ANALYSIS AND PRACTICAL CRITERIA FOR ASSESSING THE UNIFORMITY OF FABRIC MASS PER UNIT AREA

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Abstract: *The fabrics' mass per unit area (FMUA) is one of the main technological parameters in their production. This is one of the main reasons in the stage of fabric quality control obligatory to be checked the correspondence between the set mass per unit area /as a technological parameter in the weaving/ and the resulting mass per unit area of the finished fabric. In manufacturing practice, there are no clear rules or methodology to be followed when carrying out this inspection. The location over the fabric surface from which the specimens have to be taken is clearly formulated. However, taking the appropriate type and number of samples depends on the experience and skill of the quality controller. This creates preconditions for occurrence of subjective influence during the quality control of the final product in the weaving mills and the incoming fabrics in the sewing enterprises. The purpose of this work is to provide, through research and analysis, a practically accessible and scientifically sound method for determining the uniformity of mass per unit area along the length and width of the fabric (along warp and weft threads).*

Keywords: *fabrics, mass per unit area, criteria for assessing, quality.*

1 INTRODUCTION

The fabrics' mass per unit area (MUA) is one of the main technological parameters in their production [1-3]. This is one of the main reasons in the stage of fabric quality control obligatory to be checked the correspondence between the set mass per unit area /as a technological parameter in the weaving/ and the resulting mass per unit area of the finished fabric. In manufacturing practice, there are no clear rules or methodology to be followed when carrying out this inspection.

The location over the fabric surface from which the specimens have to be taken is clearly formulated [4-6]. However, taking the appropriate type and number of samples depends on the experience and skill of the quality controller. This creates preconditions for occurrence of subjective influence during the quality control of the final product in the weaving mills and the incoming fabrics in the sewing enterprises. On the other hand, the mass per unit area of fabrics is one of the main input factors influencing the quality criteria in the sewing industry. The uniformity of the mass per unit area in length and width of the fabric is of particular importance for the qualitative realization of a number of technological processes in the apparel industry. When the mass per unit area in the different fabric areas is not constant, it becomes possible the various details of the same sewing article to have different characteristics (determined by the unevenness of the mass per unit area).

From conducted scientific researches it is known that the mass per unit area influences the main technological parameters of the moisture-heat treatment of the textile materials in sewing production [7, 8]. The statistical significance of the influence of SM on the tensile strength of the needle thread has been demonstrated [9]. In general, however, there are no clearly established rules in the sewing companies for the procedure for controlling the uniformity of MUA of the fabrics (in their length and width) when receiving and storing them. This is a prerequisite for the majority of sewing companies not to carry out such control at all. The standards prescribe the manner of sampling and testing as a methodology [4-6]. However, they do not provide how to assess if the distribution of the MUA across the width of the fabric is uniform. There have been attempts at metrological selection of woven fabrics [3], which consider the complex evaluation of tissues and indirectly target the uniformity of MUA. In the light of the above, it is particularly important to look for a clearly formulated and relatively accessible and rapid method for determining the uniformity of MUA of fabrics in their length and width. In the world, some elite weaving and sewing companies are doing research on this issue, but they do not publish their results because of commercial or confidential reasons.

The present work describes the research and analysis conducted to solve these important technological issues with own resources. The application of statistical methods of analysis and evaluation put this research on a scientific basis.

2 THEORY APPROACH - OCCURRENCE OF NON-UNIFORMITY OF FABRICS IN WIDTH OF FABRIC

During the weaving process, the raw fabric is subjected to various types of stresses and deformations. The predominant group of loads is one-way oriented and applied throughout the width of the fabric. These are the attractive cross, brace, birch and similar static guides on the warp threads and the woven fabric. Sometimes, the broad bands (templets) adjustment is accompanied by a small and seemingly insignificant asymmetry, such as height relative to the midline of the loom or depth of selvedges. These differences in geometric conditions during fabric formation subsequently affect the density of the warp and weft threads, as well as their interaction and incorporation. The allowed asymmetry in the setting of the loom along its width leads to a difference and asymmetry in the distribution of the mass per unit area along the width of the fabric. By its origin and because of the principle of uniformity of the weaving cycles ($\cong$0.15 s), the longitudinal distribution of the mass per unit area varies small and is symmetrically arranged as a function of the distribution. Therefore, the longitudinal variation of the mass per unit area is determined by the normal distribution of single measurement values. Greater differences may occur between identical fabric pieces on different looms, which is generally due to subjective factors that occur during the equipment use and maintenance. There is a prerequisite for a natural reference to the variation in mass per unit area, i.e. a longitudinal variation to be applied to estimate the transverse distribution of the mass per unit area along the width of the fabric.

3 EXPERIMENTAL WORK

The purpose of this work is to provide, through research and analysis, a practically accessible and scientifically sound method for determining the uniformity of mass per unit area along the length and width of the fabric (along warp and weft threads). The practical conditions make it possible to examine only one end of the roll with input quality control. The usual allowable length of the cut sample is about 1.0 m. Considering the need to prepare test specimens for other tests, such as strength, shrinkage, etc. no more than 30 to 35 cm remain to determine the mass per unit area. This means that no more than two mass per unit area tests along the length of the section are possible - test specimen. The actual conditions allow only one longitudinal test, or 3 tests in the middle and at both ends of the fabric. With these tests, it is necessary to obtain a statistically reliable evaluation of the uniform distribution of the mass per unit area along the width of the fabric.

The advantageous opportunity is the ability to measure all the rolls in the lot/batch and so to determine the boundary criterion for deviation of uniformity, after which the top fabric in question is subject to quality declaring. The solution is to find that parameter /estimate/ that is universal in nature, such as the coefficient of variation, for example.

3.1 Conditions to execute the experiment

For the experiment was used Vamatex Leonardo looms with 8 shed frames.

The samples were prepared by the Fabric Sample Cutter SDL Atlas, and mass per unit area was measured by means of electronic scales Precisa XB620C.

Representative sample was derived from the total supply of woven fabric according to the methodology described in BDS EN 12751:2003 and the samples were prepared according to the methodology of BDS 229-92.

In this case, a passive experiment was performed, i.e., the parameters of the fabric produced were measured without changing the technological conditions of the weaving cycle.

3.2 Materials

The textile material studied was a woven fabric purposed to stamped summer garments, produced by "E. Miroglio SA" – Sliven, Bulgaria.

The woven fabric is produced from 100% PES (polyester) with a width of 145 cm and a nominal mass per unit area of 85 g/m^2. The characteristics of the woven fabric are: warp threads of Tt 5.60 tex/36 filaments at warp density of 1040 threads/dm and weft threads of Tt 5.60 tex/ /72 filaments at weft density of 460 threads/dm.

Table 1 gives the primary numerical data from the measurements of a representative fabric sample, where “StDev” is a standard deviation; “C Interval” is confidence interval. Of the total 547 fabric rolls in 21 lots, 42 were separated by random selection and measured. Measurements were made at the beginning of each roll by measuring the masses per unit area in the middle at both ends - left and right on the fabric. In order to imagine, the consecutive measurements of the sample show the change in surface mass along the entire aggregate of more than 80000 meters of fabric.

At the same time, the three measurements along the width of the fabric represent the transverse distribution of the surface mass.

3.3 Methods

In formulating the conditions and methods for conducting the experiment, the principles of the morphological method for analysis and synthesis of methods are applied [10].

Table 1 A data from the measurements of SM

2019	**Woven fabric**		**82469.0 m**			**547 rolls**			
Test №	**Fabric roll**		**Surface mass [g/m^2]**			**Cross evaluation – width**			
	Length [m]	**Width [cm]**	**Left**	**Middle**	**Right**	**Average**	**StDev**	**C Interval**	**CV**
1	**90.00**	**148.0**	**91**	**90**	**87**	**89.2**	**2.02**	**5.02**	**2.27**
2	151.00	153.0	90	88	89	**88.5**	1.00	2.48	**1.13**
3	94.00	148.0	89	89	91	**89.2**	1.15	2.87	**1.29**
4	155.00	149.0	94	92	93	**92.7**	1.26	3.13	**1.36**
5	157.70	149.0	90	90	91	**90.3**	0.58	1.43	**0.64**
6	157.00	148.0	88	87	85	**86.5**	1.50	3.73	**1.73**
7	160.50	147.0	92	91	92	**91.5**	0.87	2.15	**0.95**
8	155.20	152.5	91	88	88	**89.0**	1.73	4.30	**1.95**
9	105.70	152.0	91	90	91	**90.5**	0.50	1.24	**0.55**
10	163.00	148.0	94	92	93	**92.5**	1.00	2.48	**1.08**
11	158.20	148.0	91	90	89	**90.0**	1.00	2.48	**1.11**
12	154.80	148.5	91	88	90	**89.7**	1.53	3.79	**1.70**
13	165.10	148.0	89	88	88	**88.3**	0.58	1.43	**0.65**
14	155.40	147.5	91	89	91	**90.3**	1.15	2.87	**1.28**
15	161.20	150.0	94	91	93	**92.7**	1.53	3.79	**1.65**
16	155.00	149.0	91	88	91	**90.0**	1.73	4.30	**1.92**
17	165.00	148.0	88	88	89	**88.3**	0.58	1.43	**0.65**
18	**60.00**	**147.5**	**90**	**89**	**86**	**88.3**	**2.08**	**5.17**	**2.36**
19	159.80	149.0	91	90	90	**90.3**	0.58	1.43	**0.64**
20	**155.90**	**147.5**	**89**	**89**	**93**	**90.3**	**2.31**	**5.74**	**2.56**
21	152.80	150.0	94	93	90	**92.3**	2.08	5.17	**2.25**
22	160.00	148.0	94	93	94	**93.7**	0.58	1.43	**0.62**
23	158.40	148.0	90	89	92	**90.3**	1.53	3.79	**1.69**
24	155.90	149.0	89	89	91	**89.7**	1.15	2.87	**1.29**
25	187.90	150.0	92	93	91	**92.0**	1.00	2.48	**1.09**
26	148.80	148.0	94	94	92	**93.3**	1.15	2.87	**1.24**
27	155.10	149.0	96	92	93	**93.7**	2.08	5.17	**2.22**
28	155.10	149.0	96	92	93	**93.7**	2.08	5.17	**2.22**
29	153.70	148.5	90	90	91	**90.3**	0.58	1.43	**0.64**
30	156.10	149.5	87	90	90	**89.0**	1.73	4.30	**1.95**
31	154.50	148.0	92	93	91	**92.0**	1.00	2.48	**1.09**
32	155.60	148.5	92	94	92	**92.7**	1.15	2.87	**1.25**
33	155.30	149.0	90	89	90	**89.7**	0.58	1.43	**0.64**
34	**154.00**	**149.0**	**90**	**91**	**87**	**89.3**	**2.08**	**5.17**	**2.33**
35	158.50	150.0	92	92	91	**91.7**	0.58	1.43	**0.63**
36	158.40	150.0	92	92	93	**92.3**	0.58	1.43	**0.63**
37	153.10	150.0	91	92	94	**92.3**	1.53	3.79	**1.65**
38	154.30	148.0	89	90	92	**90.3**	1.53	3.79	**1.69**
39	154.40	150.0	91	90	91	**90.7**	0.58	1.43	**0.64**
40	181.00	149.0	92	93	90	**91.7**	1.53	3.79	**1.67**
41	152.50	150.0	92	94	92	**92.7**	1.15	2.87	**1.25**
42	155.80	151.0	94	90	93	**92.3**	2.08	5.17	**2.25**

However, the application of statistical methods must be based on a thorough knowledge and analysis of the physical nature of the relevant technological processes.

Samples of 1 m from the end of each sample shall be sampled when conducting tissue MUA uniformity tests. That is, one examines part of the batch, not the whole batch, so it is necessary to determine the confidence level [6, 11].

The absolute choice error is determined according to (1) [6, 11]:

$$q_{\overline{X}} = \frac{t \times \sigma}{\sqrt{n}} \tag{1}$$

where: *t* - Student's coefficient; *σ* - the standard deviation; *n* – number of trials.

The relative (percentage) value of the confidence level is determined according to (2) [6, 11]:

$$P_{\overline{X}} = \frac{q_{\overline{X}}}{\overline{X}}.100 \tag{2}$$

where: $\overline{X}$ - the arithmetical average of the measured MUA.

According to [11], if condition (3) is fulfilled, therefore, the accuracy of the test is sufficiently good, i.e. a sufficient number of trials are included.

$$P_{\overline{X}} \lhd 2.5\% \tag{3}$$

If condition (3) is not fulfilled, then the number of trials n must be increased so that condition (4) [11] is fulfilled.

$$n \rhd \frac{t^2 \times CV^2}{2.5^2} \tag{4}$$

where: *CV* - coefficient of variation (is a dimensionless measure of the variability of a parameter, defined as the ratio of the standard deviation to the mean).

In order to evaluate the quality of the product, it is necessary to compare the results of the surface test with the requirements of norms and standards [11]. For us, the norm is the set MUA, which must have the final product in the weaving or MUA laid in the passport of the fabric, which is obtained in the sewing company. Student's t - test can be used to make the comparison. To do this, the calculated Student's t - test value is determined as given in (5) and the Student's t - test tabular value (Student's distribution) as given in (6) [10, 11].

$$t_C = \frac{\left|\overline{X} - X_i\right|}{\sigma} \times \sqrt{n} \quad (5)$$

$$t_t \begin{Bmatrix} f = n-1 \\ r = 0{,}05 \end{Bmatrix} \quad (6)$$

where: f - degree of freedom, r - significance level, $i \in (1 \div n)$.

According to [11], if condition (7) is fulfilled, the difference between the required value (norm) for area mass and the measured average value for MUA is not statistically significant and the product can be considered qualitative. If condition (7) is not fulfilled [12], the difference between the required value (norm) for MUA and the measured average value for MUA is statistically significant and the product cannot be considered qualitative.

$$t_c \lhd t_t \quad (7)$$

In the case where the main task is focused on the uniform distribution of MUA across the width of the fabric, the following circumstances are determining. The representativeness of the two samples is guaranteed. The longitudinal distribution of the mass per unit area can cover the whole population (547 rolls of fabric), while the transverse distribution is based on 3 measurements: in the middle and at both ends. The sample in this example comprises 42 rolls of fabrics.

From this point of view, the variation of the large, longitudinal sample, which as a reference evaluates the variation in the transverse sample, is crucial. In other words, the mean value of the variation of the longitudinal distribution of the MUA can be taken as the limit value for the variation of the MUA in width for each top fabric:

$$meanCV = \frac{\left(CV^{left} + CV^{middle} + CV^{right}\right)}{3} \quad (8)$$

where: CV^{left} - coefficient of variation measurements (MUA) on the left of the roll of fabric; CV^{right} - CV measurements on the right side of the roll of fabric; CV^{middle} - CV measurements in the middle of the roll of fabric.

Another method to evaluate the distribution of MUA over the width of the fabric is to compare the variation of the longitudinal MUA with the transverse. The assumption that the transverse variation of the MUA is accepted shall not exceed the longitudinal variation of the area for the sample.

$$crossCV \leq meanCV \quad (9)$$

Otherwise, if the limit value is exceeded, the qualitative fabric is declassified or sent for another type of product.

4 RESULTS AND DISCUSSION

4.1 Experimental results

Table 2 presents the statistical estimates of the measured area distribution in longitudinal and transversal directions. The convergence of the longitudinal variation of the MUA can be seen, which for the three lines on the woven fabric varies within small limits:

CV^{left} = 2.30%; CV^{middle} = 2.17%; CV^{right} = 2.32%.

The average value of the longitudinal variation is *meanCV = 2.26%.*

Table 3 illustrates the results of the central moment of 3[rd] rank $\mu(3)$ and the central moment of 4[th] rank $\mu(4)$.

Table 2 Summary characteristics of the measured SM

2019	**Woven fabric**		**82469.0 m**			**547 rolls**			
Tests 42	**Length [m]**	**Width [cm]**	**Surface mass [g/m^2]**			**Cross evaluation – width**			
General evaluation			**Left**	**Middle**	**Right**	**Average**	**StDev**	**C Interval**	**CV**
Average	151.21	149.02	91.24	90.44	90.74	90.81	1.26	3.14	**1.39**
StDev	22.67	1.33	2.10	1.97	2.10	1.75	0.56	1.38	**0.61**
C Interval	7.06	0.42	0.65	0.61	0.65	0.54	0.17	0.43	**0.19**
CV	14.99	0.90	**2.30**	**2.17**	**2.32**	1.92	44.07	44.07	44.12

Table 3 Asymmetry and excess of the SM

Surface mass W [g/m^2]						
distribution	**moment of 3rd rank - μ(3)**			**moment of 4th rank - μ(4)**		
curve	**W left**	**W middle**	**W right**	**W left**	**W middle**	**W right**
statistical	-3.1171	-1.3025	7.2128	50.6904	30.0676	60.8130
evaluation	*asymmetry K=μ(3)/S^3*			*excess E=μ(4)/S^4*		
	-0.3371	-0.1712	0.7768	-0.3880	-0.9907	0.1163
	16.0450			1341.1560		
n=42	S_K			S_E		

In Table 3 "*K*" is the asymmetry indicator (Skewness) of the distribution curve, "*E*" is the Kurtosis, "S_K" is the standard deviation of the *K*, "S_E" is the standard deviation of the *E*.

4.2 Discussion of experimental results

The first check shows that the conditions for a uniform distribution of the longitudinal MUA, i.e. the asymmetry and excess of the distribution curves with respect to the statistical central moments of 3rd and 4th rank are many times smaller than the confidence intervals of the mathematical expectations in the samples. In this sense, the normal distributed longitudinal variation of the mass per unit area can serve as an estimate for the transverse variations.

After the verification, it is established that the unacceptable fabric rolls and their lots/batches are № 1, № 18, № 20 and № 34 (in Table 1 they are given in blue).

The experiments were performed with one type of material, but it is extremely uniform. However, differences were found in the mass per unit area at the exit of the weaving machine. Therefore, for other more uneven material, the conclusions drawn will be even more significant.

5 CONCLUSIONS

In the first place, the uniform distribution of the mass per unit area of the woven fabrics along the length and transversely, in the middle and at both ends, is simultaneously considered.

The proposed methodology for the practical evaluation of the uniform distribution of mass per unit area can equally be applied in the textile and apparel industries.

The proposed methodology is based on scientifically sound solutions to applied statistics and established practices in the approved international standards for quality management of the textile and apparel industry.

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