ISSN 1392–1320 MATERIALS SCIENCE (MEDŽIAGOTYRA). Vol. 15, No. 2. 2009

Development of Visible and Near Infrared Camouflage Textile Materials

Vitalija RUBEŽIENĖ[1*], **Gėlė MINKUVIENĖ**[1],
Julija BALTUŠNIKAITĖ[1,2], **Ingrida PADLECKIENĖ**[1,2]

[1] *Lithuanian Textile Institute, Demokratų 53, LT-48485 Kaunas, Lithuania*
[2] *Department of Textile Technology, Kaunas University of Technology, Studentų 56, LT-51424 Kaunas, Lithuania*

Received 13 June 2008; accepted 22 October 2008

Under the rapid development of surveillance and acquisition devices it became imperative to develop camouflage textiles that could protect the objects from detection by various sensors in the wide spectral range. And, as the sensor systems continue to be refined, it is necessary that the performance of camouflage materials would be continually updated. In this research the samples of woven printed camouflage fabrics, which can conceal the object both in the visible (380 nm – 780 nm) and near infrared – NIR, (780 nm – 1200 nm) radiation spectral range, were developed and investigated. Three different printing technologies (using pigments, reactive dyes and vat dyes) were used to achieve these characteristics. Colour fastness to various influences, spectral characteristics of surface colour in visible and NIR spectral range and influence of different pretreatments (washing, abrasion, repeated flexing and exposure to light) on colour change were determined and analyzed. Some advantages and disadvantages of the applied printing technologies were set. The results showed that even noticeable changes of colour intensity after some pretreatments in the visual spectral range, in many cases does not have significant influence on the spectral reflectance in the NIR range and it remains in the required level. These studies would pave the way for development and optimization of textile materials with respect to better stability of concealing properties in the visible and NIR all wearing period.

Keywords: camouflage materials, spectral reflectance, colour fastness, visual and NIR spectral range, printing.

1. INTRODUCTION

Modern camouflaged munitions of warriors should be crowded with protective properties not only in visible range but also should persist concealed in wide spectral range, including UV, near IR, far IR, radar and acoustic ranges.

Table 1 shows details of the threat wavebands and the detection systems used [1].

Generating camouflage materials that can conceal the objects both in the visible and near infrared – NIR, radiation spectral ranges, are trying to mimic natural or even artificial backgrounds, not just in terms of colours, but also patterns, gloss and texture. For the development of this kind of camouflage materials the colours and drawings, which approximate satisfy particular environment, should be chosen.

Colour can be measured in terms of CIE chromaticity coordinates (in the visible spectral range) or in terms of spectral reflectance (in visible and NIR spectral ranges) using a spectrophotometer.

In practice, each military nation has adopted its own visual colours and patterns. Mostly for woodland areas there are used these colours – khaki, green, brown, black. Additionally there are used yellow, greyish orange and other colours. Light brown, silt and brown colours are mostly used for desert.

From 2004 years Lithuanian Ministry of National Defence has confirmed new pattern for Lithuanian army woodland camouflage materials. The visual colours of this pattern shall match up appropriate indicated colours of “Pantone textile” catalogue. The view of this pattern is shown in Figure 1.

Table 1. Requirements for the camouflage, concealment and deception [1]

Radiation spectral range	Wavelength or frequency	Requirements for camouflage, methods of detection
Visible spectrum	400 nm – 800 nm	Should match colour, texture and appearance of the background. Detection by eye
UV	200 nm – 400 nm	Should match optical properties of snow and ice. Detection by UV detectors or eye
Near IR	750 nm – 2000 nm	Should match reflectance of background when viewed by image intensifiers, low-light television, IR photography
Far IR – thermal	2600 nm – 5000 nm 8000 nm – 14000 nm	Should minimize heat signature from humans or hot equipment. Detection by thermo vision
Radar	1 GHz – 18 GHz 90 DHz – 98 GHz	Should avoid movement. Detection by Doppler radar
Acoustic	20 Hz – 20,000 Hz	Should avoid sounds of rustle and swish. These sounds are caused by some kinds of textile materials. Detection by deaf-aid, microphones or ear

To provide camouflage in non visual range of spectrum, i. e., against NIR detection devices it becomes essential that camouflage fabrics should be printed with the dyes having NIR reflectance values similar to that of backgrounds. Each colour of pattern has to meet a

---

[*] Corresponding author. Tel.: +370-37-308661; fax: +370-37-308668.
E-mail address: *laboratorija@lti.lt* (V. Rubežienė)

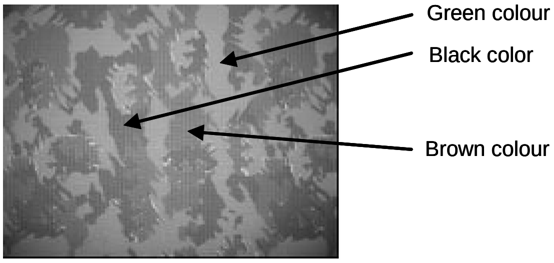

Fig. 1. The pattern of woodland camouflage of Lithuanian army uniforms (valid since 2004 years)

specified reflectance value [2].

In manufacturing of the camouflage materials that secure protective features in visible and NIR spectral ranges these coloration technologies are dominant:

- use of special selected dyes and pigments [3 – 5];
- incorporating strongly IR absorbing pigments into printing paste [6, 7];
- incorporating strongly IR absorbing pigments into the polymer at a fiber forming process [8];
- use of special and minimizing IR reflectance coatings (layers) [9, 10].

It is relatively easy to print a wide range of textile fibre types in the correct visual shades with the colour fast dyes. However it is more difficult to achieve NIR cover on the same fabric. Artificial fibres such as polyamide, polyester, aramids and their blends with natural fibres cause these particular problems.

The camouflage should stay efficient during all the wearing time, so the colour fastness to various influences and treatments becomes an extremely important parameter, ensuring the concealment of the target both in the visual and NIR radiation spectral ranges.

The aim of this study was to analyze the drawbacks of the military clothing currently worn by Lithuanian army, to identify special requirements posed for today‘s military camouflage and to investigate the wearing influence to the efficiency of the concealment properties in visual and near IR spectral range of newly developed woodland camouflage woven fabrics, intended for Lithuanian army outdoor uniforms.

2. MATERIALS AND METHODS OF THE INVESTIGATION

Experimental investigations were carried out with four woven fabrics, which were printed using three different printing technologies (Table 2). The values of the spectral reflectance in the NIR range were achieved by means of special absorbers or special dyes, integrated into printing paste.

Table 2. Specification of investigated samples

Fabric No.	Fiber content	Printing technology
1	CO 65 % + PES 35 %	Pigments
2	CO 65 % + PES 35 %	Reactive + disperse dyes
3	CO 65 % + PES 35 %	Vat + disperse dyes
4	CO 50 % + PES 50 %	Reactive + disperse dyes

CO – cotton, PES- polyester.

Colour fastness to artificial light, spectral characteristics of surface colour in visible and NIR spectral ranges before and after different pretreatments (washing, abrasion, repeated flexing, and exposure to light) and change in visible range after mentioned treatments were determined and analysed.

Washing and drying was carried out according to the procedures described in standard LST EN ISO 6330:2002 [11]. To simulate real wearing conditions the maximum number of washing cycles – 20 was chosen, as during exploitation period camouflage uniforms are washed approximately 20 ÷ 25 times. As concealing properties of camouflage fabrics shall be ensured during all wearing period, fabrics were washed 1, 5, 10 and 20 times.

Abrasion pretreatment was carried out according to the standard LST EN ISO 12947-2:2001 [12]. The samples were abraded till 5000 rubs.

Repeated flexing was performed according to the standard LST EN ISO 7854:2000 [13]. 9000 flexes were applied.

The samples of all fabrics were exposed to artificial light. The experimental investigations were carried out according to the standard LST EN ISO 105-B02:2001 [14]. The exposition was preceded till the difference between treated part of the sample and untreated part of sample became equal to 3 gray scale grade. Colour fastness to light was evaluated using blue wool references. They range from 1(very low colour fastness) to 8 (very high fastness).

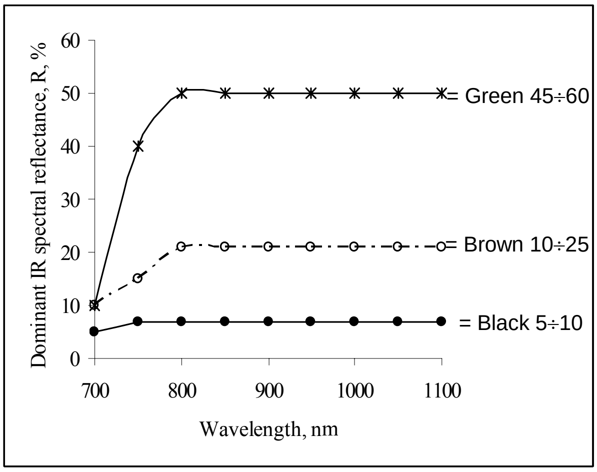

Fig. 2. Optimal values of the spectral reflectance (*R*) in NIR spectral range for different colours of the Lithuanian army’s woodland camouflage fabric

The following spectral characteristics of surface colour in visible range were measured using spectrophotometer Spectraflash SF450: spectral reflectance – R, %; colour difference – ΔE_{CMC} between test specimen before appropriate treatment and specimen after treatment. The colour change of samples after treatments (in visible range) was evaluated visually, using grey scale for assessing change in colour corresponding requirements of standard LST EN 20105-A02:1997 [15]. Grey scale ranges from 1 (considerable change) to 5 (no change). Spectral reflectance R, % of each colour of pattern in the NIR spectral range before and after treatments was measured using spectrophotometer Microflash MF45.

According to the measurements of nature objects reflectance in NIR range and results of observation of camouflage fabrics in the field conditions through night vision goggles, the optimal values of reflectance factor in NIR spectral range for Lithuanian army woodland camouflage material colours were determined (Fig. 2).

3. RESULTS AND DISCUSSION

The camouflage materials must provide concealing properties during all wearing period. These properties in the visible and NIR spectral ranges mostly depend on spectral characteristics of surface colour and particularly on spectral reflectance in these ranges. Textiles for military uniforms face a complex set of challenges during exploitation that can drastically change the colour of fabric and herewith reduce the effectiveness of camouflage. Results of some studies indicated that various factors are affecting the colour fastness and spectrophotometric properties of coloured fabrics [16 – 18]. In this study there were analysed the main effects of wear that can influence the colours of camouflage fabric: abrasion, flexing, washing, exposure to light.

Preliminary experiments and visual assessment of treated fabrics have shown (Table 3), that the foremost effects of wear that significantly act on colour change and herewith can impact camouflage concealing ability, are repeated washing and exposure to light. Influence of abrasion and flexing is inconsiderable.

Table 3. Influence of several pretreatments on colour change

Pretreatment	Colour change, grey scale grade (for all colours of the fabric)			
	Fabric No.			
	1	2	3	4
Flexing (after 9000 flexes)	5	5	5	5
Abrasion (after 5000 rubs)	3÷3 – 4	4 – 5	3 – 4	4 – 5
Repeated washing (after 20 cycles)	2÷3	2–3÷3 – 4	2 – 3÷4	3 – 4÷4
Exposure to light (after 50 hours)	4÷4 – 5	2÷3	4 – 5	3÷3 – 4

Further experimental investigations were carried on for the determination of the surface colour spectral characteristics dependence on the intensity of washing and light exposure processes.

To evaluate the colour change in the visible spectral range after appropriate treatments instrumentally determined value ΔE_{CMC} was used, instead of visual assessing using grey scale, because instrumental method is more objective than visual one. In analysing the obtained data as a criterion for colour change acceptance, limit value of $\Delta E_{CMC} = 2$ was used, as such limit often is used in technical requirements for camouflage materials [19]. While investigating the dependence of colour change on the repeated washing (Figs. 3 – 5) it was determined that the method of printing has significant influence. Pigment printed samples showed the most unacceptable colour differences, particularly for black (see Fig. 3) and green (see Fig. 5) colours. Printing with reactive or vat dyes ensure more stable colour characteristics and even after 20 washing cycles the colour differences for green colour, which is the basic colour of the pattern, are acceptable (see

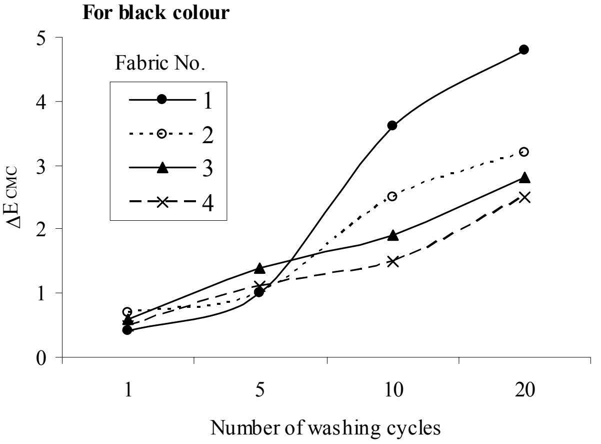

Fig. 3. Dependence of black colour change upon the washing cycles

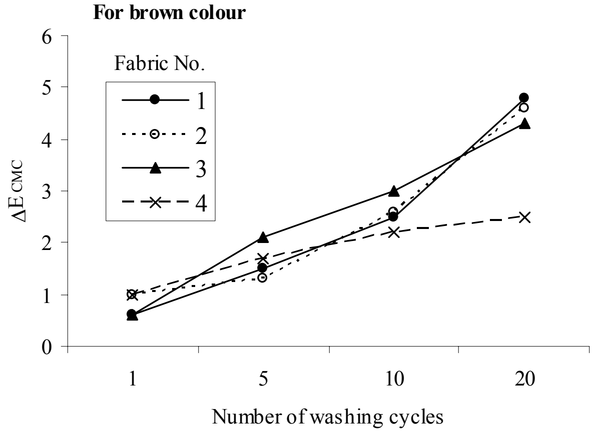

Fig. 4. Dependence of brown colour change upon the washing cycles

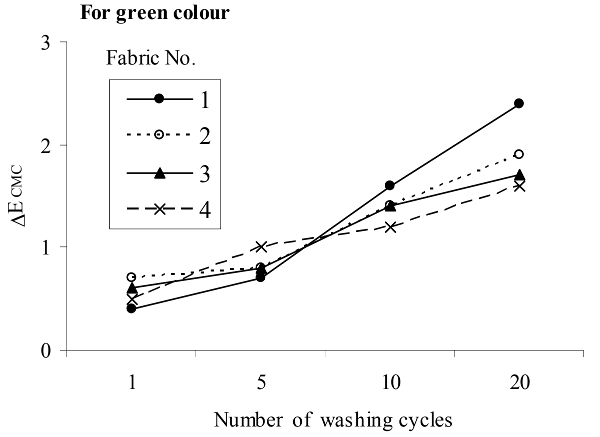

Fig. 5. Dependence of green colour change upon the washing cycles

Fig. 5). Fibre content also effects colour changes after the repeated washing. The decrease in cotton content from 65 % to 50 % (sample No.4) causes the increase in colour fastness to repeated washing and the values of ΔE_{CMC} for all colours of sample No.4 are ≤2 after 10 and 20 washing cycles, except black colour after 20 washing cycles. The effect of washing on colour fastness and spectrophotometric properties of fabrics was also investigated by other authors [1, 16], but in these studies the variations of above-mentioned parameters were not examined during intended clothing wearing period.

The influence of the exposure to light on the investigated fabrics is presented in Figure 6. The printing with vat dyes showed the highest fastness to light – it is 7 ÷ 7–5 grade (sample No.3). Printing using reactive dyes indicated significantly lower figures, only 4–5 ÷ 5 grade (sample No.2). Meanwhile the fastness to artificial light increases with the decreasing cotton percentage and for sample No.4 reaches 5 ÷ 5–6 grade. These results are in line with other studies [2, 4, 17].

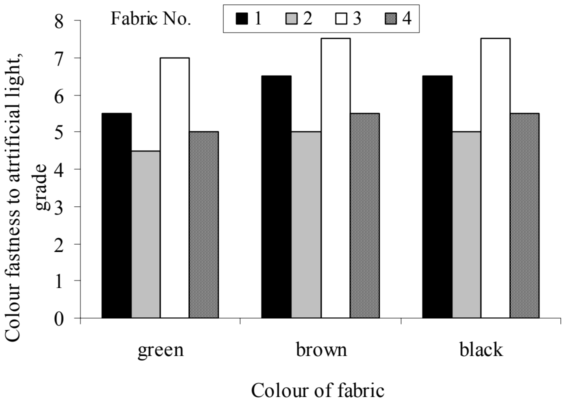

Fig. 6. Colour fastness to artificial light of treated fabric for each colour of pattern

As concealing properties in NIR range also must be ensured, the main parameter, from which this ability mostly depends – spectral reflectance (*R*), should stay in required level (see Figure 2) during all wearing period. There is quit a number of works concerning creation of NIR camouflage fabrics and optimization of their spectral characteristics [3 – 10]. However in the carried literature survey there was found no studies about the impact of effects of wear on concealing properties of camouflage materials in the NIR spectral range. Therefore the influence of the repeated washings and light exposure to spectral reflectance in the NIR spectral range was studied. The relationship between R and washing intensity is presented in Figures 7 – 9. The results of research showed that in most cases even after 20 washing cycles spectral reflectance in the NIR range increases inconsiderably and stays in the required level, with some exception in black colour. This exception is obtained because of the low black colour fastness to wet rubbing and repeated washings. It was determined that the dependence of spectral reflectance in NIR range to light exposure is also insignificant: after 50 h of exposure to artificial light, *R* increases only 0.1 % – 0.3 %.

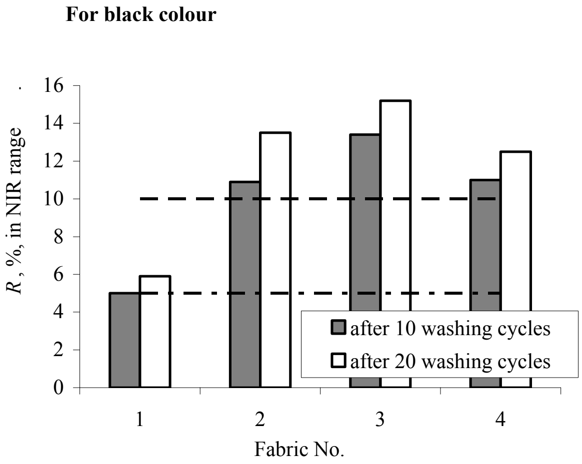

Fig. 7. Dependence of the dominant NIR spectral reflectance of black colour on the washing intensity (– – – upper limit value; – · – · – lower limit value)

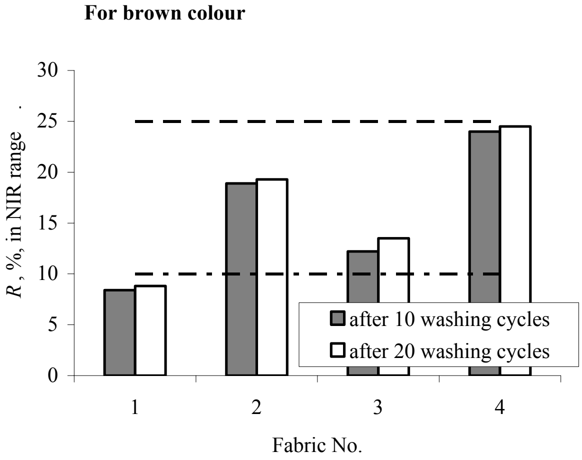

Fig. 8. Dependence of the dominant NIR spectral reflectance of brown colour on the washing intensity (– – – upper limit value; – · – · – lower limit value)

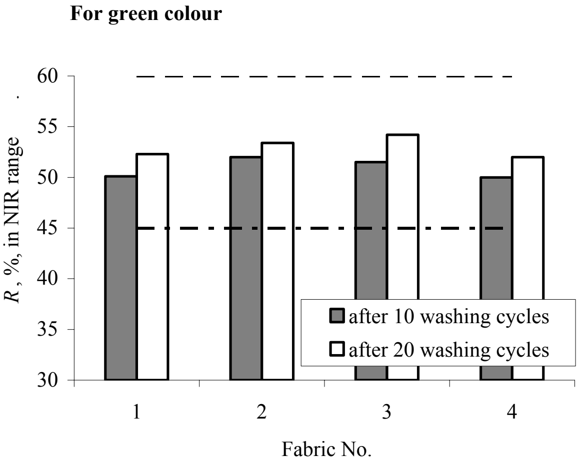

Fig. 9. Dependence of the dominant NIR spectral reflectance of green colour on the washing intensity (– – – upper limit value; – · – · – lower limit value)

The development of specific military clothing is a continuous process, with one of the most important roles belonging to the end-users, who give an objective evaluation of the functional properties of the products and therefore helps to identify the optimal values of different parameters. Therefore the prototypes of camouflage outdoor uniforms were produced from newly developed woven camouflage fabric No.4 (having the best results in this study) and presented to Lithuanian army for experimentally wearing in operating conditions.

4. CONCLUSIONS

New samples of woodland camouflage fabrics were developed and investigated for the stability of their concealing properties in the visible and NIR spectral ranges.

Analysis of the data obtained after selected pretreatments of investigated fabrics allowed to compare the applied printing technologies and to set their advantages and disadvantages in respect to concealing ability of the fabric in the visible and NIR spectral ranges. The best results were achieved in printing with reactive dyes, especially for fabric with CO 50 % + PES 50 % fibre content (fabric No.4). The main disadvantage of pigment printed fabrics is the insufficient colour fastness to repeated washings.

The main wearing conditions that mostly influence the colour change and concealing properties of camouflage fabrics in the visible and NIR spectral ranges were determined – they are: repeated washing and exposure to light. Influence of abrasion and flexing in this case is inconsiderable.

The results showed that even noticeable changes of colour intensity after some pretreatments in the visible spectral range, usually does not have meaningful influence on the spectral reflectance in the NIR spectral range.

Acknowledgments

Support of the Lithuanian Sciences and Studies Foundation is acknowledged.

REFERENCES

1. **Scott, R. A.** Military Protection. Textiles for Protection. Ed. by Scott, R.A. Cambridge, England: Woodhead Publishing Limited, 2005: pp. 597 – 621.
2. **Scott, R. A.** Textile in Defence. Handbook of Technical Textiles. Editted. by Horrocks, A. R., Anand, S. C. Cambridge, England: Woodhead Publishing Limited, 2000: pp. 425 – 460.
3. **Burkinshaw, S. M., Hallas, G., Towns, A. D.** Infra-red Camouflage *Review of Progress in Coloration* 26 1996: pp. 47 – 53.
4. **Zhang, H., Zhang, J. Ch.** Near-infrared Green Camouflage of Cotton Fabrics Using Vat Dyes *Journal of the Textile Institute* 99 (1) 2008: pp. 83 – 88.
5. **Gupta, K. K., Nishkam, A., Kasturiya, N.** Camouflage in the Non-Visible Region *Journal of Industrial Textiles* 31 (1) 2001: pp. 27 – 42.
6. US Patent 5798304. A Fabric which Presents a Non Camouflage Patter Under Visible Light and a Camouflage Pattern Under Infrared Radiation
7. **Colemen, R. A.** Application of Infrared Absorbers to Nylon 6,6. Defence Technical Information Center Accession No. ADA000832.
8. **Frankel, K., Sousa, S., Cowan, R., King, M.** Concealment of the War fighter's Equipment through Enhanced Polymer Technology. Defence Technical Information Center. Accession No. ADA433437.
9. US Patent 20070009679. **Holcombe, J. D., Manish, K., Nandi**. Infrared Suppressive Material.
10. International Patent Pub. No. WO/2006/097372 **Sioen, J. J., Wille, J.** Infrared Shielding and Radar Attenuating Textile Material.
11. LST EN ISO 6330:2002 Textiles – Domestic Washing and Drying Procedures for Textile Testing.
12. LST EN ISO 12947-2:2001 Textiles – Determination of the Abrasion Resistance of Fabrics by the Martindale Method Part 2: Determination of Specimen Breakdown.
13. LST EN ISO 7854:2000 Rubber – or Plastics-coated Fabrics – Determination of Resistance to Damage by Flexing.
14. LST EN ISO 105-B02:2001 Textiles – Tests for Colour Fastness – Part B02: Colour Fastness to Artificial Light: Xenon Arc Fading Lamp Test
15. LST EN 20105-A02:1997 Textiles – Tests for Colour Fastness – Part A02: Grey Scale for Assessing Change in Colour
16. **Ogualata, R. T., Balci, O.** Effects of Extra Washing After Treatments on Fastness and Spectrophotometric Properties of Dyed PET/viscose/elastane Fabric *Journal of the Textile Institute* 98 (5) 2007: pp. 409 – 420.
17. **Xu, W., Shyr, T., Yao, M.** Textiles' Properties in the Infrared Irradiation *Textile Research Journal* 77 (7) 2007: pp. 513 – 519.
18. **Kim, L. Y., Lee, C., Carlson, J.** Effect of Fabric Properties on Thermal Signature and Burn Injury AD-A433080 *Proceedings of the Conference,* Future Force Warriors, Defence Technical Information Centre, 2004: p. 3.
19. Terms of Contest for Outdoor Uniforms. Technical Specification for Outdoor Camouflage Uniforms. Lithuanian Armed Forces 2007: 114 p.

Presented at the 17th International Conference
"Materials Engineering'2008"
(*Kaunas, Lithuania, November 06 – 07, 2008*)