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Techical Article

Anticorrosion Performance of eco-friendly Paint Coatings

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Abstract: Principal solvent and diluent used in water-soluble paints is water, although they can contain minimum quantities of potentially hazardous organic solvents. Corrosion protection performance of this type of paints is still low compared to the organic solvent-based paints. In this paper, monitoring of dry coating thickness and adhesion, as well as salt chamber and field testing were performed in order to test coating quality. Organic solvent-based paints show superior performance compared to the water soluble paint coatings.

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INTRODUCTION

Implementation of environmental legislatives and laws that regulate allowed quantities of organic solvents in waste effluents led to comprehensive modifications of composition of protective coatings. In order to produce safe products, manufacturers were forced to develop new formulations with reduced content of organic solvent, eventually minimizing it to trace levels (Stojanović, Alar, Juraga, 2012). Introduction of so-called eco-friendly coatings have two main goals: to reduce fraction of organic components that can be released in environment and to avoid protection pigments that contain heavy metals. Water-soluble coatings, for which water is the main solvent and diluent, contain minimum quantities of environmentally hazardous organic solvents and heavy metals. Application of these coatings can be beneficial because it provides reduced emissions of hazardous organic substances in the atmosphere, as well as release of heavy metals, especially lead and chromium, into the environment (Rašković, Samardžić, Milošević, 2013).

Beside its potential benefits, improvement of protection performance of water-soluble coatings is subject open for further investigations. Although most coatings of this type provide rather good protection performance, even in very aggressive environments, it is still considerably below organic solvent-based coatings. Also, technology, which is new in industrial applications, should be adapted for ordinary user.

In order to ensure good corrosion protection of steel, one must be familiar with the technology of paint application. Even the most expensive and high quality coatings could be damaged and their performance impaired by incompetent handling before, during and after application.

Application of coating includes following procedures:

1. Preparation of substrate – cleaning and conditioning of substrate surface;
2. Application of coating;
3. Finishing (drying and hardening of coating).

One of the potential consequences of improperly performed process can be reduced protection performance, even if the coating system is properly

chosen. Pretreatment of substrate ensures good adhesion of primary layer on the metal, which is important in order to prevent detachment of coating during mechanical stress of the interface. Poor protection performance is often consequence of poor substrate pretreatment.

EXPERIMENTAL PART

Protective paints were coated on steel substrates prepared and provided by company Pretis d.d. One group consisted of phosphatized steel samples while the other one was used without phosphatizing pretreatment. Three coating systems were used (one organic and two water-based, from different manufacturers) in the following ways:

- Volatile organic solvent based coating, applied in two layers – as primary (base) and finishing layer – on both phosphatized and unphosphatized samples;
- Water based coating, also applied in two layers on both types of samples;
- Water based coating, applied in one layer („2 in 1“ system) on both types of samples.

Measurements of film thickness and adhesion, as well as salt chamber and field tests were performed after coating process.

Materials

Substrates used in this work were made from rolled, soft annealed and 100% cleaned steel, according to EN 10204 standard. Steel was coded as Č.1737 VP.

Three coating systems (paints) were used: one based on organic solvent and two based on water. Paints were obtained from two different manufacturers.

First coating system consisted of: 1. quick-drying protection base, formulated from modified alkyd resin and protection pigments, diluted by synthetic solvent; 2. quick-drying protection lacquer with pigments, based on modified alkyd resins, diluted by nitro solvent.

Second coating system was acrylic dispersion base paint with pigments, diluted by water. This paint is designed for protection of iron and steel surfaces in both open and closed spaces and it can be considered as eco-friendly.

Third coating system was paint based on aqueous dispersion of acrylic binders. This protection paint has metallic color and is also used for decorative purposes.

Coating test methods

Measurement of dry coating thickness

Measurement of dry coating thickness was performed by magnetic method with DIGI-DERM 2100 tester, according to EN ISO 2360 standard. Five measurements were performed on every sample.

Dry coating adhesion test

Coating adhesion was tested by cross-hatch test method, according to EN ISO 2409 (ISO 2409:2007). In this test, squared hatch is incised in coated surface using the special knifes, while experimental setup is adjusted according to dry film thickness:

- below 60 μm – knife separation 1 mm
- 60 – 120 μm – knife separation 2 mm

After incision and brushing, transparent duct tape was pressed over the hatch. After removing the tape, fraction of free surface was determined. Depth of incision should be adjusted so that knifes are able to penetrate the film all to the substrate surface.

Salt chamber test

Salt chamber testing is performed in order to simulate the exposure of samples to marine atmosphere. Tests were performed in salt chamber JW-150-NS, in company SurTec Eurosjaj d.o.o. Konjic, according to EN ISO 9227 standard (ISO 9227:2006). Salt chamber used in this investigation as well as experimental setup are shown in Figure 1.



Figure 1. Salt chamber front panel and position of tested samples during the test

Parameters for salt chamber testing are given in table 1.

Table 1. Test parameters

Test parameters	Salt spray test according to EN ISO 9227
Temperature	(35±2) °C
Average collected quantity on horizontal collector of 80 m^2 area	(1,5±0.5) mL/h
NaCl concentration (collected solution)	(50±5) g/L
pH value of collected solution	6,5 do 7,2
Conductivity of distilled water	Max. 20 μS/cm (25±2)°C

Field testing

Field corrosion tests were performed in atmospheric conditions, in order to determine the effects of environment on coating durability and protection performance. Samples have been mounted on inclined (45° from the surface) plate and placed near the main road in Semizovac, from 01.07.2012. to 01.10.2012.

Sample preparation

Total number of thirty 100×50 mm steel samples were prepared for experimental tests. Samples were split in two lines (phosphatized and nonphosphatized) and coated with described paints.



Figure 2. Steel substrate



Figure 3. Substrate surface surface after phosphatizing coating

Air spray coating has been carried out in company Pretis d.d. (Fig. 4. and 5.). Pretreated samples and paints were keept at room temperature prior to the coating process.



Figure 4. Paintshop in company Pretis d.d. (samples ready for painting)

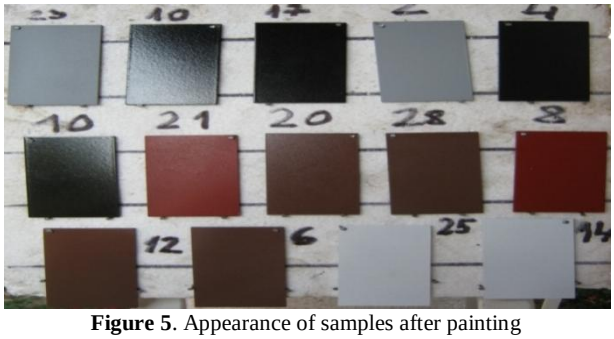


Figure 5. Appearance of samples after painting

RESULTS AND DISCUSSION

Dry coating thickness

Five measurements were performed on every sample. Measured values obtained for organic solvent based coatings are shown in Table 2., while those for water based coatings are presented in Tables 3. and 4.

It is obvious, from the results presented above, that thicker coatings were obtained from organic solvent based paints, compared to those obtained from water based paints.

Table 2. Film thicknesses for organic solvent based coatings

Film thickness / μm							
Phosphatized samples				Nonphosphatized samples			
Sample	Min. thickness	Max. thickness	Average	Sample	Min. thickness	Max. thickness	Average
1(FO)T	45,10	59,00	53,13	1(BFO)T	47,60	52,40	50,23
2(FO)T	48,50	54,10	52,17	2(BFO)T	58,70	75,80	65,20
3(FO)TP	107,40	112,40	110,10	3(BFO)TP	110,00	123,50	117,30
4(FO)TP	110,20	122,00	116,53	4(BFO)TP	115,00	134,00	125,20
5(FO)P	65,40	70,00	67,83	5(BFO)P	40,40	52,00	46,33
6(FO)P	73,50	80,40	76,43	6(BFO)P	48,30	56,90	52,13

Table 3. Film thicknesses for water based coatings

Film thickness / μm							
Phosphatized samples				Nonphosphatized samples			
Sample	Min. thickness	Max. thickness	Average	Sample	Min. thickness	Max. thickness	Average
1(FV1)T	27,00	34,20	30,33	1(BFV1)T	24,90	35,70	29,40
2(FV1)T	30,50	34,70	32,77	2(BFV1)T	25,60	32,30	28,70
3(FV1)TP	54,30	69,00	60,73	3(BFV1)TP	45,80	63,20	56,03
4(FV1)TP	52,80	60,80	56,03	4(BFV1)TP	49,40	65,00	57,96
5(FV1)P	40,50	43,30	42,00	5(BFV1)P	28,90	36,50	32,96
6(FV1)P	41,00	46,30	31,33	6(BFV1)P	35,90	41,40	38,50

Table 4. Film thicknesses for water based coatings, system 2 in 1

Film thickness / μm							
Phosphatized samples				Nonphosphatized samples			
Sample	Min. thickness	Max. thickness	Average	Sample	Min. thickness	Max. thickness	Average
1(FV2)TP	32,30	42,30	36,80	1(BFV2)TP	28,40	35,00	31,30
2(FV2)TP	35,00	40,10	37,70	2(BFV2)TP	25,00	35,80	31,26

Dry coating adhesion

Coating adhesion was tested by cross-hatch test method, according to EN ISO 2409 (ISO 2409:2007). Samples tested by this method were the same as the samples used for field testing. One group of samples was tested immediately after painting and used as a reference, while the other group consisted of samples that were exposed in atmosphere between 14.06.2012. and 24.10.2012.

Samples that were tested immediately after painting are:

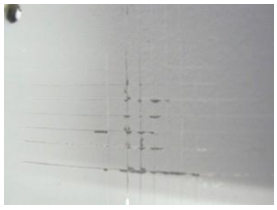
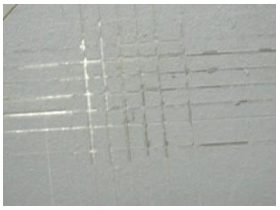
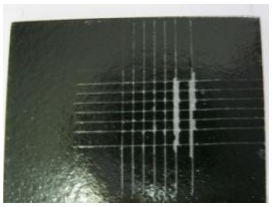
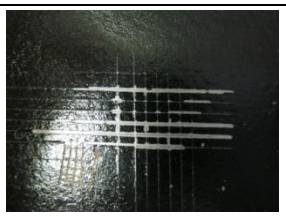
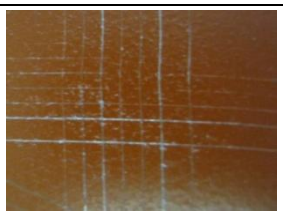
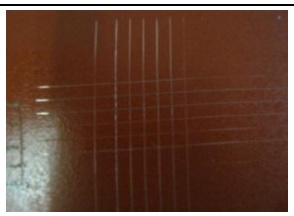
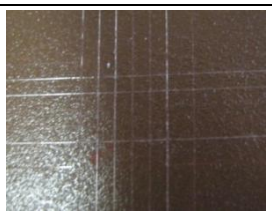
- 19(FO)T; 1(BFO)T
- 30(FO) TP; 3BFO)TP
- 22(FV1)T; 7(BFV1)T
- 18(FV1)TP; 5(BFV1)TP
- 29(FV2)TP; 15(BFV2)TP

Samples that were tested after field testing are:

- 23(FO)T; 2(BFO)T
- 16(FO)TP; 4(BFO)TP
- 21(FV1)T; 8(BFV1)T
- 20(FV1)TP; 6(BFV1)TP
- 25(FV2)TP; 14(BFV2)TP

Experimental results and adhesion ratings are presented in Tables 5. and 6.

Table 5. Adhesion ratings according to EN ISO 2409 standard (samples after painting)

Adhesion testing after coating			
Sample	Sample appearance	Coating type	Adhesion rating
19		- phosphate layer - base layer	2
1		- base layer	2
30		- phosphate layer - base layer - finishing layer	3
2		- base layer - finishing layer	3
22		- phosphate layer - base layer	1
7		- base layer	0
18		- phosphate layer - base layer - finishing layer	0
5		- base layer - finishing layer	1

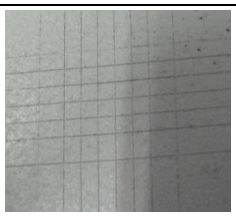
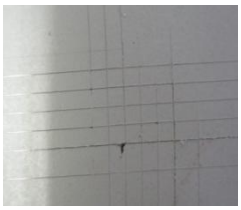
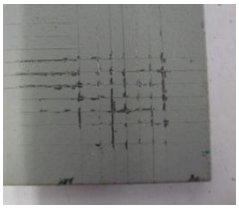
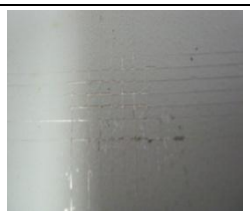
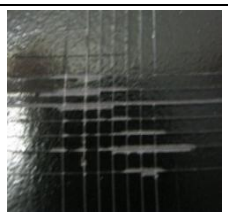
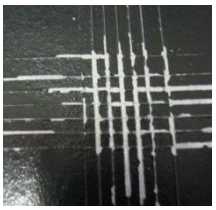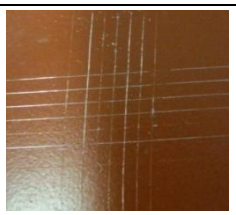
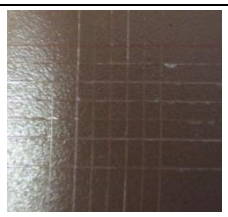
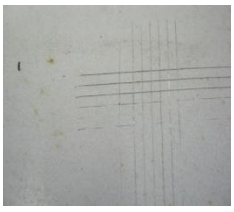
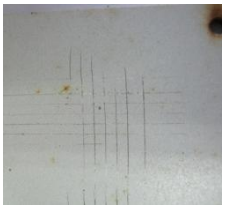
29		- phosphate layer - base layer - finishing layer	0
15		- base layer - finishing layer	1

Table 6. Adhesion ratings according to EN ISO 2409 standard (samples after field testing)

Adhesion testing after field tests			
Sample	Sample appearance	Coating type	Adhesion rating
23		- phosphate layer - base layer	2
2		- base layer	2
16		- phosphate layer - base layer - finishing layer	3
4		- base layer - finishing layer	3
21		- phosphate layer - base layer	1
8		- base layer	1

20		- phosphate layer - base layer - finishing layer	1
6		- base layer - finishing layer	1
25		- phosphate layer - base layer - finishing layer	1
14		- base layer - finishing layer	1

On the basis of obtained results, it can be noticed that water based coatings have, in general, better adhesion than organic solvent based coatings for both, phosphatized and nonphosphatized samples.

Salt chamber

Testing was performed on 12 samples, six of which were phosphatized prior the coating. After coating, incisions were made on six samples in order to increase corrosion rate. Before insertion, thickness of dry coating was determined for all samples. Results of thickness measurement are presented in Tables 7., 8. and 9.

Table 7. Thickness of organic solvent based coating

Film thickness / µm							
Phosphatized samples				Nonphosphatized samples			
Sample	Min. thickness	Max. thickness	Average	Sample	Min. thickness	Max. thickness	Average
1(FO w/o incision)TP	112,60	121,00	116,20	5(BFO w/o incision) TP	115,40	127,20	119,40
8(FO w incision) TP	139,20	152,40	145,73	11(BFO w incision) TP	120,60	138,60	127,87

Table 8. Thickness of water based coating

Film thickness / µm							
Phosphatized samples				Nonphosphatized samples			
Sample	Min. thickness	Max. thickness	Average	Sample	Min. thickness	Max. thickness	Average
22(FV1 w/o incision)TP	46,60	61,20	55,13	12(BFV1 w/o incision)TP	48,90	61,40	56,33
14(FV1 w incision)TP	45,60	67,10	55,53	15(BFV1 w incision)TP	49,60	66,30	56,90

Table 9. Thickness of water based coating system 2 in 1

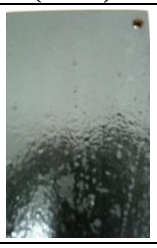
Film thickness / µm							
Phosphatized samples				Nonphosphatized samples			
Sample	Min. thickness	Max. thickness	Average	Sample	Min. thickness	Max. thickness	Average
26(FV2 w/o incision)TP	23,4	25,8	24,63	20(BFV2 w/o incision)TP	19,1	23,8	21,56
23(FV2 w incision)TP	21,2	24,2	23,06	29(BFV2 w incision)TP	17,2	25,2	22,06

Results of salt chamber testing are shown in Table 10. Duration of testing was 168 hours (from 02.04.2013. to 09.04.2013.), and it was conducted on following samples:

- 1(FO w/o incision); 8(FO w incision)
- 5(BFO w/o incision); 11(BFO w incision)
- 22(FV1 w/o incision); 14(FV1 w incision)
- 12(BFV1 w/o incision); 15(BFV1 w incision)
- 26(FV2 w/o incision); 23(FV2 w incision)
- 29(BFV2 w/o incision); 20(BFV2 w incision)

Samples chosen for testing were put in salt chamber on 02.04.2013. at 13:00.

Table 10. Salt chamber testing results

Salt chamber test			
Sample No.	Sample appearance 03.04.2013. (13:30)	Sample appearance 06.09.2013. (14:00)	Sample appearance 09.04.2013. (14:00)
1			
8			
5			
11			
22			
14			
12			

15			
26			
23			
29			
20			

Organic solvent based coatings possesses the best protection performance, as can be seen from the experimental observations. No corrosion manifestations at all could be seen at samples with organic solvent based coatings, in contrast to samples with water based ones. Also, emergence of bubbles was symptomatic for water based coatings, especially for 2 in 1 systems, where the emergence of bubbles was noticed after 24 hours.

Field testing

Field corrosion tests were performed in atmospheric conditions. Samples have been mounted near the main road in Semizovac, from 01.07.2012. to 01.10.2012. Samples selected for field testing were:

- 23(FO)T; 2(BFO) T
- 16 (FO)TP; 4 (BFO)TP
- 21 (FV1)T; 8 (BFV1)T
- 20 (FV1)TP: 6 (BFV1)TP
- 25 (FV2) TP; 14 (BFV2)TP

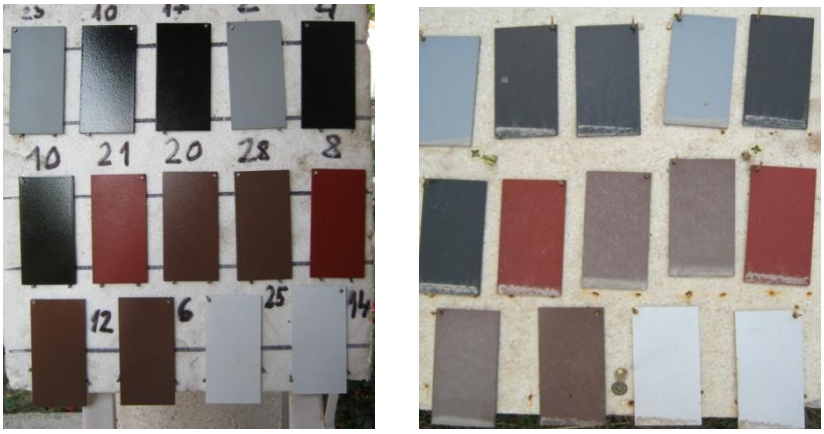


Figure 11. Tested samples at the begining (01.07.2012.) and at the end of testing (01.10.2012.)

Table 12. Results of field testing

Adhesion tests after field testing				
Sample	Coating type	Sample appearance 01.07.2012.	Sample appearance 01.10.2012.	Description of change
23	- phosphate layer - base layer			Emergence of surface corrosion – small spots
2	- base layer			Emergence of surface corrosion – small spots
16	- phosphate layer - base layer - finishing layer			No traces of corrosion
4	- base layer - finishing layer			No traces of corrosion

21	- phosphate layer - base layer			Emergence of surface corrosion – small spots
8	- base layer			Emergence of surface corrosion – small spots
20	- phosphate layer - base layer - finishing layer			No traces of corrosion
6	- base layer - finishing layer			No traces of corrosion
25	- phosphate layer - base layer - finishing layer			Emergence of corrosion on surface and edges – small spots
14	- base layer - finishing layer			Emergence of corrosion on surface and edges – small spots

Samples have been exposed to atmosphere during the period of three months. Corrosion was observed on samples with only a base layer, as well as on samples with 2 in 1 coating. Corrosive changes have not observed on samples with organic solvent based coatings as well as on water based coatings with two layers of paint.

CONCLUSIONS

Comparison and determination of protection performance for two different systems – water based and organic solvent based – was conducted.

On the basis of dry coating thickness determination, adhesion tests, salt chamber and field tests, following conclusions can be drawn:

- Thicker films are obtained for coatings with base and finishing layers;
- Water based coatings show better adhesion, compared to organic solvent based ones;
- Organic solvent based coatings show better performance in salty fog;
- Coatings based on organic solvent also show better performance in field testings.

Although water based coatings show satisfactory protection performance, it is still far bellow the performance of coatings based on organic solvent.

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Summary/Sažetak

Vodorazrjedivi premazi koriste vodu kao otapalo i razređivač, a sadrže minimalan udio organskih otapala koji zagađuju okoliš. Zaštita od korozije koju imaju ove boje još uvijek nije na nivou koji pružaju premazi na bazi otapala. Kvalitet prevlake je praćen mjerenjem debljine suhog premaza, ispitivanjem prionjivosti suhog sloja, ispitivanjem u slanoj komori i kroz terensko korozijsko ispitivanje. Pokazalo se da su debljine premaza na bazi otapala u slučaju kada je nanesen temeljni i završni sloj veće, bolja prionjivost kod vodorazrjedivih premaza, da u uslovima slane magle bolju korozijsku postojanost pokazuju premazi na bazi otapala, da su prilikom terenskog ispitivanja najbolju korozijsku postojanost pokazali premazi na bazi otapala.