# Comparative Analysis of Cotton Maturity Assessment Methods

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## ABSTRACT

*Textile product quality plays an important role for the consumer in the light of Standard ISO 9000. Different parameters determine the quality of any textile product. Fabrics characterized by a high level of aesthetic appeal should be suitable in appearance and dyeing uniformity. Such properties as fiber maturity and its distribution, number of neps and trash content and size are responsible for this aspect of quality. In 1996, the Institute of Textile Architecture purchased an AFIS system with a module enabling cotton fineness and maturity to be measured. The aim of this research was to answer questions on how methods of maturity assessment according to the GOST standards used so far in Poland and other Eastern European countries correlate with AFIS parameters.*

## Introduction

Cotton maturity is an important factor for determining cotton fiber spinnability, proneness to nepping, dyeability, yarn strength and uniformity. In East European countries this property was defined as a maturity degree and was determined by the methods described in GOST. In West European countries the cotton maturity is Maturity Ratio (MR), defined by equation (2) but in the USA, they the Percent Maturity (PM) is used which gives the mature fiber content expressed in percent.

Laboratory Committee of Gdynia Cotton Association analyzing results of round-tests carried out according to the standard PN-88/P-04675 (Anon) decided to undertake comparative maturity measurements, i.e., using AFIS system and methods according to GOST such as comparison with maturity patterns and analysis in a polarized light. The aim of research is to help the AFIS users in interpretation of values obtained from this system. We have already four AFIS owners in Poland; the Institute of Textile Architecture and the following spinning mills "ZAWIERCIE", WIMA, and "FROTEX" S.A. Below, we present shortly the basic measurement principles of mentioned above methods.

## Measurement Principles

### *Comparison with patterns*

It is a method elaborated by Fiodorov (1938) in the former Soviet Union and admitted by Polish Standard PN-88/P-04675. It is based on illustrating patterns giving the examples of fibers of different maturity degree. The picture of middle part of fibers obtained using a biological microscope is compared with patterns. The fibers are classified into 11 groups dependent on the maturity degree, i.e. from 0 to 11 with step 0,5. Assessing maturity by this method we take into consideration the ratio of the secondary wall thickness and fiber wideness, fiber character, number of twists and general fiber appearance. It is a subjective method, demanding a big experience of assessing person, but results provide very valuable information about a distribution of this feature (in addition to the mean value).

### *Method in polarized light*

Cotton fiber is characterized by an anisotrophy of light transmission, which relies on double refraction of the light beam falling on a fiber. After transmission through the fiber the beam is divided into two perpendicular beams. These beams are spread out with different speed and they are different in a phase. If analyzer, put on the way of light ray going out from the fiber, conveys these two beams into one oscillation plane, the beams interfere with each other giving colour picture of fibers.

With the increase of fiber secondary wall thickness, i.e., with the increase of cotton fiber maturity, the optical length in a fiber also increases.

Moreover, there occur layers of better macrofibryle arrangement. Therefore, fiber maturity will decide about interference colour of fiber observed in polarized light.

According to the Soviet Standards (GOST) cotton fibers are classified into the following four colour classes:

1. Mature - orange, yellow-gold, yellow-green,
2. not fully mature - yellow green with blue parts, green, blue,
3. immature - blue, blue-violet,
4. dead - violet-purple or purple as a background.

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

$$x = \sum a_i . p_i / 100 \qquad (1)$$

where: x - maturity degree,

$a_i$ -coefficients characteristic for given cotton maturity class and type of different origin set in Table,

$p_i$ - fiber share in successive maturity classes [%].

***AFIS measurement the method***

The following maturity parameters are determined on the AFIS system: immature fiber content (IFC) and Maturity Ratio (MR) defined by Lord (Lord and Heap, 1988; Pierce and Lord, 1939) as follows:

$$MR = 0.7 - (N - D)/200 \qquad (2)$$

where: N - mature fiber content,

D - dead fiber content.

According to Uster Zellwegers (ITMF, 1994) opinion fibers of MR < 0,7 are not met in practice. When cotton has MR>1, then is too mature and can create troubles during processing and mercerization.

Parameter MR is defined analogous to the basic maturity definition given by Standard ASTM D-13, as a degree of secondary wall thickness and determined by AFIS on the basis of fiber cross section. In order to describe the degree of secondary wall thickness the circularity coefficient was introduced. It is defined as a ratio of area of cross-section of fiber wall and area of a circle of the same perimeter as fiber:

where:

$$\frac{4\pi A}{P^2} = \theta \qquad (3)$$

P - perimeter of fiber cross-section, A - area of cross - section of fiber wall expressed by

$$A = T(P - \pi T) = \pi R^2 [1 - (r/R)^2] \qquad (4)$$

where: T - thickness of fiber wall, R - maximal fiber radius, r - radius of lumen

Coefficient of circularity θ is equal to 1 when fiber has a circular shape of cross-section and does not have a lumen so if r = 0. Suitable values for these for different maturity stages are given in Table 1.

***Experimental***

Preliminary research for limited types of cotton of different origin (Frydrych, 1998): showed a small correlation between maturity parameters from AFIS system and according to GOST. It was stated that correlation coefficients between Maturity Ratio and maturity degree **z** according to GOST are as follows:

in the case of polarized light method - $r_{GOST,AFIS}$ = 0.600,

in the case of comparison with patterns method $r_{GOST,AFIS}$ = 0.725.

In 1997 Laboratory Commission of GCA carried out comparative measurements of maturity according to GOST in GCA accredited Laboratory and AFIS measurements took place in accredited Laboratory of the Institute of Textile Architecture on 53 cotton varieties.

On the basis of obtained data it was stated that results of maturity degree according to both GOST methods are high correlated (r= 0.979 Fig.1), what was a basic assumption of these methods. There is also a correlation between:

Maturity Ratio and Immature Fiber Content $r_{MR,IFC}$ = 0.919 what means that these two parameters are negatively correlated (Fig.2),

Immature Fiber Content, and number of neps / gram ($r_{IFC,N}$ = 0.669), what is logical, because immature fibers cause creating neps (Fig.3),

fiber linear density and Maturity Ratio - $r_{T\square,MR}$ = 0.689.

Unfortunately, although a lot of samples were examined the correlation between Maturity Ratio and maturity degree assessed by both GOST methods was not stated.

The values of linear correlation coefficients between MR and degree of maturity according to GOST are following:

in the case of polarized light method $r_{GOST, AFIS}$ = 0.586

in the case of comparison with patterns $r_{GOST, AFIS}$ = 0.565

and the correlation between IFC and maturity degree according to GOST is also not significant:

in the case of polarized light method GOST, AFIS = - 0.432

in the case of comparison with patterns GOST, AFIS = - 0.427.

Why there is no correlation between these results? Let's try to express θ as a function of maturity degree z.

According to Fiodorov (1938) the relationship between first and second maturity definition, i.e., between circularity coefficient and maturity degree **z** according to GOST can be expressed as follows. Maturity degree according to GOST z=0, when the secondary wall thickens is T=0,025 R, where: R= r + T is a maximal radius of fiber of circular cross - section, and r is a lumen radius. Let m will be a measure of wall developing:

$$m = (D - d)/D = 1 - d/D \qquad (5)$$

where: D = 2R - diameter of fiber of circular shape of cross - section,

$d = 2r$ - lumen diameter.

Maturity degree according to GOST is expressed in a function of m as follows:

$$z = (m - 0.05)/0.15 \quad (6)$$

and after transformations

$$m = 0.15\,z + 0.05 \quad (7)$$

Comparing (5) and (7) the equation (8) was obtained:

$$d/D = r/R = 0.95 - 0.15z \quad (8)$$

It results from equation (8) that appropriate values of ratio r / R correspond to maturity degree z. Table 2

On the basis of relationship (4) the circularity coefficient of fiber cross–section can be expressed as follows:

$$\theta = 1 - (r/R)^2 \quad (9)$$

Inserting (8) into (9) we can obtain the searched relationship between θ and z:

$$\theta = 1 - [0.95 - 0.15\,z]^2 = 0.0975 - 0.285z - 0.0225z^2 \quad (10)$$

On the basis of this equation values of θ were obtained for different maturity degree z from the GOST methods. At the same time using [5] MR was recalculated into θ from the relationship:

$$\theta = 0{,}577\ MR \quad (11)$$

Next, correlation coefficients between appropriate values of circularity coefficient θ were calculated. The values of correlation coefficient between θ from equation (11) and θ from equation (10) are following:

- in the case of polarized light method – 0.7141 (Fig. 5a)
- in the case of comparison with patterns – 0.6598 (Fig. 5b).

From these figures a better correlation can be noticed. The conclusion is that we should correlate adequate values.

## Discussion of results in the light of bibliography

As a reference method for checking a correctness of the AFIS module "Fineness & Maturity" the technique of image analysis proposed by Thibodeaux (1986, 1996) was applied. Using this technique the area of cross-section of cotton fiber secondary wall and fiber cross-section perimeter were determined. 36 variants of cotton of different origin were used for determination of circularity coefficient by both methods, i.e., by image analysis and AFIS system. The coefficient of determination of the values was $R^2 = 0.87$. The values of determination coefficient for area A was $R^2 = 0.93$, but for perimeter $R^2 = 0.90$. It is worth to notice that even in this case there is not ideal agreement between these two methods.

Krowicki *et al.* (1996) stated that the area of fiber cross section from AFIS system shows high correlation with area of fiber cross–section from Arealometer (the values of correlation coefficients were 0.973, 0.970, 0.982 successively in the case of examining 1000, 2000 and 5000 fibers). The bigger amount of examined fibers, the better correlation. In our case for maturity assessment 15000 were fibers measured on AFIS system.

Reference method applying a computer image analysis technique was proposed by Schneider et al (1997). Parameter proposed by him is the ratio of area of wall cross-section and total area of fiber cross–section.

On the basis of this parameter he calculated the percent of mature fibers PM and compared it with analogical value obtained from Shirley Fiber Maturity Tester (FMT) and from a Causticaire method. Correlation of PM from FMT and Causticaire in the Faserinstitut Bremen measurements was r = 0.61.

Montalvo *et al.* (1996) carry actually comparative maturity and fineness measurements on AFIS system and FMT. Preliminary results of these measurements are not promising. It is probably caused by different principles of measurement methods and different calibration cottons. Data from FMT are applied for creating new algorithms for calibration of the AFIS module "Fineness & Maturity".

According to Price (1994) correlation coefficients between Micronaire parameter, fiber linear density or maturity cross 0.9, whereas correlation coefficients between MR and linear density are on the level 0.7, what is confirmed also by our investigations (Fig. 4).

According to Harig (1994) reproducibility of maturity results from FMT is not satisfactory. In the light of above remarks the value of correlation coefficient between circularity coefficients in the case of our results on the level 0.67 is justified, because we have here quite different measurement principles. In addition to this the assessment according to the GOST methods is influenced by a human factor.

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**Table 1. Maturity phases and values of chosen parameters.**

| Fiber phase | Circularity coefficient θ | MR | IFC [%] |
|---|---|---|---|
| Dead D | 0 < θ < 0.25 | | |
| Thinwalled | 0.25 < θ < 0.50 | 0.7 ÷ 0.8 | 14 ÷ 18 |
| Mature | θ>0.50 | 0.8 ÷ 1.0 | 8 ÷ 14 |
| Too mature | | > 1.0 | 4 ÷ 8 |

**Table 2. Values of ratio r / R for the successive maturity degree.**

| z | 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| r / R | 0.95 | 0.80 | 0.65 | 0.50 | 0.35 | 0.20 |

**Figure 1.The relationship between the maturity degree assessed by polarised light method comparing with patterns.**

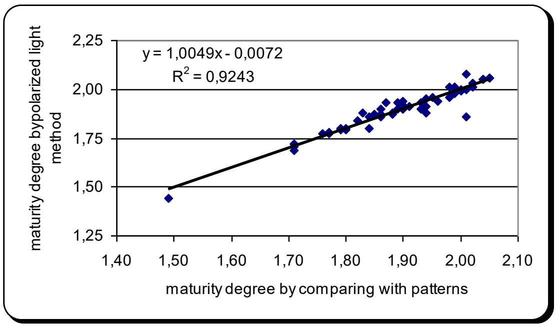


**Figure 2. The relationship between maturity ratio (MR) and immature fiber content (IFC).**

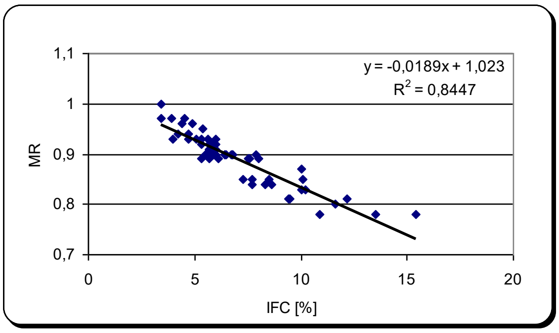


**Figure 3. The relationship between the total nep number and immature fiber content.**

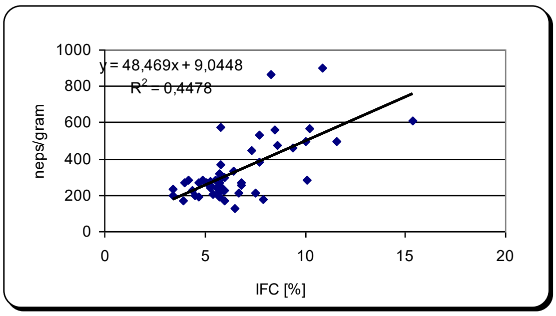


**Figure 4. The relationship between maturity ratio and fiber linear density.**

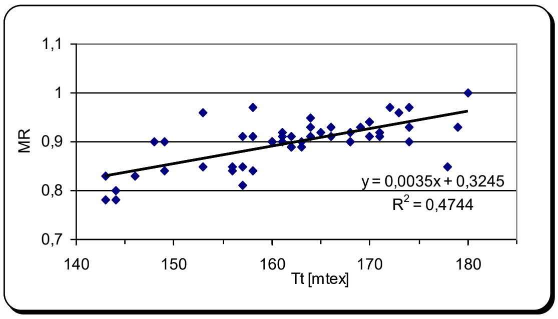


**Figure 5a. The relationship between circularity coefficient (theta) from AFIS and polarized light method.**

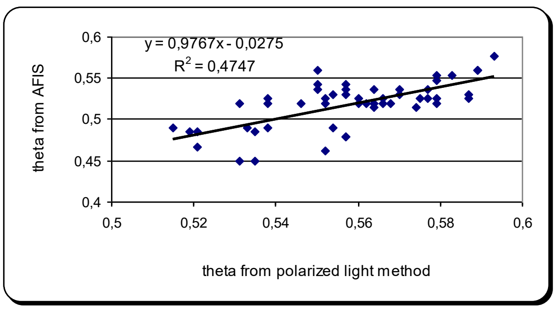


**Figure 5b. The relationship between circularity coefficient (theta) from AFIS and pattern method.**