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RESEARCH INTO THE POSSIBILITY OF USING THE NEW GENERATION PAINT SYSTEMS FOR THE ANTICORROSION PROTECTION OF STEEL STRUCTURES

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Preliminary notes

The anticorrosion protection is one of the fundamental technologies in the process of building and assembly of industrial and other plants. The aim of this paper is to research the application of the new generation paint systems for anticorrosion protection in a highly corrosive atmosphere (C5 category). The paint systems with standard solvent and with reduced content of volatile organic compounds were observed. The samples were protected with different paint systems and then tested for resistance to corrosion in aggressive environment (QUV weathering). Testing showed the possibilities in the use of the new generation paint systems for anticorrosion protection of steel structures. The research showed that the application of coatings with reduced content of volatile organic compounds can give constant quality corrosion protection to steel structures.

Key words: *corrosion*, *coatings with reduced content of volatile organic compounds, organic coatings, solvents*

Istraživanje mogućnosti primjene premaza nove generacije u zaštiti čelične konstrukcije od korozije

Prethodno priopćenje

Zaštita od korozije je jedna od osnovnih tehnologija u procesu gradnje i montaži industrijskih i inih postrojenja. U radu su istraživani sustavi premaza koji se preporučuju za atmosferu visoke korozivnosti (kategorija C5). Promatrani su premazi sa standardnim otapalom i premazi s reduciranim sadržajem hlapivih organskih spojeva. Uzorci su zaštićeni različitim sustavima premaza, a nakon toga ispitani su na otpornost prema koroziji u agresivnom mediju ubrzanim ispitivanjima u vlažnoj komori kako bi se što točnije napravila razlika između pojedinih sustava. Ispitivanjem su pokazane mogućnosti uporabe vodotopivih premaza nove generacije za zaštitu čeličnih konstrukcija od korozije. Istraživanja su pokazala da primjena tehnologije na bazi vodotopivih veziva štite od korozije ujednačenom kvalitetom čelične konstrukcije.

Ključne riječi: *korozija, vodotopivi premazi, organski premazi, otapala*

1 Introduction
Uvod

The USA direct costs caused by corrosion are assessed at US $ 276 billion i.e. 3 % gross domestic product or US $ 1 000 per capita. Possible savings are estimated to be 25-35 % [1].

The purpose of protective paints and coatings is to long enough protect from detrimental effects of environment the structural material upon which they have been deposited [2, 3, 4]. The protective function of paints and coatings is achieved first of all by separating the substrate material from environment so that they themselves have to be stable and durable as to withstand the conditions of exploitation [1, 2, 5]. Thus the foremost technical property of paints and coatings is their durability i.e. service life [6, 7].

European legal legislations strictly determine the classification, evaluation and control of all the risk parameters that can affect the health, safety and environment and they also limit the market for dangerous substances and mixtures. For that reason, the products and their application are to correspond with the existing legislation [6]. Thus it is of great importance that the new coating systems be quantified according to the existing regulations and that they provide the same quality of performance and life as the systems they replace.

2 Eksperiment
Eksperimentalni dio

The testing pieces are made of non-alloyed structural steel **S355J2** in accordance with the DIN EN 10025-2:2005 standard. The testing piece plates were of size 10 × 15 × 0,48 cm. In accordance with HRN EN ISO 8504-2:2000 the testing piece surface was then treated to the degree of cleanliness Sa 2.5 [6]. The coat systems were applied to the treated pieces by spraying and they were then left to dry for seven days. Before testing a 5 cm notch was made by a knife on all testing pieces. The four pieces thus prepared were subjected to 480 h testing in a humidity chamber i.e. one sample of each particular system.

The cyclic test in the humidity chamber consisted of alternate exposure to ultraviolet rays and of condensation. In the preparation phase the testing pieces' surfaces were treated by a jet of an abrasive according to the HRN EN ISO 8504-2:2000 standard.

The corrosion testing in a humid-warm atmosphere was carried out in accordance with the HRN EN ISO 6270-2:2005 standard in a Q-LAB type QUV Accelerated Weathering Tester, so called humidity chamber. The testing in the water vapour atmosphere served to determine the behaviour of the material exposed to the moisture saturated warm air in the presence of condensed water in the room atmosphere. Testing conditions are given in Table 1.

The testing was performed at a constant temperature of 40 °C, therefore the condensation procedure as well. The condensation conditions with exposure to the UV rays, the temperature, the amount of the UV radiation, the duration of radiation and the duration of the condensation cycle in the chamber were programmed.

***Table 1** Conditions of testing in the humidity chamber*
***Tablica 1.** Uvjeti ispitivanja u vlažnoj komori tipa QUV (Accelerated Weathering Tester)*

Testing atmosphere	Constant atmosphere with condensed water
Test cycle	8 h UV-radiation/16 h condensation
UV condensation	480 h
UV lamp	UVA -340
UV temperature	60 °C
Condensation temperature	40 °C
Moisture condensation	100 % rH

2.1 Testing of the coating properties
Ispitivanja svojstava premaza

Mechanical properties of the pieces were tested in conformity with the European standards: thickness of dry film (HRN EN ISO 2808:2007), hardness according to (HRN EN ISO 1522:2006), elasticity (HRN EN ISO 1520:2006), gloss (HRN EN ISO 2813:1997), adhesion (HRN EN ISO 2409:2007), evaluation of the surface degree of blistering (HRN EN ISO 4628-2:2003), evaluation of the surface degree of rust (HRN EN ISO 4628-3:2003), evaluation of the flaking and corrosion around the notch (HRN EN ISO 4628-8:2005) and of nuances (by reference specimen).

3 Results
Resultati ispitivanja

3.1 Testing results of the samples' properties
Rezultati ispitivanja svojstava uzoraka

One set of test plates with samples (4 plates) was left in the mechanical properties control laboratory. After 6 months the properties were tested (dry film thickness, hardness, elasticity, gloss, adhesion). The results of testing in accordance with the standards for each coating system are shown in Table 3.

Dry film thicknesses of the samples differ due to the technique of coat depositing, the density of the material, the viscosity of the material and the influence of human factor.

The appearance of samples on control plates after 6 months in laboratory (ϑ=22 ºC and rH=68 %) is shown in Figure 1. The samples with the applied coating systems 1, 2, 3, 4, are shown respectively.

Following the performed measurements of the dry film thickness (DSF) of each sample after 6 months in the laboratory according to HRN EN ISO 2808 by magnetic method using Elcometer 456, the results were computer processed by the *Elcometer Software* program. The measurements were carried out 10 times on each sample, written down in Table 4 and their mean value was statistically determined.

***Table 2 Acceptance** criteria by standards: HRN EN ISO 12944, HRN EN ISO 6270-2 and HRN EN ISO 9227*
***Tablica 2.** Kriteriji prihvatljivosti po standardima: HRN EN ISO 12944, HRN EN ISO 6270-2 i HRN EN ISO 9227*

Testing	HRN EN ISO 12944 requirements after testing
HRN EN ISO 6270-2:2005	
Degree of blistering testing and evaluation of degree of rust on a test piece plate after testing	Changes according to HRN EN ISO 4628-2:2003 d0- S0 HRN EN ISO 4628-3:2003 Ri 0
Rust on damaged area	Damage testing according to HRN EN ISO 4628-8, d < 3 mm
HRN EN ISO 9227:2006	
Testing of blistering and evaluation of rusting on the test piece plate after testing	Changes according to: HRN EN ISO 4628-2:2003 0 (S0) HRN EN ISO 4628-3:2003 Ri 0 (d=density and S=size R rust)
Rust on damaged area	Damage testing according to: HRN EN ISO 4628-8:2005, d < 1 mm

***Table 3** Testing results of corrosion characteristics of samples after six months in the laboratory* (ϑ=22 ºC *and* rH=68 %)
***Tablica 3.** Rezultati ispitivanja korozijskih svojstava uzoraka poslije šest mjeseci u laboratoriju* (ϑ=22 ºC *and* rH=68 %)

Testing according to standards	Sample 1 ZPE base/PU covering coat	Sample 2 ZPE base/PU water covering coat	Sample 3 ZPE multi-layered base/PU multi-layered covering coat	Sample 4 ZPE dispersion/PU water covering coat
Dry film thickness HRN EN ISO 2808:2007	79-84 μm	111-145 μm	99-108 μm	91-119 μm
Hardness HRN EN ISO 1522:2006	163 s	106 s	112 s	80 s
Elasticity HRN EN ISO 1520:2006	1,5	1,8	1,5	5,5
Gloss HRN EN ISO 2813:2006	80,9/93,4	63,2/81,5	32,4/77,1	77,5/87,1
Adhesion (Gt 2 mm) HRN EN ISO 2409:2007	0	0	0	0
Key: ZPE – zinc phosphate epoxy PU – polyurethane				

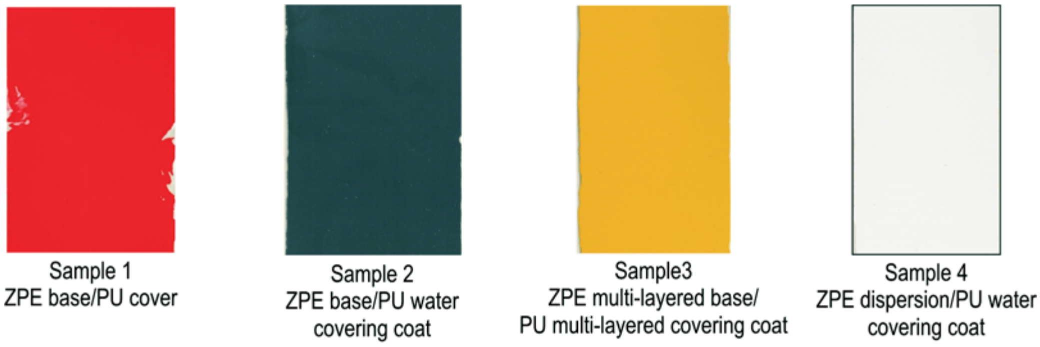


Figure 1 *Appearance of samples after six months testing in the laboratory (ϑ=22 ºC and* rH=68 %)
Slika 1. *Izgled uzoraka poslije šest mjeseci ispitivanja u laboratoriju* (ϑ=22ºC i rH=68 %)

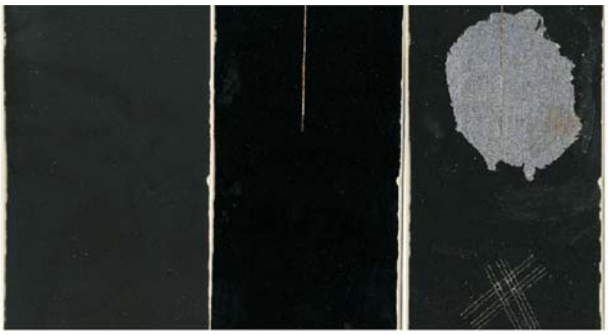
Table 4 *Test results of dry film thickness (DSF) measured by magnetic method with ELCOMETER 456*
Tablica 4. *Rezultati ispitivanja debljine suhog filma (DSF) izmjerene magnetskom metodom uređajem ELCOMETER 456*

	Dry film thickness (DSF), µm			
Dry film thickness	Sample 1 ZPE base/PU cover	Sample 2 ZPE base/PU water covering coat	Sample 3 ZPE multi-layered base/PU multi-layered covering coat	Sample 4 ZPE dispersion/PU water covering coat
DSFm.v., µm	83,1	125,8	100	104,6
Key: ZPE – zinc phosphate epoxy, PU – polyurethane				

3.2 Testing results of the samples in humidity chamber
Rezultati ispitivanja uzoraka u vlažnoj komori

One set of test plates with samples (4 plates) was placed in humidity chamber for testing. After 480 hours in the humidity chamber, all samples were tested for dry film thickness, gloss and adhesion and the corrosion tests were also performed. The results of testing according to the standards for each particular coating system are shown in Table 5. In Figures 3, 4, 5 and 6 the samples are shown in such a way that the first plate represents the control plate, the second one represents the appearance of the plate after 480 hours testing in the humidity chamber while the third plate represents the result of the cross-cut test (hardness test).

The dry film thicknesses of test pieces differ due to the coat deposition technique, the density of the material, the viscosity of the material and the influence of human factor.

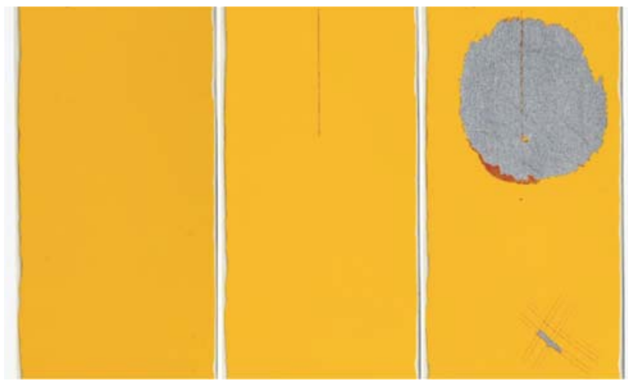


1 2 3

Figure 3 *Comparison of sample 2 (zinc phosphate epoxy basic coat/water polyurethane covering coat) after six months in the laboratory (1st sample) and after 480 hours testing in the QUV chamber (2nd sample), and the result of cross-cut test (3rd sample)*
Slika 3. *Usporedba uzorka 2 (cink fosfat epoksidni temeljni premaz/poliuretanski pokrivni premaz vodeni) nakon 6 mjeseci u laboratoriju (1. pločica) i 480 h ispitivanja u vlažnoj komori (2. pločica), te prikaz mrežice nakon ispitivanja tvrdoće (3. pločica)*

1 2 3

Figure 2 *Comparison of sample1 (zinc phosphate epoxy basic coat/polyurethane covering coat) after six months in the laboratory (1st sample) and after 480 hours testing in the QUV chamber (2nd sample), and the result of cross-cut test (3rd sample)*
Slika 2. *Usporedba uzorka 1 (cink fosfat epoksidni temeljni premaz/poliuretanski pokrivni premaz) nakon 6 mjeseci u laboratoriju (1. pločica) i poslije 480 h ispitivanja u vlažnoj komori (2. pločica), te prikaz mrežice poslije ispitivanja tvrdoće (3. pločica)*



1 2 3

Figure 4 *Comparison of sample 3 (zinc phosphate epoxy multi-layered basic coat/polyurethane multi-layered covering coat) after six months in the laboratory (1st sample) and after 480 hours testing in the QUV chamber (2nd sample), and the result of cross-cut test (3rd sample)*
Slika 4. *Usporedba uzorka 3 (cink fosfat epoksidni temeljni premaz debeloslojni/poliuretanski pokrivni premaz debeloslojni) nakon 6 mjeseci u laboratoriju (1. pločica) i 480 h ispitivanja u vlažnoj komori (2. pločica), te prikaz mrežice nakon ispitivanja tvrdoće (3. pločica)*

Table 5 *Testing results in the humidity chamber (480h)*
Tablica 5. *Rezultati ispitivanja u vlažnoj komori (480 h)*

Testing STANDARD	Sample 1 ZPE base/PU cover	Sample 2 ZPE base/PU water covering coat	Sample3 ZPE multi-layered base/PU Multi-layered covering coat	Sample 4 ZPE dispersion/PU water covering coat
Dry film thickness HRN EN ISO 2808:2007	69-78 μm	80-107 μm	81-105 μm	94-107 μm
Gloss 20°/60° HRN EN ISO 2813:1997	75,7/79,1	58,2/74,3	29,2/73,4	68,4/83,2
Adhesion (Gt 2mm) HRN EN ISO 2409:2007	0	0	0	0
Surface blistering HRN EN ISO 4628-2:2003	d0/S0	d0/S0	d0/S0	d0/S0
Notch blistering HRN EN ISO 4628-2:2003	d1/S1	d3/S1	d1/S1	d4/S1
Surface corrosion HRN EN ISO 4628-3:2003	Ri 0	Ri 0	Ri 0	Ri 0
Notch flaking HRN EN ISO 4628-8:2005	1 mm	2 mm	1 mm	2 mm
Notch corrosion HRN EN ISO 4628-8:2005	0 mm	0 mm	0 mm	0 mm
Nuance by reference specimen	satisfactory	satisfactory	satisfactory	satisfactory
Key: ZPE – zinc phosphate epoxy, PU - polyurethane				


1 2 3

Figure 5 *Comparison of sample 4 (zinc phosphate epoxy dispersion/water polyurethane covering coat) after six months in the laboratory (1st sample) and after 480 hours testing in the QUV chamber (2nd sample), and the result of cross-cut test (3rd sample)*
Slika 5. *Usporedba uzorka 4 (cink fosfat epoksidna disperzija/poliuretanski pokrivni premaz vodeni) nakon 6 mjeseci u laboratoriju (1. pločica) i 480 h ispitivanja u vlažnoj komori (2. pločica), te prikaz mrežice nakon ispitivanja tvrdoće (3. pločica)*

4 Discussion
Rasprava

The dry film thickness of all tested coat systems was constantly diminishing while the mean value of the dry film thickness was being tested (Table 5).

The coat hardness test showed that the given values were on the same level except for the water-based covering coat (sample 4, Table 3) whose measured hardness was less than the designed value.

The coat elasticity of all samples was satisfactory (Table 3), only sample 4 had a somewhat poorer result (water-based polyurethane covering coat).

The results of adhesion tests were satisfactory for all samples.

The gloss of all systems' cover coats was diminished due to the sensitivity of chemical bonds in polymer coatings to the UV light and to the short wavelengths in particular.

5 Conclusion
Zaključak

After 480 hours testing in the humidity chamber all coating systems showed the satisfactory surface protection properties (Figures 3, 4, 5 and 6). The only exception is sample 2, protected by the zinc phosphate epoxy base and polyurethane water-based covering coat, with the corrosion products visible on the surface (Figure 4). It means that the surfaces protected by this system have to be additionally protected. Samples 1, 2 and 3 showed good results in corrosion protection although the intensity of corrosion is nevertheless considerably higher in sample 2 with water-based polyurethane covering coat. The gloss of all samples was significantly changed subsequent to the testing in aggressive atmosphere.

The researches showed the possibility of application of both the coatings with high content of solid substances and the water-based coatings for the protection of steel structures. In all conducted tests these coating systems showed equal corrosion stability and the results are compatible with the most durable classical solvent based coatings.

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