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PROPERTIES OF COATING SYSTEM FOR RAIL VEHICLES

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Abstract: The article presents the results of laboratory tests of a new anti-graffiti coating system, which includes BO100-AGR. The tests were carried out in accordance with the current standards and the established internal laboratory procedures, the purpose of which was to broaden the determination of the functional properties of the tested system. The coatings were applied to the sample with S355 steel using guns SATA. Because of its properties, anti-graffiti coating system can be successfully used on rail vehicles.
Keywords: coating system, properties, application

1. INTRODUCTION

Keeping rail vehicles clean is a process complicated by necessity removing more and more aggressive and more permanent (graffiti 2K) pollution from the vehicle without damage to paint trawl to protect against corrosion. Appearance the use of anti-graffiti varnishes gave hope for facilitation this process without changes to the service life after driving. The ability to remove graffiti has already been less obtained by vehicle maintenance units clean, but often it was with a lot of inconveniences of use aggressive chemicals, using or livestock (brushes, fabrics) drawing a painting of a vehicle du or even removing it locally. It was necessary also extended vehicle downtime on the siding railway (Pasieczyński and Radek, 2016).
The protection of the manufactured product against external influences which may cause all kinds of damage is taken into account already at the beginning of the design and construction phase of vehicles, equipment or installation. As technology advances, newer and newer functions have been assigned to coatings. In the first place, the aesthetic and decorative values have been increased, while in the second place, additional reinforcements and surface adjustments have been taken care of. During operation, varnish coatings are exposed to various types of operating exposures. They contriute to the loss of protective and decorative properties of coatings. Coatings are affected by: climatic factors, i.e. ultraviolet radiation, heat, humidity, as well as aggressive media and erosive particles (Kotnarowska, 2019; Prak et al., 2022; Kotnarowska, 2010).

There is a lack of comprehensive data in national and world literature on the use of anti-graffiti coating systems to protect rolling stock more effectively (Radziszewska-Wolińska et al., 2018). The development of a paint system with reduced adhesion can be used to remove contaminants from the vehicle more easily and will make it more difficult for graffiti coatings to adhere to the top coat of the coating system on rolling stock (Pasieczyński et al., 2018).

Currently, anti-graffiti coating systems for rolling stock are experiencing high development dynamics, which have different properties (Radek et al., 2019). Graffiti paints that are difficult to remove require the use of more aggressive materials, which increase the possibility of mechanical or chemical damage of the coating system and consequently reduce the thickness of the protective coating or remove it completely. In addition, aggressive chemicals removers are dangerous to the users and environment. The article presents the comparative tests results of selected properties of anti-graffiti paint system for rolling stock industry.

2. METHODOLOGY

Samples with dimensions of 150 mm × 100 mm × 1 mm were made of S355 alloy steel. The steel sample surfaces were washed in a nitro solvent and then ground using a rotary machine with a P80 grain sandpaper and washed with solvent XPA10003. When making the samples, technology of the manufacturer supplying coating materials, used in leading companies manufacturing rolling stock, was strictly observed. The steel surface had a temperature above the dew point of at least 3 °C. When applying successive layers of the same product, particular attention was paid to evaporation time and temperature regimes of the drying process.

In order to prepare the surface and apply the coating system, rotary machines and sanding paper from Festool, guns (with nozzles) from SATA and a spray booth by Blowtherm were used.

The tests were carried out for coating systems consisting of the following layers: anti-corrosion epoxy primer, repair putty, primer filler, base coat and BO100-AGR clearcoat. Parameters for applying the anti-graffiti layer were as follows: surface temperature: 24-26 °C, working pressure 0.18-0.2 MPa, evaporation time for a single layer: 15 min, dry film thickness: 40-60 μm, application technique: pneumatic spraying, number of layers applied: 2, drying temperature: 60 °C, drying time: 60 min. Other layers were applied in accordance with technical descriptions provided by the manufacturer of a given material.

3. RESULTS AND DISCUSSION

A microstructure analysis was conducted for anti-graffiti coating systems using the *JEOL* JSM-*7100F* scanning electron microscope with field emission. The thickness of the obtained coating systems was from approx. 2300 to approx. 2500 μm. There are clear boundaries between the individual layers (Fig. 1). Fig. 1 shows the clear boundary between the varnish layers and the putty. Also the varnish layers are free of pores and microcracks.

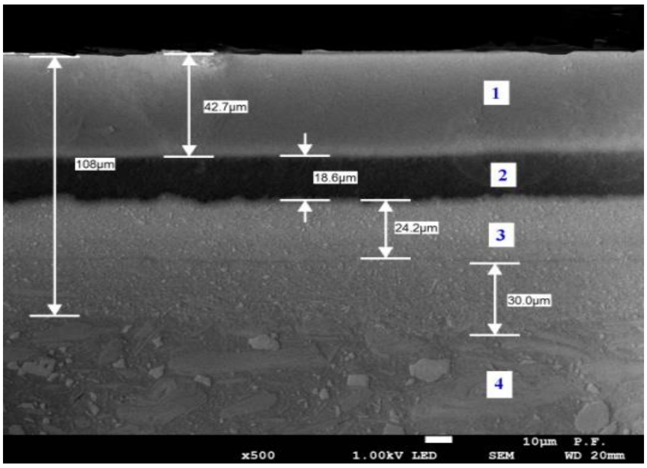

Fig. 1. SEM microphotography of the polished cross-section throug a anti-graffiti coating system on S355 carbon steel substrate: 1- anti-graffiti layer, 2 - base layer, 3 - undercoat layer, 4 - putty

The measurement of hardness of anti-graffiti BO100-AGR coating systems consisted in the measurement of pendulum damping time according to PN-EN ISO 1522 standard. The sample was placed on the device table and then the pendulum legs were gently placed on its surface. In the tests Koeniga pendulum was used. During the measurement the amount of oscillations during pendulum damping was counted from 6° to 3° from the vertical. A photocell in the device was responsible for the correct number of counts. The number of oscillations was calculated for the time of pendulum damping. In a correctly calibrated device with Koenig pendulum, one oscillation corresponds to 1.4 seconds. The measurement was taken six times on each sample in order to average the hardness depending on the coating thickness. The principle of the measurement was to change the friction surface between the coating to be tested and the pendulum's feet, which translates into pendulum damping time. Coatings of lower hardness are more easily subjected to the weight of the pendulum, whose legs penetrate the coating deeper, which results in an increased friction surface. The average damping time for Koenig's pendulum from 6 measurement tests was 120.8 s and a relative hardness of 0.5.

Individual results may vary slightly in cyclical tests. Therefore, a relative hardness has been introduced, which is calculated by dividing the sample oscillation value by the calibration oscillation value. The previous calibration ended with 180 oscillations.

Hardness measurements were also performed according to the Buchholz pressing test according to PN-EN ISO 2815. The measurements were carried out by placing a Buchholz indenter with a fixed mass of 750 g on the surface of the coating system. After 30 seconds of contact between the indenter and the surface of the anti-graffiti paint, the device was removed from the sample and then the imprint on its surface was measured. The resistance to pressure was calculated. Three measurements were made and then the average value was calculated. The smaller the footprint that the Buchholz knife imprinted on the tested surface, the harder the coating system was. The mean pressure resistance of the of anti-graffiti BO100-AGR coating systems was 85.23 and the mean scratch width was 1.17 mm.

Measurements of surface geometric structure 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.

Fig. 2 shows a sample isometric roughness of the surface of the anti-graffiti BO-100AGR coating system, while Fig. 3 shows the isometric image of the wavy surface of the coating system. The tested anti-graffiti coating systems had averaged mean arithmetic surface roughness deviations from the average surface area *Sa* = 6.6÷26.9 nm. Samples of S355 steel sanded with P80 grain sandpaper on which coatings were applied had *Sa* = 1 234.5÷1 863.2 nm. Parameter *Sa* is the basic amplitude parameter for quantifying the state of the surface being analyzed. A similar trend in the measurement of anti-graffiti and S355 coating systems 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 significantly reduced.

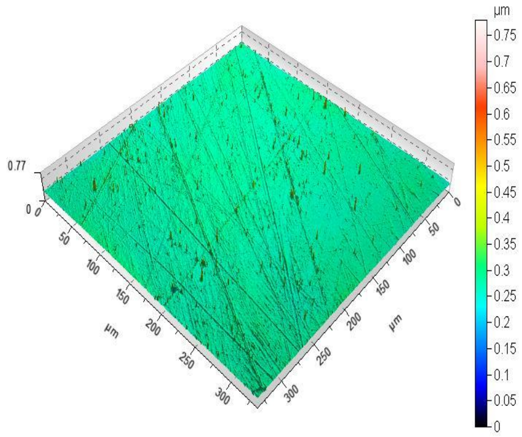

Fig. 2. Isometric view of the surface roughness of the anti-graffiti BO100-AGR coating system

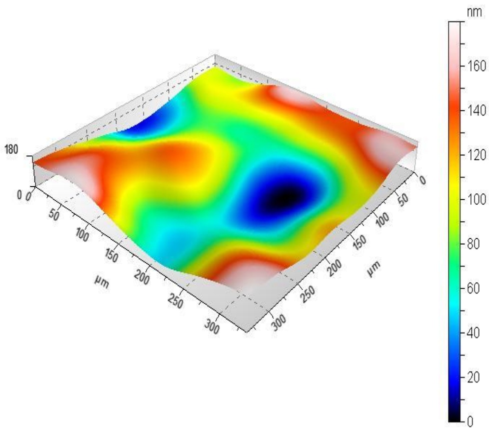

Fig. 3. Isometric view of the waviness surface of the anti-graffiti BO100-AGR coating system

The roughness of the BO100-AGR anti-graffiti coating system was measured using a TALYSURF CCI equipment. The roughness was measured in two directions perpendicular to each other. Then, the average value was calculated: Ra = 3.92÷4.04 nm. Samples of S355 steel after grinding with P80 abrasive paper, on which coatings were applied, had a roughness from 0.74 to 0.79 µm. Fig. 4 presents an example two-dimensional surface microgeometry measurement of the BO100-AGR anti-graffiti coating system. Table 1 presents the most important average roughness parameters of the tested coating system. Low value of roughness parameters also have influence on adhesion properties.

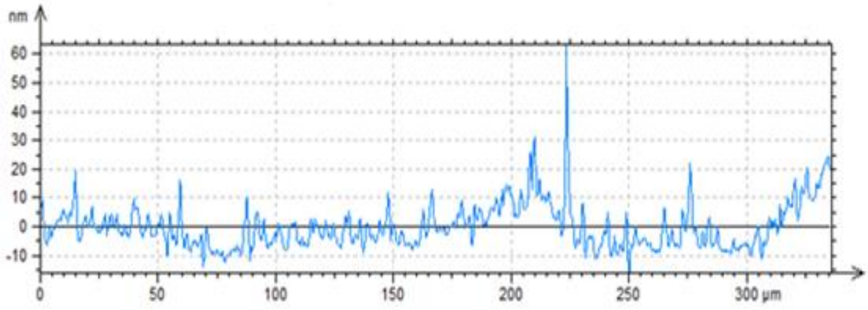

Fig. 4. View of roughness profile of BO100-AGR anti-graffiti clearcoat

Table 1
Results of roughness profile according to ISO 4287

Parameters of roughness	**Anti-graffiti coating system**
Rp [nm]	37.21
Rv [nm]	9.20
Rz [nm]	46.42
Rc [nm]	16.36
Rt [nm]	71.37
Ra [nm]	3.98
Rq [nm]	5.70
Rsk	2.08
Rku	12.94

A scratch test was conducted to test adhesion of the anti-graffiti coating systems without putty. Adhesion tests were conducted using 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 6.73 mm/min and a scratch length of 30 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 basing 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 2.

Table 2
Results of scratch adhesion tests

System	**Critical stylus load [N]**			**Mean value† [N]**
	Measurement			
	1	2	3	
BO100-AGR	41.95	47.35	47.15	45.48 ± 3.06

†scatter intervals estimated at 90% confidence level

From the obtained data it becomes evident that anti-graffiti coating system have good adhesion with the substrate material. The mean value of the critical force calculated from three measurements performed on the individual anti-graffiti coating system was 45.48 N. In addition, the low scatter of critical stylus loads indicate that the varnish layers are homogeneous and very tight.
The nanohardness and elastic modulus were investigated by nanoitender technique. This Measurement technology was possible due to the development of instruments that continuously measure force and displacement. In the measurement the load force of 3 mN and unload rating was 40 mN/min. Due to the type of material tested used creep about 3 seconds. The hardness is determined penetration depth of the indenter and a modulus of elasticity determined by the slope of the unload curve. Hardness measurements were carried out in several selected places on the surface of the paint coating. Fig. 5 shows a measurement curves that reflects the displacement of the bar as a function of force for a anti-graffiti coating system.

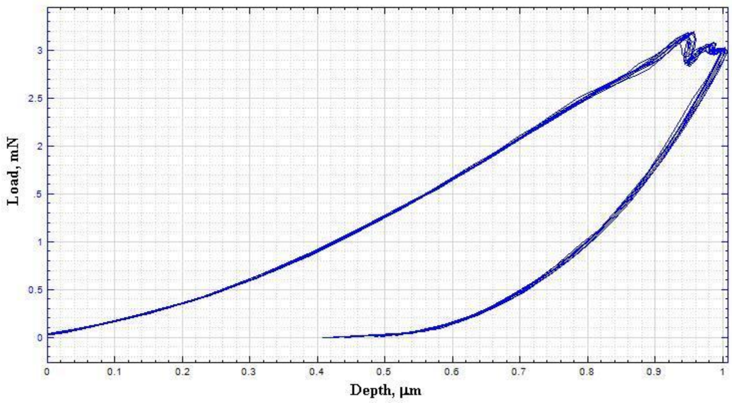

Fig. 5. Graphical interpretation of the indentation of the indenter in the material depending on load 3 mN and unload rate 40 mN/min

Practically all measuring curves overlap. This proves the accuracy and repeatability of measurements. On the basis of 10 measurements, the values of average hardness and elasticity modulus were determined and placed in Table 3. Table 3 contains the average values of hardness and elastic modulus together with the standard error.

Table 3
Value of hardness and modulus of elasticity with errors

System	Hardness [GPa]	Elastic modulus [GPa]
BO100-AGR	0.259 ± 0.004	2.900 ± 0.016

3. CONCLUSION

1. Analyzing the microstructure, it can be concluded that the thickness of anti-graffiti coating system is in the range of 2350-2450 µm. In addition, paint systems are free of pores and microcracks.
2. The Anti-graffiti BO100-AGR coating system show high hardness, low value of roughness parameters and good adhesion to the base material.

3. The high values of the slope coefficient of the surface of the Sku (kurtosis) indicate the low dispersion of the ordinate surfaces. The positive values of the asymmetry coefficient of the surface Ssk (skewness) show that making faces with a smooth surface without deep crack.
4. Anti-graffiti coating system is characterized by good mechanical properties.

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