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Influence of Yarn Count and Warp and Weft Thread Density on Colour Values of Woven Surface

Abstract

Prior to the introduction of numerical evaluation of colours and equipment to measure their values optically, it was impossible to objectively estimate colour deviations resulting from changed yarn count or changed warp- and weft-thread density. Even today, it is practically impossible to carry out a systematic research of this influence on real fabrics, because it is impossible to produce such a large number of referential patterns. CAD systems enable relatively quick and cost-effective production of simulations of multicolour patterns. They even enable certain parameters to be changed within ranges which can be hardly achieved, or not at all, in practice. By the measurements carried out on these simulations, colour deviations due to the changed yarn count or warp and weft threads density can be estimated at a wider interval. However, the aim of the research is to determine the principles of forming colour deviations, and above all to estimate quantitatively the influence of the changed yarn count and thread density on the colour values of a fabric simulation. The paper presents the simulations of a defined number of fabrics made of yarns with varying counts and densities, the results of the colour measurements, and the analysis of the colour differences.

Key words: fabric simulation, yarn count, threads density, colour values measurements.

Introduction

The properties of jacquard fabrics, which are made of differently coloured threads, differ significantly from the properties of piece-dyed or printed fabrics. By piece-dyeing only single-colour fabrics can be produced, whereas multicolour printed fabrics have both some advantages and some disadvantages in relation to fabrics made of differently coloured threads. The advantages are relatively sharp outlines of patterns and the colours of the highest saturation. The disadvantages are different appearance and quality of a fabric's face and back side, the different stability of the look, different permeability properties in particular parts of a pattern, and different possibilities of care (washing, dry cleaning). In view of these disadvantages of printed fabrics, the fabrics made of differently coloured threads are distinguished by numerous applicability advantages. They can be used as double-face fabrics, they have better permeability properties, and care is easier and causes less damage to colour surfaces.

In terms of colour, printed fabrics and the fabrics made of differently coloured threads differ by colour values in individual pattern effects. In contrast to printed fabrics, the values of the fabrics made of differently coloured threads also depend on the constructional parameters of the fabrics. Thus, with a certain number of differently coloured threads, it is possible to produce a limited but relatively large number of different colours on a fabric surface.

The following questions frequently arise in practice, but so far they have not been answered satisfactorily:

- To which extent does the colour on a fabric surface change if the warp- and weft-thread density or the yarn count decreases/increases by a certain percentage?
- Is a changed colour still acceptable to the customer?
- How is one to perceive, measure, define a desired colour?
- How objective is the measuring method?
- Is it possible to predict the colour values of a multicolour fabric on the basis of its constructional parameters and of the warp and weft colour values?
- Is it possible, and if so in which way, to make a correction which would provide an acceptable colour on a fabric surface despite changed values?

In this paper, we try to answer these questions. Although the answers should not be considered absolute and final, they will certainly clarify and more precisely identify the issue. A basic problem in answering these questions is that in practice it is impossible to produce such a large number of differently woven patterns within the entire range of possible colour combinations which would give reliable answers on the basis of spectrophotometrical measurements. In our experiments we used the analytical, calculating method and measurements carried out on the printouts of fabric computer simulations. However, it must be emphasised that the measurements on printouts differ

from those on real fabrics because they have all colour surfaces in one level (in real fabrics, individual colour surfaces are differently distributed by the depth/thickness of a fabric). Nevertheless, this method has some other advantages. It enables relatively quick and cost-effective production of a range of patterns in various colour combinations for the purpose of measurements, as well as the simulation of such woven structures, which could hardly be made or used in reality. These are the fabrics with extremely high density and maximum surface coverage, which could not be produced without special devices (stentering of weft by the entire fabric width), or fabrics with extremely low density, which could lack stability of structure during usage.

The fact that only the first question can be relatively quickly and simply answered by means of spectrophotometrical measurements indicates how complex the answers to the above questions are. Other questions can only be answered provided that certain criteria defining the unit of measure of colour deviations, the standard as a basis of comparison and the objective measurement error are set. As in dyeing and printing, the CIE $L^*a^*b^*$ colour system was used in our experiments. The unit ΔE^*_{ab} from this system was taken as a unit of measure of colour deviations. A fabric structure with almost 100% surface coverage in which the influence of foundation reflectance is the lowest was taken as a standard, reference fabric. How objective these

measurements are, to which extent they may deviate from real values, or what constitute still acceptable values of colour deviations of surfaces is not known and depends on the customer.

The last question, however, cannot be answered without an analytical approach by which other constructional parameters or the colour values of threads to be used for correcting colour differences are defined by calculation.

Theoretical Part

CIE L*a*b* colour system and colour deviations

The CIE L*a*b* colour system evaluates colour deviations by means of ΔE^*_{ab} values. Their relation with the L*, a* and b* colour values is demonstrated in Equations 1 and 2 [1]. Colour deviation in the above-mentioned system represents the shortest distance in the CIE L*a*b* co-ordinate space from the position of a certain colour to the position of the standard colour which it is compared with. In practice, the comparison is normally made between the colour obtained and the colour required and evaluated through colour values by the customer.

Theoretical calculation of the colour values of woven surfaces

The colour values of a fabric surface mainly depend on the fraction of individual colour components and their colour values. At this point the approach to this issue which has been used until now and the approach which will be used in future begin to differ. So far a warp or weft interlacing point, which has been identified by its dimensions, shape and colour characteristics with the dimensions, shape and colour values of the thread on which it is positioned, and which lies on the fabric surface, has been considered a fabric structure unit. It is true that this colour effect predominates; however, the influence of colour and size of the underlying thread and of the colour of foundation reflectance should not be neglected. Such an interpretation leads to the conclusion that the colour effect of one interlacing point is made up of the predominating colour of the thread on the surface, the colour of the underlying thread and the colour of the foundation reflectance. Only exceptionally, when a fabric has the square construction (same yarn count, same warp and weft density and non-oriented weave on both sides) and at extremely high densities which minimise the influence of underlying threads and

$$U_i = \frac{u_{on,ot} \cdot n_{ot,oi} + u_{on,wt} \cdot n_{wt,oi}}{n_{oi}} + \frac{u_{wn,ot} \cdot n_{ot,wi} + u_{wn,wt} \cdot n_{wt,wi}}{n_{wi}}$$

Equation 6

of foundation reflectance, the difference between colour effects of the interlacing point treated by one or the other method is only minimal, and the fractions of individual colour components in a colour repeat can be calculated from the warp-to-weft points ratio. This difference is, however, considerable in the case of coloured threads with varying counts and warp and weft densities, which deviate from the maximums [2]. In the first case, the fractions of individual colour components in a colour repeat are determined by using Equations (1) and (2), and in the second case in accordance with Figure 2 and by using derived Equations (3) to (6). 1, 2 and 3 are the surfaces pertaining to the warp thread, the weft thread and the foundation, d_o and d_w are the diameters of the warp and weft threads, A_o and A_w are the spaces between the warp and weft threads.

So far, the size p of the surface of individual warp and weft point has been calculated by using Equation (1):

$$p_{i,s} = \frac{1}{g_o} \times \frac{1}{g_w} \quad (1)$$

where g_o and g_w are the warp and weft densities, and the colour fraction of the i component in a repeat unit has been the following:

$$U_i = \frac{n_{oi} + n_{wi}}{n} \quad (2)$$

where n_{oi} and n_{wi} is the number of the warp and weft points of i colour, and n the total number of points in a colour repeat.

If a warp interlacing point is considered a colour surface made up of three components, the following equations are used for calculating the fraction of individual colour components in a fabric colour repeat:

$$p_{1o} = d_o \times \frac{1}{g_o} \quad (3)$$

$$p_{2o} = d_w \times \left(\frac{1}{g_o} - d_o \right) \quad (4)$$

$$p_{3o} = \left(\frac{1}{g_o} - d_o \right) \times \left(\frac{1}{g_w} - d_w \right) \quad (5)$$

where:

- d_o, d_w - the diameter of warp, weft threads;
- g_o, g_w - the density of warp, weft threads;
- p_{1o} - the surface of warp thread in the warp interlacing point;
- p_{2o} - the surface of weft thread in the warp interlacing point; and

- p_{3o} - the foundation reflectance surface in warp, weft interlacing point.

Index o applies to the warp interlacing point; and 1, 2 and 3 to the surfaces in that point in accordance with Figure 1. The fractions of individual surfaces in the warp interlacing point are calculated from the relation between Equations 3 and 1, 4 and 1, 5 and 1. Equations 3 and 4 for the surfaces 1 and 2 in the weft interlacing point are adapted accordingly, whereas the rest of the procedure is the same as in the case of the warp interlacing point.

The fraction U of i colour component in the entire colour repeat is calculated by using Equation (6) where:

- n - the number of all points in a colour repeat;
- $u_{on,ot}$ - the content of the warp thread colour in the warp interlacing point;
- $n_{ot,oi}$ - the number of the warp points on i colour warp threads;
- $u_{on,wt}$ - the content of the weft thread

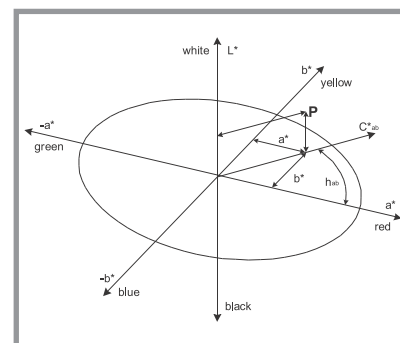


Figure 1. CIE L*a*b* colour space.

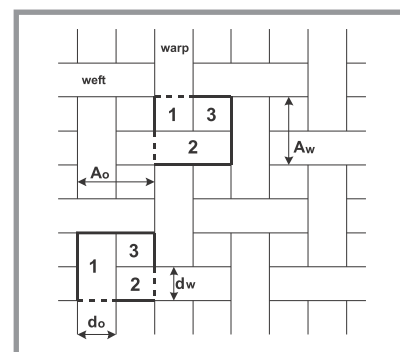


Figure 2. Schematic presentation of a fabric and interlacing point made up of three colour components.

colour in the weft interlacing point;

$n_{wb\ o_i}$ - the number of the weft points on i colour warp threads;

n_{o_i} - the sum of the warp and the weft points on i colour warp threads
 $= n_{ob\ o_i} + n_{wb\ o_i}$;

$u_{wb\ ot}$ - the content of the weft thread colour in the warp interlacing point;

$n_{ob\ w_i}$ - the number of the warp points on i colour;

$u_{wb\ wt}$ - the content of the weft thread colour in the weft interlacing point;

$n_{wb\ w_i}$ - the number of the weft points on i colour wefts;

n_{w_i} - the number of the warp and the weft points on i colour wefts
 $= n_{ob\ w_i} + n_{wb\ w_i}$.

The colour values L^* , a^* and b^* of a fabric with i colour components are calculated by using Equations (7), (8) and (9):

$$a^* = \sum_{i=1}^n (a^* U_i) \quad (7)$$

$$b^* = \sum_{i=1}^n (b^* U_i) \quad (8)$$

$$L^* = \sum_{i=1}^n (L^* U_i) \quad (9)$$

Thus, the following equation is used to calculate colour deviations:

$$\Delta E^*_{ab} = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (10)$$

which is transformed into the form in Equation 11 where:

a^*_p , b^*_p and L^*_p - the colour values of pattern;

a^*_s , b^*_s and L^*_s - the colour values of standard fabric;

a^*_i , b^*_i and L^*_i - the colour values of i component;

U_i - the fraction of i component in a colour repeat.

The presented procedure for calculating the fractions of colour components in a colour repeat, by using the CIE $L^*a^*b^*$ colour system, also permits theoretical calculation of the colour values of surfaces which are made of differently coloured threads, as well as theoretical calculation of the colour deviations ΔE^*_{ab} by using Equations (10) or (11).

Experimental Part

The simulations of bicolour fabrics in plain weave with varying warp and weft yarn count and density were produced with the Arahne CAD system [3]. All basic maximally saturated colours were combined. Red colour was always used in the warp, and other chromatics, yellow, blue and green, were combined in the weft. The colour values of the simulations were measured with the Spectrolino Spectroscan spectrophotometer manufactured by GretagMacbeth (D65, 2°). By varying the constructional parameters (yarn count and density) we wanted to establish the following factors:

- the extent of colour deviations when chromatic colours (red/yellow and red/blue) were combined;
- the extent of colour deviations when red colour was combined with complementary green colour.

The colour values, measured on the printouts of simulations of the yarns used in our experiments, are presented in Table 1.

The selected colour values of used colours point to clear, very saturated colours, which are positioned at a right angle in the CIE $L^*a^*b^*$ system. Thus, we wanted to demonstrate that the calculated and the measured results of colour deviations belonged to the best selected, because all other combinations would have represented a mixture of more similar colours.

Theoretical calculations and computer simulations were made for patterns in plain weave with warp and weft count 30 tex and density 30 threads/cm. This is a construction with an almost completely closed surface; its colour values were

taken as a standard for comparison of deviations. We investigated each influence by varying the parameter by 10% from the initial value 30 tex and 30 threads/cm to the final value of 15 tex and 15 threads/cm.

Influence of yarn count and density

Theoretically calculated changes of the colour surfaces fractions as a result of yarn count and density variations are shown in Table 2, where T_t is the yarn count, g is the thread density, S is the surface of the entire interlacing point, U is the fraction of the colour surface, o is the index of warp threads, w is the index for weft threads and f is the index for foundation (the space between threads) [4,5].

Experimental Results

Due to the extensiveness of the experimental results, only the results of colour deviations in the form of ΔE^*_{ab} values will be numerically and graphically presented for all weft thread colours. Individual colour values were calculated by using Equations (7), (8), (9), (10) and (11) and by considering the colour values and the fractions of colour components specified in Tables 1 and 2. The ΔE^*_{ab} values of the theoretically calculated colour values are shown on the left side, and the measured values are shown on the right side of Tables and Figures 3 to 5 for changing yarn count, and of Tables and Figures 6 to 8 for changing density.

Discussion

In our experimental work, both parameters varied by 10% from the initial starting values. For practical use, the colour

$$\Delta E^*_{ab} = \sqrt{\left(\sum_{i=1}^n (a^*_i U_i) - a^*_s\right)^2 + \left(\sum_{i=1}^n (b^*_i U_i) - b^*_s\right)^2 + \left(\sum_{i=1}^n (L^*_i U_i) - L^*_s\right)^2}$$

Equation 11

Table 1. Measured colour values on the printouts of simulations of the yarns used in pattern constructions.

Col. value	Warp		Weft		Foundation
	red	yellow	blue	green	white
L^*	46.99	84.4	32.96	51.99	94.18
a^*	57.51	-7.59	43.93	-52.31	4.18
b^*	16.59	68.54	-62.37	14.94	-11.20
$h_{ab} (^{\circ})$	16.09	96.32	305.16	164.06	290.47
C^*_{ab}	59.85	68.96	76.29	54.40	11.95

deviations between the patterns with the most similar constructional parameters are particularly important, the patterns 30/27, 27/30 and 27/27 in view of the standard pattern 30/30.

There is a significant difference between thread count and density variations. When the threads' yarn count varied, the changes of colour values were numerically lower due to the varying thread diameter this was taken into account both in calculations and computer simulations, and is a root function of the yarn count. That is why on principle all the changes of ΔE^*_{ab} values are absolutely lower in the case of count variations than in the case of corresponding density variations, and even reach the value of 15 (Tables and Figures 3 to 5), whereas in the case

of density variations these values reach up to 30 (Tables and Figures 6 to 8).

Influence of yarn count and density variation on the change of colour component fraction

Yarn count and density have a direct influence on the fractions of individual colour components in a colour repeat and, consequently, on the colour values of a fabric surface (Table 2, Figure 2). In all cases the change of fractions of warp (U_o) and weft (U_w) thread are linear. The difference between the variations of the two constructional parameters is that the size of a colour unit in a pattern remains unchanged with varying count, whereas with varying density this unit increases or decreases as the density var-

ies. The variation of yarn count results in the change of its diameter, which is demonstrated on the geometry model in Figure 2 as the increase or the decrease of dimensions d_o and d_w and, consequently, of the surface of a certain colour component in a colour repeat. The size S of the interlacing point (colour repeat) remains unchanged by changing yarn count. On the other hand, Table 2 shows that with all densities of warp threads, the size S of surface of a colour repeat increases as the weft threads' density decreases, because the distance $1/g_o$ and $1/g_w$ between the warp and weft threads increases.

Influence of yarn count and density variation on change of colour values and colour deviations

The influence of yarn count and density variation on colour values and colour deviations between the standard fabric with the warp and weft count 30 tex and the fabric with varying count and density is presented in Figures 3 to 8 for different weft thread colours. If the variation of these two parameters occurs in only one thread system (either warp or weft), the curve describing the change of the colour deviation is a straight line with a certain angle of inclination. In figures this is demonstrated as straight lines at a constant density of warp threads of 30 threads/cm. Other curves are virtually similar to parabolas with the lowest point, which corresponds to the square construction of a fabric, i.e. the fabric with the same constructional parameters of the warp and weft threads. If the zero point was displaced or some other fabric selected for comparison (e.g. 27/27), the deviations would take place on the straight line in relation to this standard fabric, either at a decrease or increase of the parameters mentioned.

The variation of constructional parameter in one thread system only results in greater changes of colour deviations than the variation of this parameter in both systems at the same time. In the figures, this is demonstrated as a minimum of parabolas (minimum values of ΔE^*_{ab}), which are in almost all cases located in the points where the construction has the same length per unit mass or the same densities of the warp and weft threads (30/30, 27/27, 24/24). This can be ascribed to the changed fractions of individual colour components in a colour repeat. When the constructional

Table 2. Theoretical calculation of the change of colour surfaces fraction in patterns with varying yarn count and density.

No	Influence of count						Influence of density					
	T _o	T _w	S	U _o	U _w	U _f	g _o	g _w	S	U _o	U _w	U _f
	tex	tex	cm ² 10 ⁻³	-	-	-	thr/cm	thr/cm	cm ² 10 ⁻³	-	-	-
1	30	30	1.111	0.496	0.496	0.008	30	30	1.111	0.496	0.496	0.008
2	30	27	1.111	0.517	0.472	0.011	30	27	1.235	0.538	0.447	0.016
3	30	24	1.111	0.540	0.444	0.016	30	24	1.389	0.579	0.397	0.024
4	30	21	1.111	0.563	0.416	0.021	30	21	1.587	0.621	0.347	0.032
5	30	18	1.111	0.589	0.385	0.026	30	18	1.852	0.662	0.298	0.040
6	30	15	1.111	0.618	0.351	0.031	30	15	2.222	0.704	0.248	0.048
7	27	30	1.111	0.472	0.517	0.011	27	30	1.235	0.447	0.538	0.016
8	27	27	1.111	0.491	0.491	0.018	27	27	1.372	0.484	0.484	0.032
9	27	24	1.111	0.513	0.462	0.025	27	24	1.543	0.521	0.430	0.048
10	27	21	1.111	0.535	0.433	0.032	27	21	1.764	0.559	0.376	0.065
11	27	18	1.111	0.560	0.401	0.039	27	18	2.058	0.596	0.323	0.081
12	27	15	1.111	0.587	0.365	0.048	27	15	2.470	0.634	0.269	0.097
13	24	30	1.111	0.444	0.540	0.016	24	30	1.389	0.397	0.579	0.024
14	24	27	1.111	0.462	0.513	0.025	24	27	1.543	0.430	0.521	0.048
15	24	24	1.111	0.483	0.483	0.034	24	24	1.736	0.463	0.463	0.073
16	24	21	1.111	0.504	0.453	0.043	24	21	1.984	0.497	0.406	0.098
17	24	18	1.111	0.527	0.419	0.054	24	18	2.315	0.530	0.348	0.122
18	24	15	1.111	0.553	0.382	0.065	24	15	2.778	0.563	0.290	0.147
19	21	30	1.111	0.416	0.563	0.021	21	30	1.587	0.347	0.621	0.032
20	21	27	1.111	0.433	0.535	0.032	21	27	1.764	0.376	0.559	0.065
21	21	24	1.111	0.453	0.504	0.043	21	24	1.984	0.406	0.497	0.098
22	21	21	1.111	0.472	0.472	0.056	21	21	2.268	0.435	0.435	0.131
23	21	18	1.111	0.494	0.437	0.069	21	18	2.646	0.464	0.373	0.164
24	21	15	1.111	0.518	0.398	0.084	21	15	3.175	0.493	0.310	0.197
25	18	30	1.111	0.385	0.589	0.026	18	30	1.852	0.298	0.662	0.040
26	18	27	1.111	0.401	0.560	0.039	18	27	2.058	0.323	0.596	0.081
27	18	24	1.111	0.419	0.527	0.054	18	24	2.315	0.348	0.530	0.122
28	18	21	1.111	0.437	0.494	0.069	18	21	2.646	0.373	0.464	0.164
29	18	18	1.111	0.457	0.457	0.086	18	18	3.086	0.397	0.397	0.205
30	18	15	1.111	0.480	0.417	0.103	18	15	3.704	0.422	0.331	0.246
31	15	30	1.111	0.351	0.618	0.031	15	30	2.222	0.248	0.704	0.048
32	15	27	1.111	0.365	0.587	0.048	15	27	2.469	0.269	0.634	0.097
33	15	24	1.111	0.382	0.553	0.065	15	24	2.778	0.290	0.563	0.147
34	15	21	1.111	0.398	0.518	0.084	15	21	3.175	0.310	0.493	0.197
35	15	18	1.111	0.417	0.480	0.103	15	18	3.704	0.331	0.422	0.246
36	15	15	1.111	0.437	0.437	0.126	15	15	4.444	0.352	0.352	0.296

Table 3. Colour deviations ΔE^*_{ab} of theoretically calculated and measured colour values of the patterns in a red/yellow colour combination when the yarn count is changed.

R	Theoretically determined values						Measured values					
Y	T _{t0} , tex						T _{t0} , tex					
T _{t_w} , tex	30	27	24	21	18	15	30	27	24	21	18	15
30	0.00	2.06	4.39	6.72	9.32	12.20	0.00	2.61	4.56	7.90	10.60	13.50
27	2.09	0.64	2.51	4.81	7.41	10.30	0.80	0.51	2.77	5.29	8.48	11.83
24	4.45	2.63	1.68	3.16	5.59	8.44	3.78	2.91	1.13	2.55	6.14	9.09
21	6.82	4.99	3.36	3.05	4.57	7.10	6.05	4.07	3.65	0.91	4.41	7.83
18	9.46	7.65	5.91	4.84	4.99	6.65	8.94	7.46	5.12	2.04	2.34	5.25
15	12.39	10.61	8.85	7.56	6.97	7.61	12.74	10.46	7.69	5.78	8.79	7.85

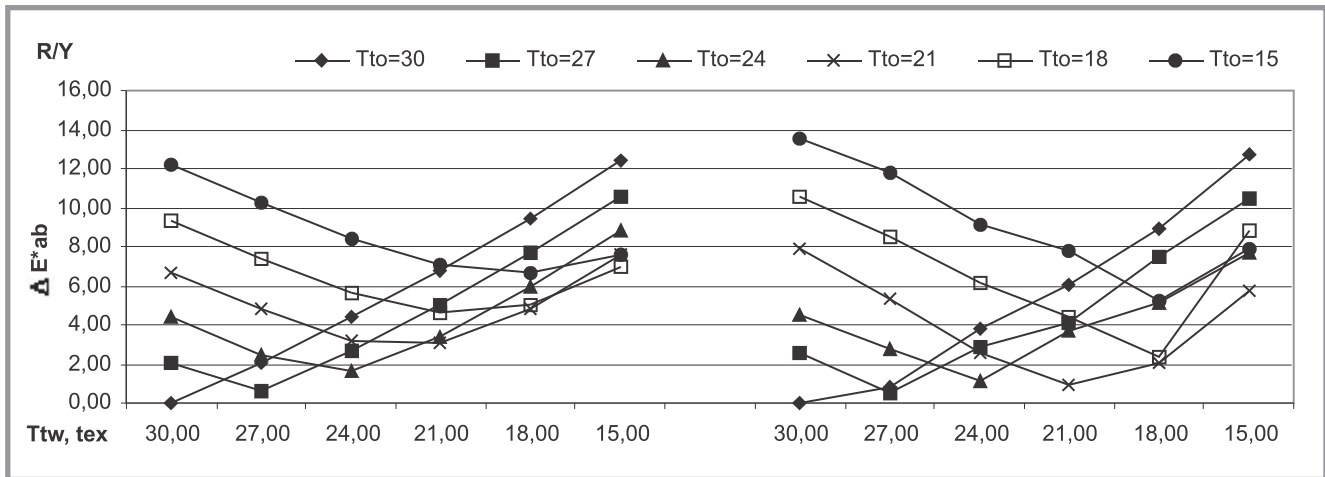


Figure 3. Graphic presentation of the colour deviations ΔE^*_{ab} of theoretically calculated (left side) and measured colour values (right side) of the patterns in a red/yellow colour combination when the yarn count is changed.

Table 4. Colour deviations ΔE^*_{ab} of theoretically calculated and measured colour values of the patterns in a red/blue colour combination when the yarn count is changed.

R	Theoretically determined values						Measured values					
B	T _{t0} , tex						T _{t0} , tex					
T _{t_w} , tex	30	27	24	21	18	15	30	27	24	21	18	15
30	0.00	1.80	3.84	5.88	8.16	10.69	0.00	1.79	3.59	6.58	8.13	11.75
27	1.90	0.72	2.21	4.19	6.46	8.97	2.03	1.35	1.52	4.10	6.56	9.53
24	4.06	2.58	1.89	3.00	5.02	7.45	3.81	1.99	0.96	2.31	4.23	7.54
21	6.21	4.75	3.58	3.44	4.61	6.66	5.80	4.19	2.50	1.34	2.85	6.28
18	8.62	7.21	5.96	5.33	5.62	6.97	8.12	6.38	4.40	2.58	1.60	4.36
15	11.28	9.94	8.72	7.96	7.82	8.57	10.94	9.34	7.26	5.51	1.60	3.45

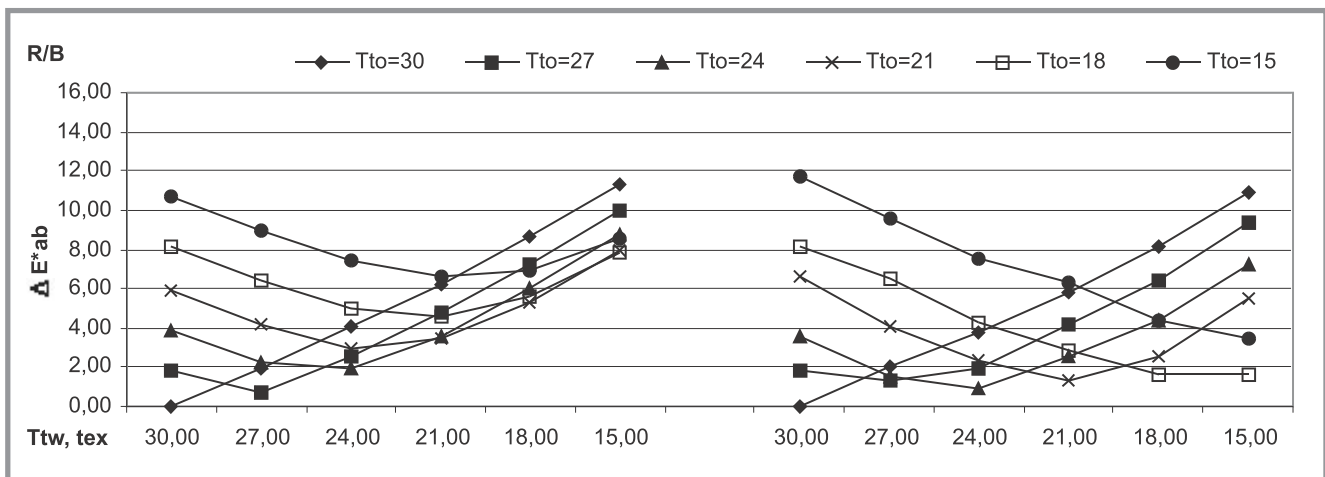


Figure 4. Graphic presentation of the colour deviations ΔE^*_{ab} of theoretically calculated (left side) and measured colour values (right side) of the patterns in a red/blue colour combination when the yarn count is changed.

Table 5. Colour deviations ΔE^*_{ab} of theoretically calculated and measured colour values of the patterns in a red/green colour combination when the yarn count is changed.

R	Theoretically determined values						Measured values					
G	T _{t0} , tex						T _{t0} , tex					
T _t , tex	30	27	24	21	18	15	30	27	24	21	18	15
30	0.00	2.49	5.30	8.12	11.27	14.75	0.00	2.94	6.15	8.65	12.72	15.61
27	2.48	0.52	2.95	5.76	8.92	12.41	2.44	0.50	3.13	6.65	10.87	13.04
24	5.29	2.92	1.37	3.39	6.45	9.92	4.47	2.72	0.41	2.74	7.45	11.48
21	8.10	5.72	3.34	2.48	4.51	7.75	7.84	6.54	3.03	0.67	3.49	8.77
18	11.24	8.86	6.37	4.43	4.06	6.15	12.20	9.19	6.97	3.13	0.96	4.36
15	14.71	12.34	9.82	7.63	6.05	6.19	15.64	14.96	11.41	8.49	7.05	5.99

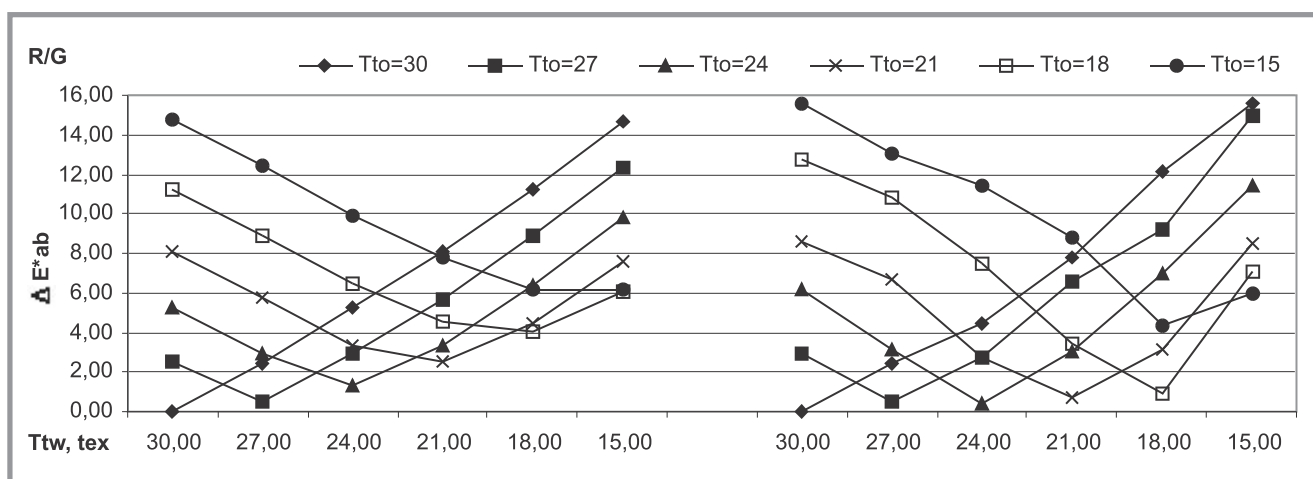


Figure 5. Graphic presentation of the colour deviations ΔE^*_{ab} of theoretically calculated (left side) and measured colour values (right side) of the patterns in a red/green colour combination when the yarn count is changed.

Table 6. Colour deviations ΔE^*_{ab} of theoretically calculated and measured colour values of the patterns in a red/yellow combination when the density is changed.

R	Theoretically determined values						Measured values					
Y	g ₀ , thr/cm						g ₀ , thr/cm					
g _w , thr/cm	30	27	24	21	18	15	30	27	24	21	18	15
30	0.00	4.16	8.32	12.49	16.65	20.81	0.00	5.21	11.04	17.41	24.43	28.97
27	4.23	1.57	4.77	8.88	13.07	17.27	2.88	2.15	7.83	13.25	21.24	25.71
24	8.46	5.06	4.20	6.91	10.76	14.90	6.32	2.80	4.55	11.09	17.18	23.08
21	12.68	9.31	7.34	7.91	10.61	14.28	9.69	6.75	4.68	9.20	15.09	21.36
18	16.91	13.63	11.47	11.10	12.68	15.64	13.93	11.78	7.21	9.99	14.83	21.35
15	21.14	17.97	15.83	15.16	16.15	18.53	16.46	13.92	11.99	11.6	17.00	22.26

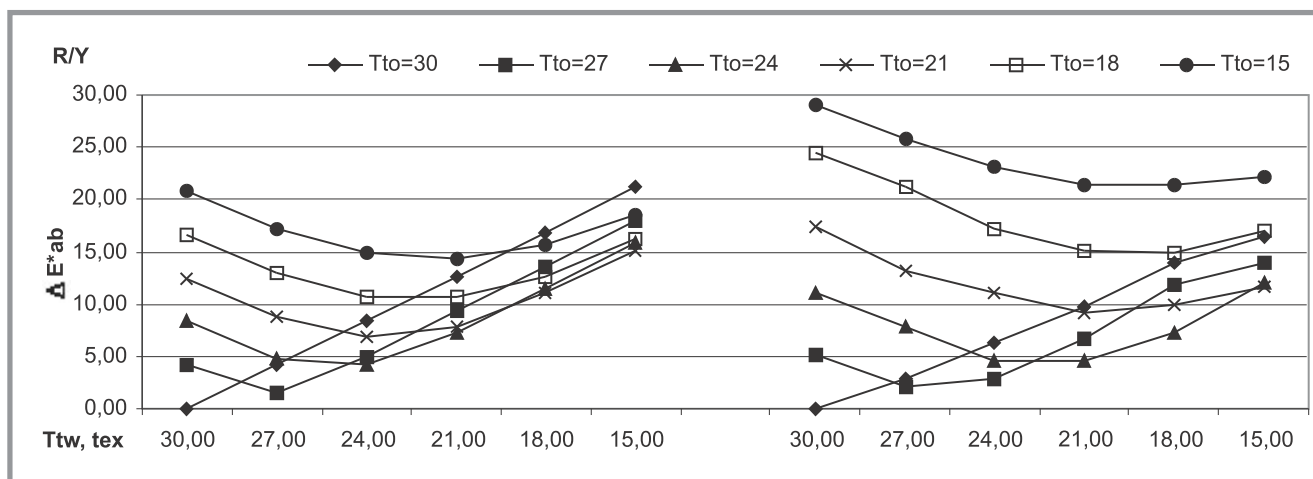


Figure 6. Graphic presentation of the colour deviations ΔE^*_{ab} obtained by theoretical calculation (left side) and by measurements (right side) of the patterns in a red/yellow combination when the thread density is changed.

Table 7. Colour deviations ΔE^*_{ab} of theoretically calculated and measured colour values of the patterns in a red/blue colour combination when the density is changed.

R	Theoretically determined values						Measured values					
B	g_o , thr/cm						g_o , thr/cm					
g_w , thr/cm	30	27	24	21	18	15	30	27	24	21	18	15
30	0.00	3.65	7.30	10.95	14.6	18.25	0.00	4.48	7.34	12.36	15.83	19.17
27	3.86	1.76	4.31	7.82	11.44	15.10	3.82	2.02	4.93	9.60	12.83	17.99
24	7.71	5.13	4.73	6.90	10.10	13.62	8.46	5.55	4.12	6.69	9.27	13.13
21	11.57	9.11	8.05	8.91	11.24	14.35	12.68	10.46	8.08	6.16	7.98	12.22
18	15.42	13.16	12.08	12.50	14.28	17.01	18.68	15.68	13.14	11.95	12.33	15.25
15	19.28	17.23	16.30	16.69	18.30	20.86	23.12	21.16	17.40	16.53	16.42	20.79

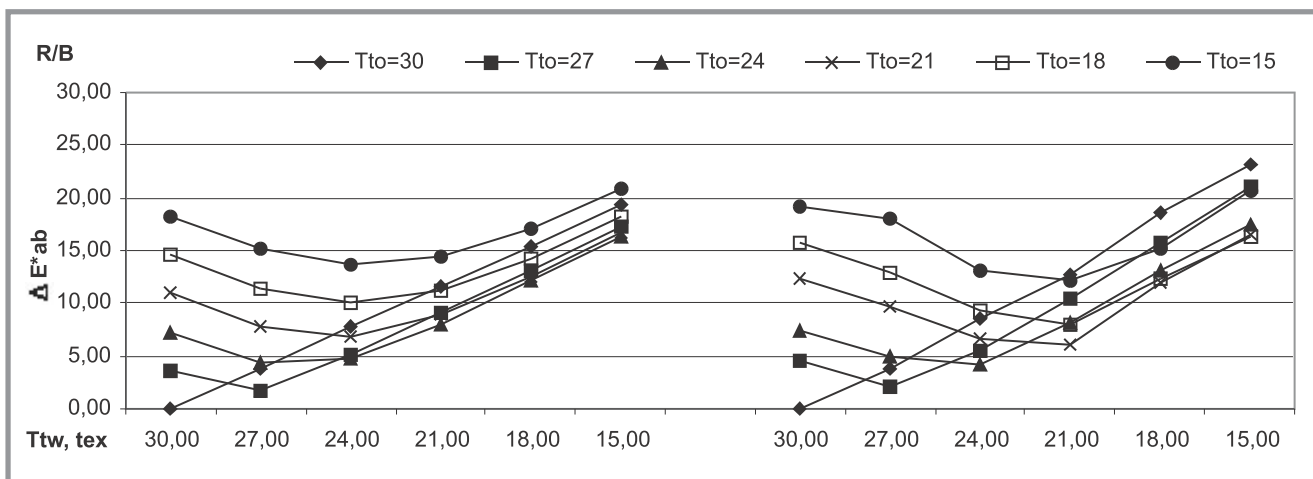


Figure 7. Graphic presentation of the colour deviations ΔE^*_{ab} obtained by theoretical calculation (left side) and measurements (right side) of patterns in a red/yellow colour combination when the thread density is changed.

Table 8. Colour deviations ΔE^*_{ab} of theoretically calculated and measured colour values of the patterns in a red/green colour combination when the density is changed.

R	Theoretically determined values						Measured values					
G	g_o , thr/cm						g_o , thr/cm					
g_w , thr/cm	30	27	24	21	18	15	30	27	24	21	18	15
30	0.00	5.04	10.08	15.11	20.15	25.19	0.00	4.40	10.39	16.52	22.19	28.48
27	5.02	1.27	5.48	10.51	15.58	20.67	6.27	1.65	4.61	11.90	19.65	24.26
24	10.05	5.41	3.41	6.93	11.76	16.82	11.74	6.95	3.20	6.53	13.62	19.60
21	15.07	10.41	6.82	6.42	9.63	14.18	18.50	14.21	9.55	6.53	9.91	15.14
18	20.10	15.46	11.59	9.49	10.30	13.51	25.09	20.37	16.75	11.41	10.38	14.42
15	25.12	20.52	16.60	13.95	13.35	15.05	30.24	27.81	21.72	17.23	14.73	17.16

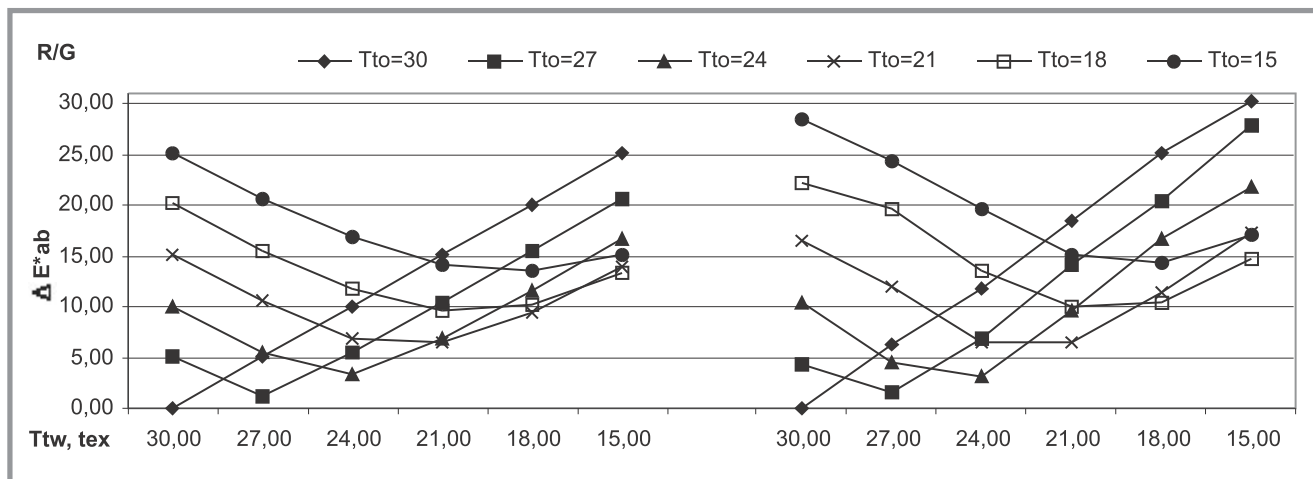


Figure 8. Graphic presentation of the colour deviations ΔE^*_{ab} obtained by theoretical calculation (left side) and measurements (right side) of the patterns in a red/green colour combination when the thread density is changed.

parameter is changed (increased) in one thread system only, the fraction of this colour component increases, whereas the fraction of the other colour component decreases; this leads to higher colour deviation in comparison with woven fabrics taken as standard (30/30). But if the thread count or density of both thread systems change equally, the fraction of the warp and weft change proportionately, and their influence on the colour values of a fabric surface is similar to that in the standard fabric. In such cases the colour deviations ΔE^*_{ab} are lower.

Analysis of colour deviations in relation to used colour combinations

The course of the curves which describe the change of colour values of the simulations in dependence of the weft thread colour is very similar, but numerically different for different weft colours in both threads' count variations (Figures 3-5) and density variations (Figures 6-8). In general, the highest values of colour deviations appear in the case of green weft threads, which is a complementary colour to the red of the warp threads in both the theoretically determined and the measured values. The lowest ΔE^*_{ab} values occur in the case of blue weft.

By thread count variations of the patterns with the red/green colour combination, the colour parameters L^* and b^* change only slightly, whereas the a^* values range from approximately -16 (attributable to the green colour of the weft) to +16 (attributable to the red colour of the warp), and the ΔE^*_{ab} values are even as high as 16. In the patterns with yellow weft the colour differences are between 12 and 14, and with blue weft between 11 and 12. By variations of thread density, the ΔE^*_{ab} value with yellow and green weft rises up to as much as 30 in the measured colour values of simulations.

Comparison of theoretically calculated and measured colour values

The differences between the calculated and measured values of colour deviations occur in both types of variation. This can be attributed mainly to the selection of individual colours of threads, and the shading of these threads on simulation printouts (changed yarn diameter because of interlacing), which imparts a more plastic, three-dimensional appearance and influence

to the measured colour values. On the other hand, when colour values are determined by calculation, which takes into account the same unchanged diameter of threads, there is no such factor which might occur in simulations, nor consequently in the printouts and spectrophotometrical measurements. As a consequence, the curves of the colour deviations of the theoretically determined colour values are uniform, without any significant deflection or change proportionately to the variation of warp and weft threads count and density. Their values, of course, change in dependence of the weft colour. The curves of the measured colour values are less uniform and less proportionate with more deflections; however, in general they pursue the predicted colour deviations such as are demonstrated by the theoretically determined colour values. Both the calculated and the measured values exhibit the highest colour deviations with the red/green combination, and the lowest with the red/blue combination.

Conclusions

The ΔE^*_{ab} value from the CIE $L^*a^*b^*$ colour system is taken as a unit of measure for evaluating colour deviations. A square fabric construction with minimum colour influence of the foundation reflectance was selected as a reference, standard fabric. On the basis of theoretical calculations and measurements on the printed simulations, the following conclusions have been drawn:

- Spectrophotometrical methods are adequate and objective for determining the colour values of the fabric surface made of differently coloured warp and weft threads.
- When the constructional parameters of a fabric and the colour values of threads are known, the colour values of fabric can be predicted, because the changes of colour values are linear in dependence of the extent of variation of these parameters.
- Colour deviations are in general higher if the variations occur in one thread system only (particularly in the case of yarn count variation).
- Variations of yarn count and density have a similar influence on the fabric colour values; however, the values of colour deviations when the yarn count is changed are inferior by about one-

third at the same percentage of variations, because the yarn diameter is a root function of the yarn count.

- The colour deviations measured differ from the calculated colour deviations, but the differences become important only at relatively high variations of constructional parameters.
- The calculated and measured colour deviations presented in this paper are among the highest possible because the selected colours of the warp and weft threads are highly saturated and the variations of count and density high. In most other cases, these colour deviations would be lower than presented.
- The influence of the count and density variations depends on the combination of colours in the warp and weft; the combination of complementary colours (red/green) in general renders the highest values of colour deviations than the combination of two chromatic colours as red/yellow and red/blue.

During further investigation these findings must be verified on real fabrics. The findings show that the measured and the calculated colour deviations are in good correlation, and that analytical calculating method can be used for correcting individual colour values resulting from projected constructional variations. It is possible to determine other constructional parameters or colour values of individual threads by calculation in order to obtain satisfactory colour deviations.



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