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Performance tests of paint coatings used for masking armaments and military equipment

Norbert Radek

norrad@tu.kielce.pl | https://orcid.org/0000-0002-1587-1074

Mechatronics and Mechanical Engineering, Kielce University of Technology

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Abstract

The paper presents an analysis of the operational properties of paint coatings for use in military technology in the field of masking. The assessment of the properties was performed on the basis of measurements of the surface geometric structure and adhesion using the peel method. The measurements of specular gloss, colour in the range of 400-700 nm and reflectance in the range of 350-1200 nm were made in relation to the requirements of the Polish Defence Standard NO-80-A200. Coating systems are characterised by their low roughness and good adhesion. Due to their operational properties, the developed coating systems can be used on armaments and military equipment.

Keywords: coating, functional properties, armaments and military equipment

1. Introduction

From the beginning of civilisation, people have been fighting among themselves between different tribes, groups, states and alliances and they continue to do so now and in the future. One of the effective methods of achieving an advantage over the opponent in offensive and defensive actions is masking (Sanecki 1979; Sanecki 1981; Mroczek 1984; Wysocki et al. 2020). By definition, masking is a type of security for combat operations and consists in hiding forces and resources to avoid recognition by the enemy or misleading them about the location of troops. Masking is a broad concept and depending on the scope of tasks and the level of command, it may include the strategic, operational or tactical level.

The production of protective coatings on machine parts is economically justified when their parts or surface layer is worn out and when different characteristics are required from the surface layer than from the core. Currently, there is a focus on various surface engineering technolgies in the devlopment of coatings (Kotnarowska 2010; Pasieczyński et al. 2018) with a particular emphasis on coatings produced by beam technologies using concentrated energy streams (Radek et al. 2018).

The subject of this paper relates to direct camouflage, and in particular camouflage painting (permanent coating systems), which alongside ad hoc measures such as the application of leaves, branches and camouflage coverings (camouflage nets) forms the basis of modern camouflage. It is one of the cheaper and more effective way of concealing one's own forces from the enemy and thus gaining a strategic advantage in terms of both defence and attack. The main task of effective camouflage is to eliminate revealing features (Dojlitko 2015), i.e. those that enable one's own objects to be distinguished from the background terrain and these may include colour, shape, size, gloss and texture (Yang et al. 2023). On the modern battlefield, an increase in the use of multispectral sensors has been observed which enables reconnaissance in many ranges of electromagnetic radiation, but the human eye still remains the basic observation "instrument", where the visible range is assumed to be from 400 nm to 700 nm.

Military equipment is subjected to many forms of operational exposure during its service life. The main forms of exposure include:

- the impact of atmospheric conditions such as solar radiation, which includes ultraviolet radiation and has a particularly negative effect on the camouflage coating;
- rainfall;
- cyclic condensation on the surface causing penetration of the coating;
- operation across a wide temperature range from -60°C to +70°C;
- exposure to a wide range of operating media such as diesel, unleaded petrol and petroleum-based lubricants;
- exposure resulting from the type of operation of military equipment, which include decontamination measures;
- possibility of the coating being scratched.

2. Experimental procedure

Specimens were prepared from DC01 steel with a thickness of 3 mm which were then ground with P80-grit sandpaper. On such prepared samples, epoxy primer BP450-1000, which is a component of the set of special paints, was applied with a dry film thickness of 60 μm ±10 μm. After four hours, special paints BW400-6031 (green), BW400-8027 (brown), BW400-9021 (black) were then applied in two layers at room temperature. The dry film thickness of the special paints was 60 μm ± 10 μm. The application of both the primer and the special paints was performed with a conventional pneumatic gun. Such prepared samples were aged for 21 days at 23°C ± 1°C and a relative humidity level of 50% ± 5%.

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After the required curing time, samples were tested for selected properties according to the applicable standards. Measurements were performed for the following parameters: surface geometric structure, adhesion (by pull-off test), gloss, colour and reflectance.

Measurements of surface geometric structure (SGS) were conducted at the Laboratory of Computer Measurements of Geometric Quantities of the Kielce University of Technology. The tests were performed using a Talysurf CCI optical profilometer using the coherent correlation interferometry method, enabling a resolution of 0.01 nm with a Z axis. The measurement result was recorded in a matrix of 1024 x 1024 measuring points using the x10 lens, which gave a measured area of 1.65 mm x 1.65 mm and a horizontal resolution of 1.65 mm x 1.65 mm.

The pull-off measurements were conducted using the manual PosiTest AT pull-off device (DeFelsko Corporation). The abrasive blasted steel substrate (thickness of 3 mm) with a camouflage coating system were tested. The measurements involved bonding a standardised dolly to the surface of the coating system using epoxy adhesive. After 48 hours, the excess glue surrounding the dolly was removed, the dolly break was performed and the tensile stress value was read.

The measurements of colour parameters were conducted using Minolta Spectrophotometer CM-700d (Konica Minolta).

Gloss measurements were taken using a Byk micro-Tri-gloss (BYK-Gardner) fitted with a polished black glass as the working measurement standard.

The spectral characteristics of the reflected radiation (reflectance) were performed with a Jasco V-770 spectrophotometer (Jasco) at the following measurement parameters: measuring range 350-1200 nm, measurement every 0.2 nm.

3. Results and discussion

3.1. Measurements of the surface geometric structure

Ten measurements were made on samples of the camouflage coating system and DC01 steel, which allowed the results to be averaged. The obtained images of surface stereometry and their analysis using the TalyMap Platinium software enabled the evaluation of the geometrical structure of the examined surfaces.

Figure 1 shows a sample isometric roughness of the surface of the camouflage coating system, while Figure 2 shows the isometric view of the roughness surface of DC01 steel. Table 1 summarises the most important SGS parameters of the tested camouflage coating systems.

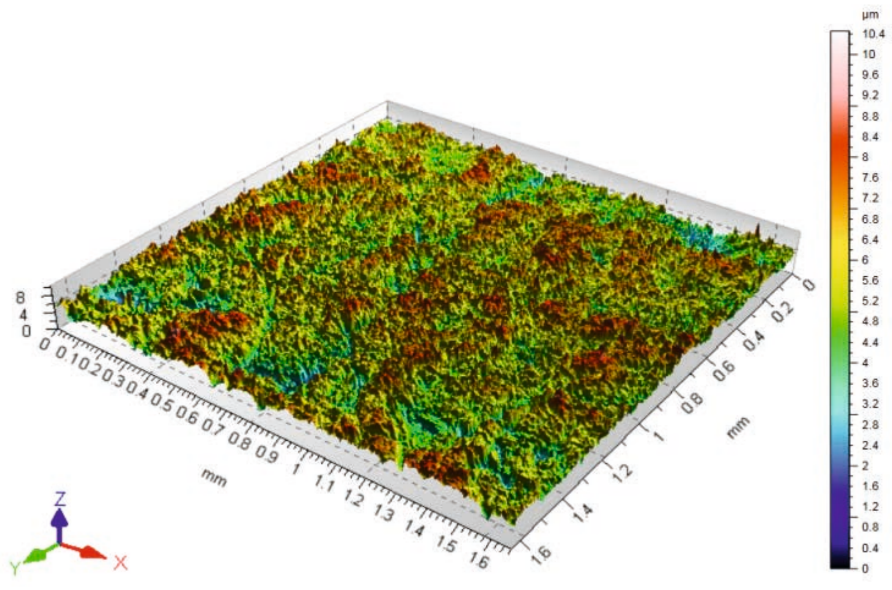

Fig. 1. Isometric view of the S-L surface (roughness) of the camouflage coating system (own elaboration)

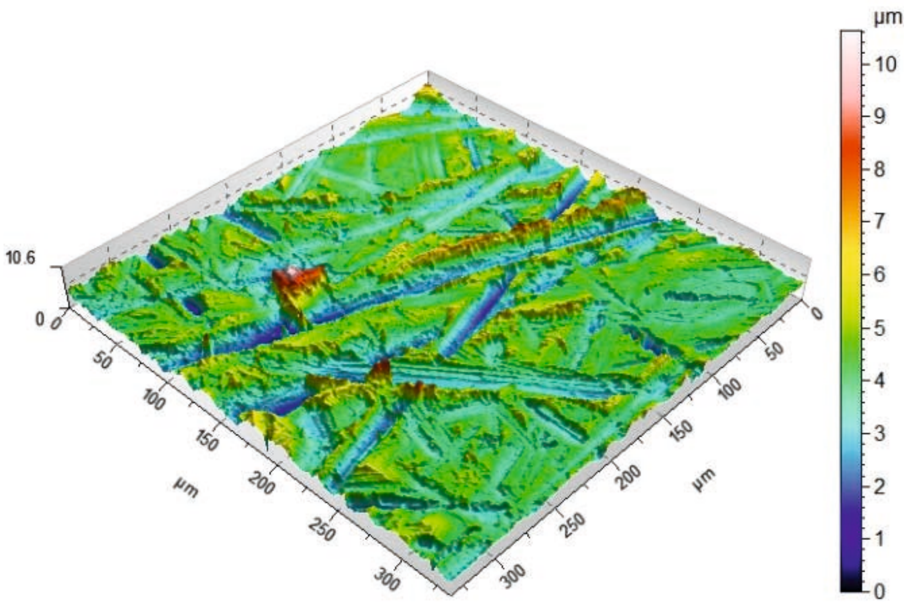

Fig. 2. Isometric view of the S-L surface (roughness) of DC01 steel (own elaboration)

The tested camouflage coating system had averaged mean arithmetic surface roughness deviations from the average surface area of *Sa* = 2.6–2.9 µm. Samples of DC01 steel, after grinding with P80-grit sandpaper on which the coatings were applied, had *Sa* = 1.9–2.3 µm. The *Sa* parameter is the basic amplitude parameter for quantifying the state of the surface being analysed. A similar trend in the measurement of the camouflage coating system and DC01 steel was observed for the quadratic surface roughness *Sq*, which has a strong correlation with the *Sa* parameter. As a result of the application of the coating, the surface roughness slightly increased.

Table 1. Averaged parameters of the surface geometric structure

SGS parameters	DC01 steel	Camouflage coating system
Sq [µm]	2.8	3.6
Ssk	0.14	-0.4
Sku	4.7	3.3
Sp [µm]	10.6	12.2
Sv [µm]	16.9	18.5
Sz [µm]	23.3	30.6
Sa [µm]	2.1	2.8

As a result of the tests simulating operational exposures, the SGS parameters of masking coating systems increased from about 20% to 30%. The varnish coating systems had a value of *Sa* = 3.13–3.78 µm.

3.2. Pull-off test for adhesion measurement

In order to determine the degree of adhesion of individual layers of the coatings to each other and to the metal surfaces, an pull-off test was performed. The test determined the tensile strength which must be impacted to the camouflage coating system in order to cause rupture of the coating in a direction perpendicular to the substrate. Table 2 shows the pull-off adhesion results according to PN-EN ISO 4624, while Figure 3 shows the surface of the samples and the surface of the dolly.

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Fig. 3. Example view of sample and dolly after pull-off adhesion test (own elaboration)

Table 2. Pull-off test results according to PN-EN ISO 4624

Camouflage coating system	Adhesion [MPa]	Adhesion average value [MPa]	Standard deviation [MPa]	Nature of the fracture
BP450-1000 (primer) BW400-6031 (top coat)	7.94	7.43	0.77	100% cohesive failure of BP450-1000
	6.23			
	7.18			
	6.74			
	8.17			
	7.66			

Based on the obtained results, it can be concluded that the camouflage coating system has very good adhesion to the substrate (Fig. 3). The fracture was a cohesive failure of the BP450-1000 primer layer and the mean tensile stress oscillated at around 7 MPa (Table 2).

3.3. Colour measurements

Colour measurements were conducted with measurement parameters of d/8, SCI and 10°. The colour difference ΔE* was determined by measuring the samples before and after the temperature exposure. The results are summarised in Tables 3-5 and in Figure 4-6.

Table 3. Colour parameters for BW400-6031 (green)

BW400-6031 (green)	90°C	110°C	130°C	150°C	170°C	190°C	210°C	230°C	250°C
L*	34.72	34.69	35.15	35.20	35.07	35.69	36.09	35.27	35.12
a*	-5.53	-5.49	-5.26	-5.17	-5.38	-5.40	-5.52	-4.15	-2.72
b*	6.13	6.22	5.55	5.71	5.91	5.94	6.51	7.05	6.83
ΔE*	**0.38**	**0.61**	**0.16**	**0.55**	**0.72**	**0.94**	**1.68**	**1.74**	**2.86**
ΔE* in reference to NO-80-A200	**0.82**	**0.89**	**0.12**	**0.16**	**0.44**	**0.69**	**1.38**	**1.79**	**2.73**

Table 4. Colour parameters for BW400-8027 (brown)

BW400-8027 (brown)	90°C	110°C	130°C	150°C	170°C	190°C	210°C	230°C	250°C
L*	46.06	46.05	45.99	45.93	45.90	45.88	45.77	44.90	44.67
a*	3.48	3.47	3.50	3.51	3.57	3.67	3.84	4.33	5.17
b*	10.76	10.77	10.87	10.90	11.05	11.15	11.23	11.47	11.50
ΔE*	**0.17**	**0.15**	**0.21**	**0.18**	**0.21**	**0.39**	**0.61**	**1.12**	**2.18**
ΔE* in reference to NO-80-A200	**0.98**	**0.97**	**0.93**	**0.88**	**0.89**	**0.92**	**0.90**	**1.08**	**1.79**

Table 5. Colour parameters for BW400-9021 (black)

BW400-9021 (black)	90°C	110°C	130°C	150°C	170°C	190°C	210°C	230°C	250°C
L*	24.48	23.58	24.41	24.46	22.43	23.55	22.73	23.28	23.56
a*	-0.02	-0.10	-0.07	-0.09	-0.11	-0.04	-0.08	-0.10	-0.13
b*	-0.40	-0.51	-0.47	-0.51	-0.50	-0.47	-0.45	-0.47	-0.39
ΔE*	**0.10**	**0.19**	**0.33**	**0.17**	**0.10**	**0.09**	**0.04**	**0.15**	**0.20**
ΔE* in reference to NO-80-A200	**0.90**	**0.53**	**0.88**	**0.94**	**1.34**	**0.49**	**1.05**	**0.62**	**0.43**

The analysis of the obtained results shows that in the case of the camouflage coating system with green paint, up to a temperature of 190°C, the colour change is small and equal to ΔE* = 0.94 at 190°C. At higher temperatures, the colour of the coating becomes more yellow and red and the change increases to ΔE* = 2.86 at 250°C.

For a camouflage coating system with brown paint, the colour changes slightly towards yellow. Above 210°C, the colour becomes more red and the colour change parameter ΔE* increases to 2.18 at 250°C.

The camouflage coating system with black paint does not change significantly over the entire range of temperatures tested. The greatest colour difference ΔE* = 0.33 occurs at 130°C.

In all of the above cases, the colour change is below the requirements of the defence standard, which allows ΔE*=3, meaning that the requirements of the defence standard are met.

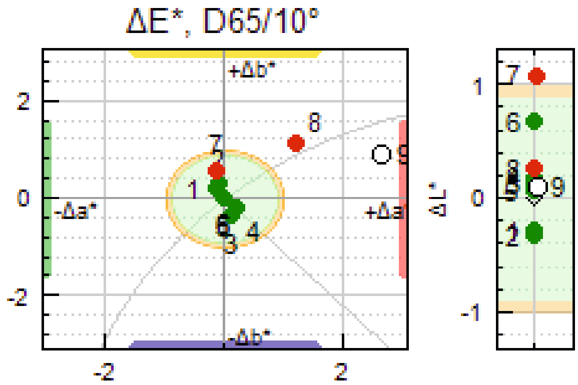

Fig. 4. Colour parameters for BW400-6031 (green). 1 – 90°C, 2 – 110°C, 3 – 130°C, 4 – 150°C, 5 – 170°C, 6 – 190°C, 7 – 210°C, 8 – 230°C, 9 – 250°C

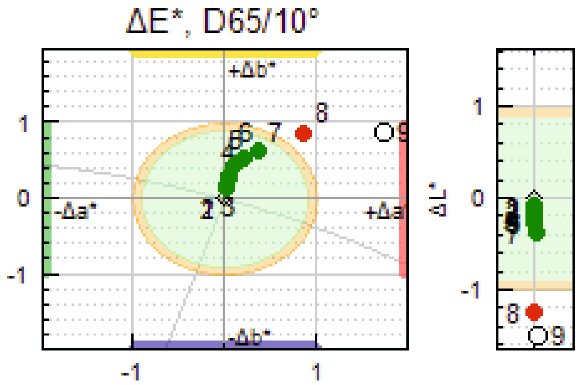

Fig. 5. Colour parameters for BW400-8027 (brown). 1 – 90°C, 2 – 110°C, 3 – 130°C, 4 – 150°C, 5 – 170°C, 6 – 190°C, 7 – 210°C, 8 – 230°C, 9 – 250°C

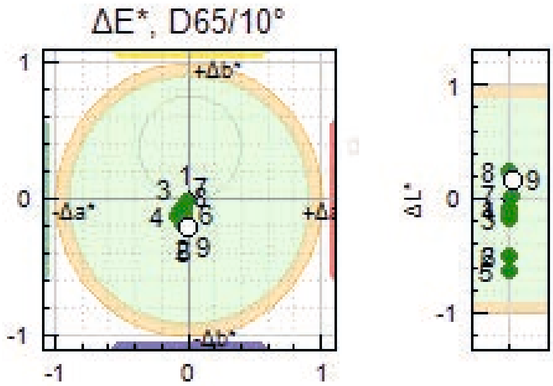

Fig. 6. Colour parameters for BW400-9021 (black). 1 – 90°C, 2 – 110°C, 3 – 130°C, 4 – 150°C, 5– 170°C, 6 – 190°C, 7 – 210°C, 8 – 230°C, 9 – 250°C

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3.4. Gloss measurement

Gloss measurements were performed according to PN-EN ISO 2813 using a measurement geometry of 85°, which is designed for surfaces with a matte finish. Table 6 shows the results of gloss measurements of the tested samples.

Table 6. Change of gloss parameter after temperature exposure, GU

		90°C	110°C	130°C	150°C	170°C	190°C	210°C	230°C	250°C
BW400-6031 (green)	Before	4.0	4.0	7.0	5.6	5.4	6.9	7.3	3.4	6.1
	After	3.9	4.0	6.7	6.6	6.3	7.3	7.3	3.6	5.8
	Difference	**-0.1**	**0.0**	**-0.3**	**1.0**	**0.9**	**0.4**	**0.0**	**0.2**	**-0.3**
BW400-8027 (brown)	Before	5.5	5.5	5.2	5.2	5.2	5.2	5.1	5.4	9.3
	After	5.3	5.2	5.2	5.2	4.7	4.7	4.6	5.5	8.9
	Difference	**-0.2**	**-0.3**	**0.0**	**0.0**	**-0.5**	**-0.5**	**-0.5**	**0.1**	**-0.4**
BW400-9021 (black)	Before	3.4	2.9	4.0	4.2	2.7	2.5	2.8	2.7	4.3
	After	3.4	2.8	4.0	4.4	2.7	2.7	2.9	2.6	4.2
	Difference	**0.0**	**-0.1**	**0.0**	**0.2**	**0.0**	**0.2**	**0.1**	**-0.1**	**-0.1**

Based on the obtained results, there was no effect of temperature change in the studied range on the gloss of the camouflage coating in all tested colours. In every case, the tested parameter was below 8 GU, which is a requirement of the NO-80-A200 standard.

3.5. Determination of the spectral reflectance characteristics

Figures 7-9 show the effect of temperatures from 90°C to 250°C on the reflectance of the camouflage coating system in green, brown and black colour with reference to the requirements of defence standard NO-80-A200:2021.

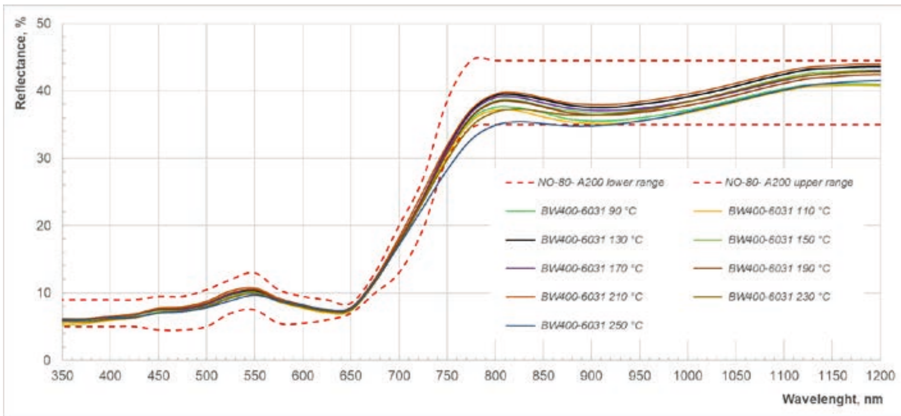

Fig. 7. Effect of temperatures from 90°C to 250°C on the reflectance of the BW400-6031 (green) camouflage paint coating system (own elaboration)

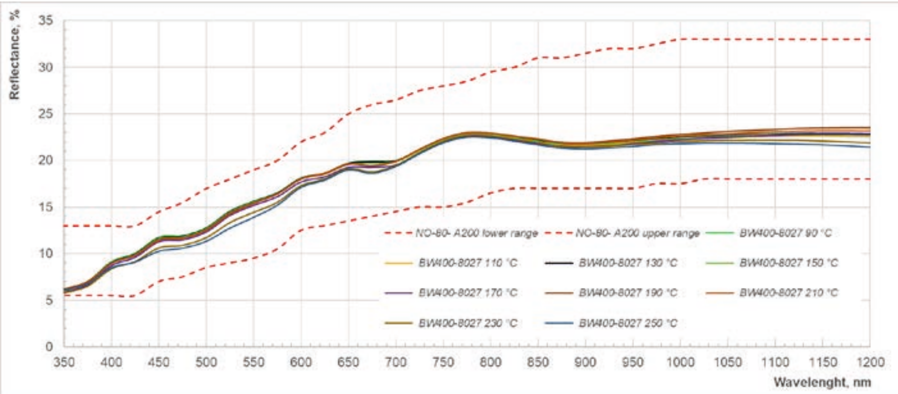

Fig. 8. Effect of temperatures from 90°C to 250°C on the reflectance of the BW400-8027 (brown) camouflage paint coating system (own elaboration)

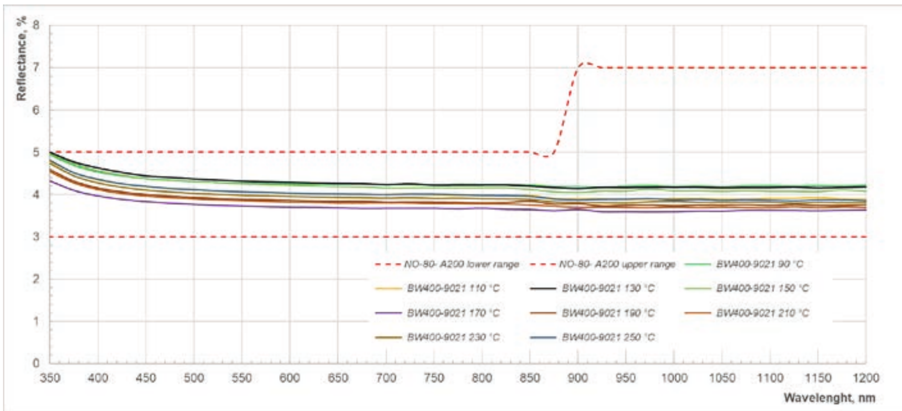

Fig. 9. Effect of temperatures from 90°C to 250°C on the reflectance of the BW400-9021 (black) camouflage paint coating system (own elaboration)

On the basis of the determined spectral characteristics (Fig. 7) of the camouflage coating system with a green topcoat, it can be observed that at a temperature of 250°C, there is a slight change in the reflectance of electromagnetic radiation in the range of 750–900 nm, which exceeds the lower limit of the requirements set by the defence standard in the present case.

In the case of a camouflage coating system with a brown topcoat (Fig. 8), the change in electromagnetic wave reflectance is small and remains within the requirements of the defence standard.

The camouflage coating system with a black topcoat (Fig. 9) also varies slightly, remaining between the lower and upper limits of the defence standard requirements for black.

4. Summary

Based on the test results obtained, the following conclusions were drawn:

- The camouflage coating system has very good adhesion to the substrate, the failure of the system occurred in the BP450-1000 primer layer.
- In a study of the effect of temperature in the range of 90–250°C on the effective camouflage of a coating consisting of BP450-1000 epoxy primer and BW400 special paints in green, brown and black, it was found that temperatures up to 250°C do not cause visible damage to the coating in the form of flaking, blistering, cracking, etc.
- Over the tested temperature range, there was no significant change in the gloss of the coatings.
- The colour of the green and brown topcoats changed towards yellow and red, while the black colour remained largely unchanged.
- The electromagnetic wave reflectance from the camouflage coatings in the 350–1200 nm range did not show a significant change.
- Temporary exposure of the camouflage coating to temperatures in the range of 90–250°C does not reduce the effective camouflage of the coating.

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