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Mechanical Properties of Anti-Graffiti Coating Systems used in the Railway Industry

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Abstract. The paper presents comparative tests results of selected properties of anti-graffiti paint systems for rolling stock industry. The system consists of a high solid corrosion protection primer, putty, filler, basecoat and anti-graffiti clearcoat. The research was based on an anticorrosion coatings system with a transparent layer with reduced adhesion of each subsequent types of contamination. The results of the research focus on the analysis of microstructure and measurements of nanohardness and adhesion.

Introduction

By applying new engineering materials or protective coatings, it is possible to improve the functional properties of machine parts so that they are resistant to corrosion, abrasion and erosion, and possess high fatigue strength [1-10].

The new materials, for instance alloy steels, are usually costly, which is undesirable, because the higher the cost of the material, the higher the price of a finished product. However, if an element is to be subjected to high loads, then strength rather than cost is a primary factor.

Applying protective coatings to machine parts is economically justifiable if the wear is local or if the coating material is expected to display properties different from those of the substrate.

Paint systems for rolling stock must fulfill mechanical and qualitative properties to protective and decorative properties maintenance longer on the vehicle. These requirements include adhesion, resistance to weather conditions (humidity, UV, corrosion) as well as hardness and specialized properties such as anti-graffiti. In addition to the above-mentioned requirements, as well as ease of application and operation, coating systems intended for rolling stock must also have adequate fire performance [11].

The paper presents comparative tests results of selected mechanical properties of anti-graffiti coating systems for rolling stock industry.

Materials

Coatings were applied with a SATA spray gun on the S355 carbon steel; before the application the surface of the steel was polished with 80-grit sandpaper. The coating systems consisted of the following layers: anti-corrosion epoxy primer, repair filler, primer filler, basecoat and anti-graffiti XPC60011, XPC60012, XPC60036, BO100-AGR clearcoats. Each layer was applied and dried in

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accordance with the requirements of technological cards. The prepared samples were conditioned at 23 °C and 50 % humidity for minimum 7 days in order to perform tests on dry coating.

Microstructure analysis

A microstructure analysis was conducted for anti-graffiti coating systems using the *JEOL JSM-7100F* scanning electron microscope with field emission and the Hirox KH-8700 light microscope.

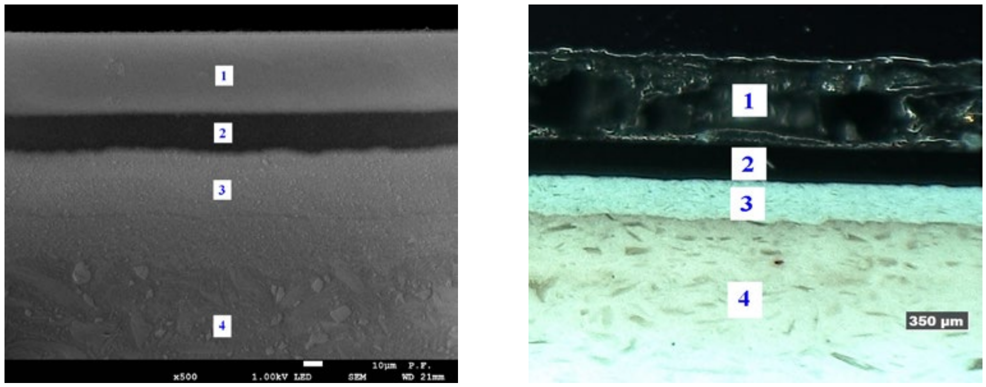

Fig. 1. SEM (left) and LM (right) micrographs of the polished cross-section throug a anti-graffiti XPC 60012 coating system on S355 carbon steel substrate: 1- anti-graffiti layer, 2 - base layer, 3 - undercoat layer, 4 - putty

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 a clear boundary between the varnish layers and the putty. Also, the varnish layers are free of pores and microcracks.

Adhesion tests

A scratch test was conducted to test the adhesion of the anti-graffiti coating systems without a putty. The adhesion tests were conducted using a 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 the 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.

Table 1. Results of scratch adhesion tests

System	Critical stylus load [N]			Mean value† [N]
	Measurement			
	1	2	3	
XPC 60011	45.10	47.05	46.90	46.35 ± 1.09
XPC 60012	47.45	46.95	42.55	45.65 ± 2.70
XPC 60036	45.15	46.05	43.85	45.02 ± 1.11
BO100-AGR	41.95	47.35	47.15	45.48 ± 3.06

†scatter intervals estimated at 90% confidence level

It becomes evident from the obtained data that anti-graffiti coating systems have good adhesion with the substrate material. The mean value of the critical force calculated from three measurements

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performed on the individual anti-graffiti coating systems was from 45.02 to 46.35 N. In addition, a low scatter of critical stylus loads indicates that the varnish layers are homogeneous and very tight.

Nanoindentation of anti-graffiti coating systems

Production of coatings with the required properties is a major research challenge. In the manufacturing process it is necessary to indicate controllable parameters and properties expected from the resulting coating. A multitude of controlled parameters and their values make large number of combinations effects costs high. In our case, it is the hardness and modulus of elasticity of paint coatings.

The hardness and elastic modulus were investigated by the 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 equalled 3 mN and unload rating was 40 mN/min. Due to the type of material tested used creep of about 3 seconds. The hardness is determined by the penetration depth of the indenter and the 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. 1 shows measurement curves that reflect the displacement of the bar as a function of force for an anti-graffiti XPC 60012 coating system.

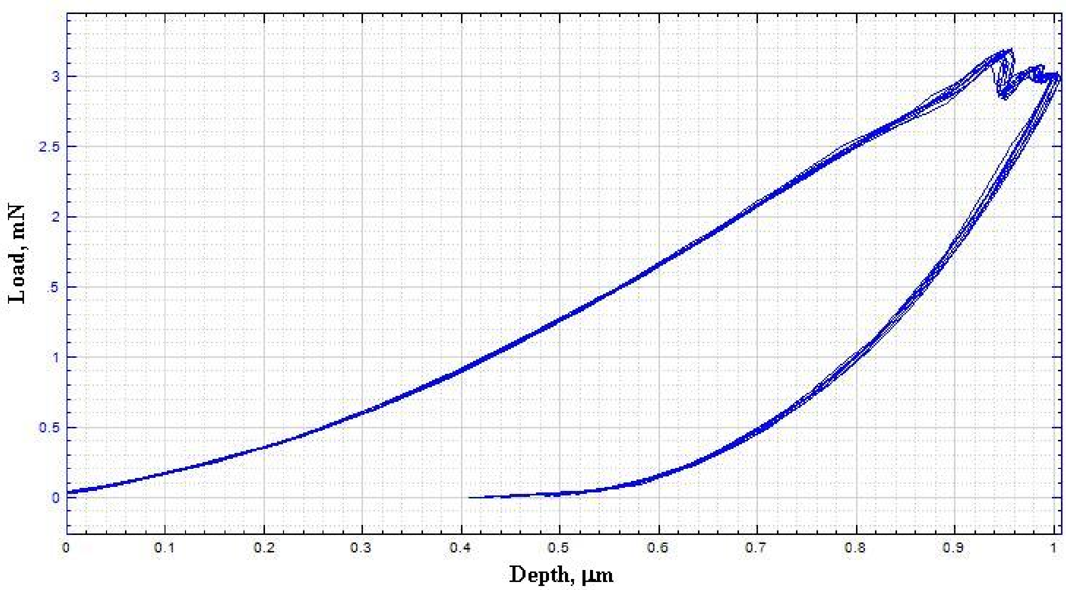

Fig. 1. Graphical interpretation of the indentation of the indenter in the material depending on the load of 3 mN and unload rate of 40 mN/min

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 2.

As shown in Table 2, four coating systems were tested. 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

System	Hardness [GPa]	Elastic modulus [GPa]
XPC 60012	0.229 ± 0.005	2.700 ± 0.050
BO100-AGR	0.259 ± 0.004	2.900 ± 0.016
XPC 60011	0.265 ± 0.004	2.843 ± 0.017
XPC 60036	0.258 ± 0.003	2.842 ± 0.022

Summary
In the present study, it was clearly presented that the anti-graffiti coating systems are characterized by good mechanical properties. They have a homogeneous structure and are free of defects.

Further research will be targeted at the determination of corrosion and erosion resistance. With deeper investigation on the impact of particular factors, it should include statistical multivariate analyzes [12, 13], including both, RSM (the response surface methodology) [14] as well as a factorial modeling [15] and also methods of the image analysis [16-20] to detailed investigate scratched surfaces.

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