Evaluation of Color Difference, Whiteness, and Luster of Multifilament Polyester Woven Fabrics

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ABSTRACT

This paper investigated the color difference, whiteness, and luster of multifilament polyester woven fabrics based on weave pattern, weft density, dye concentration, and interaction between super bright warp yarns and semi dull weft yarns. Plain, weft rib (2/2), sateen (1/4)(3) and steep twill(2/3) was selected as weave pattern. Warp yarn type and its count, and warp density were kept constant. Measurement of whiteness was conducted on pre-treated un-dyed fabric samples. Color difference and luster of samples was evaluated after dying in warp and weft direction separately. Plain and weft rib (2/2) weaves showed the lowest and highest value of whiteness and luster respectively. Interaction between weave pattern and application of super bright yarn as warp was obtained in these parameters. The luster and whiteness of samples was decreased by increase in weft density. The trend of luster and color difference in weft and warp direction by increasing the weft density was not similar and was dependent on dye concentration and effectiveness of super bright warp yarns according to fabric pattern. Woven fabrics with steep twill (2/3) and weft rib (2/2) revealed the highest values of color difference compared with plain and sateen (1/4)(3) in warp direction. In weft direction, plain weave showed the lowest value of color difference and all three others had almost the same level of color difference. Moreover, the visual assessment was organized based on twenty-two observers in standard condition and D65 light source.

Keywords: Weave Pattern, Luster, Color Difference, Weft Density, Polyester Woven Fabric.

INTRODUCTION

Surface color measurement and color matching has an important role in the objective determination of the appearance of color. Colorimetric research studies were almost fully effective in qualifying the color of uniform color surface (uniform color printed-paper, fabrics woven from uniform color thread, fabrics produced with dyeing or printing) [1].

The complexity of textile products, the diversity of textures, and the materials used produce variable color, which was dependent on several parameters, such as illumination, spectral distribution of the color stimulus, as well as the surface state of the textile. This surface state was presented in several forms according to its utility and the parameters of its construction, leading to a difference in color from one structure to another [2].

The luster of an object has a significant effect on its perceived color. This applies to all kinds of objects: colored fabrics, printed images, painted surfaces, etc. All else being equal, matte objects appear less intensely colored with lower chroma and higher lightness than the corresponding glossy objects [3]. Luster and color are two associated physical phenomena, which demand particular attention from the textile designer, due to their prominent influence on the appearance of woven fabrics. When light falls on a fabric some of it may be reflected at the surface of the fibers, sometimes passing through one or more fibers before being so reflected ,and some may be reflected by irregularities within the fibers. The former reflection may be more or less regular, as if from a mirror and gives rise to luster; the latter is diffuse, reducing luster and, if the fabric is dyed, giving rise to color [4].

In addition to the quality of the dyestuff itself, which may be brilliant or dull; a weave which presents large continuous areas of yarn to view, such as sateen, gives a higher luster than one where there are many thread interfacings, such as. a plain weave or a crepe weave[4].

In the literature, several studies were carried out to model the textile properties. Although numerous works were developed to model the textile structure, in particular woven fabrics, the influence of structure on color remains unknown and little work was carried out on this topic. The effect of constructional parameters of polyester woven fabrics such as weft density, pattern, fiber fineness, and fiber number in weft yarn on fractional reflectance was evaluated by Akgun et.al [5].

The influence of yarn count and thread density on the color values of a simulated fabric was studied by Gabrijrlcic and Dimitrovski [6]. Correction of color values of woven fabrics using changes to constructional parameters, namely, weft density, warp yarn fineness, and warp density was presented by Dimitrovski and Gabrijrlcic [7]. Simulations of woven fabrics were used for this purpose. Lee and Sato [8] studied the relation between reflected light, the physical properties of woven fabrics and the psychological perception of their texture.

Akgun et.al [9], studied the effect of weft density, weft yarn filament number, fiber fineness, and weave pattern of un-dyed woven fabrics on reflectance percentage. They found that a change in weave pattern from plain to satin increased the percentage reflectance. An increase in weft density similarly increased the percentage reflectance.

Senthilkumar et.al [10], studied the effect of humidity, fabric surface geometry, and dye type on the color of cotton fabrics. They found that due to increased effective surface area, 1/3 twill exhibited higher increase in their depth of color than plain woven fabrics.

It must be realized that observations of color effects are purely subjective and, even when free from physiological defects such as color-blindness, no two people agree in their description of every color effect. However, there is a wide general agreement between the descriptions given by a number of people and we can talk of an 'average observer' and use his description of what he sees [4].

The current research attempted to explain the effect of structural parameters of polyester multifilament woven fabric. Weft density and weave pattern and also dye concentration on color difference, whiteness, and luster of samples. Super bight multifilament yarns and semi-dull multifilament yarns were used as warp and weft respectively to know the interaction of super bright warp yarns with other parameters. ANOVA was also managed at 95% confidence level using SPSS software. Moreover, the visual assessment was organized based on twenty-two observers in standard conditions and D65 light source. Visual assessment of samples in four categories was preformed and samples in different weft densities with steep twill (2/3) and sateen (1/4)(3) were judged. Besides samples with 20 and 29 wefts per centimeter and different patterns was judged by observers.

MATERIALS AND METHODS

Polyester woven fabrics were produced on a Projectile P7300 weaving machine with 330 cm width under controlled condition. The properties of warp and weft yarn, which were used to produce fabrics, are presented in *Table I*. The warp density of all samples was 58 per cm and the weft density was varied in four levels, 20, 23, 26, and 29 per cm. Four kinds of weave pattern were selected as follow: plain (code: P), sateen (1/4)(3)(code: S), weft rib2/2(code: R), and steep twill 2/3(code: T). The schematic of selected patterns is illustrated in *Figure 1*. Totally, 16 samples were produced and their physical properties are shown in *Table II*. Cover factor of fabrics was calculated based on an image processing technique. The samples were scanned using a CanoScan LiDE 100(Made by Canon) scanner with 1200 dpi in grayscale mode. Using a simple program written by Matlab software the cover factor of fabrics was calculated. In this program at first enhancement contrast was made based on histogram equalizing algorithm and then the image was changed to binary format based on threshold algorithm [11].

The cover factor indicated the extent to which the area of a fabric was covered by one set of threads. [12].

Weight and thickness of woven fabrics was measured according to ASTM-D1777 and ASTM-D3776 standard methods respectively [13, 14].

TABLE I. Properties of weft and warp yarns of woven fabrics.

Parameter	Weft Yarn	Warp Yarn
Kind	Texturized, Semi-dull	Texturized, Super bright
Count(den)	150/34f	150/34f
Breaking Strength(gf/den)	2.88	3.39
Breaking Elongation (%)	22.42	38.05
Fiber cross section	Round	Round

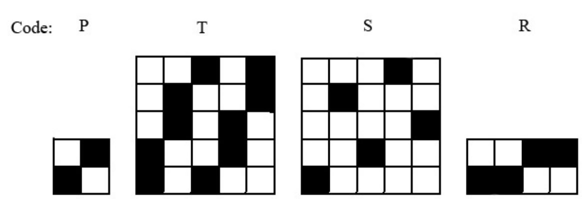

FIGURE 1. The illustration of weave pattern.

The dyeing procedure and auxiliaries that were applied for dyeing of polyester woven fabrics are shown in *Table III*. A computerized laboratory-dyeing machine called Polymat from Datacolor was used. The Time-Temperature curve for dyeing samples is illustrated in *Figure 2*. Reduction cleaning of samples was done using hydro and alkali. Three levels of dye concentration namely; 0.25, 0.5, and 1%; were used for dying of woven fabrics.

The color and whiteness of samples were measured by a Texflash spectrophotometer from Dataclor. Each sample was tested four times and the average was considered. The CIE L*a*b* color system was used to evaluate color deviations by means of ΔE^*_{ab} values. The unit ΔE^*_{ab} from this system was taken as a unit of measure of color deviations. Color deviation in the above-mentioned system represented the shortest distance in the CIE $L^*a^*b^*$ co-ordinate space from the position of the standard color which it is compared with. The following equation was used to calculate the ΔE^*_{ab} Eq. (1)[15].

$$\Delta E_{ab} = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2} \quad (1)$$

TABLE II. Physical properties of woven fabrics.

Sample Code	Pattern Code	Weft Density (1/cm)	Weight (g / m2)	Thickness (mm)	Cover Factor (%)
P.20	P	20	74.00	0.26	85.46
P.23	P	23	76.36	0.27	88.27
P.26	P	26	78.60	0.27	89.90
P.29	P	29	80.64	0.27	90.32
T.20	T	20	69.22	0.34	86.39
T.23	T	23	74.23	0.34	87.47
T.26	T	26	79.82	0.34	88.57
T.29	T	29	81.02	0.34	92.09
S.20	S	20	65.80	0.28	87.36
S.23	S	23	72.12	0.29	88.84
S.26	S	26	75.18	0.30	89.77
S.29	S	29	80.74	0.30	91.21
R.20	R	20	73.72	0.25	86.99
R.23	R	23	77.36	0.26	88.18
R.26	R	26	80.54	0.27	89.42
R.29	R	29	84.52	0.27	91.18

To measure the luster of woven fabrics, a MiniGloss (Model: 101N, SDL International) instrument was used. The measuring angle of reflection was 60 degree. Each sample was tested five times and average of them was calculated.

The visual assessment of luster on four groups of dyed samples was performed based on judgment by 22 observers. Samples were sorted based on their luster. For ranking of samples, all were mounted in a special light cabinet under D65 light source.

TABLE III. Dyeing bath contents.

Generic Name	Concentration	Commercial	Acetic Acid	Carrier	Dispersing agent	L:R
C.I. Disperse Blue56	0.25 ,0.5 and 1%	Sumikarone Blue EFBL	30 ml/lit	1 g/1	1.5 g/l	30:1

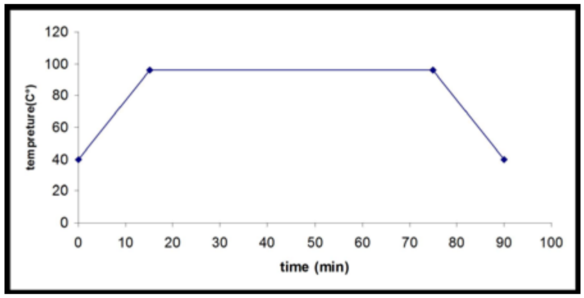

FIGURE 2.Time-temperature curve of sample dyeing.

RESULTS AND DISCUSSION

Luster

In *Figure 3* the luster values of un-dyed woven fabrics is presented. If we compare the luster of woven fabrics before and after dying (as shown in *Table IV*), the obvious decrease of luster can be observed.

As shown in *Table IV*, in all cases by increasing the weft density the reduction of luster was observed in both weft and warp directions. This trend was more obvious in the warp direction. By increasing the weft density, the partial cover factor of weft yarn was increased compared with warp yarn. Therefore, the reduction of luster in warp direction could be because of more effect of weft yarn, which was semi-dull, in surface unit of fabric. Also, the crimp of warp yarns had a direct relationship with weft density. By increasing the warp crimp, the fabric roughness increased and hence a lower amount of light reflection could occur. According to *Table IV* and regarding the trend of luster in the weft direction, it could be said that by increasing the weft density, the solid area on the surface of fabric, which reflected the light, increased and this might be a reason for the increase of luster, but the effect of warp yarns on surface unit of fabric was reduced. It seems that these two parameters neuter each other and no distinct trend of luster in weft direction was observed. This trend was also observed on the un-dyed samples in *Figure 3*.

The increase of dye concentration was caused the reduction of luster in both directions. The decrease of luster in steep twill(2/3)(code:T) pattern by dyeing the samples with 1.00% dye concentration compare with samples dyed with 0.25% , ranged from 42.11% to 40.00% in the warp direction and was between 41.66% and 50.00% in the weft direction.

In the warp direction, the steep twill(2/3)(code:T) and weft rib (2/2)(code:R) patterns showed the highest value of luster followed by sateen(1/4)(code:S) and finally plain(code:P) weaves. This trend was not observed in the weft direction and the highest value of luster was for the sample woven with R pattern followed by S, T, and P pattern weaves.

It was clear that the plain weave that has the most interaction between warp and weft yarns showed the lowest values of luster. These points acted as light scattering points on the fabric surface.

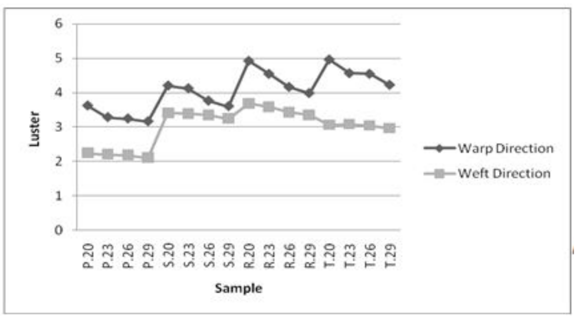

FIGURE 3. Luster of un-dyed woven fabrics.

The luster value of samples woven with R weave in the warp direction could be because of a larger number of super bright warp yarns that are adjacent on the surface of the fabric structure which made a solid area on the fabric surface. In this pattern, the two adjacent warp yarns had same movement in pattern. The samples woven with steep twill (2/3) also had floats of warp yarn. These results showed that not only the floats of yarn in one direction may affect the luster of fabric, but also the position of yarns beside each other according to fabric pattern had influence on luster of woven fabrics. The lower luster value of Sateen (1/4) (3) weave compared with T and R weave in warp direction confirmed the effect of position of super bright warp yarns which were on the front side of R and T weave and was dominant on the back side of S weave, Although it was reported that the reflection in satin pattern was highest compare with plain, 1/2 twill [9].This result confirmed the more effectiveness of multifilament yarn type on color properties of woven fabric than fabric pattern. In the weft direction, the S pattern which had the most smoothness on surface because of the longest of weft float, showed the higher values of luster compare with T and P patterns. We could say that the surface uniformity showed a more dominant effect on luster than texture of woven fabric which was caused by the super bright warp yarn position on the fabric surface in the T pattern.

Analysis of variance at 95% confidence level confirmed the effect of weft density, dye concentration, and weave pattern on the luster of woven fabric in weft and warp directions. Based on the Tukey test, no statistically significant effect between samples woven with R, T, and S patterns in the weft direction in different values of weft density was observed; but in the warp direction there was significant difference between samples woven with R and T pattern compared to the S pattern.

Finally, the correlation between lusters of woven fabrics in different dye concentrations revealed that the correlation coefficient in most cases was between 0.90 and 1.00. This means that there is a linear relationship between the luster of dyed samples due to increasing the dye concentration from 0.25% to 1.00%.

TABLE IV. Luster of woven fabrics before and after dying in different condition.

Sample	Un-dyed Samples		Dyed Samples					
			Dye Concentration (%)					
			0.25		0.50		1.00	
	Warp Side	Weft Side	Warp Side	Weft Side	Warp Side	Weft Side	Warp Side	Weft Side
P.20	3.6	2.2	1.7	0.9	1.3	0.6	0.8	0.4
P.23	3.3	2.2	1.4	0.8	1.2	0.6	0.8	0.4
P.26	3.2	2.2	1.4	0.8	1.2	0.6	0.8	0.4
P.29	3.2	2.1	1.3	0.8	1.1	0.6	0.7	0.3
S.20	4.2	3.4	1.8	1.6	1.6	1.2	1.2	0.9
S.23	4.1	3.4	1.8	1.5	1.6	1.1	1.2	0.9
S.26	3.8	3.3	1.8	1.4	1.5	1.1	1.0	0.8
S.29	3.8	3.2	1.8	1.4	1.5	1.1	1.0	0.8
R.20	4.9	3.7	2.1	1.6	1.7	1.3	1.2	0.9
R.23	4.5	3.6	2.0	1.6	1.5	1.3	1.1	0.9
R.26	4.2	3.4	2.0	1.6	1.5	1.3	1.1	0.9
R.29	4.0	3.3	1.6	1.4	1.3	1.1	1.2	0.9
T.20	5.0	3.1	2.0	1.3	1.7	1.0	1.2	0.7
T.23	4.6	3.1	1.9	1.2	1.5	1.0	1.1	0.6
T.26	4.5	3.0	1.9	1.2	1.5	0.9	1.1	0.7
T.29	4.2	3.0	1.9	1.2	1.5	1	1.1	0.7

Color Difference

According to *Figure 4 and Figure 5*, in all samples by increasing the dye concentration, the color difference was increased. Also, by increasing the weft density the color difference decreased. This could be because of increase of fabric weight and therefore increase of material on the surface of fabric, which reduces the dye uptake. This trend was more obvious in the warp direction.

The color difference in the warp direction was more than in the weft direction in all samples, except pattern S which showed the lowest difference between its warp and weft directions. If we consider the *Figure 1*, it could be found that this pattern had the longest float of weft yarn (semi-dull yarn) on fabric surface. On the other hand, the effect of applying polyester super bright yarns in warp direction in obtaining the following results was confirmed.

In the warp direction, color difference of woven fabrics produced by T and R patterns was more than woven fabrics produced by P and S patterns in all weft densities. This could be because of their texture, which was in pattern T longest float of super bright warp yarn and two adjacent warp yarns in R pattern. Samples produced by P pattern revealed the lowest values of color difference after dyeing. This could be because of the texture feature of this pattern, which had the highest number of interlacing points per unit area of fabric. On the other hand this could be because of the lower effective surface area of this pattern compare with other ones [10].

In the weft direction, samples produced by P pattern and R pattern revealed the lowest and highest values of color difference after dyeing, respectively. In weft rib (2/2) which had a symmetrical texture of warp and weft yarns, two adjacent super bright warp yarns showed their effectiveness. The color difference of samples produced by T, and S patterns was at the same level because of their texture and position of weft yarn on the front side of the fabric. When the weft density was increased to 26 per centimeter, the difference with samples woven with R pattern was also decreased. It seems that by increasing the weft density, uniformity of surface showed more effect than that of super bright warp yarns. The interaction between the texture of pattern, weft density, and super bright warp yarns was also confirmed in this parameter.

Analysis of variance at 95% confidence level confirmed the effect of weft density, dye concentration, and weave pattern on color difference of woven fabric in the warp direction. In the weft direction, the weft density did not show a significant effect on color difference of dyed woven fabrics.

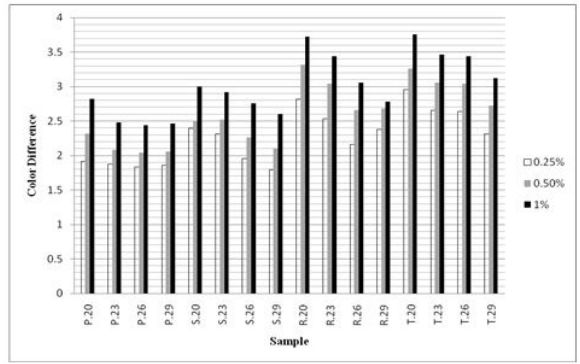

FIGURE 4. Color difference of samples after dyeing in warp direction.

Whiteness

As shown in *Figure 6*, the plain weave showed the lowest value of whiteness followed by T, S and R weaves. The whiteness value of samples woven with plain weave could be because of its highest number of intersections in unit of pattern. The increase of weft density caused the decrease of whiteness in T, and R patterns, but the P and S patterns did not show clear trend on whiteness by increasing the weft density. This could be because of more interlacing points per surface unit of fabric by increasing the weft density, which was caused the higher diffusion of light from the fabric surface.

The trend of whiteness was more visible in R pattern. The R pattern had more uniform floats of weft and warp yarn on the fabric surface and this could cause more whiteness, this trend was also obtained in the color difference of samples.

Surprisingly, although the surface of S pattern was covered by semi-dull weft yarn, it showed whiteness values higher than samples woven with T pattern, but this difference was marginal. The lower number of interlacements in surface unit and hence highest uniformity of surface especially in higher weft density might have more effect on whiteness compare with super bright yarn floats on fabric surface in the warp direction.

ANOVA results revealed the significant effect of weave pattern and weft density at 95% confidence level on whiteness of fabrics. Based on the Tukey test, the P pattern showed the significant difference with T, R, and S patterns in all weft densities, and these patterns did not show significant effect at the 95% confidence level in 26 and 29 weft yarns per centimeter.

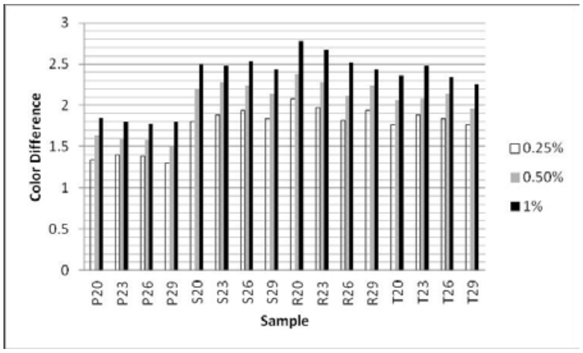

FIGURE 5. Color difference of samples after dyeing in weft direction.

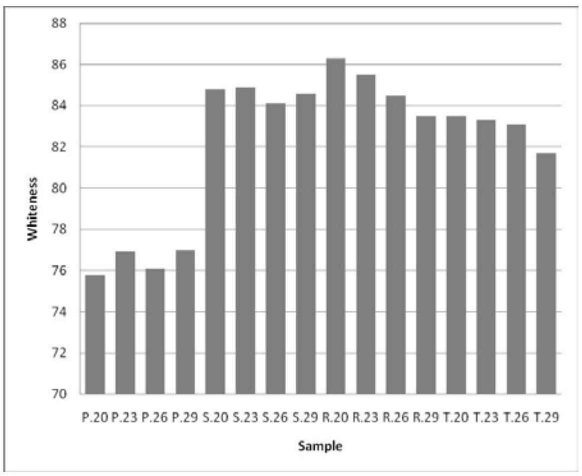

FIGURE 6. Whiteness of un-dyed samples.

Visual Assessment on Luster

Twenty two observers whose age ranged between 18-25 were chosen for this study. Eleven participants were male and eleven were female. All experiments were managed in a light cabinet with D65 light source. Our experiments were organized in four steps. Effect of weave pattern in 20 and 29 weft density and then effect of weft density on T and S weave patterns were evaluated on un-dyed samples. So each observer was asked to rank the four samples according to their luster. All samples were mounted in the light cabinet in the warp direction together and the observers arranged them. As shown in *Table V*, there was a significant agreement among the judges for selecting the T pattern in samples produced by 20 wefts per centimeter. 77.27% of observers selected the T pattern as the sample which showed the highest value of luster, and 63.64% of observers select the P pattern as lowest value of luster. The R pattern obtained the vote of 14 observes as second rank which was 63.64%. According to *Table VI*, when the weft density was increased to 29 per centimeter, again the P pattern gained the lowest ranking (68.18%). But the agreement between observers was decreased dominantly, especially for the S pattern. It seems that the difference between sample luster was not obvious by increasing the weft density and surface uniformity of this pattern, especially in higher values of weft density. This trend was confirmed by experimental results as shown in *Table IV*.

In *Table VII*, the judgment of observers is presented about the samples with T pattern with 20 to 29 wefts per centimeters. It can be seen that observers divided the samples in two distinct groups. In first group the samples with 20 and 23 wefts per centimeter and in second one the samples with 26 and 29 wefts per centimeter. This trend was confirmed by our experimental results. In S pattern (As shown in *Table VIII*), there was a significant agreement among the judges. It is clear from *Table VIII*; based on observers' opinions; that by increasing the weft density the luster was decreased. This trend was confirmed by our experimental results.

CONCLUSION

In this study effect of weave pattern, weft density and dye concentration, on color difference, whiteness, and luster of multifilament texturized polyester woven fabrics were evaluated. Dyeing at three levels (0.25%, 0.50%, and 1%) was found statistically significant at 95% confidence level on luster and color difference of the samples. Color difference of samples was affected by uniformity of fabric surface, float length of weft and warp yarns, and interaction between these two mentioned parameters and weft density. Dyeing caused the decrease of luster in all concentrations. Visual assessment of samples in four categories was preformed, and samples in different weft densities with steep twill (2/3) and sateen (1/4)(3) were judged. Also samples with 20 and 29 weft yarns per centimeter and different patterns were judged by observers. The steep twill gained the highest number of observer votes when samples with same weft densities were compared. Our experimental results were confirmed by observer judgment in most cases. In our next step of research, we aim to study the effect of yarn structure, namely twisted, flat, and texturized combined with yarn color on color values of woven fabrics in different fabric constructions and weave patterns.

TABLE V. Observers' opinion on luster of samples with 20 wefts per cm and different patterns.

Rank	T.20	R.20	S.20	P.20	T.20 (%)	R.20 (%)	S.20 (%)	P.20 (%)
1	17	0	2	2	77.27	0	9.09	9.09
2	1	14	5	2	4.55	63.64	22.73	9.09
3	2	7	11	4	9.09	31.81	50.00	18.18
4	2	1	4	14	9.09	4.55	18.18	63.64

TABLE VI. Observers' opinion on luster of samples with 29 wefts per cm and different patterns.

Rank	T.29	R.29	S.29	P.29	T.29 (%)	R.29 (%)	S.29 (%)	P.29 (%)
1	12	5	4	1	54.55	22.73	18.18	4.55
2	6	11	4	1	27.27	50.00	18.18	4.55
3	3	5	9	5	13.64	22.73	40.91	22.73
4	1	1	5	15	4.55	4.55	22.73	68.18

TABLE VII. Observers' opinion on luster of samples with T pattern in different value of weft density.

Rank	T.20	T.23	T.26	T.29	T.20 (%)	T.23 (%)	T.26 (%)	T.29 (%)
1	9	9	1	3	40.91	40.91	4.55	13.64
2	9	9	4	0	40.91	40.91	18.18	0
3	4	1	16	1	18.18	4.55	72.73	4.55
4	0	3	1	18	0	13.64	4.55	81.82

TABLE VIII. Observers' opinion on luster of samples with S pattern in different value of weft density.

Rank	S.20	S.23	S.26	S.29	S.20 (%)	S.23 (%)	S.26 (%)	S.29 (%)
1	16	2	2	2	72.73	9.09	9.09	9.09
2	4	15	1	2	18.18	68.18	4.55	9.09
3	1	2	15	4	4.55	9.09	68.18	18.18
4	1	3	4	14	4.55	13.64	18.18	63.64

REFERENCES

[1] H. Gabrijelcic, K. Dimitrovski," Use of regression methods for determining the relation between theoretical-linear and spectrophotometrical color values of bicolor woven structures", *Coloration Technology*, Vol.125, pp.74-85, 2009.

[2] A. Moussa, D. DuPont, D. Steen, X. Zeng, "Color Change as a Result of Textile Transformations", *Coloration Technology*, Vol.124, pp. 234-242, 2008.

[3] E. N. Dalal, K.M., Natale-Hoffaman,"The Effect of Gloss on Color", *Color Research and Application*, Vol.24, No.5, pp. 369-376, 1999.

[4] Z. Grosicki, "Watson's Textile Design and Color", Butterworth &Co publisher, ISBN 0 408 70515 9, 1975, 1st Edition,England.

[5] M. Akgun, B. Becerir, H.R. Alpay, "Assessing the relationship among fabric constructional parameters, fractional reflectance and cover factors of polyester fabrics by experimental and mathematical methods", *Fibers and polymers*, Vol. 11, No.2, pp.291-302,2010.

[6] H. Gabrijelcic, K. Dimitrovski, "Influence of yarn count and warp and weft thread density on color values of woven surface", *Fibers &Textiles in Eastern Europe*, Vo.12, No.1, pp.32-39, 2004.

[7] K. Dimitrovski, H. Gabrijelcic, "Correction of color values of woven fabrics using changes to constructional parameters", *AUTEX Research Journal*, Vol.4, No.4, pp.187-193, 2004.

[8] W. Lee, M. Sato, "Visual Perception of Texture of Textiles", *Color Research and Application Journal*, Vol.6, No.6, pp.469-, 2001.

[9] M. Akgun, B. Becerir, H. R. Alpay,"The Effect of Fabric Constructional Parameters on Percentage Reflectance and Surface Roughness of Polyester Fabrics", *Textile Research Journal*, first published on January 18, 2012.

[10] M. Senthilkumar, N.Selvakumar, R.Shamey, "The Effect of humidity, fabric surface geometry and dye type on the colour fabrics dyed with a select range of anionic dyes", *Dyes and Pigments Journal*, Vol.90,pp.225-232,2011.

[11] R. C. Gonzalez, R.E. Woods, "Digital Image processing", 2nd Edition, Pearson Education Publication, 2002.

[12] A.R. Horrocks, S.C. Anand," *Handbook of Technical Textiles*", 1st edition, Woodhead Publication, 2000.

[13] ASTM D1777-96, Standard test method for Thickness of Textile Materials, 2011.

[14] ASTM D3776-96, Standard test method for mass per unit area of fabric, 2011.

[15] S. Millward, "Color Difference Equations and Their Assessment", Test Target Journal, Vol.9, pp.19-26, 2009.

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