FUNCTIONAL PROPERTIES OF COATING SYSTEMS FOR WEAPONS AND MILITARY VEHICLES

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Abstract

The evolution of paint coatings is rapid, multidirectional, and most interesting. Progress in the field of polymer coating technology stems from the three most important functions: the decorative function, the protective function, and the informative function. Paint systems account for approximately 50% of all coating systems. About 95% of steel structures are estimated to be safeguarded against corrosion with protective coatings, including as much as 90% – with paint coatings. The service life of paint systems ranges from several months to several years. A special group of paint systems is paint coatings for military applications, mainly for camouflaging weapon systems and military equipment. Paint coatings are fundamentals of camouflage – they camouflage vehicles/objects in the optical range, both visible light (VIS) and the near-infrared (NIR) range. The main task of effective camouflage is to eliminate those features that may cause the object to be differentiated from its surroundings, i.e., those that make it possible to distinguish one's assets from the background, and these may include, for example, color, shape, size, gloss, and texture. The paper analyzes the functional operational properties of two-layer coatings for use in military technology. The properties were evaluated based on microstructure analysis and measurements of surface geometric structure, nanohardness, and adhesion. The tests were carried out for two-layer masking coating systems made in three variants: coating system (SP1), coating system modified with carbon nanotubes (SP2), coating system modified with glass microspheres (SP3). Paint coating systems were applied by pneumatic spraying to DC01 steel samples using SATA guns. Due to their operational properties, the developed coating systems can be used on weapons and military vehicles.

Keywords: Coating system, properties, surface geometric structure, adhesion, nanohardness, weapons and military vehicles

1. INTRODUCTION

The properties of the surface layer affect the service life of machines and devices. The surface fundamentally affects the functional properties of objects and products. This is important both for quality reasons [1,2] and in connection with the durability of protected objects, especially important in terms of the circular economy [3], resulting from, among others, increasingly stringent energy, production [4], and consumption [5,6] limitations. Regardless of this, research related to the surface layer [7] significantly influences the development of technology [8] and materials [9], including socially important biomaterials [10-12]. Several physicochemical phenomena, such as chemical catalysis, corrosion, wear (abrasive, adhesive, abrasive-adhesive, erosive, cavitation, fatigue), adhesion, adsorption (physical and chemical), flotation, depend on and occur on the surface of the material or with its participation. The operational durability of the surface layer depends on many complex structural, operational, and material factors, which include, among others [13]:

- chemical and phase composition, microstructure, and mechanical properties of the material, state and values of residual stresses, crack resistance, and corrosion resistance.
- conditions and type of operation.
- method and nature of loading.

Currently, there is a dynamic development of coating production processes using various surface engineering technologies. The process of evolution of paint coatings is interesting. It is very fast and multidirectional [14]. The progress in the field of polymer coating technology is caused by three of the most important functions. i.e., decorative [15], protective [16], and information [17]. A special group of paint coatings is paint coating systems for military applications, mainly for masking weapons and military equipment [18].
The paper presents the results of operational tests of paint coating systems developed using carbon nanotubes and glass microspheres. The current research includes analysis of the microstructure and measurements of the geometric structure of the surface, adhesion, and nanohardness.

2. MATERIALS

The specimens with dimensions of 150 mm x 100 mm x 1 mm were made of low-carbon steel DC01. The steel samples were first washed with XPA10006 remover to degrease the surfaces. Then, a grinding operation was performed using a rotary machine and P80 grit sandpaper. The final stage of surface preparation was washing the surface with XPA10006 solvent. Masking coating systems were applied in a Blowtherm spray booth, using SATA guns. Masking coating systems were applied by air spray in three options:

- paint system (SP1): primer coating, masking coating (green),
- paint system (SP2): primer coating, masking coating (green) + carbon nanotube modification (0.02% by weight),
- paint system (SP3): primer coating, masking coating (green) + modification with glass microspheres (2.4% mass share).

3. RESULTS AND DISCUSSION

A microstructure analysis was conducted for masking coating systems using the HITACHI S-3500N scanning electron microscope. The thickness of the obtained masking paint systems for military facilities was from approx. 141 to approx. 157 µm. **Figure 1** shows an example of the SP2 masking system. Analysis of the microstructure of the masking systems confirmed clear boundaries between individual layers, the paint system, and the steel substrate. It was also found that the masking paint systems were free from structural defects. i.e., microcracks and pores.

A scratch test was conducted to test the adhesion of the paint systems without putty. Adhesion tests were conducted using the Revetest Scratch Xpress instrument (CSM Instruments, Switzerland). The measurements were performed at a load increase rate of 11 N/min, a table feed rate of 4.49 mm/min, and a scratch length of 20 mm.

A special Rockwell diamond cone indenter with a corner radius of 200 µm was used to scratch the samples at a gradually increasing normal load. The information about the cracking or peeling of layers was obtained based on the measurements of the material resistance (tangential force) and the registration of acoustic emission signals. The lowest normal force causing a loss of adhesion of the coating to the substrate is called a critical force and is assumed to be the measure of adhesion. The results are presented in **Table 1**.
From the obtained data, it becomes evident that coating systems have good adhesion with the substrate material. The mean value of the critical force calculated from three measurements performed on the individual

masking coating systems was from 41.38 to 46.49 N. In addition, the low scatter of critical stylus loads indicates that the layers are homogeneous and very tight.

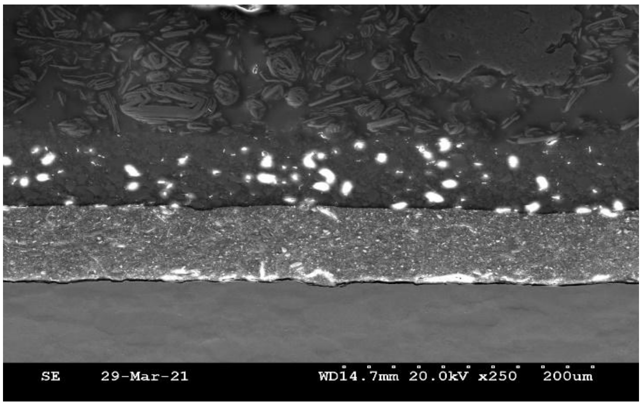

Figure 1 Microstructure of the SP2 masking system

Table 1 Results of scratch adhesion tests

Masking coating systems	Critical stylus load (N)			Mean value† (N)
	Measurement			
	1	2	3	
SP1	45.15	38.71	40.27	41.38 ± 3.36
SP2	44.92	45.39	47.35	45.89 ± 1.29
SP3	47.48	46.83	45.16	46.49 ± 1.20

†scatter intervals estimated at 90% confidence level

The hardness and elastic modulus were investigated using the nanoindentation technique. This measurement technology was possible due to the development of instruments that continuously measure force and displacement. In the measurement, the load force was 20 mN, and the unload rating was 40 mN/min due to the type of material tested, which used creep for about 5 seconds. The hardness is determined by the penetration depth of the indenter, and the modulus of elasticity is determined by the slope of the unload curve. Hardness measurements were carried out in several selected places on the surface of the paint coating. On the basis of 10 measurements, the values of average hardness and elasticity modulus were determined. **Table 2** contains the average values of hardness and elastic modulus, together with the standard error.

Table 2 Value of hardness and modulus of elasticity with errors

Coating systems/material	Hardness (GPa)	Elastic modulus (GPa)
SP1	0.335 ± 0.003	7.637 ± 0.021
SP2	0.216 ± 0.008	5.394 ± 0.053
SP3	0.302 ± 0.005	5.859 ± 0.037
steel DC01	9.700 ± 0.800	121.00 ± 5.200

The highest nanohardness was found in steel DC01, and it amounted to 9.7 GPa. The Young's modulus was also the highest for low-carbon steel DC01, and its value was at the level of 121 GPa. Analyzing the data included in **Table 2**, it can be concluded that all paint coatings had similar nanohardness values. The nanohardness measured on the surface of the coating systems was in the range of 0.216 GPa to 0.302 GPa. A similar analogy can be observed when analyzing the values of Young's moduli for the tested paint layers (**Table 2**). The highest value of the longitudinal elasticity modulus was found in the SP1 paint system in relation to the other two coating systems. The Young's modulus measured on the surface of the masking system was 7.637 GPa.

Measurements of surface geometric structure (SGS) were carried out at the Laboratory of Computer Measurements of Geometric Quantities of the Kielce University of Technology. 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 resolution. The measurement result is recorded in a matrix of 1024x1024 measuring points using the x10 lens, giving a measured area of 1.65 mm x 1.65 mm and a horizontal resolution of 1.65 μm x 1.65 μm. Ten measurements were made on samples of coating systems and steel DC01, allowing averaging of the results. The images obtained from surface stereometry and their analysis using the software TalyMap Platinum allowed us to evaluate the geometrical structure of the examined surfaces. **Figure 2** shows a sample isometric roughness of the surface of the steel DC01, while **(Figure 3)** shows the isometric image of the wavy surface of the steel. **Table 3** summarizes the most important SGS parameters of the tested masking coating systems.

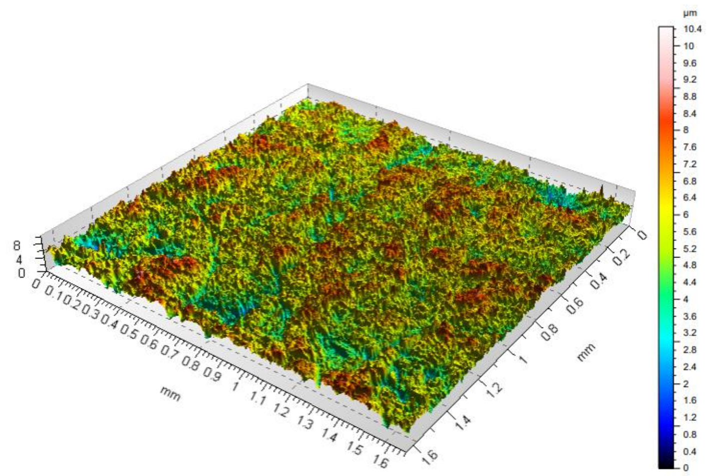

Figure 2 Isometric view of the surface roughness of the steel DC01

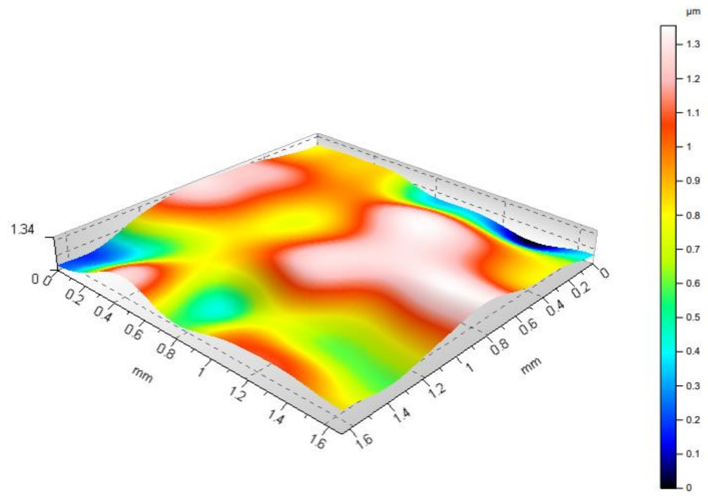

Figure 3 Isometric view of the waviness surface of the steel DC01

The tested coating systems had an average mean arithmetic surface roughness deviation from the average surface area *Sa* = 2.272-3.111 μm. Samples of steel DC01 sanded with P80 grain sandpaper on which coatings were applied had *Sa* = 0.798-0.883 μm. Parameter Sa is the basic amplitude parameter for quantifying the state of the surface being analyzed. A similar trend in the measurement of paint coatings and low-carbon steel was observed for the quadratic surface roughness *Sq*, which has a strong correlation with the *Sa* parameter. Additional information on the surface shape of the tested modifications is provided by the amplitude parameters: skewness coefficient *Sku* and the concentration coefficient *Ssk*. These parameters are sensitive to the occurrence of local elevations or depressions on the surface, including defects. The obtained kurtosis values close to *Sku* = 3 indicate that the ordinate distribution for all samples is close to the normal distribution. The highest value was obtained for the modification of the masking system with glass microspheres. Analyzing **Table 3**, it results that only the SP3 paint system had a positive value of the surface asymmetry coefficient *Ssk* (skewness), which indicates that we are dealing with a smooth surface devoid of deep scratches. The coating without modification (SP1) and the coating modified with carbon nanotubes (SP2) had negative *Ssk* values, which indicated rather a plateau shape of these surfaces in comparison to the coating modified with glass microspheres (SP3). The lowest value of the *Ssk* parameter was measured for the SP1 coating system.

Table 3 Averaged parameters of the surface geometric structure of coating systems

SGS Parameters	**Masking coating systems**		
	SP1	**SP2**	**SP3**
Sq [µm]	2.841	3.110	3.949
Ssk	-0.217	-0.169	0.393
Sku	3.285	2.954	3.565
Sp [µm]	29.616	18.150	22.781
Sv [µm]	50.238	21.323	30.112
Sz [µm]	79.853	39.473	52.893
Sa [µm]	2.272	2.486	3.111

4. CONCLUSIONS

Based on the study, the following conclusions can be formulated:

- as a result of the microstructure analysis, it was found that the paint systems were free from pores and microcracks,
- the two-layer coatings were characterized by good mechanical properties,
- masking coating systems had higher parameters of the geometric structure of the surface in relation to the substrate material (more than three times),
- the SP3 painting system had a positive value of the surface asymmetry coefficient *Ssk*, which indicates that we are dealing with a smooth surface without deep scratches.

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