

# Structural Modelling of Blackout Fabrics Patterned by Weave Used as a Curtain in Interior Public Spaces

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## Abstract

In the first part of this article a new construction of blackout fabrics and attempts at modifying them are described. The assumption of the research was to obtain a weaving barrier against visible light (VIS) in weave-patterned fabric (jacquard) used as a curtain designed for public buildings. For this purpose the possibility of obtaining barrier properties in one-warp and build-up thread fabric was checked. Afterwards the barrier properties of the weaving structures designed were evaluated by the spectrophotometric method according to standard methodology. The level of barrier properties achieved confirms the legitimacy of the hypothesis about the possibility of acquiring such properties in patterned jacquard fabrics. The article presents the first attempt at an objective assessment of the barrier properties of jacquard blackout fabrics conducted based on digital image analysis. The experimental results proved that the method proposed allows to detect the structural interstices of woven fabric correctly, which can be used to assess the value of barrier features. The work is a summary of achievements in the field of the design and assessment of barrier properties of a new type of blackout fabrics.

**Key words:** blackouts, curtains, weaving blackout, light barrier properties, visible radiation (VIS), suspension systems' load, digital image analysis system.

## Introduction

Modern textile decorative materials combine aspects of design with special properties resulting from their use. Market competition and the high demands of investors have contributed to the development of multifunctional textiles. In addition to the basic functions, special requirements regarding the safety of human life and health are placed on textiles intended for public space management [1, 2]. A research program and fabric structures have been developed to improve the safety of buildings. In the case of decorative fabrics used as curtains in interiors of the hotel sector and business area, a combination of decorative and special barrier functions against visible radiation is justified. Currently two systems of fabrics are in use to manage the window surfaces of public buildings, since blackout fabrics alone do not fulfil decorative functions well enough. Previous attempts to obtain such functions were carried out by printing techniques. The limited aesthetic values of those curtains resulted in their use in lower category facilities. Yet blackouts exist as monochrome fabrics with a smooth texture. For a full decorative effect, two systems of fabrics are applied: smooth blackout fabric and an accompanying decorative, jacquard fabric. So far no research has been conducted on the possibility of obtaining the full functionality of barrier fabrics patterned with weaves. The introduction of a new type of curtain fabric requires the development of tools to assess the bar-

rier properties. This article presents the first construction of multifunctional curtain fabric with blackout properties as well as an objective assessment of the optical barrier phenomenon, using digital image analysis.

## Experiments

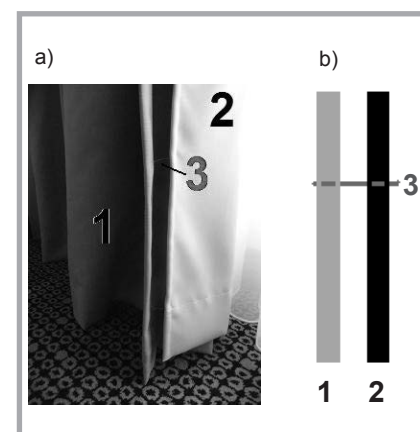
### Materials

#### Basics of modelling multi-layer blackout fabric

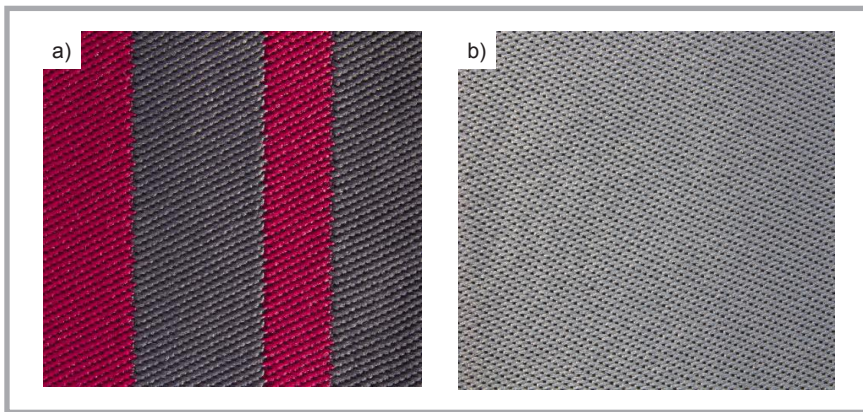
As mentioned above, the window decorating system with blackout functionality is currently based on the use of two fabrics: a decorative one and an accompanying barrier against solar radiation. **Figure 1** presents an illustration of a common solution involving curtain fabrics hung in line on a suspension system. Due to exploitation functionality, there is a requirement to link both fabrics. A permanent connection, which means stitching the fabric, is not preferred. In the example shown in **Figure 1**, point connections on curtains by means of a plastic linker were tested. The method of joining them increases the weight of the curtains to be hung simultaneously on the suspension system. The negative effect of using two joined curtain fabrics is overloading the support elements of the suspension system [3]. As a result, this represents a threat to the health and life of users and service. The fabrics load suspension system is not the subject of inspection, it is analysed only if an accident has happened. In practice, a large amount and weight of

fabrics cause problems when mounting, as well as during maintenance and re-mounting. No notice was taken here of the issue of the significant increase in the costs of the investment.

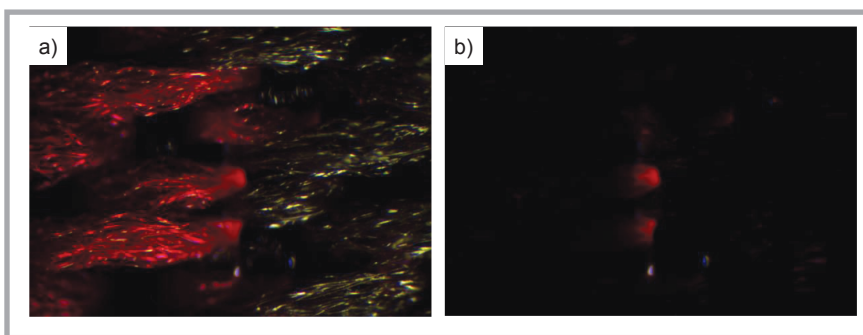
One of the possibilities of minimising the weight of the window decoration is to replace two fabrics with one product which combines aesthetic and special qualities. At the Institute of Textile Architecture of Lodz Technical University, multifunctional curtain fabric was developed as an alternative to solutions previously used. At the beginning of the research, design assumptions were defined, *t* presented in **Table 1**.



**Figure 1.** Illustration of in-line hanging of two fabrics: decorative and barrier, a) exemplary embodiment and b) drawing model, where: 1 – decorative jacquard fabric, 2 – blackout, 3 – plastic linker.



**Figure 2.** View of blackout fabric patterned by jacquard technique: a) right side (upper layer) of fabric, and b) left side (lower layer) of fabric.



**Figure 3.** Image of fabric structure taken by optical microscope: a) with use of a microscopy light source, b) without light source [7].

The blackout properties of fabrics can be obtained in the process of finishing or with the weaving technique. Masking coating is most commonly used in the finishing process, while weaving techniques are used to hide the black weft or warp in the middle layer (multi-layer fabrics with a darkening layer). Woven blackout is also known as blackout with black thread. Optical barrier properties of that fabric are obtained by combining the yarn parameters, types of weaves and filling of the fabric with threads. The key to modelling the fabric properties, and hence to designing multilayer blackout fabrics, is basic knowledge of the fabric

structure, as well as understanding of the weave's impact on the generation of special properties [4]. In the research presented, fabric constructions were directed to obtaining the total optical barrier in conjunction with the weave patterning, irrespective of there not being a patterned back side of the fabric. These activities were carried out with the intention to reduce the areal density of the fabric and to obtain functional properties in accordance with the product's purpose. According to the rules of creating complex weaves, and the correctness of the weaving process, a triple build-up weft structure based on satin weave was devel-

**Table 1.** Summary of design assumptions of triple build-up threads blackout fabric with an outer layer patterned with weaves.

No	Design assumptions for blackout fabric	
1.	Technology	Weaving technology with jacquard pattern
2.	Number of warp layers	3
3.	Thread 1 external – upper	Decorative layer patterned by weave
4.	Thread 2 middle	Layer providing barrier properties required
5.	Thread 3 external – bottom	Smooth outer layer
6.	Functions of fabric	Decorative and barrier against VIS radiation
7.	Level of barrier properties	According to PR/17/2007, PN-EN ISO 13758-1. Textiles
8.	Usage properties	According to intended use
9.	Application	Blackout-type curtain in public buildings

oped [5]. For realisation of the research goal, a striped pattern was designed, with sharp contours that facilitate analysis of the impact of the structure on the fabric barrier properties. The weaving process was carried out on a Picanol Gamma 8-J rapier loom (Belgium) with a black warp. With the weave patterning and weaving process parameters selected, a product was manufactured that fulfilled the assumptions/objectives set out in **Table 1**. A view of the structure of the fabric's left and right side is shown in **Figure 2**.

The fabric designed and produced had a warp density of 300 threads/dm, weft density of 700 threads/dm, and mass per square metre of 248 g/m<sup>2</sup>. It was made with 167/48 x 2 dtex textured polyester black warp yarn coupled pneumatically and with 167/48 x 1 dtex textured polyester weft yarns. For each layer of the weft the following weaves were applied: 1/7 satin, 2/2 twill and 7/1 satin. The new type of blackout fabric structure patterned with weaves developed is the subject of a patent application [6].

Compared to the practically used blackout systems, the assumption of a reduction in the weight of the product was fulfilled because the test fabric produced for the research had a surface mass similar to that of the smooth blackout i.e approx. 248 g/m<sup>2</sup>, which is usually combined with decorative fabric of surface mass within the range of 250-300 g/m<sup>2</sup> (see **Figure 1**).

## Methodology

### Evaluation of barrier properties of blackout fabric patterned by weave

An organoleptic evaluation of the test fabric allowed to indicate particular spots in the fabric structure where the barrier properties are lowered/reduced. The correlation between the pattern and locations of this irregularity formation was found. In order to confirm this, micro observations of the fabric's structure in patterned locations were recorded using an optical Opta-Tech microscope (Poland) under 22x magnification with light passing through the sample.

It can be initially stated that the reason for forming shine-through spots was the loosened fabric structure. In the transmitted light the structure disclosed spots in places of patterning. In further proceedings of the research an objective method of measuring the barrier properties was applied, carried out using a 550 Jasco UV/VIS spectrophotometer (Japan) equipped with an integrating sphere in accordance with test

**Table 2.** Values of spectral average light transmittance for standard fabrics – approved for sale, and fabrics tested [7].

Wavelength, nm	Transmittance T, %		
	Background of test fabric	Pattern of test fabric	Approved blackout fabric
400	0.01079	0.01295	0.02050
450	0.00108	0,00000	0.01403
500	0.00218	0.00218	0.04140
550	0.00109	0.00218	0.03820
600	0.00656	0.00984	0.04918
650	0.05686	0.12357	0.06889
700	0.39584	0.46732	0.13855

**Table 3.** Complex weaves and cross-sections of blackout fabrics.

Weave	Complex weave	Cross-section of warp
2/2		
3/5		
1/3		

procedure PR/17/2007 [8,9], based on PN-EN ISO 13758-1 Textiles [10]. In order to verify the level of optical barrier properties, the light transmittance was determined with a wavelength ranging from 400 to 700 nm in 12 rectangular samples taken from each specific area of the fabric. Samples containing the pattern were prepared from the test fabrics to generate shine-through spots. Samples of the background were included because in transmitted light they behaved in a dissimilar way. The result was an arithmetic average calculated using spectral average light transmission. The light barrier properties are considered appropriate when the total spectral transmittance of light radiation is within the range of 0-2%. The spectral transmittance of multilayer fabric with an outer patterned layer at a wavelength change is shown in **Table 2**.

The optical characteristics of blackout fabrics – a commonly used fabric of the public

fabric trading market (denoted as an authorized fabric) were adopted as the reference level. The transmittance values obtained for that fabric were considered the limit values in assessing the level of barrier properties. Thus the accepted limit of transmission was  $T_g = 0.069$ .

Based on research results of the transmittance level evaluated as low as 0-0.05%, the conclusion regarding very good barrier properties against visible light (VIS) is justified (the final values for wavelengths above 630 nm were discarded due to the impact of sample colour). Such a low level of transmittance does not confirm the hypothesis about the possibility of a local decline in barrier properties related to shine-through areas in the fabric structure (visible to the naked eye). The results of the tests confirm this as well as their graphical interpretation in **Table 3**, which does not correspond with the real image of samples

is shown in **Table 2**. Despite the fact that the transmittance of the background and pattern of the samples observed were very similar, it proves the too low sensitivity of the research method. Further proceedings of the research focused on finding appropriate assessment tools and on the ways of minimising the impact of patterning on the transmission of light through this type of fabric.

It can be preliminary stated that the cause of shine-through spots is the improper construction of the middle “layer”, which settles the level of barrier properties. In such a case, a 2/2 twill weave of the middle “layer” may be disrupted in comparison to the external weaves suggested. The term disrupted means any deformities in the course of the thread resulting from the interaction between local structures of the fabric produced by the other layers. Finding the relation between the weaves of every weft layer is a solution to shine-through spots

**Table 4.** Structure view of blackout fabric patterned by weave.

Weaves of middle layer	Pattern	Background
2/2		
3/5		
1/3		

**Table 5.** Graphical interpretation of shine-through spots in fabrics patterned with weaves at the patterned location.

SAMPLE F1	SAMPLE F2	SAMPLE F3

**Table 6.** Quantitative interpretation of shine-through spots in samples with pattern.

Sample	Count, pixel	Total area, pixel	Average sizer, pixel	area, %
F1	61	1386.000	22.721	0.451
F2	195	676.000	3.467	0.220
F3	121	909.000	7.512	0.296

appearing in the fabric structures. For this purpose, modification of the fabric's structure in terms of an invisible middle "layer" was proposed, for which 3/5 and 1/3 twill weaves were used. In the next stage of the research, three options of weaves (2/2, 3/5, 1/3) were compared. The complex weaves and cross-sections along the first warp are presented in **Table 3**.

Samples of the new fabric version were taken for further structure analysis and for evaluation of barrier properties of the fab-

ric produced. Samples from the patterned area were marked F1, F2 & F3 and samples from the smooth background of the fabric – F4, F5 & F6.

#### Objective evaluation of barrier properties of jacquard fabric with blackout features

Based on the literature, it can be stated that computer image analysis is a widely used tool for assessing textile structure [11-13]. Many scientific papers were related to the use of that technique for defect identifica-

tion in textile products and analysis of their causes [14-16]. In an attempt to objectify the assessment of the phenomenon of light passing through a fabric structure, digital image analysis was performed using the ImageJ program. Digital image materials were recorded with an optical microscope – Delta Optical Smart at 50X magnification. An LED panel was used as a light source, upon which fabric samples were put. The main goal of constructing the test stand for fabric analyses was finding a possibility of objective assessment of samples with a larger surface, including a report of the pattern. The most important element of the stand was the light source. The main criteria of light source selection were good uniformity, homogeneity and stability in time on the area observed. After testing different kinds of light sources, an LED panel of the ART company of 220 x 220mm with an illumination intensity of 1260 lm was chosen to satisfy the requirements. Observations were conducted under darkened conditions which eliminated the influence of spectral characteristics and the colour temperature of the light source. The only parameter of the light affecting the results of investigations was the illumination intensity, which should be adjusted experimentally. Too high intensity values may cause additional excitation of the material examined (it should be considered a noise), while low intensities lead to loss of information about shine-through spots. A fabric structure with a defect in patterning and smooth background structure was analysed. A graphical interpretation of the results of the research is presented in **Table 4**.

The process of image analysis consists of sampling and post-process quantifying of the image. In order to improve image quality and highlight the shine-through spots, the conversion to greyscale, colour inversion, enhancement of contrast and the degree of brightness were applied successively. Views of the processed images are provided in **Tables 5** and **7**. On their basis, identification of the shine-through spots' distribution was made. In the next stage of the research, qualitative and quantitative analysis of the spots was carried out. The description of the pores in the fabric structure uses the number of pixels in the lumens, the average of their sizes, the total area they occupy, and the percentage of the luminal surface in the total image area. Results of the analysis are shown in **Tables 6** and **8**.

In terms of the fabric's structure construction, it can be concluded that the middle layer 2/2 weave (sample F1) allows to ob-

tain a very compact structure of the background, however on the board of the patterned motive the most unfavourable shine-through spots were generated, being of the largest sizes. The aggregations are arranged in a repetitive sequence, which is easily recognized by the human eye, occupying nearly 0.5% of the sample. The best barrier properties were shown by the 3/5 twill weave in the middle layer (sample F2), characterised by shine-through spots of the smallest size and lowest surface occurrence. In addition, these spots are favourably irregularly (or even chaotically) distributed, which makes the human eye not follow them. Whereas the rule is that structure improvement in the direction of the total barrier properties is accompanied by deterioration of the purity of the pattern contour.

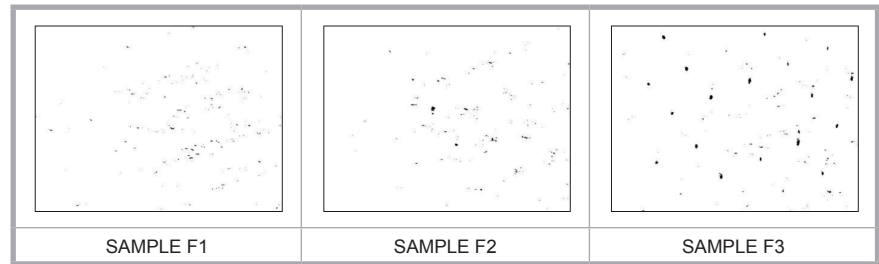
The analysis above demonstrated the helpfulness of the image analysis methodology applied to estimate the quality and further classifications of blackout fabrics. It seems important that the analysis be carried out simultaneously for the same parameter clearances and their distribution. Determination of an acceptable threshold level of barrier properties of blackout fabrics must refer to the size as well as the percentage of shine-through spots on the sample's surface.

## Conclusions

Possibilities of obtaining barrier properties in jacquard patterned fabrics against visible light have been recognized in the article. A new type of blackout curtain patterned by the jacquard technique was designed and produced. The new curtain performs two functions – decorative and barrier, therefore it can be used in window spaces. The solution brings many benefits in terms of minimising the load of suspension systems and improving the safety of buildings.

In the next stage of the study, a standard method for assessing the barrier phenomena of manufactured fabrics was used in accordance with test procedure PR / 17/2007 based on PN-EN ISO 13758-1 Textiles. The research results allowed to qualify a fabric as belonging to the category textile barrier products against visible light. The organoleptic assessment of specific places – structural relations between the layers of fabric, allowed the identification of shine-through spots in the structure of the fabric visible to the naked eye, demonstrating reduced or lack of barrier properties against external radiation. The usefulness of the methodology applied for patterned blackout fabrics has been con-

**Table 7.** Graphical interpretation of shine-through spots in background samples.



**Table 8.** Quantitative interpretation of shine-through spots in background samples.

Sample	Count	Total area	Average sizer	% area
F4	189	579.000	3.063	0.188
F5	165	679.000	4.115	0.221
F6	137	1277.000	9.321	0.416

firmed. The method is based on point measurements and hence does not take into account the local structure disruptions that occur during patterning in the process of layer replacement. In the case of patterned blackout fabrics, surface measurement is required (defined surface of fabric). Objective evaluation of barrier properties of blackout fabric was performed with the digital image analysis method. The efficiency of this method for the evaluation of barrier properties of the fabric structure has been established. The possibility of defining the limited barrier properties from the quantity, size and distribution of shine-through spots has been identified.

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