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The Influence of Operational Exposure on Changes in Parameters of Effective Camouflage of Coatings Used in Military Technology

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ABSTRACT

The paper presents an assessment of the effect of artificial aging conditions on the properties of varnish coating systems used for effective masking of military equipment and the service life of this type of coating protections was determined. As part of the research, operational exposures were simulated in the form of: accelerated corrosion tests in an artificial atmosphere in accordance with PN-EN ISO 12944–6, a continuous condensation environment at elevated temperature in accordance with the PN-EN ISO 6270–2 standard and short-term temperature impact up to 250 °C. The evaluation of the properties was carried out on the basis of measurements of the surface geometric structure and adhesion by the peel-off method. On the other hand, measurements of specular gloss, color 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. The operational durability of the paint coatings was assessed in terms of damage in accordance with PN-EN-ISO 4628.

Keywords: camouflage coating, special paint, aging, gloss, colour, reflectance.

INTRODUCTION

The protection of a manufactured product against external influences which can cause all kinds of damage is taken into account from the very beginning of the design and construction of vehicles, equipment or installations. As technology progressed, coatings began to be assigned newer and newer functions. In the first instance, the aesthetic and decorative qualities were enhanced, while in the second, care was taken to provide additional reinforcement as well as to adjust the surface.

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 dynamic development of coating manufacturing with various surface engineering technologies [6, 12, 18]. With particular emphasis on coatings produced by beam technologies using concentrated energy stream [24–26].

Varnish coating systems account for approximately 50 % of all coating systems. It is estimated that about 95 % of steel structures are protected against corrosion by protective coatings, of which as much as 90 % by paint coatings [5]. The service life of paint coating systems ranges from several months to several years [13].

Camouflage is a broad concept and can include strategic, operational or direct levels [14, 23]. The subject of the article relates to direct camouflage, and in particular camouflage painting (permanent coating systems), which alongside ad hoc measures such as 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 gain an advantage in both defence and attack [3]. The main task of effective camouflage is to eliminate unmasking features [8], i.e. those that enable one's own objects to be distinguished from the background terrain, and these may include colour, shape, size, gloss, texture [17, 27, 28]. On the modern battlefield, observed an increasing in the use of multispectral sensors, which enable reconnaissance in many ranges of electromagnetic radiation, but the human eye still remains the basic observation "instrument" [9], where the visible range is assumed to be from 400 nm to 700 nm (Figure 1).

In the natural environment, the sun is the primary light source characterised by a uniform spectral distribution. All objects absorb part of the energy at characteristic frequencies [7], so that reflectance curves for individual substances can be determined (Figure 2).

The receptors (cones) [10] in the human eye do not perceive a continuous spectral characteristic, but depending on the receptor type are sensitised to particular frequencies [4]: the L receptor – maximum sensitivity around 565 nm, the M receptor – around 530 nm, the S receptor – maximum around 420 nm (Figure 3).

Based on this property of the human sense of vision, among other things, a perceptually reasonably uniform CIE L*a*b* colour model was built [11] – used to describe and compare colours seen by humans according to the formula:

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2} \tag{1}$$

where: ΔL – difference in brightness for compared colours,
Δa – difference of the chromatic component a,
Δb – difference of the chromatic component b

The optical impression, which in the case of coatings refers to the smoothness of the surface, depends on the degree of reflection and diffusion of light. It is assumed that the more light is diffused, the more matt the surface is, and where there is a greater proportion of reflected light, the more glossy the surface is [20].

The parameters of colour, gloss and spectral characteristics for paint coatings should be similar to those for the terrain background and, in addition, maintain their ranges throughout the service life, in accordance with the parameters described in the Polish Defence Standards [21].

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

- the impact of atmospheric conditions such as solar radiation, which includes ultraviolet

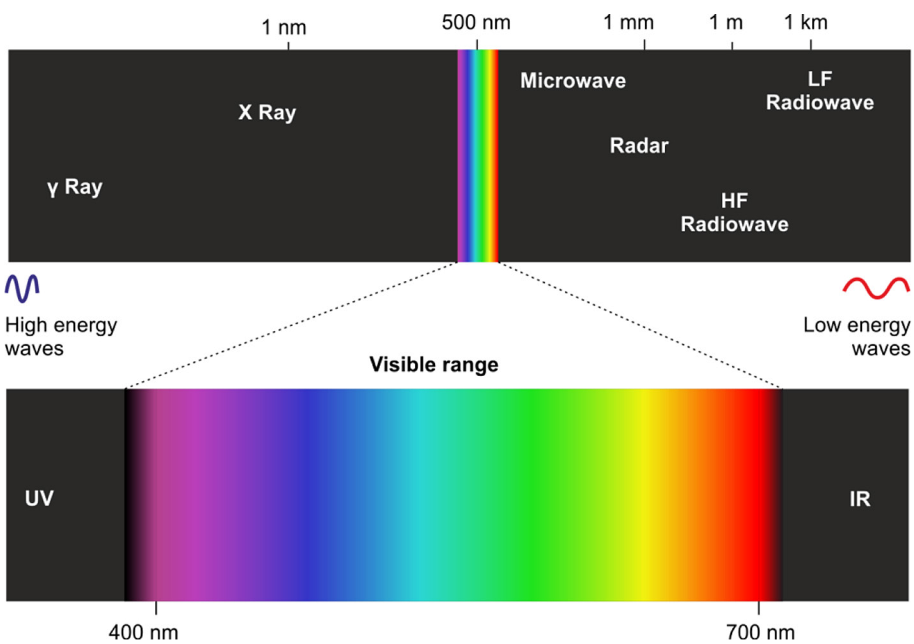


Fig. 1. Diagram of the electromagnetic radiation spectrum [22]

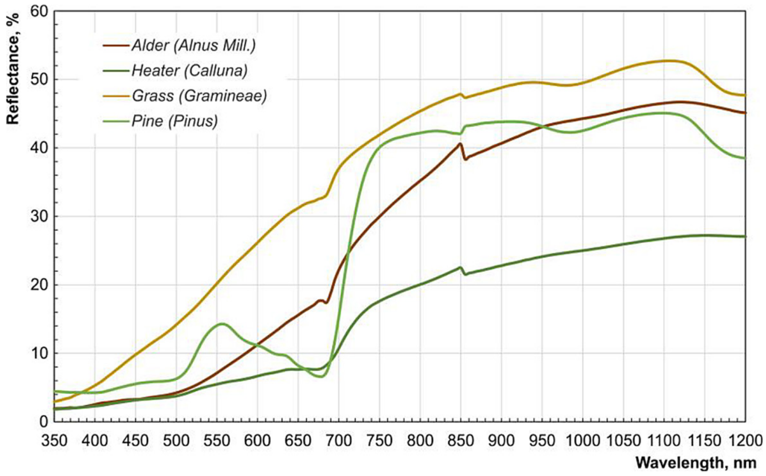


Fig. 2. Spectral characteristics of vegetation in Poland

radiation, which has a particularly negative effect on the camouflage coating,
- rainfall,
- cyclic condensation on the surface causing penetration of the coating,
- operation over 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,
- exposures resulting from the type of operation of military equipment, which include decontamination measures,
- possibility of scratching the coating.

In addition to the above operational exposures, there are other specific exposures resulting from the intended use of the equipment or its components, e.g. short-term exposure to temperatures of up to 250 °C occurring in the area of the rocket launcher.

The paper presents study of the influence of various operational exposures on parameters such as gloss, colour and reflectance, which are decisive for the effective camouflage of military equipment. The effects of artificial ageing conditions were analysed, including temperatures up to 250 °C, ultraviolet radiation, a corrosive atmosphere and condensation humidity.

MATERIALS AND METHODOLOGY

Specimens were prepared from DC01 steel with a thickness of 3 mm which were then ground with P80-grit sandpaper. On such preparing samples epoxy primer BP450–1000 which is part of the special paints set was applied with a dry film thickness of 60 μm ±10 μm. After 4 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 primer as well as special paints was carried out with a conventional pneumatic gun. Such prepared samples were aged for 21 days at 23 °C ± 1 °C and 50% ± 5% relative humidity.

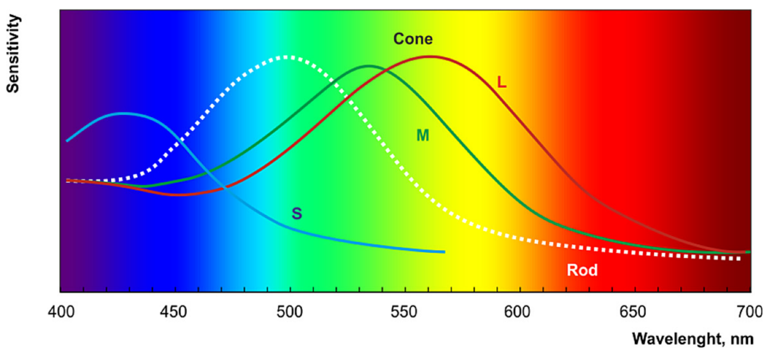


Fig. 3. Sensitivity of S, M, L receptors in relation to frequency [16]

After ageing time, samples were tested for selected properties according to the applicable standards. The following measurements were made: geometrical structure of the surface, adhesion by pull-off test, gloss, colour, reflectance and artificial aging tests: salt, light, condensation and climatic ageing chambers.

Measurements of surface geometric structure (SGS) were carried out at the Laboratory of Computer Measurements of Geometric Quantities of the Kielce University of Technology. The tests were carried out using a Talysurf CCI optical profilometer using the coherent correlation interferometry method, enabling a resolution of 0.01 nm with a z axis [15]. The measurement result was recorded in a matrix of 1024 × 1024 measuring points using the ×10 lens, which gave a measured area of 1.65 mm × 1.65 mm and a horizontal resolution of 1.65 μm × 1.65 μm.

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

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

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

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.

A study of the effect of ultraviolet radiation on the camouflage coating system was carried out in Q-LAB’s QUV/spray chamber.

Accelerated corrosion tests were carried out in accordance with the WKD SC450 chamber of Weiss Umwelttechnik GmbH.

The low temperature resistance test was carried out in a WKL64/70 climate chamber from Weiss Umwelttechnik GmbH.

The resistance to condensation moisture was tested in the Kohler HK310 humidity chamber.

RESULTS AND DISCUSSION

Measurements of the surface geometric structure

Ten measurements were made on samples camouflage coating system and DC01 steel, allowing averaging of the results. The obtained images of surface stereometry and their analysis using the TalyMap Platinium software allowed to evaluate the geometrical structure of the examined surfaces [1, 2].

Figure 4 shows a sample isometric roughness of the surface of the of the camouflage coating system, while Figure 5 shows the isometric view of the wavy surface of the coating system. Table 1 summarizes the most important SGS parameters of the tested camouflage coating systems.

The tested camouflage coating system had averaged mean arithmetic surface roughness deviations from the average surface area 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 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 coating application, the surface roughness was slightly increased.

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 were characterized by the value of the Sa = 3.13÷3.78 μm parameter.

Pull-off test for adhesion measurement

In order to determine the degree of adhesion of individual layers of coatings system to each other and to metal surfaces an pull-off test was carried out. The test determined the tensile strength which must be impacted to the camouflage coating system in order to cause rupture 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 6 shows the surface of the samples and the surface of the dolly.

Based on the results obtained, it can be concluded that the camouflage coating system has

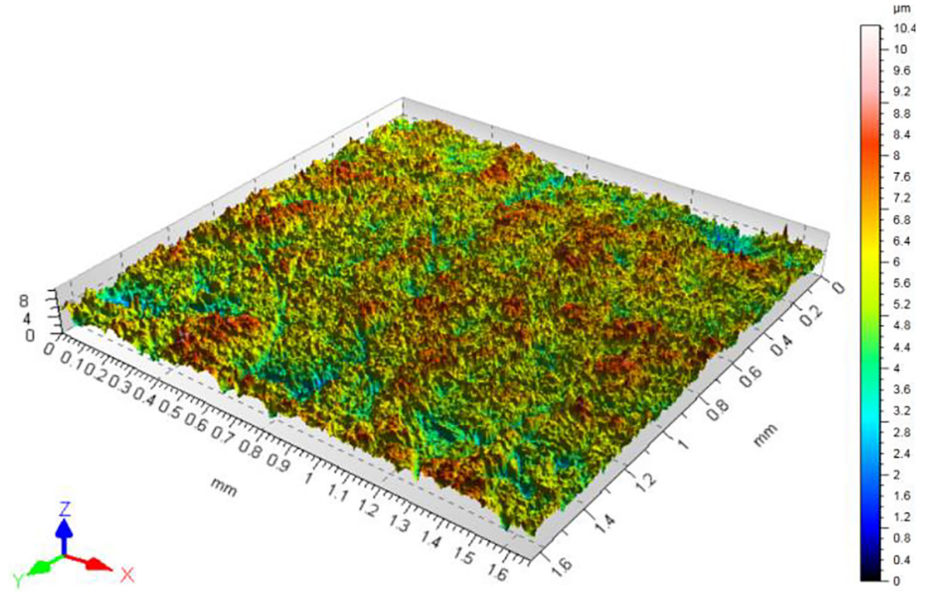


Fig. 4. Isometric view of the S-L surface (roughness) of the camouflage coating system

very good adhesion to the substrate (Figure 6). The fracture was cohesive failure of the BP450–1000 primer layer and the mean tensile stress oscillated around 7 MPa (Table 2).

Short-term exposure to temperatures up to 250 °C

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 3 shows the results of gloss measurements of the tested samples.

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.

Colour measurements

Colour measurements were carried out with measurement parameters: d/8, SCI, 10°. The colour difference ΔE* was determined by measuring

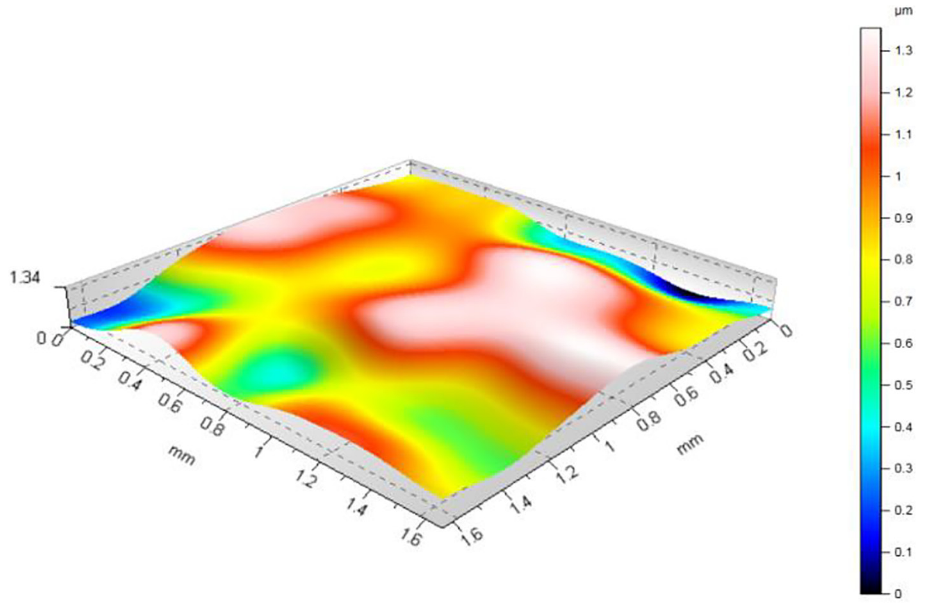


Fig. 5. Isometric view of the waviness surface of the camouflage coating system

Table 1. Averaged parameters of the surface geometric structure

SGS parameters	Camouflage coating system
Sq [μm]	3.6
Ssk	-0.4
Sku	3.3
Sp [μm]	12.2
Sv [μm]	18.5
Sz [μm]	30.6
Sa [μm]	2.8

the samples before and after temperature exposure. The results are summarized in Tables 4–6 and in Figure 7–9.

The analysis of the obtained results showed 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 toward more 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 occurring 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.

Determination of the spectral reflectance characteristics

Figures 10–12 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.

On the basis of the determined spectral characteristics (Figure 10) 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 in the present case exceeds the lower limit of the requirements set by the defence standard.

In the case of a camouflage coating system with a brown topcoat (Figure 11), 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 (Figure 12) also varies slightly, remaining

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			

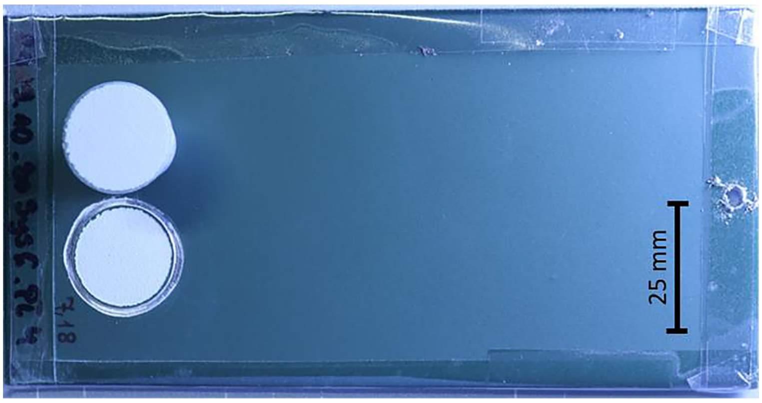


Fig. 6. Example view of sample and dolly after pull-off adhesion test

Table 3. Change of gloss parameter after temperature exposure, GU

Specification		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

Table 4. 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
Δ*E**	0.38	0.61	0.16	0.55	0.72	0.94	1.68	1.74	2.86
Δ*E** 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 5. 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
Δ*E**	0.17	0.15	0.21	0.18	0.21	0.39	0.61	1.12	2.18
Δ*E** in reference to NO-80-A200	0.98	0.97	0.93	0.88	0.89	0.92	0.90	1.08	1.79

between the lower and upper limits of the defence standard requirements for black.

Resistance to cyclic ageing conditions

The durability of a paint system depends on many external factors, including: environmental aspects, the shape of the structure, surface preparation, application and drying of the individual system layers. Furthermore, the behaviour of a coating system over time is influenced by its chemical properties, such as the type of film-forming substance, the type and quantity of pigments used, the use of additives which change the properties of the coating material (fillers, plasticisers, dispersants, etc.).

There are many tests for assessing the service life of coating systems. The commonly used are tests for resistance to condensation moisture and salt spray. It should be noted that the results

Table 6. 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
Δ*E**	0.10	0.19	0.33	0.17	0.10	0.09	0.04	0.15	0.20
Δ*E** in reference to NO-80-A200	0.90	0.53	0.88	0.94	1.34	0.49	1.05	0.62	0.43

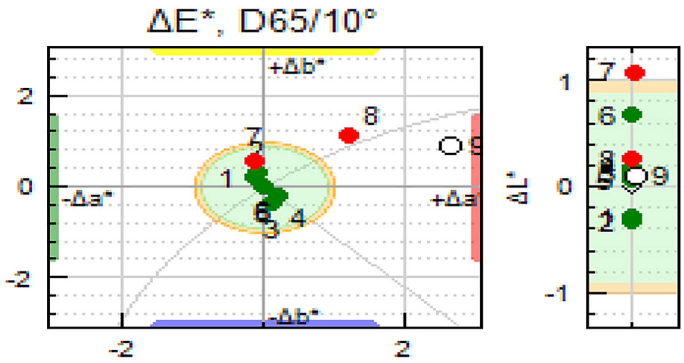


Fig. 7. Colour parameters for BW400–6031 (green). 1 – 90 °C, 2 – 110 ˚C, 3 – 130 ˚C, 4 – 150 ˚C, 5 – 170 °C, 6 – 190 °C, 7 – 210 °C, 8 – 230 °C, 9 – 250 °C

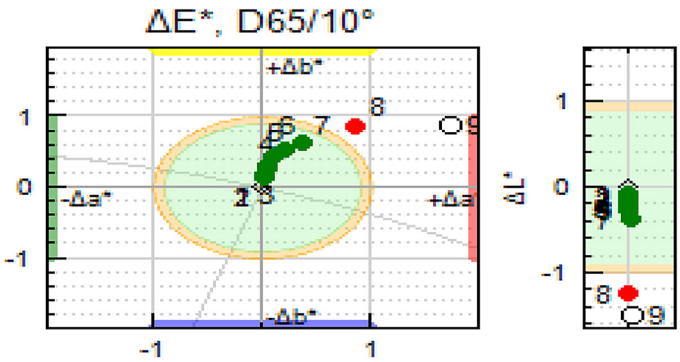


Fig. 8. Colour parameters for BW400–8027 (brown). 1 – 90 °C, 2 – 110 °C, 3 – 130 °C, 4 – 150 °C, 5 – 170 °C, 6 – 190 °C, 7 – 210 °C, 8 – 230 °C, 9 – 250 °C

obtained with artificial ageing in ageing chambers do not necessarily correspond to the actual objects exposed under natural operating conditions. In order to reflect the actual conditions, tests combining the action of different ageing chambers (humidity, salt, UV, climate) are increasingly common and these are cyclic tests. One such test is the cyclic test proposed in PN-EN ISO 12944–6, which combines the operation of three chambers: a salt spray chamber, a UV-A chamber and a climatic chamber (Figure 13). The camouflage coating system test was carried out in accordance with PN-EN ISO 12944–6 and included 2688 h of sample exposure. The specimens were cut into the substrate with a width of 2 mm scribe in accordance with Annex A of PN-EN ISO 12944–6. The 7-day cycle was repeated until the target exposure time was reached. Cycle consisted of a test in a UV light chamber according to PN-EN ISO 16474–3 for 3 days. In next step the samples were transferred to a salt chamber according to PN-EN ISO 9227 NSS for 3 days. At the end the samples

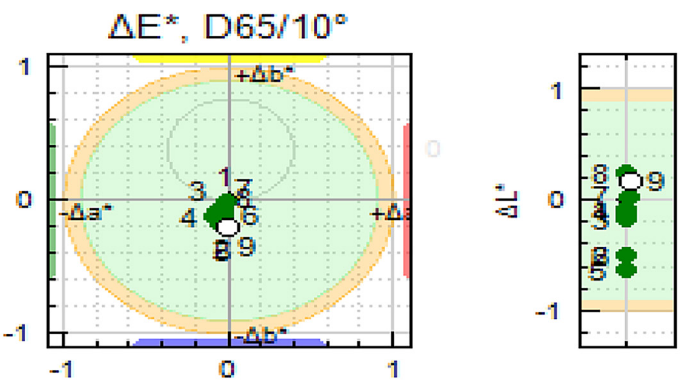


Fig. 9. Colour parameters for BW400–9021 (black). 1 – 90 °C, 2 – 110 °C, 3 – 130 °C, 4 – 150 °C, 5 – 170 °C, 6 – 190 °C, 7 – 210 °C, 8 – 230 °C, 9 – 250 °C

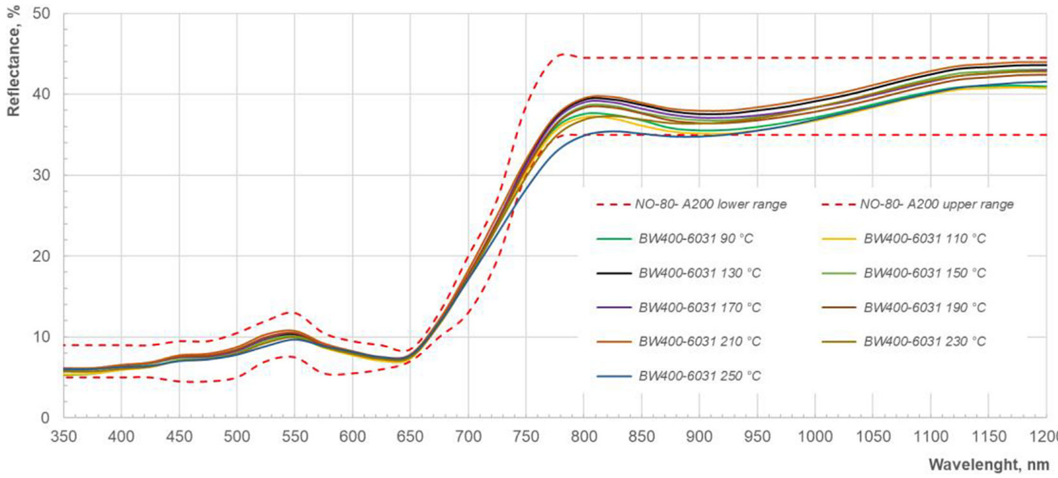


Fig. 10. Effect of temperatures from 90 °C to 250 °C on the reflectance of the BW400–6031 (green) camouflage paint coating system

were exposed in a climate chamber set at -20°C for 1 day.

The effects of atmospheric conditions on coatings exposed to daylight can be tested in chambers using fluorescent lamps at controlled temperature and humidity, with the possibility of water spray. During the research on the effect of ultraviolet radiation on the masking coating system, UVA-340 fluorescent lamps were used to simulate daylight in the ultraviolet range. The samples were irradiated for 4 h at an irradiance of 0.83 W/m^2/nm. This was followed by condensation of moisture on the samples for 4 h with UV light off. The programme was repeated until the samples were exposed for 72 h.

Accelerated corrosion testing was carried out in artificial corrosion atmosphere test chambers. The atmosphere used accelerates corrosion processes on the coating system. The intensification of corrosion processes takes place through the application of suitably selected factors such as temperature, relative humidity, moisture condensation, concentration of corrosive components. The corrosion resistance tests of the camouflage coating system were carried out according to PN-EN ISO 9227 in the WKD SC450 chamber. The samples were placed in a salt chamber where a nozzle sprays a 5% solution of sodium chloride in demineralised water (pH = 6.5–7.2). The temperature inside the chamber was 35 °C ± 2 °C. Solution mist precipitation was 1.5 cm^3/h ± 0.5 cm^3/h.

After exposure in the salt chamber, the samples were rinsed with demineralised water and placed in a climate chamber at -20 °C for 24 hours. The test specimens were evaluated for changes according to PN-EN ISO 4628. Table 7 shows the results of the camouflage coating system and the appearance of the coating after the test.

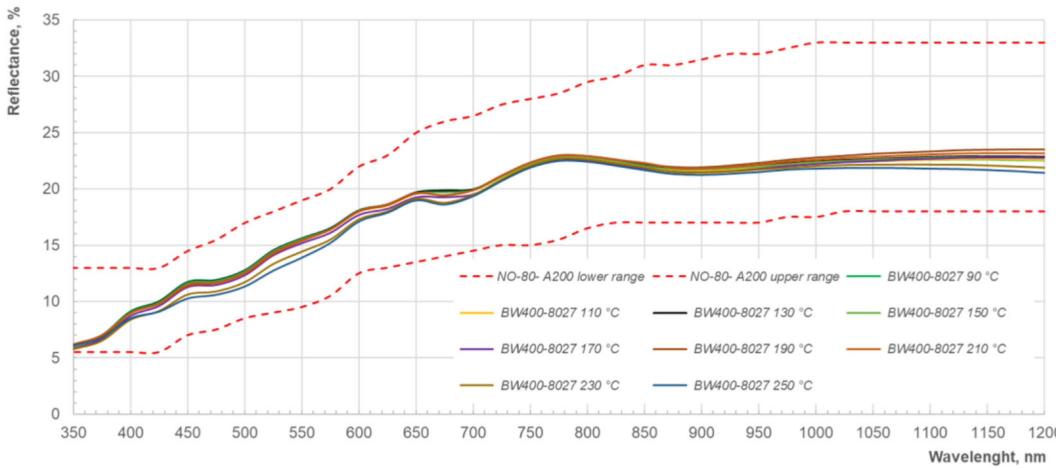


Fig. 11. Effect of temperatures from 90 °C to 250 °C on the reflectance of the BW400–8027 (brown) camouflage paint coating system

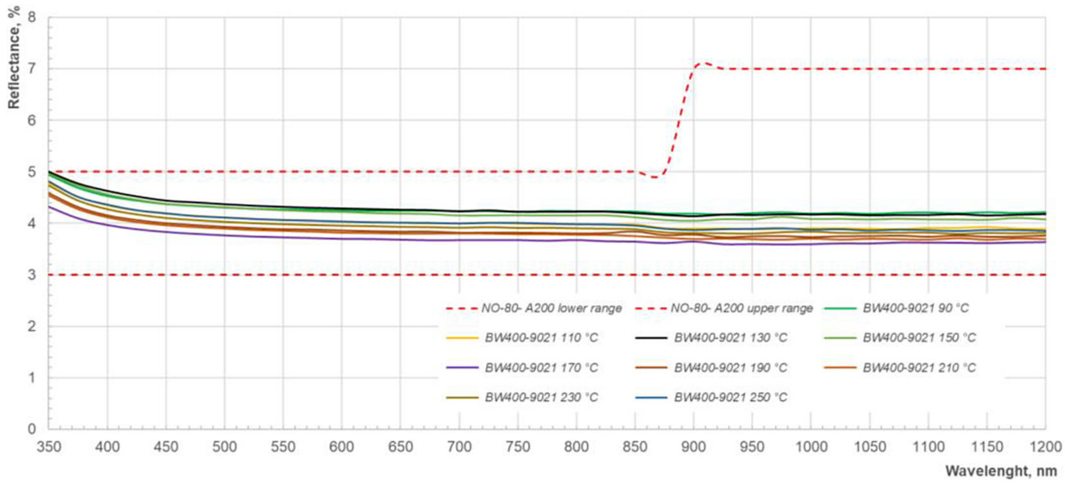


Fig. 12. Effect of temperatures from 90 °C to 250 °C on the reflectance of the BW400–9021 (black) camouflage paint coating system

The camouflage coating system after the cyclic ageing test showed no change on the surface of the specimen at an exposure time of 2688 hours excluding the area around the scratch. The average degree of corrosion of the tested samples around the scribe was 2.4 mm, which is within the range of values permitted by the PN-EN ISO 12944–6 standard. However, it is difficult to relate the obtained corrosion resistance time of the coating system to the resistance time under real conditions, because in reality there are many additional factors that are difficult or impossible to obtain under aging chamber test conditions.

Gloss measurement

The effect of cyclically changing aging conditions on the gloss parameter was investigated. Table 8 shows the results of gloss measurements of the tested samples in 85° measuring geometry. The result is the average of the measurements obtained for the three tested samples.

The test results showed an increase in the gloss of the samples in comparison to the state before the test. The gloss change was a maximum of 3 GU. However, in every case, the gloss values were below 8 GU, which is a requirement of the NO-80-A200 defence standard.

Colour measurement

The results of the colour change of the BW400–6031 camouflage coating system under artificial ageing conditions are presented in Table 9 and Figure 14.

After an exposure time of 1680 h, the colour change was ΔE*=0.99, while after 2688 h the studied parameter increased to ΔE*=1.73. Analysis of figure 14 shows that the colour of the coating becomes bluer during the test and, as indicated by the parameter L* the brightness of the coating increases.

The observed colour changes in relation to the appearance of the coating before the test and the requirements of the defence standard NO-80-A200 in terms of colour coordinate values was within the permissible range of ΔE*=3.00.

Determination of the spectral reflectance characteristics

Spectral characteristics of reflectance with reference to the NO-80-A200 defence standard

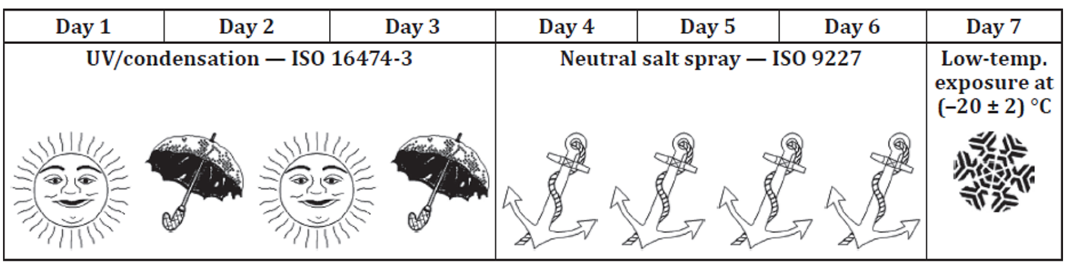
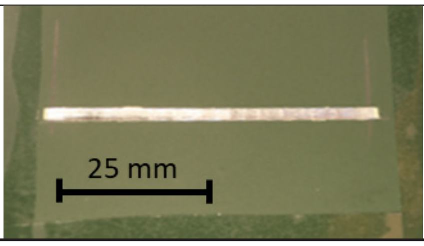
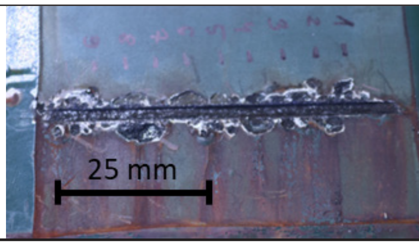


Fig. 13. Cyclic ageing test according to PN-EN ISO 12944–6 (Annex B) [19]

Table 7. Results the camouflage coating system after the cyclic corrosion test according to PN-EN ISO 12944–6

Duration of exposure to cyclic climatic conditions, h	2688
Resistance to cyclic climatic condition, h	More than 2688
Degree of blistering	0 (S0)
Degree of rusting	Ri0
Degree of flaking	0 (S0)
Degree of cracking	0 (S0)
Degree of filiform corrosion	0 (S0)
Degree of corrosion around the scribe, mm	2.4
The sample appearance before testing:	The sample appearance after testing:
	

were performed before and after an exposure time of 2688h (Figure 15).

The cyclic ageing test did not cause any changes in the course of electromagnetic radiation reflectance of the tested coatings. In the visible light wavelength range, i.e. 350–720 nm, no significant differences in the reflectance spectrum were observed. Similarly, in the near-infrared range of 750–1200 nm, the spectrum before and after exposure to ageing conditions had similar spectrum waveforms. The spectrum (Figure 15) of the reflectance of the camouflage coating with the green topcoat before and after the test cycle remains within the requirements of the defence standard.

Resistance to condensation humidity

Moisture condensing on the surface of the coating allows many ions to pass into solution and thus form an electrolyte, causing possible electrochemical corrosion of the substrate. Testing in an ageing chamber designed to create conditions of continuous condensation on the coating surface at elevated temperatures, i.e. 40 °C ± 1 °C, provides the possibility to test accelerated exposure of the resistance of a coating system to this type of exposure. Table 10 shows the results of testing the camouflage coating system in humidity chamber. During the test, the changes that occurred on the surface of the coating were evaluated according to PN- EN ISO 4628.

The camouflage coating system, after testing in a humidity chamber, showed no change over an exposure time of 720 hours. No changes to the coating in the form of rusting, blistering, cracking or flaking were observed when the system was exposed to ageing conditions.

Gloss measurement

The effect of an atmosphere containing condensation moisture on the gloss parameter of a green topcoat camouflage coating was investigated. Table 11 shows the results of the measurements. The gloss was tested in a measuring geometry of 85°. The gloss value shown is the average of the measurements obtained for the three tested samples.

Table 8. Gloss of the coating before and after exposure to cyclic ageing conditions, GU

BW400–6031 (green)	Before exposure	4.4
	After exposure	7.2
	Difference	2.8

Table 9. Colour parameters for BW400–6031 (green) after exposure to cyclic ageing conditions

BW400–6031 (green)	Exposure time [h]	
	1680	2688
*L**	35.78	36.45
*a**	-4.87	-5.06
*b**	5.03	4.59
Δ*E**	0.99	1.73
Δ*E** in reference to NO-80-A200	0.85	1.61

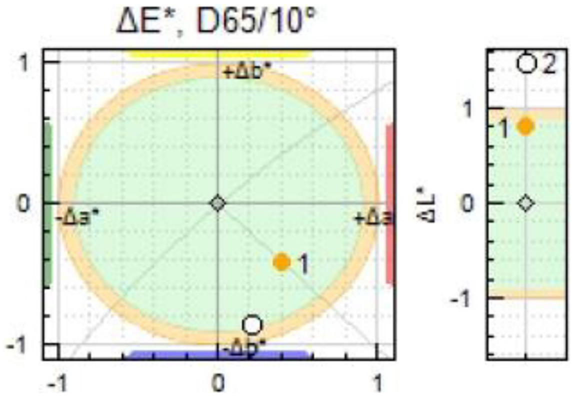


Fig. 14. Colour parameters for BW400–6031 (green). 1 – 1680h exposure, 2 – 2688h exposure

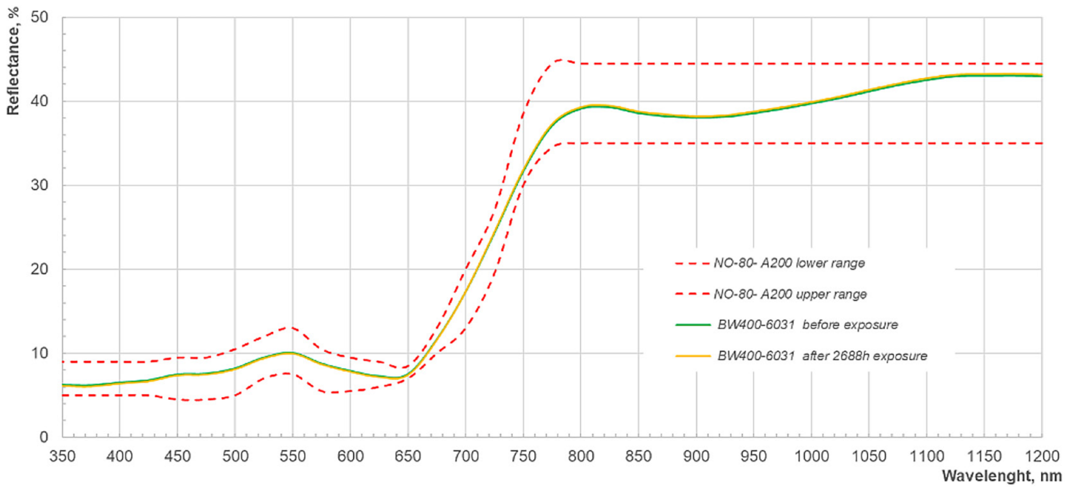
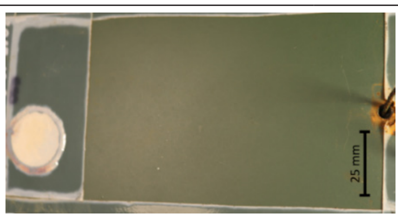


Fig. 15. Influence of cyclic changing climate conditions on the reflectance of BW400–6031 (green) camouflage coating

After exposing the samples in a humidity chamber, the gloss of the camouflage coating system was measured. The parameter tested was below 8 GU in accordance with the requirements of defence standard NO-80-A200. The increase in gloss compared to the measurements before exposure to the ageing conditions was small and amounted to about 2 GU.

Table 10. Final results for the camouflage coating system after testing in accordance with PN-EN ISO 6270–2

Exposure time to condensation moisture [h]	720
Resistance to condensation moisture [h]	More than 720
Degree of blistering	0 (S0)
Degree of rusting	Ri0
Degree of flaking	0 (S0)
Degree of cracking	0 (S0)
Appearance of the sample after testing:	



Colour measurement

Table 12 shows the colour parameters of the green topcoat camouflage system after an exposure time of 720 hours in a humidity chamber. The results obtained were compared with those of the pre-exposure sample, as shown in Figure 16.

After the test, the colour change in relation to the standard – unaged sample – was ΔE*=1.20,

Table 11. Gloss of the coating before and after exposure to condensation moisture, GU

BW400–6031 (green)	Before exposure	5.5
	After exposure	7.8
	Difference	2.3

Table 12. Colour parameters for BW400–6031 (green) after exposure to condensation moisture

BW400–6031 (green)	Exposure time [h]
	720
*L**	36.40
*a**	-5.20
*b**	4.40
ΔE*	1.20
Δ*E** in reference to NO-80-A200	1.69

while the same parameter in relation to the colour coordinate values set by the NO-80-A200 defence standard was ΔE*=1.69.

Determination of the spectral reflectance characteristics

The spectral characteristics of the reflectance of the camouflage coating system before and after an exposure time of 720 h were determined (Figure 17). The results obtained were compared with the limits established in the NO-80-A200 defence standard for the colour green.

For coatings with a green finish, the change in electromagnetic wave reflection is small, remaining between the lower and upper requirements of the defence standard for the colour (Figure 17). Aging conditions as condensation moisture caused a slight shift in the reflectance spectrum in the range of 350–750 nm. This shift was more noticeable in the range of 750–1200 nm. However, it should be noted that the nature of the spectrum waveform did not change.

CONCLUSIONS

Based on the test results obtained, it was found that 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 90–250 °C on the effective camouflage of a

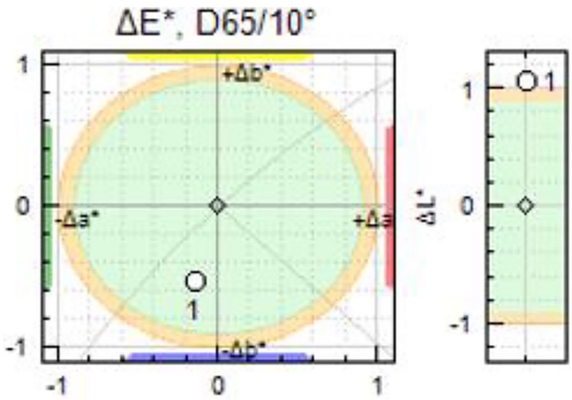


Fig. 16. Colour parameters for BW400–6031 (green). 1–720 h exposure

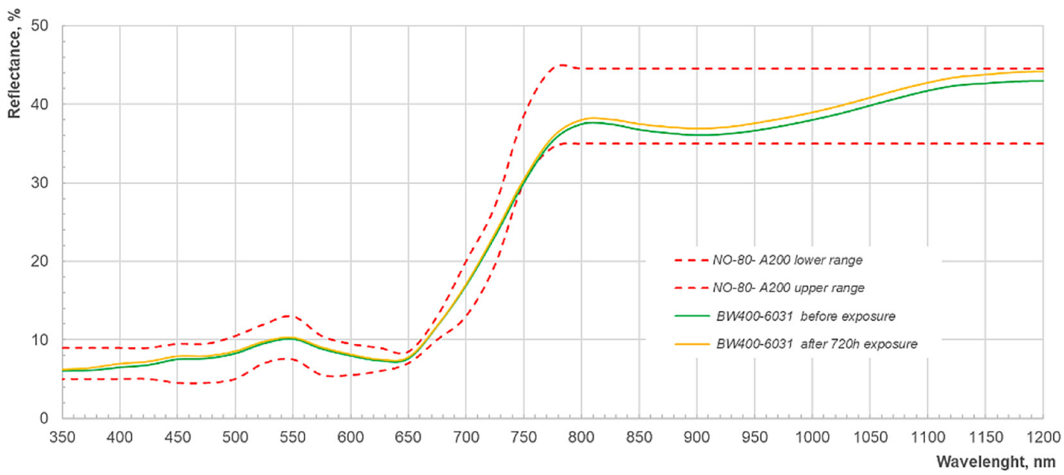


Fig. 17. Effect of condensation moisture on the reflectance of BW400–6031 (green) camouflage coating

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 temperature range tested there was no significant change in the gloss of the coatings. The colour of the green and brown topcoats changed towards more yellow and red, while the black colour remained without significant difference. 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 90–250 °C does not reduce the effective camouflage of the coating.

Cyclically changing ageing conditions taking into account the effects of UV-A radiation, corrosive atmospheres and low temperatures did not significantly deterioration of the key parameters of the camouflage coating system. The samples tested did not show any changes to the coating in the form of blistering, cracking, flaking or rusting. The average degree of corrosion of the samples after the test was 2.4 mm and was within the range permitted by PN-EN ISO 12944–6. The gloss of the exposed coatings increased by an average of 3 GU compared to the non-aged samples. Despite this, the gloss values still remained below 8 GU. The colour of the coatings changed slightly towards more blue. The spectral characteristics of the green-finish camouflage coating under the influence of cyclically changing climatic conditions did not change. The results show that, despite the use of a number of different ageing accelerators, there are no significant changes in parameters affecting the limitations of effective coating camouflage and system durability.

The test in the humidity chamber according to PN-EN ISO 6270–2 of the camouflage coating system did not cause any changes to the coating in the form of rusting, blistering, cracking or flaking. The gloss of the exposed coatings increased, but was still below 8 GU. The reflectance and colour parameters of the tested coatings were within the ranges allowed by the NO-80-A200 defence standard. The test performed confirmed the good resistance of the camouflage coating system to exposure conditions.

The operational exposures that are the subject of this article did not significantly affect the camouflage coating system tested and did not affect its effective camouflage properties

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