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Analysis of the surface geometric structure of the anti-graffiti coating systems intended for rolling stock

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The paper presents the results of the properties of anti-graffiti coating systems for rolling stock. The determination was based on measurements of surface geometric structure and analysis of microstructure. The tests were carried out on the following anti-graffiti coating systems: XPC 60011, XPC 60012, XPC 60036, BO100-AGR. The above systems consisted of the following layers: corrosion epoxy primer, putty, primer filler, basecoat and clearcoats anti-graffiti. The coatings were applied to the sample with S355 steel using guns SATA. Because of its properties, anti-graffiti coating systems can be successfully used on rail vehicles.

KEYWORDS: anti-graffiti coating system, surface geometric structure, rolling stock

Introduction

During operation, varnish coatings are exposed to various types of factors that contribute to the loss of protective and decorative properties of these coatings. These are climatic factors, i.e. ultraviolet radiation, heat and humidity, as well as aggressive media and erosive particles [1-3].

Geometrical structure of the surface has a significant impact on many processes occurring in the surface layer and is one of the most important factors determining its qualitative values. It determines the operational properties of machine elements, e.g. friction conditions on the contact surfaces of cooperating elements, contact stresses, fatigue strength, corrosion resistance, tightness of joints, surface heat radiation or magnetic properties. Surface geometric structure (SGP) is defined as the set of all unevenness resulting from machining processes and material wear. Operational data prove that about 90% of all production shortages are due to mechanical damage to the surface, such as fatigue cracks, cracks caused by stress caused by corrosion, abrasive corrosion wear, corrosion or erosion.

The SGP is divided into components: surface roughness, surface undulation and shape deviations. This division is based on the proportions of height and wavelength of inequality. For comprehensive surface roughness characteristics, surface profile parameters - height, distance and hybrid (Ra , Rc , Rz , Rt , Rp , Rv , Rq , RSm , Rdq) - and functions (amplitude density curve, material share curve, spectral power density function) are used [4]. Parameters of surface stereometry most often used are Sa , Sz , Sp , Sv , Sq , Ssk , Sku [5]. Data on the principles of filtering the results of surface topography measurements are contained in the PN-EN ISO 25178-3: 2012 standard [6].

Numerous publications have been devoted to issues related to measurement methods and the assessment of surface roughness and waviness [7-12]. This paper presents results of SGP measurements and analysis of the microstructure of anti-graffiti coating systems for rolling stock.

Materials and processing parameters

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 cabin had the function of removing the excess of sprayed paint and was covered with foil and secured with a gel preventing settling the applied coating of impurities in the form of dust on the surface. In addition, it was equipped with a thermostat maintaining a constant temperature with the possibility of raising it to approximately 60 °C when drying samples of larger dimensions. For drying smaller samples, the WKL 64/70 climate cabin from Weiss Umwelttechnik GmbH was used, allowing temperature and humidity control.

The steel samples were protected with coating systems according to the diagram shown in fig. 1. The corrosion protection primer was not taken into account in the tests - due to its small thickness and low impact on the results of operational tests.

BO100-AGR varnish, developed at F.H. BARWA, was chosen for comparative tests, and three PPG varnishes: XPC 60011, XPC 60012, XPC 60036.

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.

Fig. 1. Diagram of the anti-graffiti coating system

Discussion of research results

■ **Microstructure analysis.** Samples for metallographic tests were excised using an ISOMET cutter. Then, the cut samples were embedded in thermosetting conductive resin BUEHLER KonductoMet using the BUEHLER SimplyMet 3000 inclusion press. Metallographic specimens were ground on a BUEHLER MetaServ 250 grinder with water papers with a grain gradation of 80 to 2500, each at an angle of 90° to the direction of the crack arose as a result of previous machining. Sample polishing was carried out on a BUEHLER EcoMet 250 grinder-polisher with pneumatically controlled clamp and rotational speed. The polishes were polished on MicroDiamant Mambo dresses in suspension Micro-Diamant O.P.S. $0.05\ \mu\text{m}$.

The obtained metallographic specimens were subjected to microscopic observations. JEOL scanning electron microscope, type JSM-7100F with field emission (SEM) was used for microstructure tests.

The photo (fig. 2) shows an example micro-structure of the XPC 60012 anti-graffiti coating system. Based on the results obtained, it was found that the minimum thickness of the anti-graffiti coating was about $37\ \mu\text{m}$, and the maximum thickness - about $41\ \mu\text{m}$. SEM analysis confirmed that the thickness of the base coat was between 19 and $20\ \mu\text{m}$. The primer coating had a thickness of about $30\ \mu\text{m}$ to $35\ \mu\text{m}$. The layer of putty had the greatest thickness - approximately $2210\div 2250\ \mu\text{m}$.

Fig. 2 shows clear boundaries between individual layers. The boundary between paint layers and putty is also clear. Paint coatings are free of pores and microcracks.

Analyzing the morphology of other anti-graffiti coating systems (XPC 60011, XPC 60036, BO100-AGR), it was found that the thicknesses of individual layers were comparable with the thicknesses of the XPC 60012 anti-graffiti coating layers. The thickness of the produced anti-graffiti coating systems was from about $2,300\ \mu\text{m}$ to about $2,400\ \mu\text{m}$.

Fig. 2. SEM microstructure of the cross-section of the XPC 60012 anti-graffiti coating system on a S355 alloy steel substrate: 1 - anti-graffiti varnish layer, 2 - base coat layer, 3 - underlay coat layer, 4 - putty

■ **Measurements of geometric structure of the surface.** SGP measurements were carried out in the Laboratory of Computer Measurements of Geometric Quantities at the Kielce University of Technology. They used an optical device Talysurf CCI, based on the method of coherent correlation interferometry, enabling measurement with resolution in the axis with up to $10\ \text{pm}$. The measurement result is recorded in a matrix of 1024×1024 measuring points, which with the lens with magnification of $\times 50$ gives a measured area of $0.33\ \text{mm} \times 0.33\ \text{mm}$ and a horizontal resolution of $0.33\ \mu\text{m} \times 0.33\ \mu\text{m}$.

Ten measurements were made of each sample with anti-graffiti coating systems and samples made of S355 steel, which allowed for averaging of the test results.

The analysis of the obtained surface stereometry using TalyMap Platinum software enabled the assessment of the geometric structure of the tested surfaces.

Fig. 3. Isometric image of the S-L (roughness) surface of the XPC 60012 anti-graffiti coating system

Fig. 4. Isometric image of the surface waviness of the XPC 60012 anti-graffiti coating system

Fig. 3 presents an example isometric image of the geometrical structure of the SL surface (roughness) of the XPC 60012 anti-graffiti coating system, obtained after using a $0.08 \text{ mm} \times 0.08 \text{ mm}$ Gauss filter, in fig. 4 - isometric image of surface waviness, and in fig. 5 - ordinate distribution with the load capacity curve of this coating system. In table And the most important averaged values of SGP parameters for S-L surfaces were summarized.

The tested anti-graffiti coating systems had averaged values of the average arithmetic deviation of the surface roughness from the average surface Sa of the order of $6.4 \div 24.6 \text{ nm}$. For S355 steel samples after grinding with P80 grained sandpaper, the Sa parameter was $1234.5 \div 1863.2 \text{ nm}$.

The Sa parameter is the basic amplitude parameter for quantitative assessment of the condition of the analyzed surface.

A similar trend in the results of measurements of anti-graffiti coating systems and S355 steel was observed for the mean square surface roughness deviation Sq , which was characterized by a strong correlation with the Sa parameter. As a result of the coating, the surface roughness was significantly reduced.

The occurring component of the surface waviness with a fairly significant proportion may result from the applied method of coating.

High values of the surface slope coefficient Sku (kurtosis) obtained for all tested coatings testify to the low dispersion of the surface ordinates. For each surface, positive values of the surface asymmetry coefficient Ssk (skewness) were obtained, which, however, prove that we are dealing with smooth surfaces without deep scratches. The smallest value of the Ssk parameter, measured for the XPC 60011 coating, results from the scratches appearing on its surface.

Fig. 5. Ordinate distribution and the surface load capacity curve S-L (roughness) of the XPC 60012 anti-graffiti coating system

TABLE I. Averaged values of parameters of the geometrical structure of the S-L surface (roughness)

Anti-graffiti coating system	XPC 60012	XPC 60036	XPC 60011	BO100-AGR
S_q , nm	17.9	28.5	65.1	9.1
S_{sk}	2.4	3.8	0.7	1.4
S_{ku}	35.2	29.1	18.0	19.5
S_p , nm	242.7	288.4	432.6	108.2
S_v , nm	283.7	129.1	370.6	112.8
S_z , nm	526.4	417.6	803.2	221.0
S_a , nm	11.3	15.6	24.6	6.4

Roughness profile parameters were calculated as average values from 102 profiles. Anti-graffiti coating systems were characterized by the R_a parameter value of $5.5 \div 23.3$ nm. Samples made of S355 steel (after grinding with P80 sandpaper), which were coated, had a roughness R_a of $706.4 \div 741.8$ nm.

An example profile of the BO100-AGR anti-graffiti coating system is shown in fig. 6. In tab. II, the most important averaged roughness profile parameters of the tested anti-graffiti coating systems are summarized.

Analysis of the presented results (tab. II) confirms that a very important factor influencing the geometrical structure of the coating is the proper preparation of the base material. Although the roughness of the surface protected by the coating is much lower compared to the roughness of the starting material, however, traces of the previous machining, which was grinding, can be seen on the isometric images of the S-L (roughness) surfaces of the tested coatings.

Fig. 6. Example of the roughness profile of the BO-100 AGR anti-graffiti coating system

TABLE II. Averaged roughness profile parameters

Anti-graffiti coating system	XPC 60012	XPC 60036	XPC 60011	BO100-AGR
R_p , nm	95.8	194.2	319.4	57.5
R_v , nm	62.4	115.1	242.0	25.6
R_z , nm	158.2	309.3	561.5	83.1
R_c , nm	54.1	94.6	386.0	26.4
R_t , nm	308.2	485.7	961.9	197.7
R_a , nm	10.0	16.5	23.3	5.5
R_q , nm	16.3	30.7	57.2	9.3
R_{sk}	1.1	2.1	2.2	1.6
R_{ku}	21.4	23.0	32.8	18.6
R_{Sm} , μm	11.4	8.9	30.9	10.6
R_{dq} , $^\circ$	1.7	3.1	5.4	0.3

Summary

On the basis of the research carried out and the results obtained, the following conclusions can be drawn:

- A very important factor influencing the geometrical structure of the coating system is the proper preparation of the base material. Painting systems are characterized by less roughness in relation to the base material (by two orders of magnitude). In addition, the obtained isometric images of coating systems show traces of the previous treatment, which was grinding.
- Thickness of anti-graffiti coating systems is in the range of 2300÷2400 μm . Painting systems are free of pores and micro-cracks.

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