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Analysis of Printed Fabrics for Military Camouflage Clothing

Abstract
Several basic properties of fabrics for camouflage clothing and protection for military purposes are described. The physical and mechanical properties of the yarns and fabrics and their physiological properties with different structural parameters of fabrics were tested. The structural fabric parameters and after-treatment conditions affect the physical-mechanical and physiological properties of the fabrics. The correlation values of individual parameters are relatively high. The influence of abrasion on colour shades applied to camouflage fabrics is different, indicating a different resistance to the colour fastness of the fabrics.

Key words: *printed fabrics, camouflage fabrics, military clothing, protective clothing, physical-mechanical properties, physiological properties.*

Introduction

Technical textiles provide invaluable properties for military purposes, which are necessary for movement, survival and struggle in a hostile environment. Soldiers must dress in such a way that they feel comfortable and can also survive; it is therefore of paramount importance that the clothing and associated equipment are lightweight, compact, durable, stable and of high performance. Requirements placed on textile material protecting individuals in life critical situations in terms of protection from various environmental conditions and combat threats result in the significant investment of financial resources in the development of advanced materials and technical textiles for military use. The main functional criterion which fabrics for military purposes should meet include the physical and camouflage requirements, resistance to various environmental conditions, water, wind, fire, heat, specific battlefield threats, and economic conditions. Except for making military clothing for different conditions and uses, camouflage fabrics are used for tactical and ballistic protective vests, helmet protection, protection of military equipment in the field and complete camouflage of military facilities. Hence, these textiles are often treated for resistance to UV, water, fire, heat and wind, and it is very important that they still remain relatively lightweight [1, 2].

A human being cannot successfully function without a full sense of comfort. The comfort properties of materials are largely reflected in the psychological factors that may cause psychological discomfort that interferes with the motivation and readiness to perform high risk tasks. Therefore requirements for comfort and flexibility are made on these fabrics which will allow the good mobility and psychological stability of soldiers. Thus it is desirable that the fabrics are made from natural fibres that are lightweight, stable, durable and resistant to external conditions. Since it is difficult to make a fabric that would simultaneously meet all these requirements, they are made from a combination of natural and synthetic fibres, making it possible to fulfill almost all requirements that are made of them.

One of the most prominent features of comfort for military clothing is the property of thermal comfort, i.e. comfort or discomfort associated with how hot or cold one feels. Thermal comfort is closely related to changes in physiological variables, such as the skin and temperature, and is a function of environmental variables such as temperature, humidity and wind speed, the activity level of the individual, the properties of clothing in terms of water tightness, and the water vapour permeability of the fabric. Protective clothing of low resistance to water vapour permeability can cause heat stress and the occurrence of large amounts of perspiration of the wearer, thus hindering visual, cognitive, physical and psychological characteristics [3]. Soldier equipment is very complex and quite difficult, especially if bullet-proof vests are made with built-in metal plates. Accordingly, wearing such equipment requires the good fitness and physical endurance of soldiers. Basic ergonomic principles require that the burden is as close as possible to the body, thus preserving the wearer's balance and stability. This means that the soldier suit and vests or sewn fabric carry almost all the soldier equipment, meaning that it has to be functionally perfect in seamed and seamless places. Such reasoning has resulted in the concept of a soldier suit, vest and belt for carrying loads, which allows soldier mobility, with easier access to certain parts of the equipment and reducing own contours.

The aim of the camouflage properties of military camouflage fabrics, which will be dealt with in this paper, is to break the silhouette of a human body or military facility with printed samples of the colours of their direct environment in order to achieve imperceptibility [4].

Furthermore materials for military clothing have many other protective properties, which are achieved by various processes in chemical finishing, i.e. certain substances are applied to the surface of the textile fabric, where they are retained,

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Table 1. Size recipes.

Sample	Size recipes
Sample A	500 l water + 75 l condensate 17 kg INEX 773C (PVAL) 34 kg FIBROSINT C75 (synthetic size) 2 kg AVIROL 308AS (antistatic agents, softeners)
Sample B	500 l water + 75 l condensate 46 kg INEX 746H (PVAL) 35 kg FIBROSINT C75 (synthetic size) 2 kg AVIROL 308AS (antistatic agents, softeners)
Sample C	500 l water + 75 l condensate 25 kg FIBROSINT C75 (synthetic size) 2 kg AVIROL 308AS (antistatic agents, softeners)

not penetrating into the yarn. Therefore, continuous use leads to the abrasion of textile materials, thus destroying the surface layer, which causes the gradual disappearance of the coated film, further leading to the loss of properties required for the application of such a fabric in actual environmental conditions [5, 6].

Each military nation adapts the look of camouflage materials (colours and patterns) to their application needs and environmental conditions in which the fabric will be used (forest, desert, ...) in order to achieve adequate camouflage properties. Camouflage properties must also cover a wide range of the electromagnetic spectrum, including ultraviolet (< 400 nm) and the visible spectrum (400 - 800 nm).

Experimental and results

In the analysis of military camouflage garment fabrics the following three groups of samples were used: sample A, sample B and sample C. Each group includes several types of samples, an analysis of which can provide an overall assessment of the finished fabrics:

- raw warp and weft yarn
- sized warp yarn
- raw fabric
- finished fabric.

The raw warp and weft yarns used for all groups of samples are a blend of cotton and polyamide 6.6 at a ratio of 50/50%. In order to achieve less deformation of warp threads in the weaving process and higher machine efficiency and to improve fabric quality, sizing was carried out according to defined conditions and recipes for the samples (***Table 1***).

Most fabrics used for this purpose were woven in simple and basic weaves: plain weave, twill, satin, rips, Panama, and combinations thereof. A sample of fabric A was woven in a combination of plain weave and rep weave, sample B - in 5-end satin, and sample C was woven in twill 2/2 (***Table 2***). Fabric samples were woven on a cam air-jet weaving machine.

After weaving, the fabric was dyed with vat dyes. After the dyeing process, the fabrics were finished with a variety of protective finishing treatments: waterproofness, water repellency, oil repellency, resistance to infrared light, UV radiation, heat, fire, soiling, anti-static treatment, etc. To test the yarn and fabric samples, standardised methods were used. Determination of yarn linear density was tested according to HRN ISO 2060:2003, and yarn hairiness was tested on the basis of registering fibres protruding from the yarn structure according to ASTM D 5674-01 on a Zweigle G 565 tester. Testing of yarn unevenness was performed using the capacitance method on a Keisokki instrument according to ISO 16549:2004, while yarn twist was tested on a MesdanLab Twist tester according to Standard ISO 17202. Breaking properties (breaking force, breaking elongation, work to rupture and yarn tensile strength) of the yarn before and after sizing were tested according to Standard ISO 2062 on a Textechno Statimat M tensile tester (***Table 3***).

Table 2. Sample weaves.

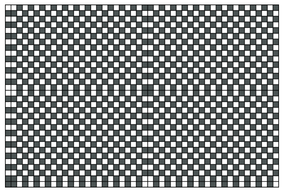
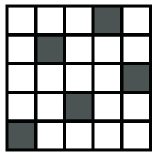
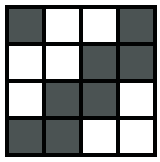
Sample	Weave
Sample A	 Plain + rep
Sample B	 5-end satin
Sample C	 Twill 2/2

Table 3. *Yarn parameters tested before and after sizing; T_t - linear density of yarn, tex Tm - yarn twist, twists/m, H - yarn hairiness, number of fibres longer than 1mm protruding from the yarn surface, U – unevenness, %, F_r - breaking force of raw yarn, εr - elongation at break of raw yarn, %, Wr - work to rupture of raw yarn, cN×cm, σr - breaking strength of raw yarn, cN/tex, F_S - breaking force of sized yarn, cN, ε_S - elongation at break of sized yarn, %, W_S – work to rupture of sized yarn, cN×cm, σ_S - breaking strength of sized yarn, cN/tex, $\overline{X}$ - mean, CV - coefficient of variation, %.*

Yarn property			Sample A		Sample B		Sample C	
			Warp	Weft	Warp	Weft	Warp	Weft
Raw	Material composition		PA 6.6/ Cotton 50/50	PA 6.6/ Cotton 50/50	PA 6.6/ Cotton 50/50	PA 6.6/ Cotton 50/50	PES/Cotton 50/50	PES/Cotton 50/50
	T_t, tex		17×2	40	30	50	20×2	20×2
	T_m, twist/m		622/938	673	678	485	557/846	557/846
	H, number of protruding fibres		1462.30	1413.30	1607.70	3057.00	681.30	681.30
	U (CV,%)		9.14	9.24	9.83	8.88	8.86	8.86
	F_r ,cN	$\overline{X}$	702.01	753.51	551.48	893.53	839.60	839.60
		CV	6.72	6.61	7.98	6.61	7.24	7.24
	ε_r, %	$\overline{X}$	14.94	14.38	14.47	17.26	9.13	9.13
		CV	11.08	17.68	21.57	6.02	7.99	7.99
	W_r, cN×cm	$\overline{X}$	3479.73	3968.50	2738.90	5516.37	2176.47	2176.47
		CV	16.41	24.44	31.70	9.64	14.63	14.63
	σ_r, cN/tex	$\overline{X}$	20.65	19.83	18.38	17.87	20.99	20.99
		CV	6.72	6.61	7.98	6.61	7.24	7.24
Sized	F_S, cN	$\overline{X}$	775.72	/	646.27	/	964.74	/
		CV	5.66		7.04		5.08	
	ε_S, %	$\overline{X}$	6.71		5.95		6.47	
		CV	34.29		23.23		28.55	
	W_S, cN×cm	$\overline{X}$	1603.76		1162.22		1221.09	
		CV	44.50		32.03		41.14	
	σ_S, cN/tex	$\overline{X}$	22.82		21.54		24.12	
		CV	5.66		7.04		5.08	

Table 4. *Fabric parameters tested before and after chemical finishing treatment; F_{rf} - breaking force of raw fabric, N, ε_{rf} - elongation at break of raw fabric, %, w - fabric width, cm, m - fabric mass per unit area, g/m^2, d - fabric density, threads/1cm, t - fabric thickness, mm, F_{ff} - breaking force of finished fabric, N, ε_{ff} - elongation at break of finished fabric, %, $\overline{X}$ - mean value, CV - coefficient of variation, %.*

Fabric			Sample A		Sample B		Sample C	
			Warp	Weft	Warp	Weft	Warp	Weft
Raw	W, cm		159		159		149	
	m, g/m^2		220		280		250	
	t, mm		0.436		0.557		0.439	
	d, threads/cm		36.0	20.7	46.7	29.1	36.2	21.0
	F_{rf}, N	$\overline{X}$	689.73	451.11	828.66	750.21	784.53	496.87
		CV	3.58	2.17	1.57	1.96	5.45	4.56
	ε_{rf}, %	$\overline{X}$	39.67	24.83	33.50	30.00	20.33	16.50
		CV	0.73	1.16	3.95	1.67	6.19	3.03
Finished	F_{ff}, N	$\overline{X}$	681.37	441.30	777.99	845.01	774.73	500.14
		CV	3.55	2.22	2.55	5.00	2.19	1.96
	ε_{ff}, %	$\overline{X}$	43.17	22.50	32.33	35.67	18.67	17.00
		CV	5.47	5.23	6.25	5.67	5.58	2.94

Table 5. *Material resistance to heat and air permeability and bursting strength.*

Fabric property	Sample A		Sample B		Sample C	
	X	CV, %	X	CV, %	X	CV, %
Resistance to heat permeability - R_{et}, m^{2}KW^{-1}	0.0185	3.9	0.0127	1.3	0.0203	2.0
Resistance to air permeability, mm/s	22.244	4.2	10.220	4.6	36.972	6.3
Ball burst strength, N	910.0	9.4	1596.6	13.2	773.0	12.1

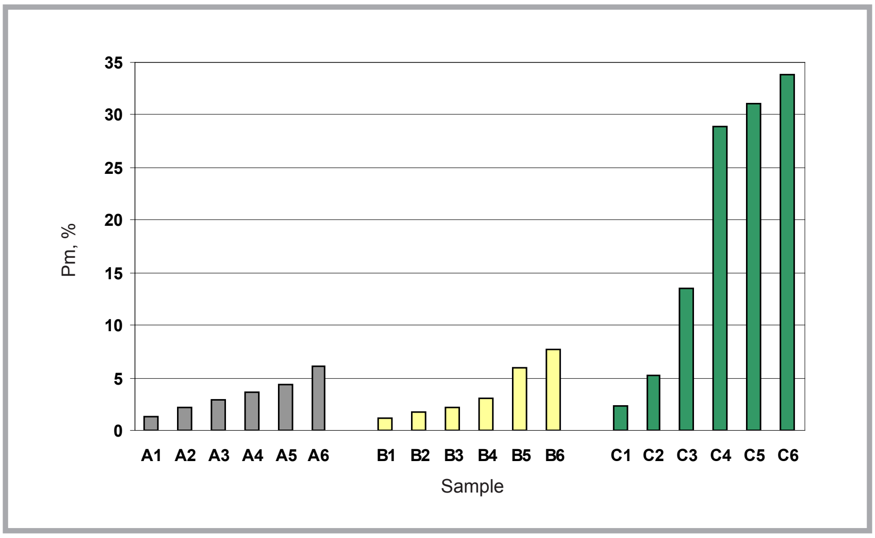


Figure 1. *Presentation of mass loss (Pm) according to 6 intervals for samples tested;* ***where****: A – sample A, B – sample B, C – sample C; 1 – 10,000, 2 – 20,000, 3 – 30,000, 4 – 40,000, 5 – 50,000, 6 - 60,000 abrasion cycles.*

The testing of basic fabric parameters was also performed. The fabric density or number of threads per length unit was determined according to Standard EN 1049-2:1993, and determination of the mass per unit area was performed according to Standard ISO 3801:1977. The breaking force and breaking elongation of the fabrics before and after treatment was tested on a Textechno Statimat M tensile tester according to Standard ISO 13934-1:1999 (***Table 4***).

One of the most important properties of technical textiles for military purposes is material resistance to heat permeability and the possibility of the free passage of water vapour (perspiration) through the material. Modern laboratory methods allow us to measure the permeability of heat and water vapour through the material and the material resistance to water vapour using a so called hot plate. The test was carried out in accordance with Standard ISO 11092:1993. The results of these tests are shown in ***Table 5***.

Also, one of the most important indicators of textile material quality and the value of the finished product is its use durability. Therefore abrasion resistance is very important for textile material used for military purposes [7]. To test the abrasion resistance of the fabrics, the Martindale method was used in accordance with Standard ISO 12947-3:1998 - Determination of mass loss was used. Testing was done according to predetermined intervals to determine the mass loss or in six intervals (10,000, 20,000, 30,000, 40,000, 50,000 and 60,000 cycles of abrasion), respectively. Mass losses were calculated for all samples according to the six intervals, shown in ***Figure 1***.

The quality of military camouflage fabric depends on the colour fastness to various influences to which this material is exposed. In addition to fastness to light, the heat, water, and colour fastness to abrasion is also very important. When evaluating colour fastness to abrasion, it is about assessing a change in colour shade that is different after use in comparison to the original one. An assessment was made with the instrumental method (which is very simple and objective, and the results are reliable) using a remission spectrophotometer, Datacolour Spectraflash PLUS-CT SF 600, the results of which are shown in the CIELab system (***Figure 2***) [8].

Discussion

Camouflage fabrics, with their multiple-use in clothing, camouflaging soldiers and military equipment, are one of the main components under war conditions. The production and structural parameters of these fabrics, their physical and mechanical properties, dyeing by means of the printing technique and chemical finishing affect the fulfillment of the numerous and high demands placed on them. For a textile material which is used for military purposes, its resistance to the variety of conditions to which the material is exposed is important.

In the weaving process, especially on air-jet looms, there are a few problems that affect the entire process of fabric manufacturing. These problems are caused by the interaction of weaving conditions and yarn properties. The shed formation, cyclic strain, and abrasion of threads with elements of the loom cause thread breakage. In order to solve these problems, the yarn used as warp yarn has to be sized, resulting in enhanced physical and mechanical properties or increased strength and reduced hairiness. This allows to reduce warp breakage, achieving a higher efficiency of weaving machines and thus increasing fabric quality.

Material resistance to heat permeability for outdoor clothing is important, especially during cold winters and hot summer days. The results of the samples tested (***Table 5***) show that sample C has the highest resistance to heat (0.0203 m^2KW^{-1}), which has plied yarn in the warp and weft. Sample B (0.0127 m^2KW^{-1}) has the lowest resistance to heat, which is to be expected because it has a single yarn in the warp and weft, being more open, thus allowing heat to pass through more easily. Moreover the fabric is woven in satin weave with greater thread floating (than in a plain, rep or twill weave), allowing greater heat permeability. Resistance to air permeability follows the course of resistance to heat permeability of the samples. Sample C has the highest resistance to air permeability (36.972 mm/s), while sample B has the lowest (10.220 mm/s). The resistance of the samples to ball bursting is contrary to these two parameters: Sample B (1596.6 N) has the highest resistance to bursting; it also has the highest breaking forces of both the raw and finished fabrics as well as of the weft, and sample C (773.2) has the lowest resistance to bursting. The test results for abrasion resistance are expressed as the mass loss after each interval or after a certain number of cycles (***Figure 1***). For sample A the linear mass loss of the samples tested, an average of 0.8%, is easily observable for each new interval, which occurred gradually by increasing the number of cycles until interval 6, when an almost double mass loss was recorded compared to the previous average loss, causing the occurrence of holes in the sample. For sample B the mass loss was recorded for each interval, an average of 0.7%, to interval 4, after which a significant drop in mass of an additional 2.9% to interval 5 was recorded, and an additional 1.6% to interval 6, which again indicates the occurrence of holes I the material. The highest mass loss per interval was recorded for sample C, or it indicated the greatest destruction of the material. Up to interval 2 the mass loss increased by 2.8% compared to interval 1, to interval 3 by another 8.4%, and to interval 4 by additional 15.3%, followed by a complete destruction of the material

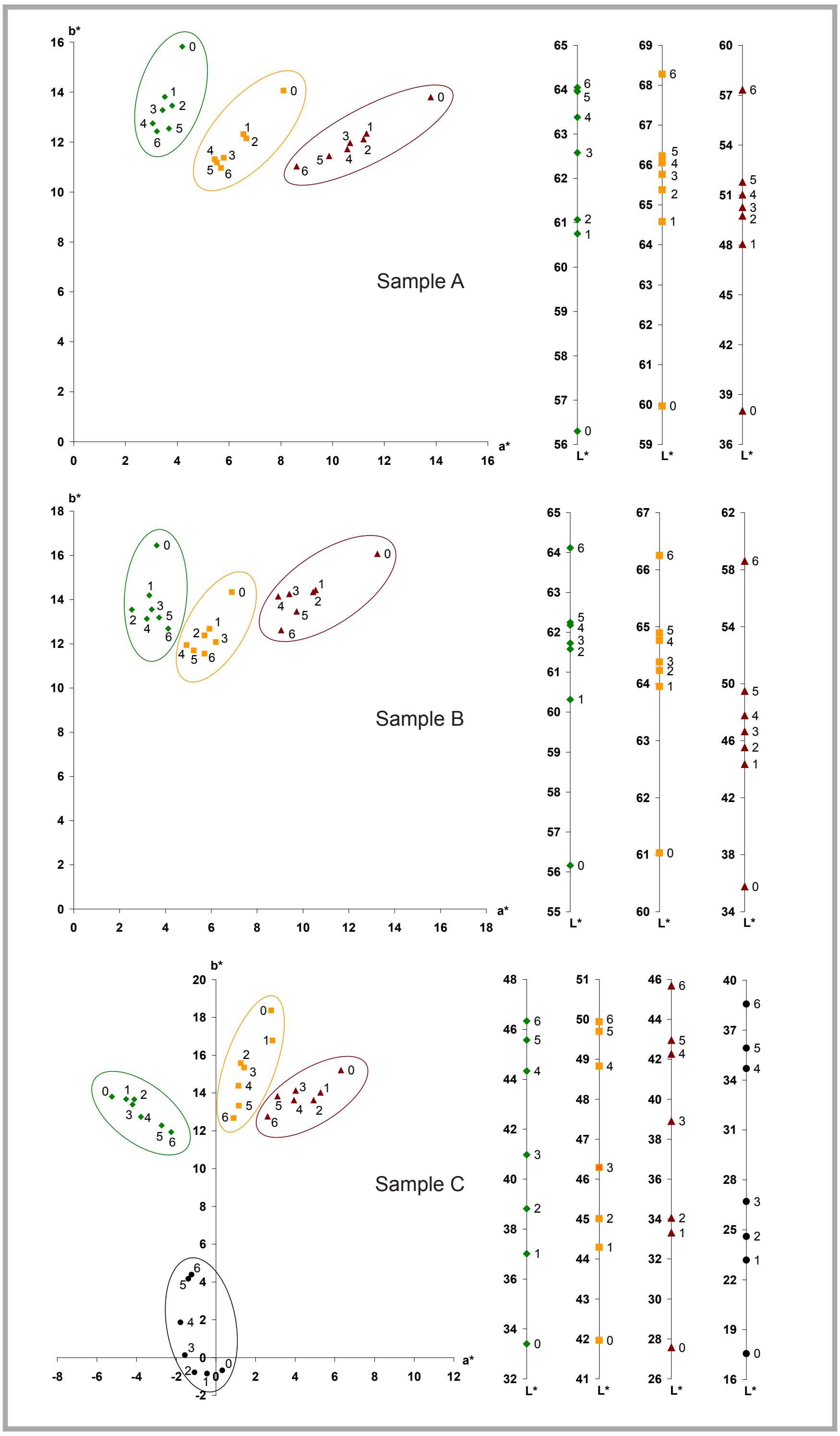


Figure 2. *Presentation of changes in the colour shade of samples A, B and C caused by abrasion; where: green marks - green on the sample, beige marks - beige on the sample, brown marks - brown on the sample, black marks - black on the sample, 0 - unabraded sample, 1 - sample after 10,000, 2 - sample after 20,000, 3 - sample after 30,000, 4 - sample after 40,000, 5 - sample after 50,000, 6 - sample after 60,000 abrasion cycles.*

surface. Further mass loss increased by only 2.5% to interval 5 and interval 6, respectively. It follows from the above that it is possible to conclude that sample C shows the lowest resistance to abrasion, when after interval 2 or 20,000 abrasion cycles the occurrence of holes on the material is possible, and to interval 4 or after 40,000 cycles, complete material destruction occurs. The parameters obtained by testing sample B indicate the occurrence of holes at interval 5 or after 50,000 abrasion cycles, which is much better compared to sample C; thus it can be concluded that the abrasion resistance of sample B is significantly higher. However, the best results of abrasion resistance in terms of the smallest mass loss and latest occurrence of holes are shown by sample A, but only at interval 6 or after 60,000 abrasion cycles.

Many parameters affect the abrasion resistance of materials: raw material composition, yarn fineness and strength, fabric density and the weave in which the fabric is woven. The samples of yarns tested consisted of a blend of natural and synthetic fibres (cotton and PA 6.6, and PES in the ratio of 50/50) in order to satisfy a wide range of requirements made on such materials. The samples of yarns tested consisted of a blend of natural and synthetic fibres (cotton and PA 6.6, and PES in the ratio of 50/50) in order to satisfythea wide range of requirements placed on such materials, from comfort and flexibility, which can be achieved using natural fibres, to durability and resistance, which can be obtained using synthetic fibres. Although PA 6.6 and PES are very similar in their properties, there is still a difference which (as seen from the test results) significantly affects the properties of the yarns and finished fabrics. Standard strength values of these fibres range from 25 - 55 cN/tex for PES and from 30 - 68 cN/tex for PA 6.6, this difference being also reflected in the strength of the yarn (***Table 3***). This difference can be associated with the fabric resistance to abrasion, where sample C, composed of a blend of cotton/PES, recorded the highest mass losses and greatest material destruction (***Figure 1***). In connection with this the phenomenon, besides the raw material composition in the yarn, several other construction fabric parameters are involved. Samples A and B, which are composed of yarns of an equal blend of cotton/PA 6.6, despite the differences in the linear density of the yarn, fabric density, mass per unit area and weave (***Tables 3*** and ***4***), give very similar results for abrasion resistance compared to sample C (***Figure 1***), which can be explained by the raw material composition of the yarns used for weaving the fabrics or by the use of the stronger PA 6.6. On the other hand, the differences in abrasion resistance and mass loss between samples A and B are explained with other structural parameters. Thus, despite a higher fabric density, higher mass per unit area, but also higher strength of sample B, it had lower abrasion resistance, higher mass loss, and an earlier occurrence of destruction after a smaller number of abrasion cycles than in the case of sample A. The reason for this phenomenon can be sought in the weave in which these fabrics were woven, which gives an advantage to sample A because it was constructed in a combination of plain and rep weave, where plain weave is characterised by its tight and dense structure and by the most frequent changes in the warp and weft interlacing points. Abrasion greatly affects the quality of the dyed sample, evaluated using the colour fastness grade. The impact of sample abrasion on colour shades present on the samples is shown in the CIELab system, being the most suitable for numerical evaluation of colours. In the coordinate system a*/b*, the position of colours and saturation (chromacity) of an individual shade at each lightness level (L*) is obtained. The remoter the position of the measured sample in the CIEL*a*b* diagram from the central point of aromaticity, the more saturated or purer the colour is. It follows from the above that according to the diagrams shown in ***Figure 2***, changes in the saturation and lightness of a certain colour shade caused by the number of abrasion cycles can be easily observed. In all samples tested, the unabraded samples were the remotest from the point of aromaticity, meaning that here the colour shades are the most saturated, as could be supposed. By means of the abrasion procedure and a gradual increase in the number of abrasion cycleces (10,000, 20,000, ...), the values of the graphs approach the point of aromaticity, which means that the chromaticity (saturation by a specific shade) gradually decreases, while the shade lightness increases. All these changes significantly affect the quality of the fabrics in terms of colour fastness.

Conclusions

The following conclusions can be drawn on the basis of the tests performed and by comparing the results presented:

The fabrics that are used for camouflage and the like are usually woven on cam looms, whereby simple basic weaves are used. Fabrics are often woven from cotton yarns or in a blend with synthetic fibres. These are often plied yarns woven with a relatively great density. In such a way a strong and compact fabric with a uniform surface suitable for applying dyes and other agents to achieve better properties is produced. The warp is sized because the yarn in the fabric should maintain the properties it possessed before weaving.

Physiological properties of these fabrics are important, especially if used for field clothing in various weather conditions. Different agents allowing air and sweat permeability, but disabling water and water vapour are applied to these fabrics. The utility value of camouflage fabrics depends on the fabric's physical and mechanical properties. Mass loss or abrasion resistance is usually the weakest link in the use of these clothing fabrics. The first fabric deformations are reflected by changing the colour shades. The CIELab system is the most suitable system for numerical evaluation of colours. The first deformations occur in the limb bends. Today, the fabrics are usually laminated with nanopur coating on the reverse side of the fabric, improving the physical-mechanical and physiological properties of composite materials.

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References

1. Horvat-Varga S. Utjecaj tehnoloških parametara u procesu visokofrekventnog spajanja odjeće, Magistarski rad, Tekstilno-tehnološki fakultet. Sveučilišta u Zagrebu, 2009.
2. Tehnički podaci tekstilne tvornice Čateks d.d., Čakovec
3. Mijović B, Skenderi Z, Salopek I. Comparison of Subjective and Objective Measurement of Sweat Transfer Rate. *Collegium antropologicum* 2009; 33, 2: 315-320.
4. Kübra Kaynak H, Topalbekiroğlu M. Influence of fabric pattern on the abrasion resistance property of woven fabrics. *Fibres & Textiles in Eastern Europe*, 2008; 16,1(66): 54-56.
5. Kovačević S, Pruss A. Utjecaj dinamičkih naprezanja u tkanju na smanjenje prekidne sile i otpornosti na habvanje osnovinih niti. *Tekstil* 2000; 49, 9: 473-477.
6. Kovačević S, Strmečki V. Nove tehnologije i novi proizvodi u području tkanja. *Tekstil* 2000; 49, 1: 21-28.
7. Friškovec M, Gabrijelčič H. Development of a procedure for camouflage pattern design. *Fibres & Textiles in Eastern Europe* 2010; 18,4(81): 68-76.
8. Parac-Osterman Đ, Joanelli M. Računalno određivanje razlike u boji i tolerancije u tekstilu. Tekstil.

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