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Assessment and Verification of the Functionality of New, Multi-Component, Camouflage Materials

Abstract
The article presents new textile structures (woven and knitted fabrics) featuring camouflage properties in visible (VIS) and near infra-red (IR) radiation bands. The textiles were designed and made for masking individuals and their personal equipment. Their design, diversified by applied yarns, weaves and way of distribution of metalised yarns on the surface of fabrics is discussed. Levels of the resulting physical, mechanical and functional parameters of woven and knitted fabrics are presented, both raw and after finishing treatment.

Key words: *woven fabric, knitted fabric, camouflage fabrics, VIS range, IR range.*

Introduction

The purpose of camouflage is preventing the detection and identification of objects, in the broad sense of the word, by misinforming, pretence and hiding. The development of modern detection means which work in a wide range of electromagnetic radiation stimulates the development of camouflage agents, including paint, screens, maquettes, and camouflage covers [1 - 4].

Recently the following trends have been observed in the field of special materials and related technologies,ncluding, inter alia, research on:
- lightweight materials providing equivalent functionality,
- materials that improve protection and survivability,
- materials that reduce detectability [5].

There are products or textile compositions featuring masking properties under visible (VIS), near infrared (IR), thermal and radar bands. They are used primarily to cover solid objects or vehicles [6 - 22]. These large and heavy structures are manufactured i.a. by the following companies: GMA Cover Corp. (USA), Heatcoat Fabrics Ltd. (UK), SAAB Group (Sweden), Fibrotex (Israel), and Miranda Ltd. (Poland) [8, 23 - 26]. Mostly they are multi-layer products with a mesh as the external one, with extra details which simulate leaves, grass, metallic foil etc., applied to hide an object by altering its signature or pretending its presence on an observed field. Due to their heavy weight they require special transportation means and, in many cases, supporting frame constructions [8, 26].

Individuals camouflage themselves mainly in the visible (VIS) and near infrared (IR) bands by using uniforms, coverlets or sheets made of special *woven* fabrics, *knitted fabrics*, nonwovens or compositions thereof [27 - 34]. Well known and recognised worldwide manufacturers of such clothing are i.a. Crye Precision LLC (USA), HyperStealth Biotechnology Corporation (Canada), SAAB GROUP (Sweden), Oztekteskil (Turkey), Special Materials Corp. (Russia), Intermat Group S.A. (Greece), and MIWO MILITARY (Poland) [6, 25, 35 - 39]. For making-up the clothing they use textiles distinguished by the marking property obtained by applying adequate yarns [40] and its distribution in the fabric [41 - 44] as well as by adequate dye and print [45 - 48].

The aim of the works was to create textile structures (woven and knitted fabrics) for camouflage applications (in VIS, IR and radar bands), simultaneously featuring anti-electrostatic properties. The properties presumed were achieved by selection of textile materials, the structure design of knitted and woven fabrics (weaves, density of thread arrangements) as well as by applying proper finishing treatment. A light-green colour was assumed as the target, which is one of the uniform colours included in the defence standard [49].

A significant impact on the camouflage properties (VIS and IR) of new textile structures, and its other parameters, including physical and mechanical properties, is the structure. Under this concept we can understand both types and compounds of yarns applied and their quantity, the distribution on the surface of the fabric and the ways of interleaving each other.

The textile structures (woven and knitted fabrics) described in the present paper incorporate the following yarns:
- Polyester filament - responsible for the appropriate level of physical and mechanical properties,
- Conductive yarns of various percentage share of metals and carbon and dyed in bulk with soot - responsible for the reemission coefficients, which determine the absorption properties within the near-infrared radiation range [40].

They were the initial material, converted into woven or knitted fabrics with various weaves, densities of thread arrangements, and distributions of particular kinds of yarns with each other and across all the fabric structure.

Afterwards they were subjected to finishing treatment – dyeing the colour chosen by the gestors: camouflage light-green. The final result of the research were new woven and knitted fabrics featuring camouflage properties in the visible (VIS), near infrared (IR) bands as well as anti-radar ones, which are defined in detail by national standardisation documents [49]. The present paper discusses work on structures which provide the two kinds of camouflage mentioned above.[1] The research works apply a third type of camouflage (anti-radar), which will be the subject of another publication.

Subject of research

The object of the study presented are multi-component textile structures (raw and after finishing treatment) featuring camouflage properties under visible light, near infrared and bands, developed and made-up during research works realised at MORATEX.

The research covered woven fabrics and knitted fabrics made with use of polyester yarns (background), polyester dyed in bulk with soot and conductive yarns of 5, 15, 20 and 30% steel (Inox®, Bekinox®), with a share of silver-coated copper wire and carbon fibre (Beltron®). When designing the woven fabrics the following assumptions were made:

- different, yet repetitive occurrence of conductive yarns in both systems (in warp and in weft),
- share of polyester yarns dyed in bulk with soot in the warp only.

A different concept was adopted when developing the *knitted fabrics*. In this case the aim was to obtain an opposite result (presumably "chaos") than for woven fabrics using polyester and conductive yarns only.

Yarns

In the process of designing the woven and knitted fabrics, application of the following types of yarns was assumed

- basic yarns
  - PES 167×2 dtex,
  - PES 84×2 dtex,
  - PES 300 dtex – all white, supplied by PPH Legs Sp. z o.o.
- conductive yarns
  - PES 167×2 dtex,
  - PES 84×2 dtex all dyed in bulk with soot, supplied by OPTEX S.A.
  - PES 85%/Steel 15%, Nm 50/2 (40 tex), made by Predilnica Litija
  - PES 80%/Steel 20%, Nm 50/1 (20 tex), made by Bekaert, Belgium
  - PES 80%/Steel 20%, Nm 50/2 (40 tex), made by Bekaert
  - PES 95%/Steel 5%, Nm 50/1 (20 tex), made by Schoeller GmbH & CoKG, Switzerland
  - PES 70%/Steel 30%, Nm 50/2 (40 tex), made by Schoeller GmbH & CoKG
  - PES 95%/Steel 5%, Nm 50/2 (40 tex), made by Schoeller GmbH & CoKG

Woven fabric

Variants of woven fabrics developed with various share of metal in the yarns and various displacement of conductive yarns are presented in ***Tables 1*** and ***2***.

Knitted fabrics

Variants of knitted fabrics developed with various share of metal in the yarns and various stitches are presented in ***Tables 3*** and ***4***.

Table 1. *Variants of the woven fabrics developed of various share of metal in yarns – the characteristics.*

Code of sample	T4	T5	T6	T7
Conductive yarns				
Warp	PES 167×2 dtex dyed in bulk with soot	PES 84×2 dtex dyed in bulk with soot		
	PES 85%/Steel 15%, Nm 50/2 (40 tex)	PES 80%/Steel 20%, Nm 50/1 (20 tex)	PES 95%/Steel 5%, Nm 50/1 (20 tex)	PES 70%/Steel 30%, Nm 50/2 (40 tex)
Weft	PES 85%/Steel 15%, Nm 50/2 (40 tex)	PES 80%/Steel 20%, Nm 50/2 (40 tex)	PES 95%/Steel 5%, Nm 50/1 (20 tex)	PES 70%/Steel 30%, Nm 50/2 (40 tex)
Weave	2/2 Z derivative of twill 1/3 Z	1/1 plane weave	2/2 Z derivative of twill 1/3 Z	1/1 plane weave
Deployment of conductive yarns (grid of size warp × weft), mm	3.2 × 3.0	2.9 × 2.8	1.4 × 1.5	2.8 × 3.0
Weave report				

Table 2. *Variants of woven fabrics developed of various displacement of conductive yarns – the characteristics.*

Code of sample	T1	T2	T3
Weave	2/1 Z twill		
Deployment of conductive yarns (grid of size warp x weft)	1.4 × 1.5	1.0 × 1.1	2.0 × 2.0
Weave report			

Table 3. *Variants of knitted fabrics developed of various share of metal in yarns – the characteristics; *) images taken with a UMO 12 Digital Microscope from Delta Optical.*

Code of sample	D 1	D 2
Conductive yarns	PES 95%/Steel 5%, Nm 50/2 (40 tex)	PES 70%/Steel 30%, Nm 50/2 (40 tex)
Type of knitted fabric	warp-knitted on the basis of weave – a tulle	
Illustrative image of knitted fabric	magnification × 20*	

Table 4. *Variants of knitted fabrics developed of various stitch; *) images taken with the UMO 12 Digital Microscope from Delta Optical.*

Code of sample	D3	D4	D5
Type of knitted fabric	mesh fabric with rectangular a-jour	mesh fabric with hexagonal a-jour	warp-knitted, based on weave – double tricot atlas
Illustrative image of knitted fabric	magnification × 15*		

Research methodologies

Laboratory evaluation of the variants of textile structure presented was conducted according to the following standards:

- for component yarns
  - linear density in tex according to Standard PN-EN ISO 2060:1997 "Textiles - Yarn from packages - Determination of linear density (mass per unit length) by the skein method",
  - breaking force in cN; elongation at break in %; tenacity in cN/tex according to Standard PN-EN ISO 2062:2010 "Textiles - Yarns from packages - Determination of single-end breaking force and elongation at break using a constant rate of extension (CRE) tester",
  - reemission coefficients according to Standard NO-84-A203:2004/A1:2010 "Provision of uniforms – Spectral characteristics of colours – Requirements and test methods."
- for raw woven/knitted fabrics
  - mass per unit area in g/m^2 according to Standard PN-ISO 3801:1993 "Textiles - Woven fabrics - Determination of mass per unit length and mass per unit area"; according to Standard PN-P-04613:1997 "Textiles - Knitted and stitch bond-

Table 5. Results of metrological tests of white polyester yarns.

Parameter/yarn designation	PES 84×2 dtex	PES 167 dtex	PES 167×2 dtex	PES 300 dtex
Material composition, %	PES – 100			
Linear density, tex	17.3 ± 0.1	17.4 ± 0.1	38.2 ± 0.3	33.7 ± 0.2
Breaking force, cN	623 ± 21	600 ± 16	1140 ± 37	1190 ± 21
Elongation at break, %	16.0 ± 1.0	19.0 ± 1.0	28.0 ± 1.0	30.0 ± 1.0
Tenacity, cN/tex	36.6	35.3	30.0	36.2

Table 6. Results of metrological tests of polyester yarns dyed in bulk with soot.

Parameter/yarn designation	PES 84×2 dtex	PES 167×2 dtex
Material composition, %	PES - 100	PES - 100
Linear density, tex	16.8 ± 0.1	40.0 ± 0.2
Breaking force, cN	517 ± 22	1180 ± 26
Elongation at break, %	20.0 ± 1.0	29.0 ± 1.0
Tenacity, cN/tex	30.4	29.6

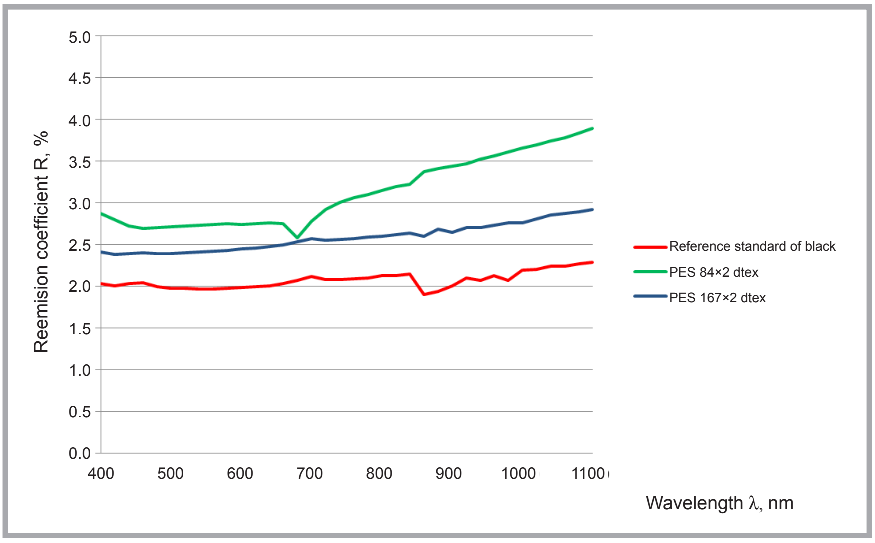

***Figure 1.** Reemission coefficients for the reference standard of black and yarns dyed in bulk with soot.*

ed fabrics - Determination of mass per unit length and mass per unit area"(knitted fabrics),

- maximum tensile force in N according to Standard PN-EN ISO 13934-1:2002 "Textiles - Tensile properties of fabrics - Part 1: Determination of maximum force and elongation at maximum force using the strip method" (woven fabrics),
- tear force strength in N according to Standard PN-EN ISO 13937-2:2002 "Textiles - Tear properties of fabrics - Part 2: Determination of tear force of trouser-shaped test specimens (Single tear method)" (woven fabrics),
- bursting strenght in N according to Standard PN-EN ISO 9073-5:2008 "Textiles - Test methods for nonwovens - Part 5: Determination of resistance to mechanical penetration (ball burst procedure)" (knitted fabrics),
  - surface resistance in Ω according to Standard PN-EN 1149-1:2008 "Protective clothing - Electrostatic properties - Part 1: Test method for measurement of surface resistivity",
  - reemission coefficients according to Standard NO-84-A203:2004/A1:2010. "Provision of uniforms – Spectral characteristics of colours – Requirements and test methods."
- for finished woven/knitted fabrics
  - surface resistance in Ω according to Standard PN-EN 1149-1:2008 "Protective clothing - Electrostatic properties - Part 1: Test method for measurement of surface resistivity",
  - reemission coefficients and CIELAB values according to Standard NO-84-A203:2004/A1:2010. "Provision of uniforms – Spectral characteristics of colours – Requirements and test methods."

Results and discussion

Both the yarns i.e. component materials of the camouflage textile structures discussed, and the variants of the structures presented (raw and finished ones) were subjected to comprehensive metrological assessment.

Average values of the results achieved are presented in ***Tables 5 - 11*** and in ***Figures 1 - 4***.

Table 5 shows characteristics of polyester yarn filament applied as the "background" for the camouflage textile structures discussed.

These yarns feature good levels of the breaking force parameter, which had an effect on the final fabrics as appropriately high strength parameters.

Moreover, in the textile structures proposed, yarns dyed in bulk with soot were applied (woven fabrics), the properties of which are shown in ***Table 6***.

Due to the fact that all textile raw materials absorb radiation of the near infrared range to a small degree, around 10 - 20%, therefore their reemission coefficient is within the range of 80 - 90%. Upon dyeing them with most dyes dedicated for textile purposes, the reemission coefficients remain practically constant, which means that neither the polyester fibre nor disperse pigments used for dyeing them absorb infrared radiation at the reemission coefficients required in our country. Therefore one of the methods to achieve the coefficients is to introduce to the fibre the additions able to absorb infrared radiation massively, such as soot. Soot absorbs 98% of the infrared radiation because it is the substance closest to the "perfect black body", which absorbs all the radiation range shed on it [50, 51].

Laboratory studies have shown that the values of remission coefficients for yarns PES 84×2 dtex and PES 167×2 dtex (***Figure 1***) are in the range 2.5 - 4%, which puts them at a level very close to the reference standard of black, which was PES yarn dyed with the pigment Black 7 (soot) in this research work.

The second kind of conductive yarns applied to the textile structures developed (woven fabrics and knitted fabrics) were metallised yarns. Their presence in the structures discussed was a result of an-

Table 7. Results of metrological tests of conductive yarns.

Parameter/yarn designation	Product no. 53978 Nm 50/1 (20 tex)	Product no. 53933 Nm 50/2 (40 tex)	Product no. 53934 Nm 50/2 (40 tex)	Bekinox BK Nm 50/2 (40 tex)	Mixed yarn Nm 50/2 (40 tex)
Material composition, %	PES – 95, Steel – 5		PES – 70, Steel – 30	PES – 80, Steel – 20	PES – 85, Steel – 15
Linear density, tex	20.0 ± 0.4	40.1 ± 0.3	40.4 ± 0.5	41.0 ± 0.2	40.1 ± 0.2
Breaking force, cN	422 ± 24	947 ± 34	706 ± 30	1010 ± 38	482 ± 18
Elongation at break, %	19.0 ± 1.0	19.0 ± 1.0	17.0 ± 1.0	14.0 ± 1.0	8.5 ± 1.0
Tenacity, cN/tex	21.1	23.7	17.6	24.5	20.6

Table 8. Results of metrological tests of raw woven fabrics.

Parameter	T1	T2	T3	T4	T5	T6	T7
Mass per unit area, g/m^2	125 ± 1	135 ± 1	125 ± 1	251 ± 2	130 ± 1	131 ± 1	145 ± 1
Maximum tensile force, N							
– warp	1200 ± 18	1100 ± 30	1200 ± 27	2000 ± 46	1100 ± 40	1200 ± 20	1200 ± 14
– weft	800 ± 19	820 ± 44	810 ± 31	1000 ± 24	800 ± 11	870 ± 27	920 ± 13
Elongation, %							
– warp	28.0 ± 1	28.0 ± 1	29.0 ± 1	49.0 ± 1	29.0 ± 1	25.5 ± 1	36.5 ± 1
– weft	24.0 ± 1	25.5 ± 1	25.0 ± 1	29.0 ± 1	19.0 ± 1	26.5 ± 1	24.0 ± 1
Tear force strength, N							
– warp	54 ± 1	47 ± 2	53 ± 1	98 ± 4	34 ± 2	57 ± 3	35 ± 1
– weft	50 ± 4	47 ± 1	50 ± 2	86 ± 2	35 ± 1	52 ± 1	37 ± 2
Surface resistance, Ω	$< 2\times10^3$						

other camouflage property i.e. anti-radar camouflage, which will be the subject of a separate publication. Therefore on the basis of data presented in ***Table 7***, one might analyse their basic parameters, impacting the properties of final fabrics.

It should be emphasised that the proper selection of conductive yarn share in the raw (undyed) textile structures achieved an initial remission coefficient of approximately 50%, which was related to the raw grey colour of yarns resulting from the percentage of metal in it.

The following textile structures were generated of the three types of yarns described above:

- woven fabrics of PES white, PES black dyed in bulk with soot and conductive yarns, (***Table 8***),
- knitted fabrics of PES white and conductive yarns (***Table 9***).

Data presented in ***Table 8*** show that the raw woven fabrics discussed feature similar-range area densities (125 - 145 g/m^2). The only outstanding variant is T4 of a mass per unit area of 251 g/m^2, with its other mechanical parameters also being high. At this stage of analysis no significant effect of the weave (1/1, 2/2Z, 2/1Z) on the basic properties of the woven fabrics was observed.

However, it was determined, that all woven fabrics discussed have an additional feature, which is low surface resistance ($< 2\times10^3$), and thus they may find application among protective clothing capable of dissipating electrostatic charge .

The values of test results of the raw textile knitted structures presented in ***Table 9*** allow to conclude that:

- application of yarns with a higher percentage of steel, with the same weave (knitted fabric D1 and D2) and similar mass per unit area decreases the value of bursting strength by about 20%, which was observed for the variant containing 30% steel,
- modification of the structure of knitted fabric using the same materials (knitted fabrics D3, D4 and D5) gives the effect of changes in bursting strength. In terms of mechanical parameters, knitted fabric D5 is the best,
- all knitted fabrics, as discussed earlier for woven fabric, have a surface resistance at a level of $< 2\times10^3$ Ω, which qualifies them also for application in protective clothing capable of dissipating electrostatic charge.

Table 9. Results of metrological tests of raw knitted fabrics.

Parameter	D1	D2	D3	D4	D5
Mass per unit area, g/m^2	120 ± 1	122 ± 1	130 ± 1	125 ± 1	127 ± 2
Bursting strength, N	510 ± 20	400 ± 20	238 ± 17	235 ± 11	355 ± 23
Surface resistance, Ω	$< 2\times10^3$				

In order to confirm the camouflage properties of the raw textile structures, the reemission coefficients were determined. It should be noted that with raw fabrics it is impossible within the visible light band to obtain the correct result i.e. located in the full spectral characteristics. Therefore the results obtained were subjected to analysis within the near infrared range i.e. 700 - 1100 nm.

Figure 2 shows remission coefficients of the face of these woven fabrics.

The studies confirmed that for all variants of woven fabrics a share of black yarns dyed in bulk with soot and of conductive yarns (containing 5, 15, 20 and 30% steel) giving a grey colour to woven fabric effectively lowered their reemission coefficients in the near infrared (700 - 1100 nm) to a level ranging within the limits prescribed.

Figure 3 shows values of reemission coefficients of the face of the knitted fabrics produced.

The courses of reemission curves (***Figure 3***) allow to state that all the raw knitted fabrics have reemission coefficients in the near-infrared band within the range of 40 - 65% (ie. they fit within the area between upper and lower limits). These are structures with various shares of steel: 5 and 30% steel content in the component yarn.

The next stage of works aimed at achieving camouflage properties under visible light was to complete the finishing treatment of the raw fabrics.

The newly developed raw fabrics, both woven and knitted ones, were subjected to the process of dyeing with selected and properly composed suspension dyes in order to achieve a light-green colour, defined by the L, a, b colour coordinates, included in the defence standard [49]. Selection of uniformed dyeing in this particular colour allows to apply the knitted and woven fabrics developed in a broader range of camouflage products, compared to dyeing in other uniformed colours defined in the standard [49] i.e. black and white.

Additionally the woven fabrics were treated to give them water- oil- and dirt-resistance. As the data gathered in ***Table 10*** show, such treatment had an impact on the reduction (acceptable) in their physical and mechanical parameters, especially the tear force strength.

Concerning knitted fabrics, the dyeing process did not significantly affect the level of strength parameters, while the mass per unit area of the structures discussed increased, as expected (***Table 11***).

According to the assumptions, the final fabrics developed should have camouflage properties under both visible and radar bands. Therefore tests of these properties were carried out in parallel due to their tight connection, which was a key factor when choosing optimal variants of the structures.

Figure 4 (see page 78) shows the reemission coefficients for selected optimal textile structures (woven fabric T6 and knitted fabrics D4). Such a selection was made in recognition of their best anti-radar camouflage properties, which will be the subject of a separate publication, as was previously mentioned.

According to the requirements of Standard [49], except the reemission coefficients, the parameter that determines camouflage under visible light (VIS) is the acceptable value of colour difference ΔE^*_{ab}. This difference is calculated on the basis of the size of L*, a*, b* values assessed for the fabric tested and for the standard specified in Standard [49].

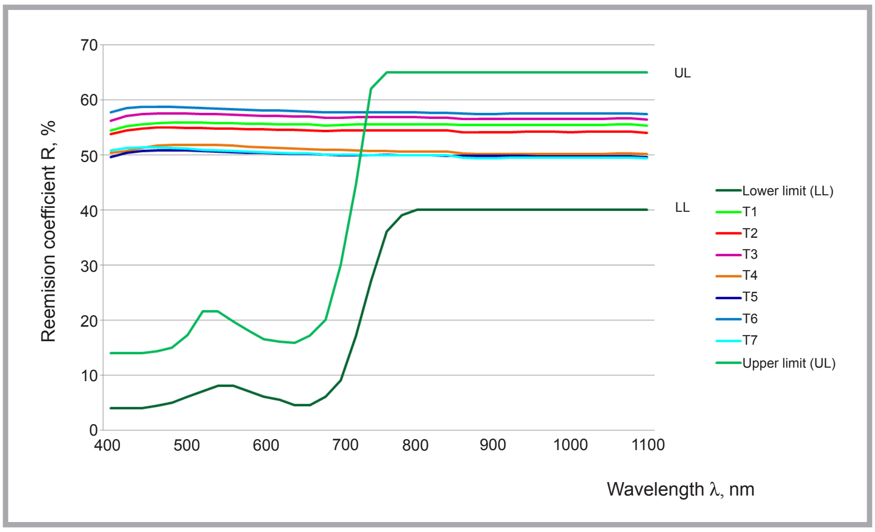

Figure 2. *Reemission coefficients of raw woven fabrics.*

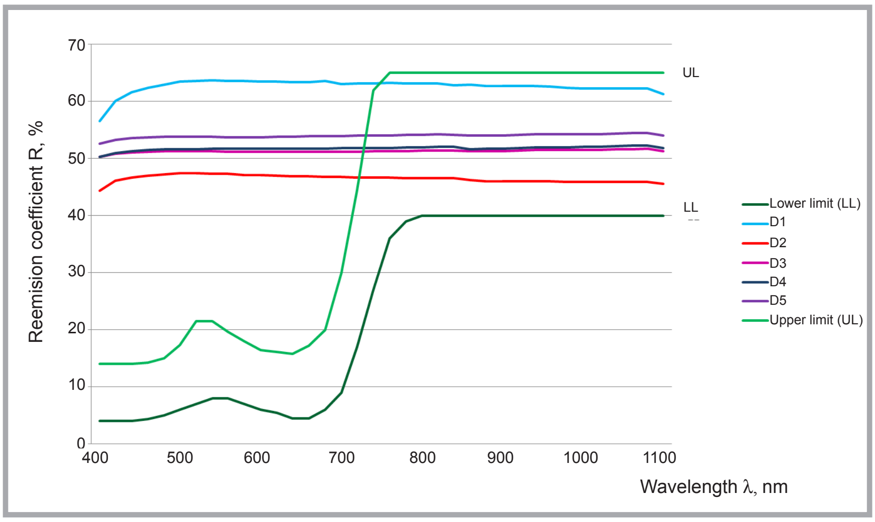

Figure 3. *Reemission coefficients of raw knitted fabrics.*

Table 10. *Results of metrological tests of finished woven fabrics.*

Parameter	T1	T2	T3	T4	T5	T6	T7
Mass per unit area,	130 ± 1	137 ± 1	123 ± 1	266 ± 2	138 ± 1	136 ± 1	162 ± 1
Maximum tensile force, N - warp - weft	 1220 ± 18 730 ± 18	 1160 ± 30 782 ± 44	 1210 ± 27 7740 ± 19	 2080 ± 46 935 ± 23	 1115 ± 40 722 ± 10	 1250 ± 20 750 ± 15	 1273 ± 14 868 ± 12
Elongation, % - warp - weft	 26.0 ± 1 23.0 ± 1	 27.0 ± 1 24.5 ± 1	 29.0 ± 1 26.5 ± 1	 43.0 ± 1 29.0 ± 1	 31.0 ± 1 22.0 ± 1	 28.5 ± 1 22.0 ± 1	 34.5 ± 1 26.0 ± 1
Tear force strength, N - warp - weft	 34 ± 1 30 ± 4	 28 ± 2 28 ± 1	 31 ± 1 27 ± 2	 72 ± 4 66 ± 2	 22 ± 2 17 ± 1	 39 ± 2 38 ± 1	 18 ± 1 18 ± 2
Surface resistance	$< 2\times10^{3}$						

Table 12 (see page 78) presents the results of testing the characteristics of the report of the light green colour for selected optimal structures. The results show that the colour reports are compliant with the requirements included in Standard [49].

The analysis of tests results of the woven and knitted fabrics developed confirms the validity of the assumptions concerning:

- application of the basic and conductive yarns,
- development of woven and knitted structures,
- proper selection and quantitative match of dye agents.

Table 11. Results of metrological tests of finished knitted fabrics.

Parameter	D1	D2	D3	D4	D5
Mass per unit area, g/m2	133 ± 3	141 ± 3	146 ± 2	138 ± 4	135 ± 2
Bursting strength, N	540 ± 20	428 ± 21	259 ± 16	261 ± 24	370 ± 25
Surface resistance, Ω	< 2×10³				

Table 12. Characteristics of colour report of woven and knitted fabric dyed light green.

Colour	CIELab values			Acceptable values of ΔE^*_{ab}
	L*	a*	b*	
	CIELab unit			
Standard	35.17	0.40	11.76	1.5
Knitted fabric D4	36.38	0.09	12.63	1.5
Woven fabric T6	35.35	-0.12	11.92	0.7

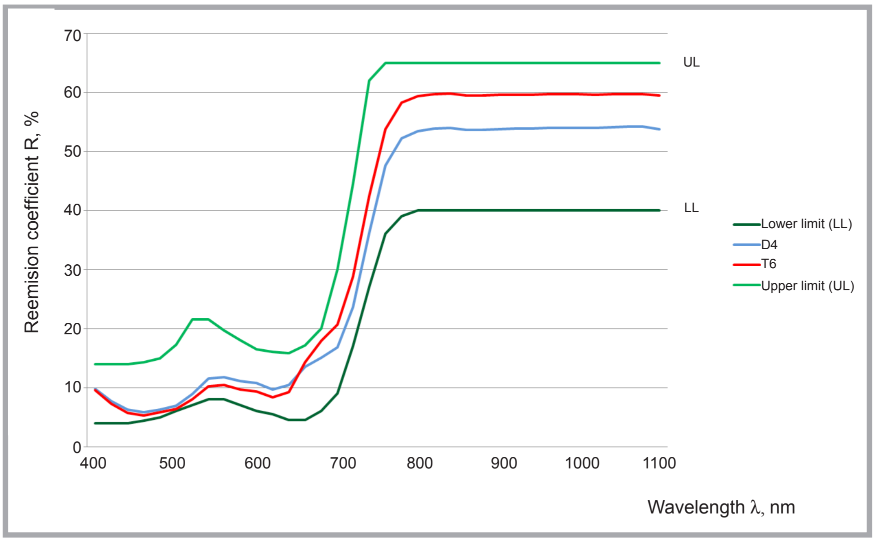

Figure 4. Reemission coefficients of representatives of woven and knitted fabrics after finishing.

As a result, at a pilot-scale the woven and knitted fabrics were successfully created, which feature camouflage properties in both visible (VIS) and near infrared (IR) bands, simultaneously capable of protecting against the adverse impact of an electromagnetic field. Woven fabric T6 and knitted fabric D4 proved to have the best camouflage properties in the optical band.

Conclusions

1. The following factors have an impact on the level of reemission coefficient in the near-infrared band (IR) i.e. 700 - 1100nm, required by Standard [49] for woven and knitted raw fabrics:
   - presence of yarns dyed in bulk with soot,
   - presence of conductive yarns,
   - structure of textile fabrics i.e. knitted and woven fabrics subjected to analysis (application for protection at Patent Office of RP no. W 120169, P-396078)
2. Raw textile structures subjected to the finishing process – dyeing a light green camouflage colour, with selected, dedicated compositions of dyes (the subject of application for protection at the Patent Office of RP) feature a reemission coefficient (gained at the raw stage) and colour factor (gained after finishing treatment) for the VIS range, ie. 400 - 700 nm at the level required.
3. When finished all woven and knitted fabrics discussed meet Polish requirements for camouflage in the visible (VIS) and near-infrared (IR) bands, ie. a wavelength within the range of 400 - 1100 nm. The authors of the paper recommend woven fabric T6 and knitted fabric D4 due to their best anti-radar masking abilities, which are not discussed in the present publication.
4. The use of conductive yarns gave an additional feature to both knitted and woven fabrics, which is antielectrostatic properties. Therefore they may be applied in protective clothing compliant with the requirements of Standard PN-EN 1149-1:2008.
5. The analysis of anti-radar properties of the woven and knitted fabrics developed will complement the research works developed above, as a subsequent, separate publication.

Editorial note

1. *The paper was elaborated within the frame of Key Project POIG.01.03.01-00-006/08 co-funded from the funds of European Regional Development Fund within the frame of Innovative Economy Operational Programme.*
2. *Metrological research on yarns, woven and knitted fabrics were performed at the accredited Laboratory of Metrology at the Institute of Security Technologies "MORATEX" in Lodz, POLAND.*
3. *Research on the remission coefficients and colour coordinates of yarns, woven and knitted fabrics were performed at the Institute of Leather Industry in Lodz, POLAND.*

References

1. Hurnik P. Masking the forces, capabilities and needs. In: WITI, Warsaw 10.1994: 6-28.
2. Norma PN-V-01005:2000. Masking the land troops directly. Masking people, equipment and objects. Terminology.
3. The PN-O-13-001:1995 Standard, The Infrared technology. Terminology.
4. Pielużek A. Masking and reconnaissance in the visible, thermal and radar bands. In: WITI Seminar, Warsaw 10.1994: 29-49.
5. Collective work ed. by Mierczyk Z. Modern technologies of weapons systems. Publisher: WAT 2008: 694-705.
6. www.intermatgroup.com (accessed: 23.10.2009).
7. www.intermatstealth.com/intermatstealth.html (accessed 23.10.2009).
8. www.miranda.pl (accessed 23.10.2009).
9. www.gmacover.com (accessed 23.10.2009).
10. www.eccosorb.com (accessed 23.10.2009).
11. Patent WO 2008060251, Multispectral Camouflage Net.
12. Patent JP 2006308258, Camouflage Material and Camouflage Product.
13. Patent US 5798304, Camouflage fabric.
14. Patent EP 0633447, Camouflage device.
15. Patent JP 3028697, Camouflage material.

16. Patent US 4767649, Broad spectrum camouflage mat and screen
17. Patent DE 3135586, Camouflage device on vehicle to prevent detection
18. Patent US 4479994, Camouflage Blanket
19. Patent EPO 945698, Multispectral Camouflage Device For Exhaust Fumes of a Military Vehicle
20. Patent FR 2716962, Decoy E.G. of a Combat Vehicle
21. Patent US 4287243, Mat for Multispectral Camouflage of Objects and Permanent Construction
22. Patent DE 2006013405, Camouflage Material for Camouflaging Mobile Vehicles
23. http://www.gmacover.com (accessed 25.06.2012).
24. http://www.heathcoat.co.uk (accessed 25.06.2012).
25. http://www.saabgroup.com/en/About-Saab/Company (accessed 25.06.2012). profile/Organisation/Security-and-Defence-Solutions (accessed 25.06.2012).
26. http://www.fibrotex.net/mobile.asp (accessed 25.06.2012).
27. Patent JP 2006308258, Camouflage Material and Camouflage Product
28. Patent JP 2006300480, Far Infrared Camouflage Material and Far Infrared Camouflage Clothes Using It
29. Patent EP 0816793, Personal Protection Liner For Infantry
30. Patent JP 8014799, Camouflaged Sheet, camouflaged Clothes And Camouflaged Tent
31. Patent WO 9508435, Infrared Camouflage Covering
32. Patent CA 1225239, Camouflage System
33. Patent KR 920004614, Camouflage
34. Patent RU 2129173, Protective Cloth
35. http://www.cryeprecision.com (accessed 15.06.2012)
36. http://www.hyperstealth.com (accessed 15.06.2012).
37. http://oztektekstil.com.tr (accessed 15.06.2012).
38. http://miwomilitary.pl (accessed 15.06.2012).
39. http://npo-sm.ru/english/fontan.php (accessed 15.06.2012).
40. Redlich G, Obersztyn E, Fortuniak K, Król I, Maklewska E, Olejnik M, Bartczak A. Electro-conductive raw materials in highly specialised products. Technical Textiles no. 3-4/2010:12-18.
41. Patent WO 2007069803. Camouflage Textile With Non-Electrolytic Plated Fibre.
42. Patent DE 202004012271. Tarpaulin For Camouflaging Objects And Persons Comprises A Textile Top Layer With Camouflage Printing, An At Least Approximately Opaque Membrane, And A Woven Or Knitted Layer.
43. Patent WO 03045685. Camouflage.
44. Patent EP 1033550. Camouflage material.
45. Kovacevic S, Gudlin Schwarz I, Duracevic V. Analysis Of Printed Fabrics for Military Camouflage Clothing. FIBRES & TEXTILES in Eastern Europe 2012; 20, 3(92): 82-86.
46. Friskovec M, Gabrijelcic H. Development of a Procedure for Camouflage Pattern Design. *FIBRES & TEXTILES in Eastern Europe* 2010; 18, 4(81): 68-76.
47. Patent WO 2007070539, Novel Dyed fabric With Visible And Near Ir Differential Signature.
48. Patent US 6127022, Deception method and product.
49. NO-84-A203:2004/A1:2010. Provision of uniforms – Spectral characteristics of colours – Requirements and test methods.
50. Krzysztofik I, Osiecki JW. Detection and tracking of targets. Kielce University of Technology Publishing House, Kielce 2008: 83-90.
51. Więcek B, De Mey G. IR thermal vision. Fundamentals and applications.

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