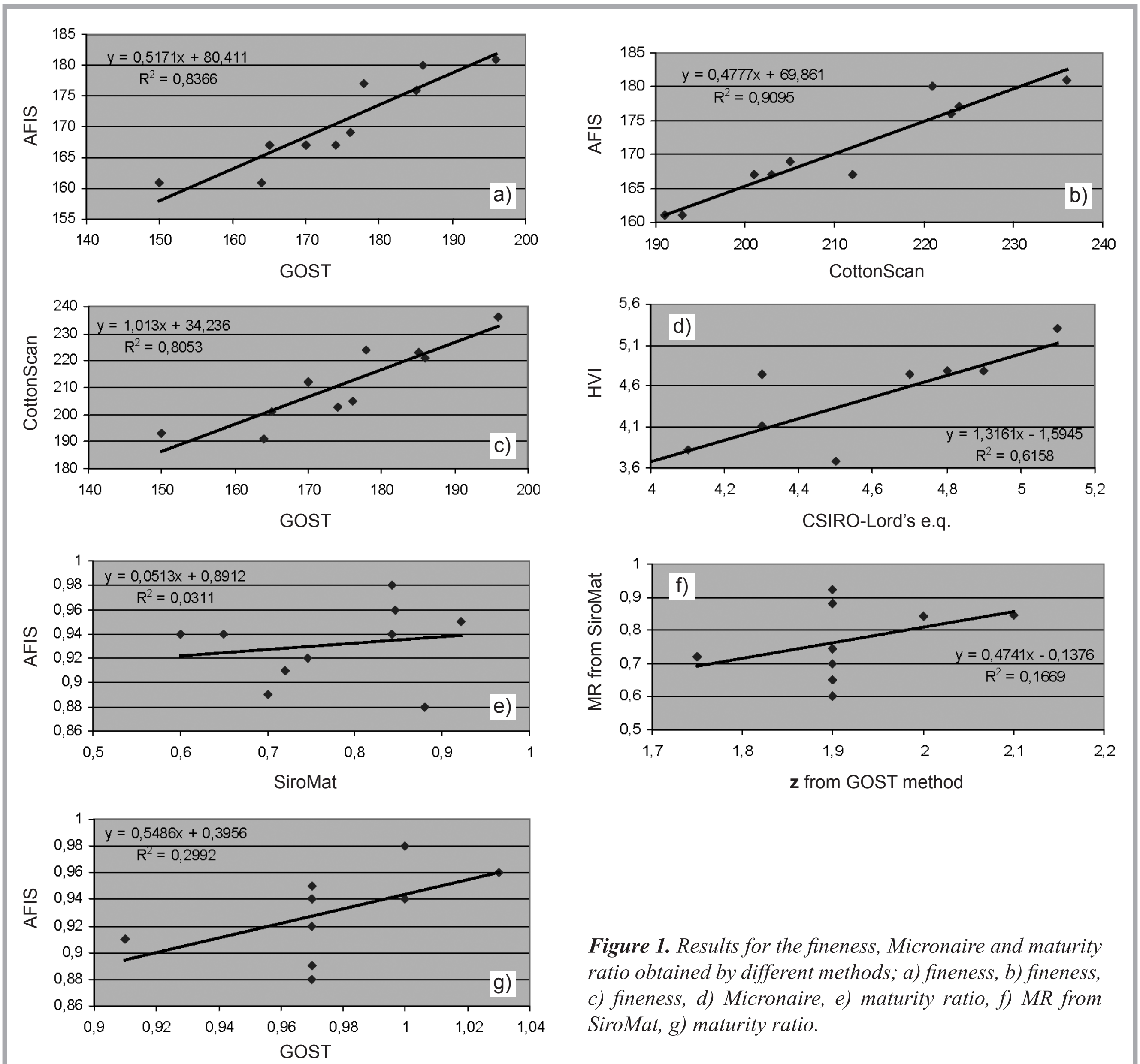

Figure 1. *Results for the fineness, Micronaire and maturity ratio obtained by different methods; a) fineness, b) fineness, c) fineness, d) Micronaire, e) maturity ratio, f) MR from SiroMat, g) maturity ratio.*

fineness were determined for 11 cotton samples. Results for the fineness and Micronaire are presented in ***Table 1***. The cotton samples were measured on an AFIS (10 repetitions) at the WIMA spinning mill, on an HVI at the GCA (5 repetitions), on a CottonScan (3 repetitions) and SiroMat (2 repetitions) at CSIRO and on an ITRU UAK-1+ system at the ITRU Group. Additionally, the GCA analyses of the cotton fineness and maturity were made according to the Uzbeck standard based on GOST. In ***Tables 1*** and ***2*** standard deviation values are given in brackets.

Figure 1. (a÷f) presents results for the fineness, Micronaire and maturity ratio obtained by different methods.

Comparing the fineness methods, the best correlation is found in the case of the AFIS and CottonScan methods (r = 0.95 ***Figure 1b***), a quite good correlation between the results from the AFIS and GOST methods (r = 0.91 ***Figure 1a***), and the worse correlation (below 0.90) was in the case of both methods working on the same principle (gravimetric, ***Figure 1c***).

In any case, the absolute values shown by each method are different and can be placed in the following order: $Tt_{AFIS} < Tt_{GOST} < Tt_{CottonScan}$. In other words fineness values from the CottonScan are much higher than those from GOST and AFIS. In the case of Micronaire, there was quite a good correlation between HVI and CottonScan (on the level r = 0.90).

Table 3. *Micronaire values by different methods.*

Lp.	Cotton samples	Y-section microscope	ITRU Surface	Air Flow method
1.	Calibration cotton (Mic = 2.70)	3.07	3.05	2.70
2.	Calibration cotton (Mic = 4.56)	3.30	3.65	4.56
3.	Calibration cotton (Mic = 3.99)	3.17	3.55	3.99
4.	Uzbeck (079-550)	3.37	3.99	4.40
5.	Kirgiz (258-018)	3.70	4.31	4.00
6.	Ege	4.07	4.80	4.90

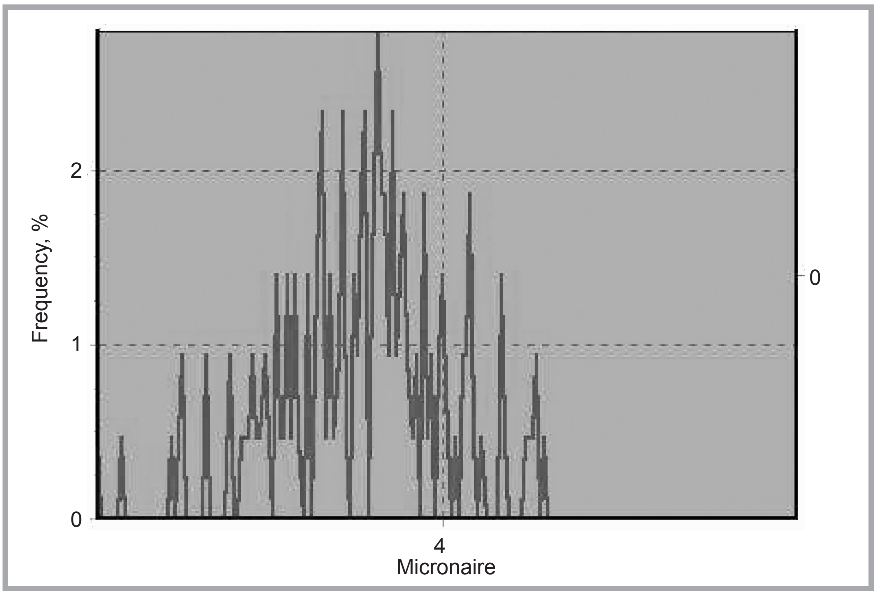

Figure 2. ITRU UAK-1+ Micronaire distribution. Parametrs of recording: Itru-UAK-1 Microanire Frequency Distibution; Test No: 1 Fibre Type: 3,99 Micornaire Calibrated Cotton 4/7/04 Ave: 3,92: Minimum: 3,11: Maximum: 4,92: Std.: 0,33 Mode: 3,83: Median: 3,86: CV%: 8,39.

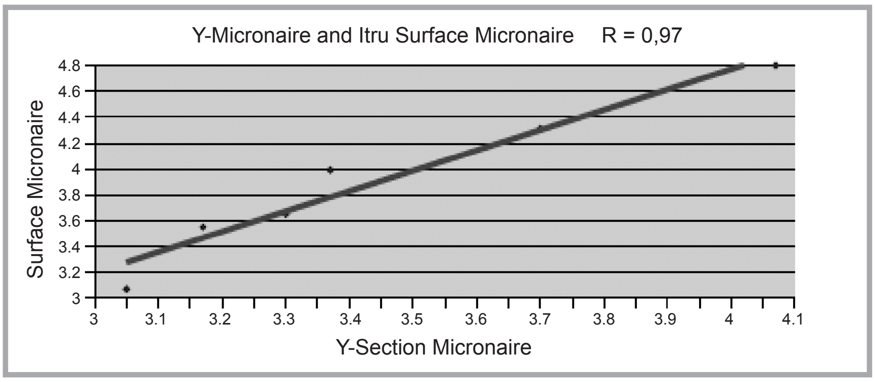

Figure 3. Y-section Micronaire versus the ITRU UAK-1+ surface Micronaire.

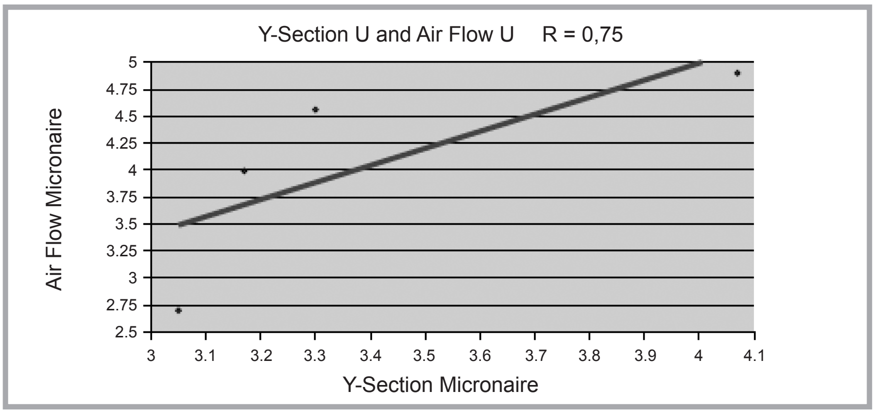

Figure 4. Y-section Micronaire versus the air-flow Micronaire.

Comparing the maturity assessment methods, a lack of correlation was noted. The best correlation was found between the AFIS and GOST MR results (r = 0.55, presented in ***Figure 1g***). In the case of both methods based on fibre colours in polarised light (i.e., GOST and SiroMat), the correlation coefficient is r = 0.41 (***Figure 1f***). Such a big difference in results based on the same measurement principle should be discussed by SiroMat designers and constructors. The absolute values of MR from SiroMat are lower than those obtained from AFIS and GOST.

ITRU UAK-1 results

Samples with known Micronaire (calibrated cotton samples) and unknown Micronaire (no calibrated cottons) values were tested using a digital microscope to estimate the Y-section Micronaire values from single fibre test results and then compared with ITRU UAK-1+ test results. Additionally, the fibres were measured on a Micronaire device, the results of which are presented in ***Table 3***. The distribution of the Micronaire is presented in ***Figure 2***. The correlation relationships between the Y-section Micronaire and the ITRU UAK-1+ Micronaire are presented in ***Figure 2***, and those between the Y-section Micronaire and that established by the Air-flow method are given in ***Figure 3***.

Conclusions

1. The CottonScan fineness results correlate well with the AFIS results, and the Micronaire results correlate well with the HVI ones.

2. There is no good correlation between the SiroMat maturity results and any other method. The best correlation of the maturity results was found between the AFIS and GOST MR (r = 0.55, presented in ***Figure 1g***). In the case of both methods based on fibre colours in a polarised light (i.e., GOST and SiroMat), the correlation coefficient is r = 0.41. In any case, such a big difference in maturity results assessed by methods based on the same measurement principle (GOST and SiroMat) should be discussed by the designers and constructors of SiroMat. In the case of the GOST method, the result can be influenced by the operator, whose judgment is subjective. At any rate, the operators doing it have many years of experience.

3. Cotton can be classified in terms of the Micronaire range**,** which is specific to each variety. If the Micronaire values are above or below this limit, there could be different varieties within one sample. Any cotton variety has a Micronaire range, which varies from the minimum to the maximum; this value can be determined by variance analyses using ITRU Surface Micronaire Systems.

4. Single fibre Y-section microscope analyses can be used effectively to estimate the Micronaire (with r = 0.97)

with the ITRU Surface System and (with r = 0.75, using Air-Flow Systems). According to the producer – the ITRU Group, this system can also prove the correctness and reliability of ITRU Surface Micronaire estimation algorithms. The Micronaire calibration of cotton samples in the ITRU UAK+ system could be carried out by Y-section microscope analyses to get more reliable results.

References

1. *Gordon S.G. and Naylor, G.R.S. (2008), Cotton Fibre Linear Density and Maturity Measurement and Application, 29th International Cotton Conference Bremen, 159-180.*
2. *Naylor G.R.S. and Sambell, J. (1999), Measuring cotton fineness independently of maturity using the Sirolan-Laserscan, Beltwide Cotton Conferences, National Cotton Council, Orlando FL.*
3. *Naylor G.R.S. (2001), Cotton maturity and fineness measurement using the Sirolan-Laserscan, Beltwide Cotton Conferences, National Cotton Council, Anaheim CA.*
4. *Gordon S. G. and Naylor, G. R.S. (2004), Instrumentation for rapid direct measurement of cotton fibre fineness and maturity, Beltwide Cotton Conferences, National Cotton Council, San Antonio TX.*
5. *Gordon S.G., Naylor G.R.S. and van der Sluijs, M.H.J. (2004), New developments in cotton quality assessment: The Australian direction, 27th International Cotton Conference Bremen, Germany, 41-54.*
6. *Higgerson G.J., Le, C.V., Long, R.L., Lucas, S.R., Naylor, G.R.S. and Purmalis, M.M. (2007), Inter-laboratory evaluation of Cottonscan instruments for determining average fibre linear density (fineness) of cotton lint samples, 4th World Research Cotton Conference, Lubbock TX.*
7. *Gordon S.G., Lucas, S.R. and Phair, N.L. (2005), Method and apparatus for testing fibres, Patent No. AU2005000061.*
8. *Lord E. and Heap, S.A. (1988), The origin and assessment of cotton fibre maturity, International Institute for Cotton, 40 pp.*
9. *ITRU Group Ltd. (2006), 'ITRU Fibre Tester UAK-1+, An eagle vision, fibre/sliver/spinning technology information system', Technical Information Summary.*
10. *Frydrych I. (2008), Fibre / Sliver / Spinning Technology Information System – ITRU Fibre Tester UAK-1+, Meeting of the CCTM of ITMF, Bremen.*
11. *Frydrych I.(2005), Cotton – systems and methods of assessment (in Polish), Editor Technical University of Lodz.*
12. *PN-88/P-04675.*

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