Work Package 4: Tests on selected products – results of the Croatian team

Addendum to the final report| June 2021

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NUMBER OF PARTNER	COUNTRY	NUMBER OF OBJECTS	NUMBER OF SAMPLES
P13	**Croatia**		**96**

Due to unforeseen reasons, Sisak Municipal Museum (Partner 13) could not carry out the WP4 activities on schedule.

This report is an addendum to the final WP4 report, completed in July 2020.

The present report has been prepared by the Sisak Municipal Museum in collaboration with METRIS (Partner 11).

Appendices to the present report are not public but are available on demand contacting the Sisak Municipal Museum or the CAPuS project coordinator.

Contents

1. Introduction

Sisak Ironworks Sculpture Park consists of 38 metal sculptures of middle and large format exhibited in the Caprag neighbourhood of the City of Sisak, Croatia.

The sculptures were created by the most prominent ex-Yugoslav artists in the period from 1971. To 1990. in which the artist colony was active. The colony itself was a part of cultural policy of Sisak Ironworks with the intention of creating a more inviting living environment for the employees and their families, but also to further educate them in the field of culture.

The sculptures were created in close collaboration between the artists and the workers, using mostly the materials produced or used by the Ironworks factories.

After the economic crisis in the 1980-ies that led to a lack of necessary investments in the modernisation of production facilities and the War of Independence in Croatia in the 1990-ies, the importance of the Sisak Ironworks was slowly diminished, and the Sisak Ironworks ceased to exist in its former shape. Some of the production plants were later privatised and continued parts of the production, and others were completely closed down with some of the new owners selling of the existing machinery as scrap metal and closing some of the plants completely. Given that the Ironworks was no longer functioning as a “single body” many other activities, including the artists’ colony ceased to exist.

The remnants of these cultural policies exist even today, and they are most visible in the form of the sculptures that are exhibited all throughout the neighbourhood of Caprag, the library that still works today and a collection of paintings created in the colonies that is now a part of Sisak Municipal Museum collections.

The sculptures were re-discovered by Marijan Crtalić, visual artist and performer from Sisak who has explored the industrial heritage of Sisak in several of his projects.

In 2008. Sisak Municipal Museum educator Marijan Bogatić inspired by and in collaboration with Marijan Crtalić, along with a team of students taking part in the project Volunteers camp created the first documentation forms for the sculptures from the Ironworks colonies, along with other sculptures, monuments and memorial sites in the City of Sisak. This documentation was later used for application for legal protection of the Sculpture Park from the Ministry of Culture of the Republic of Croatia. The legal protection was formalised in 2012.

With the passing of time more and more sculptures get damaged either because of natural factors (decay of coatings, exposure to the elements, corrosion etc.) or vandalism (improper use, intentional damaging, stealing of the parts etc.). Because of this, several sculptures have been removed from their places and placed in a Museums storage facilities until the conditions for their return are met.

Given that conservation-restoration of painted metal outdoor sculptures represents a special problematic, with principles of work somewhat different from typical procedures in conservation-restoration of cultural heritage objects, different methods and products needed to be tried before their application on real objects. For this purpose a two-line of research methodology was developed with the idea of testing methods for removal of old coatings from the sculptures and testing different commercially available coating systems for later application to the sculptures. This methodology will be described in the next chapter.

Photo 1: Vera Fischer: „Simetrija“ (Symmetry), 1973.

Photo 3: Milivoje Babović: „Skulptura V“ (Sculpture V)

Photo 5: Josip Diminić: „Objekt II“ (Object II)

Photo 2: Milena Lah: „Galebovo krilo“ (Seagull's Wing)

Photo 4: Zlatko Zlatić: „Zgurić i obitelj“ (Zgurić and Family)

2. The methodology

The methodology of testing is divided in two lines of testing in order to find answers to two main questions/goals:

1. determining the most efficient method of removal of old paint systems from the sculptures

2. determining the best commercially available epoxy+polyurethane coating system for application on outdoor painted steel sculptures.

The first goal is achieved through preparation of 36 test plates that are coated with alkyd binder based coating system and artificially aged that will simulate the surface of the sculptures. After the ageing and necessary measurements, the coatings will be removed with different methods of stripping/cleaning, both chemical and mechanical.

The goal is to determine which method or combination of methods will most efficiently remove the aged coatings while also having the least possible amount of adverse effects, either on the base metal, the person performing the cleaning or the environment.

The second goal is achieved through preparation of 60 test plates divided into 4 sets. First set is coated with the same alkyd binder based coating system as in the first line of testing, in order to have a reference point for comparison of the results obtained from testing of epoxy+pur systems. The following three sets are coated with the epoxy+pur coating systems by three different producers that have met the initial criteria for selection of epoxy+pur coating systems:

1. possibility of application in C5 category of environment corrosivity and long lasting (30 years)

2. possibility of application by paintbrush, roller and airbrush

3. availability in RAL tone system/possibility of production of desired shade/tone

4. availability in semi-gloss finish

After the preparation of the test plates they are aged either in salt spray chamber or by natural exposition, except for the reference test plates from each of the sets. The results are obtained from different tests and measurements as described in the methodology.

The complete methodology is available in the Appendix 1.

3. Preparation of the test plates for application of the coating systems

As per the methodology, a total of 96 test plates have been produced. The test plates have been made of cold rolled steel in the dimensions 100mm X 150mm X 3mm. The test plates have been weighted before the start of the preparation. The preparation of the surface consisted in degreasing and surface cleaning by solvents in accordance with HRN EN ISO 1514, sandblasting by aluminium oxide (corundum) at 6-8 bar pressure and then cleaned again by solvents. The test plates were weighted again after the sandblasting and the surface profile (roughness) was measured. After this the test plates have been stored in vacuum sealed bags until the moment of application of the coating.

3.1 Preliminary analysis of the test plate material

Preliminary analysis were executed by METRIS on three randomly selected samples of the test plates (TPS-1, TPS-2 and TPS-3) and they included GDS analysis, observation by stereomicroscope, observation by light microscope, and observation by electron microscope. The scope of these analysis was to establish the exact composition of the base metal, the structure of the surface before cleaning by sandblasting and possible contaminants left on the surface from the production process.

3.1.1 Results of GDS analysis of base metal with relevant parameters[1]

Name	C %	Mn %	Si %	P %	S %	Mo %	Ni %	Cr %	Cu %	Al %	As %
CAPUS TPS-1	0,0767	0,37	0,0267	0,0092	0,0077	0,0012	0,0038	0,0174	0,0185	0,0588	0,0031
CAPUS TPS-2	0,077	0,375	0,0208	0,009	0,0081	0,0015	0,0036	0,0181	0,0187	0,0578	0,0017
CAPUS TPS-3	0,08	0,375	0,0186	0,0096	0,0079	0,0015	0,0037	0,0181	0,0185	0,0581	0,0025

Name	Voltage/V	Current/mA	Pressure/Torr
CAPUS TPS-1	1002	35	3,95
CAPUS TPS-2	1002	35	3,95
CAPUS TPS-3	1002	35	3,96

The tables give the mean values of the measured mass fractions (w) of individual elements in the sample expressed in percentages (%) and the conditions of the analysis: voltage, current and pressure. Electronic data processing displays a summary of test results with all relevant parameters and data.

Based on the results obtained by GDS analyses, metal base plates are low alloy steel and have served to confirm that mock-up plates are made from the same material.
One plate has been taken from each ‘’batch’’ in order to confirm this hypothesis

3.1.2 Observation by stereomicroscope[2]

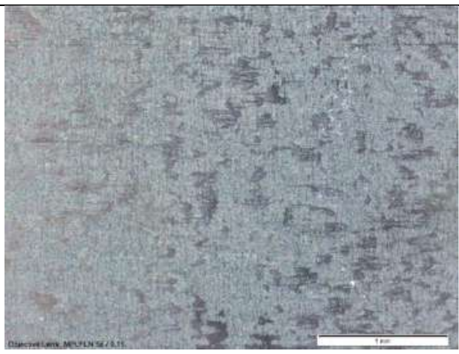
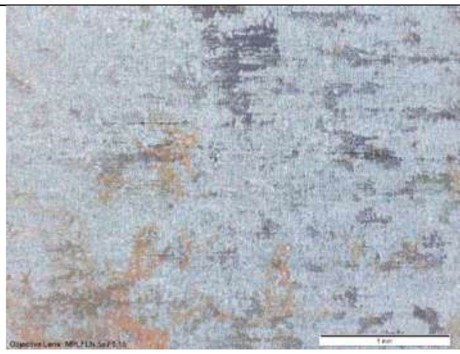
Observation by stereomicroscope was performed by METRIS with magnifications of 6,3X and 20X.

[1] Data and text presented in part 3.1.1 is taken from WP4 analysis report by METRIS (see Appendix 5)
[2] Table presented in part in part 3.1.2 is taken from WP4 analysis report by METRIS (see Appendix 5)

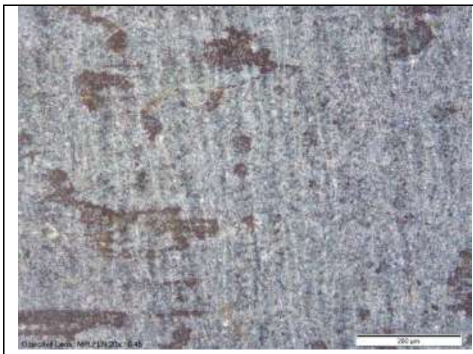
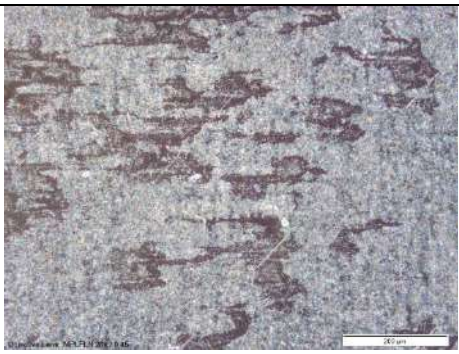
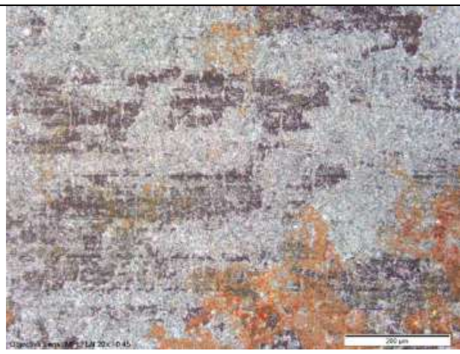
Observation by stereomicroscope, P=6,3X		
TPS-1	**TPS-2**	**TPS-3**
		
Observation by stereomicroscope, P=20X		
TPS-1	**TPS-2**	**TPS-3**
		

3.1.3 Observation by light microscope[3]

Observation by light microscope was performed by METRIS with magnification of 50X and 200X.

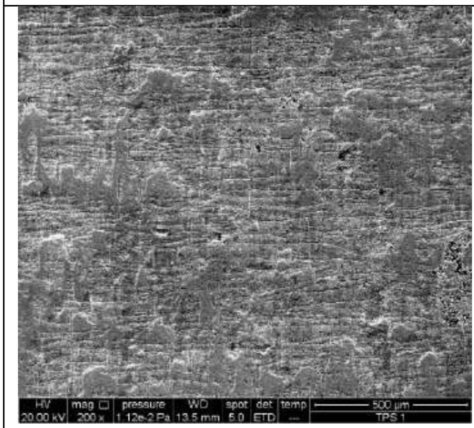
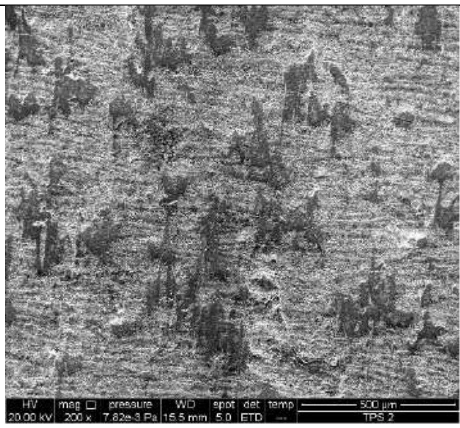
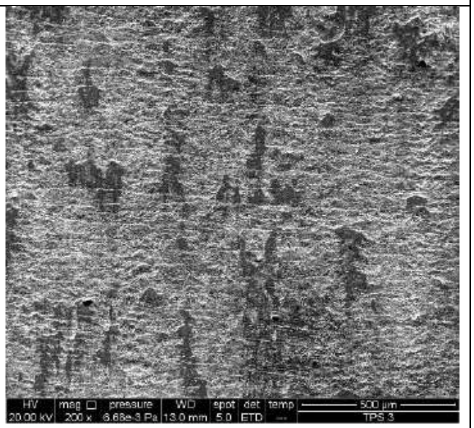
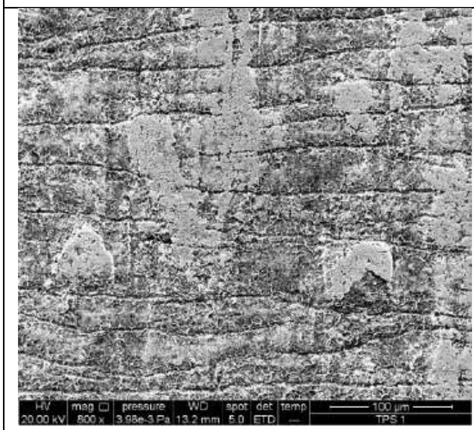
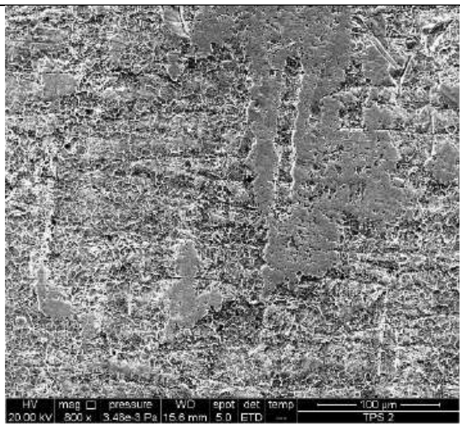
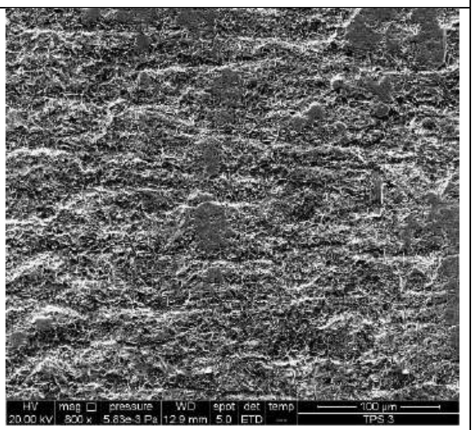
Observation by light microscope, P=50X		
TPS-1	**TPS-2**	**TPS-3**
		
Observation by light microscope, P=200X		
TPS-1	**TPS-2**	**TPS-3**

[3] Table presented in part in part 3.1.3 is taken from WP4 analysis report by METRIS (see Appendix 5)

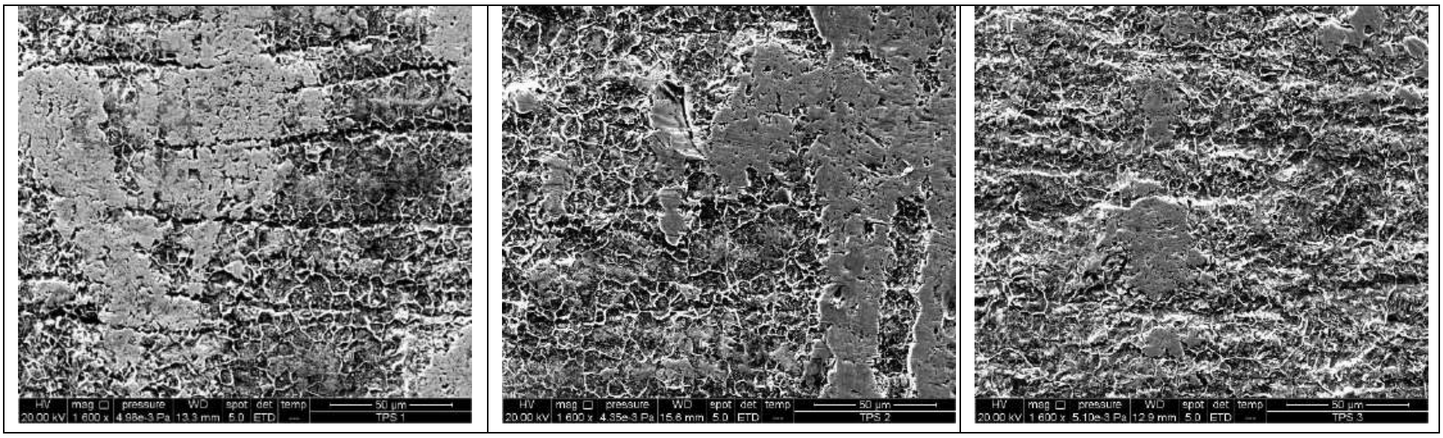
		

3.1.4 Observation by scanning electron microscope[4]

Observation by scanning electron microscope was performed by METRIS with magnification of 200X, 800X and 1600X.

Observation by scanning electron microscope, P=200X		
TPS-1	**TPS-2**	**TPS-3**
		
Observation by scanning electron microscope, P=800X		
TPS-1	**TPS-2**	**TPS-3**
		
Observation by scanning electron microscope, P=1.600X		
TPS-1	**TPS-2**	**TPS-3**

[4] Table presented in part in part 3.1.4 is taken from WP4 analysis report by METRIS (see Appendix 5)



3.2 Sandblasting of the test plates

Given that the vast majority of the coating systems producers require that the surface that will be coated needs to be prepared (sandblasted) to the minimum of Sa 2,5 according to ISO 8501 standard and with the surface profile values usually between 40 and 70 microns (defined by the producer), it was decided that the test plates will be prepared partially to this standard.

The test plates were sandblasted in a controlled environment, using a very pure abrasive – Cobra 150 mesh produced by Renfert (pure corundum). The working pressure of the sandblaster unit was around 7 bar.

3.2.1 Weighting results

The following values of mass were recorded for each of the test plates before and after the initial preparation of surface by sandblasting:

Plate nr.	Weight before sandblasting		Weight after sandblasting	
	Plate (g)	Average (g)	Plate (g)	Average (g)
1	348,578	348,578	348,507	348,507
	348,579		348,507	
	348,578		348,507	
2	351,335	351,335	351,269	351,269
	351,335		351,269	
	351,335		351,269	
3	347,829	347,829	347,728	347,728
	347,830		347,728	

Plate nr.	Weight before sandblasting		Weight after sandblasting	
	Plate (g)	Average (g)	Plate (g)	Average (g)
	347,829		347,728	
4	348,269	348,269	348,172	348,172
	348,269		348,172	
	348,269		348,172	
5	349,798	349,798	349,646	349,646
	349,798		349,645	
	349,798		349,646	
6	348,826	348,826	348,601	348,601
	348,826		348,601	
	348,826		348,601	
7	349,105	349,105	348,869	348,869
	349,105		348,869	
	349,105		348,869	
8	349,643	349,643	349,425	349,425
	349,643		349,425	
	349,643		349,425	
9	350,992	350,992	350,830	350,830
	350,992		350,830	
	350,992		350,831	
10	351,324	351,324	351,236	351,236
	351,323		351,236	
	351,324		351,236	
11	352,208	352,208	352,083	352,083
	352,208		352,083	
	352,208		352,083	
12	351,603	351,603	351,414	351,414
	351,603		351,413	

Plate nr.	Weight before sandblasting		Weight after sandblasting	
	Plate (g)	Average (g)	Plate (g)	Average (g)
	351,603		351,414	
13	352,852	352,852	352,678	352,678
	352,851		352,678	
	352,852		352,678	
14	355,852	355,852	355,712	355,712
	355,852		355,712	
	355,852		355,712	
15	352,602	352,602	352,463	352,463
	352,603		352,463	
	352,602		352,463	
16	352,781	352,781	352,651	352,651
	352,782		352,652	
	352,781		352,651	
17	354,435	354,435	354,274	354,274
	354,435		354,274	
	354,436		354,274	
18	352,333	352,333	352,233	352,233
	352,333		352,233	
	352,333		352,232	
19	353,967	353,967	353,869	353,869
	353,967		353,869	
	353,967		353,869	
20	345,050	345,050	344,880	344,880
	345,050		344,880	
	345,050		344,879	
21	346,495	346,495	346,337	346,337
	346,494		346,337	

Plate nr.	Weight before sandblasting		Weight after sandblasting	
	Plate (g)	Average (g)	Plate (g)	Average (g)
	346,495		346,337	
22	344,235	344,235	344,170	344,170
	344,235		344,170	
	344,235		344,170	
23	350,263	350,263	350,159	350,159
	350,263		350,159	
	350,263		350,159	
24	346,620	346,620	346,555	346,555
	346,621		346,555	
	346,620		346,555	
25	349,859	349,859	349,770	349,770
	349,859		349,770	
	349,859		349,770	
26	349,783	349,783	349,677	349,677
	349,783		349,677	
	349,783		349,677	
27	351,148	351,148	351,062	351,062
	351,148		351,062	
	351,148		351,062	
28	348,782	348,782	348,638	348,638
	348,782		348,638	
	348,782		348,638	
29	353,378	353,378	353,259	353,259
	353,377		353,259	
	353,378		353,258	
30	352,460	352,460	352,365	352,365
	352,460		352,366	

Plate nr.	Weight before sandblasting		Weight after sandblasting	
	Plate (g)	Average (g)	Plate (g)	Average (g)
	352,460		352,365	
31	353,469	353,469	353,337	353,337
	353,469		353,337	
	353,469		353,337	
32	354,336	354,336	353,621	353,621
	354,336		353,621	
	354,336		353,620	
33	352,218	352,218	352,054	352,054
	352,218		352,054	
	352,218		352,054	
34	352,457	352,457	352,295	352,295
	352,457		352,295	
	352,457		352,295	
35	354,308	354,308	354,126	354,126
	354,308		354,126	
	354,308		354,126	
36	350,441	350,441	350,282	350,282
	350,441		350,282	
	350,441		350,282	
37	346,984	346,984	346,823	346,823
	346,984		346,823	
	346,984		346,823	
38	347,758	347,758	347,625	347,625
	347,758		347,625	
	347,758		347,625	
39	345,960	345,960	345,818	345,818
	345,960		345,818	

Plate nr.	Weight before sandblasting		Weight after sandblasting	
	Plate (g)	Average (g)	Plate (g)	Average (g)
	345,961		345,818	
40	352,691	352,691	352,589	352,589
	352,691		352,589	
	352,691		352,589	
41	353,168	353,168	353,091	353,091
	353,167		353,091	
	353,168		353,091	
42	354,236	354,236	354,074	354,074
	354,236		354,074	
	354,236		354,074	
43	352,011	352,011	351,886	351,886
	352,012		351,886	
	352,011		351,886	
44	349,557	349,557	349,403	349,403
	349,557		349,404	
	349,557		349,403	
45	351,201	351,201	351,067	351,067
	351,201		351,067	
	351,201		351,067	
46	349,271	349,271	349,168	349,168
	349,271		349,168	
	349,271		349,168	
47	349,949	349,949	349,871	349,871
	349,949		349,871	
	349,949		349,871	
48	350,840	350,840	350,779	350,779
	350,840		350,779	

Plate nr.	Weight before sandblasting		Weight after sandblasting	
	Plate (g)	Average (g)	Plate (g)	Average (g)
	350,840		350,779	
49	350,148	350,148	350,093	350,093
	350,148		350,093	
	350,148		350,093	
50	352,446	352,446	352,389	352,389
	352,446		352,389	
	352,446		352,389	
51	347,494	347,494	347,408	347,408
	347,494		347,408	
	347,494		347,408	
52	352,718	352,718	352,590	352,590
	352,718		352,590	
	352,718		352,590	
53	353,914	353,914	353,800	353,800
	353,914		353,800	
	353,914		353,800	
54	351,448	351,448	351,333	351,333
	351,448		351,333	
	351,449		351,333	
55	353,867	353,867	353,727	353,727
	353,867		353,727	
	353,868		353,727	
56	354,661	354,661	354,539	354,539
	354,661		354,539	
	354,661		354,539	
57	350,604	350,604	350,454	350,454
	350,604		350,454	

Plate nr.	Weight before sandblasting		Weight after sandblasting	
	Plate (g)	Average (g)	Plate (g)	Average (g)
	350,604		350,454	
58	351,209	351,209	351,046	351,046
	351,209		351,046	
	351,209		351,046	
59	347,284	347,284	347,203	347,203
	347,284		347,203	
	347,284		347,204	
60	354,596	354,597	354,507	354,507
	354,597		354,507	
	354,597		354,507	
61	353,424	353,424	353,335	353,335
	353,423		353,335	
	353,424		353,335	
62	353,831	353,831	353,751	353,751
	353,831		353,751	
	353,831		353,751	
63	353,255	353,255	353,167	353,167
	353,255		353,167	
	353,255		353,167	
64	350,902	350,903	350,730	350,730
	350,903		350,730	
	350,903		350,730	
65	349,917	349,917	349,817	349,817
	349,916		349,817	
	349,917		349,817	
66	351,174	351,174	351,102	351,102
	351,174		351,102	

Plate nr.	Weight before sandblasting		Weight after sandblasting	
	Plate (g)	Average (g)	Plate (g)	Average (g)
	351,174		351,103	
67	353,276	353,276	353,215	353,215
	353,276		353,215	
	353,276		353,215	
68	350,051	350,051	349,946	349,946
	350,051		349,946	
	350,051		349,946	
69	352,146	352,146	352,030	352,030
	352,146		352,030	
	352,146		352,030	
70	351,737	351,737	351,563	351,563
	351,737		351,563	
	351,737		351,563	
71	351,774	351,774	351,629	351,629
	351,774		351,629	
	351,774		351,629	
72	350,552	350,552	350,423	350,423
	350,552		350,423	
	350,552		350,423	
73	351,892	351,892	351,769	351,769
	351,892		351,769	
	351,892		351,769	
74	353,452	353,452	353,271	353,271
	353,452		353,271	
	353,452		353,271	
75	352,423	352,423	352,257	352,257
	352,423		352,257	

Plate nr.	Weight before sandblasting		Weight after sandblasting	
	Plate (g)	Average (g)	Plate (g)	Average (g)
	352,423		352,257	
76	353,774	353,774	353,623	353,623
	353,774		353,623	
	353,774		353,623	
77	351,017	351,017	350,836	350,836
	351,018		350,836	
	351,017		350,836	
78	350,193	350,193	350,055	350,055
	350,193		350,055	
	350,193		350,055	
79	349,518	349,518	349,404	349,404
	349,518		349,404	
	349,518		349,404	
80	347,139	347,139	347,054	347,054
	347,139		347,054	
	347,139		347,054	
81	349,776	349,776	349,620	349,620
	349,776		349,620	
	349,776		349,620	
82	355,168	355,168	355,144	355,144
	355,168		355,144	
	355,168		355,144	
83	348,711	348,711	348,653	348,653
	348,711		348,653	
	348,711		348,653	
84	354,632	354,632	354,579	354,579
	354,632		354,579	

Plate nr.	Weight before sandblasting		Weight after sandblasting	
	Plate (g)	Average (g)	Plate (g)	Average (g)
	354,632		354,579	
85	353,265	353,265	353,216	353,216
	353,265		353,216	
	353,265		353,216	
86	352,325	352,325	352,273	352,273
	352,324		352,273	
	352,325		352,273	
87	352,583	352,583	352,503	352,503
	352,583		352,503	
	352,583		352,502	
88	352,869	352,869	352,812	352,812
	352,870		352,812	
	352,869		352,811	
89	354,356	354,356	354,335	354,335
	354,356		354,335	
	354,356		354,335	
90	352,660	352,660	352,614	352,614
	352,660		352,614	
	352,660		352,615	
91	352,733	352,733	352,665	352,665
	352,733		352,665	
	352,733		352,664	
92	352,471	352,471	352,400	352,400
	352,471		352,400	
	352,471		352,400	
93	354,592	354,592	354,582	354,582
	354,592		354,582	

Plate nr.	Weight before sandblasting		Weight after sandblasting	
	Plate (g)	Average (g)	Plate (g)	Average (g)
	354,593		354,582	
94	353,119	353,119	353,082	353,082
	353,119		353,082	
	353,119		353,082	
95	350,468	350,468	350,395	350,395
	350,468		350,395	
	350,468		350,395	
96	351,594	351,594	351,504	351,504
	351,594		351,504	
	351,594		351,504	

3.2.2 Surface profile measurement results

The following values of surface profile were recorded for each of the test plates:

Plate nr.	Roughness after the sandblasting in µ (average from 10 measurements)
1	15,20
2	18,10
3	16,60
4	15,90
5	18,20
6	17,10
7	17,30
8	16,73
9	13,90
10	16,80
11	23,27
12	18,20
13	17,75

Plate nr.	Roughness after the sandblasting in µ (average from 10 measurements)
14	15,40
15	17,70
16	17,60
17	17,10
18	16,40
19	18,50
20	16,20
21	14,20
22	22,90
23	18,50
24	13,60
25	15,30
26	17,30
27	19,50
28	16,50
29	18,10
30	17,70
31	16,80
32	18,90
33	15,60
34	21,60
35	17,40
36	16,10
37	15,80
38	15,27
39	14,80
40	17,90
41	19,60
42	17,00
43	16,10
44	15,50
45	18,79
46	14,25
47	14,30
48	20,20
49	16,40

Plate nr.	Roughness after the sandblasting in µ (average from 10 measurements)
50	16,60
51	16,00
52	20,40
53	18,00
54	16,80
55	16,33
56	17,00
57	16,60
58	21,00
59	17,60
60	20,10
61	17,40
62	17,20
63	15,40
64	17,80
65	19,80
66	17,80
67	15,20
68	17,20
69	15,80
70	19,80
71	21,00
72	17,40
73	21,60
74	15,60
75	19,20
76	16,20
77	17,40
78	16,20
79	15,00
80	16,00
81	18,60
82	20,30
83	19,60
84	20,40
85	17,60

Plate nr.	Roughness after the sandblasting in µ (average from 10 measurements)
86	18,00
87	22,20
88	19,80
89	19,00
90	18,60
91	21,20
92	19,40
93	20,20
94	21,20
95	18,00
96	20,00

4. Coating systems: selection and application

For the purposes of the research two types of commercially available coating systems needed to be purchased: alkyd based coating system for the first line of research and EPOXY+PUR system for the second line of research.

4.1 Selection of the coating systems

Following the developed methodology, several producers/sellers of EPOXY+PUR coating systems have been contacted in order to acquire the coating systems that will be tested.

As per methodology, the coating systems had to meet certain criteria:

1. Applicability in C5 category of environment corrosivity and long lasting (30 years)

2. Possibility of application by paintbrush, roller and airbrush

3. Availability in RAL tone system or the possibility of production of desired shade/tone

4. Availability in semi-gloss finish

Generally speaking, EPOXY+PUR coating systems are suitable for use in C5 category of environment corrosivity if they are applied following the instructions given by the producer (especially the minimum thickness and adhesion to the surface).

The following tones have been selected to be acquired from all of the producers:

1. RAL 1026 (Luminous yellow)
2. RAL 5002 (Ultramarine blue)
3. RAL 3024 (Luminous red)
4. RAL 9005 (Jet black)

Some of the contacted producers declined to produce their coatings in some of the selected tones, because they can not guarantee the longevity of the product with certain pigments. These producers were eliminated because of the condition 3. (availability in RAL tone system or the possibility of production of desired shade/tone)

All of the aforementioned coatings were ordered in semi-matt finish (also called semi-gloss by some of the producers).

Finally, four coating systems by 3 different producer were selected for application. One coating, used for the first line of testing (Research of the methods used for removal of the old coating systems from the sculptures) was based on alkyd resin binders and the other three, used for the second line of testing (Research of the commercially available EPOXY+PUR coatings for application on the sculptures) were based on EPOXY+PUR binders (epoxy binder based base coat and polyurethane binder based top coat).

The following products were used for testing:

1. Helios Hrvatska d.o.o.: AGROHEL ES primer – one component primer based on alkyd binder
2. Helios Hrvatska d.o.o.: REZISTOL enamel A – one component topcoat based on modified alkyd binder
3. Helios Hrvatska d.o.o.: REZISTOL primer E ZP MIOX – two component primer based on epoxy binder and polyamideamine hardener

4. Helios Hrvatska d.o.o.: REZISTOL enamel 2K PUR – two component polyurethane topcoat based on acrylic binder and aliphatic isocyanate hardener
5. Nova-chem d.o.o.: Novapox primer - two component primer based on epoxy binder and hardener
6. Nova-chem d.o.o.: Novapur P topcoat – two component polyurethane topcoat
7. Chromos-Svjetlost d.o.o.: KEMEPOX HB PRIMER G0 – two component primer based on polyamide curing epoxy resin
8. Chromos-Svjetlost d.o.o.: KEMOLUX 2K PU finishing coat – two component topcoat based on polyurethane resin

Technical and safety data sheets obtained from producers are available in Appendix 2.

4.2 Application of the coating systems

The selected coating systems have been applied to the prepared test plates (as described before) by hand, using a brush. The coating were applied in the following order:

Plate nr.	Name of the coating applyed	Colour (RAL code)
1 - 9, 46 - 48	Helios Hrvatska d.o.o.: AGROHEL ES primer +REZISTOL enamel A	3024 (Luminous red)
10 - 18, 43 - 45	Helios Hrvatska d.o.o.: AGROHEL ES primer +REZISTOL enamel A	5002 (Ultramarine blue)
19 - 27, 40 - 42	Helios Hrvatska d.o.o.: AGROHEL ES primer +REZISTOL enamel A	1026 (Luminous yellow)
28 - 39	Helios Hrvatska d.o.o.: AGROHEL ES primer +REZISTOL enamel A	9005 (Jet black)
49 - 52	Helios Hrvatska d.o.o.: REZISTOL primer E ZP MIOX + REZISTOL enamel 2K PUR	5002 (Ultramarine blue)
53 - 56	Helios Hrvatska d.o.o.: REZISTOL primer E ZP MIOX + REZISTOL enamel 2K PUR	3024 (Luminous red)
57 - 60		

	Helios Hrvatska d.o.o.: REZISTOL primer E ZP MIOX + REZISTOL enamel 2K PUR	1026 (Luminous yellow)
61 - 64	Helios Hrvatska d.o.o.: REZISTOL primer E ZP MIOX + REZISTOL enamel 2K PUR	9005 (Jet black)
65 - 68	Nova-chem d.o.o.: Novapox primer + Novapur P topcoat	3024 (Luminous red)
69 - 72	Nova-chem d.o.o.: Novapox primer + Novapur P topcoat	5002 (Ultramarine blue)
73 - 76	Nova-chem d.o.o.: Novapox primer + Novapur P topcoat	9005 (Jet black)
77 - 80	Nova-chem d.o.o.: Novapox primer + Novapur P topcoat	1026 (Luminous yellow)
81 - 84	Chromos-Svjetlost d.o.o.: KEMEPOX HB PRIMER G0 + KEMOLUX 2K PU finishing coat	5002 (Ultramarine blue)
85 - 88	Chromos-Svjetlost d.o.o.: KEMEPOX HB PRIMER G0 + KEMOLUX 2K PU finishing coat	1026 (Luminous yellow)
89 - 92	Chromos-Svjetlost d.o.o.: KEMEPOX HB PRIMER G0 + KEMOLUX 2K PU finishing coat	9005 (Jet black)
93 - 96	Chromos-Svjetlost d.o.o.: KEMEPOX HB PRIMER G0 + KEMOLUX 2K PU finishing coat	3024 (Luminous red)

5. Ageing

In order to analyse and compare the selected coating systems, the coated test plates needed to be artificially and naturally aged.

5.1 Natural ageing

Natural ageing process was executed in accordance with ISO 2810 standard. An exposure rack was produced and the test plates were exhibited on it. The exposure rack is situated in the neighbourhood Caprag, just a few hundred meters from sculptures from the Sisak Ironworks Sculpture Park. It can be concluded that they have been exposed to the same weather conditions as the sculptures in this period.

The exposure rack houses 28 test plates, covering all of the selected coating systems with the following layout:

39	42	45	48	51	52	55	56	59
60	63	64	67	68	71	72	75	76
79	80	83	84	87	88	91	92	95
96								

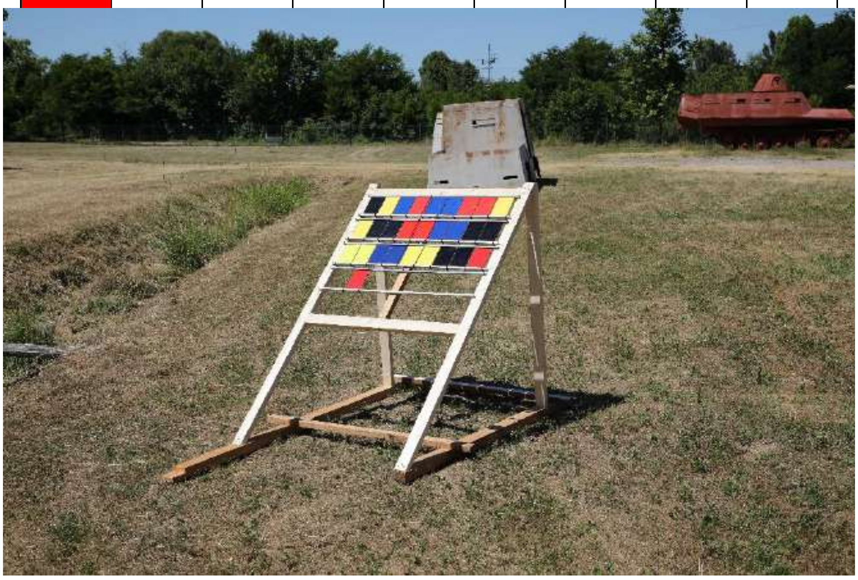


Photo 6: Outdoor exposure rack on the site of exposure inside the „Barutana" complex in neighbourhood Caprag, Sisak

Given that the used coating systems have a very long predicted lifespan (30+ years according to some manufacturers), the results of natural ageing are very limited considering the short period of exposition but can be indicative of major defects of a certain coating system or useful in comparison with the results of accelerated ageing.

In our case there were minor changes in visual aspect of the test plates that were exposed for 1 year, but using different analytical methods, a certain changes were noticed.

Another very useful way of evaluating the atmosphere in which the test plates are exposed is visual observation of the residues collected on the surface of the test plates. In our case this was done by using a digital microscope with a light source and a polarising filter with magnifications of 50x and 200x.

Using this method of imaging and comparing the unexposed (referent) test plates with the exposed ones it was very obvious that even though at this point in time there is minimal industrialisation in the proximity of the exposure rack, there is still quite a lot of residue on the surface of the test plates left by the atmospheric deposition in the period of 1 year.

The comparative images can be found in the Appendix 3.

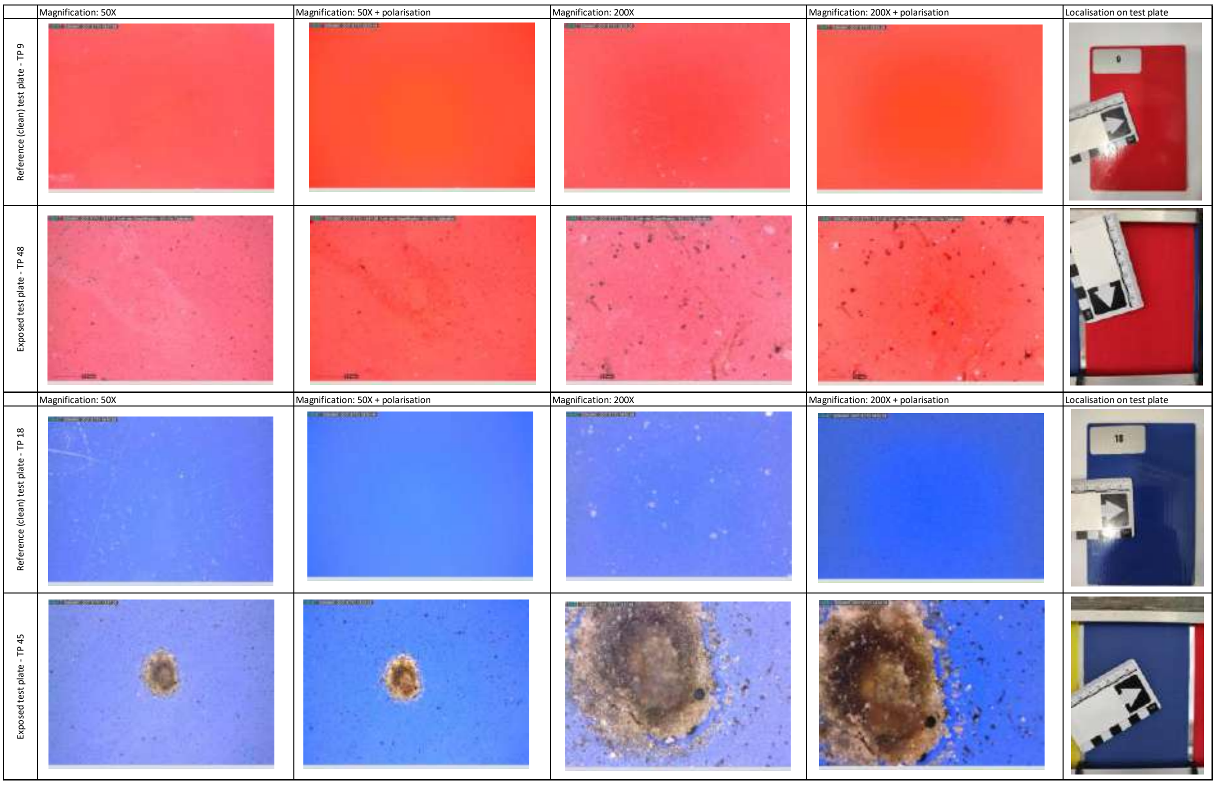


Photo 7: Examples of comparation of residue present on the exposed test plates taken from Appendix 3

5.2 Salt spray chamber ageing

The method of ageing in the salt spray chamber or in our case neutral salt spray chamber in accordance with ISO 9227 is a method that exposes the test plates to wetting by misted solution of NaCl in the required concentration at the temperature of 35°C.

This method simulates the highly corrosive atmosphere described as category C5 in ISO 12944. During the exposition period (1440h for the 1. set of test plates coated with alkyd based system and 1200 for all other sets) the test plates were aged with the conditions that exceeds the category of high durability (7-15 years) in C5 corrosivity conditions.

The results of the ageing can be found in Appendix 4.

Photo 8: test plate before exposure in the salt spray chamber

Photo 9: test plate after exposure in the salt spray chamber

Photo 10: test plates during the ageing in the salt spray chamber

6. Testing of the removal methods

In order to determine the best method of removing the old coatings from the sculptures in the future, different methods for removal were tested on the salt spray chamber aged test plates.

6.1 Testing of different chemical stripping products

This phase of testing was intended to select one of the commercially available stripping products or solvents. During this phase six products in total were tested – four stripping products and two solvents. The following products were tested:

1. Radikal Abbeizer by Borma Wachs B.P.S. srl
2. Sverniciatore Superattivo by Saratoga INT. Sforza spa
3. MoTip Paint Remover by Motip Dupli b.v.
4. Luxal Desol by Chromos boje i lakovi d.d.
5. Acetone p.a.
6. Toluene p.a.

Technical and safety data sheets for all of the used products obtained from the distributors are available in the Appendix 5.

The test plates were divided in to 6 test fields and the products were applied. The commercial stripping products were in a form of gel, except for MoTip Paint Remover which comes in a form of spray. The two solvents were applied in a form of pack made of cotton wool soaked in the solvent and covered with foil in order to stop the evaporation.

The testing areas were arranged in the following way:

Number of the test plate	
1. Borma Wachs - Radikal Abbeizier	2. Saratoga - Sverniciatore Superattivo
3. MoTip - Paint Remover	4. Chromos boje i lakovi - Luxal Desol
5. Acetone p.a.	6. Toluene p.a.

Photo 11: Test plates before and after the initial cleaning using 6 chemical stripping products

During the initial tests, reports were created for each of the cleaned test plates, and are available in the Appendix 6.

Following the visual examination and notes taken during the cleaning process, the Sverniciatore Superattivo by Saratoga INT. Sforza spa was selected as most successful in removing the coating system layers.

6.2 Testing of the selected chemical stripping product

The selected product for chemical stripping - Sverniciatore Superattivo by Saratoga INT. Sforza spa, was applied to the whole surface of the next four test plates in order to confirm its results from the previous tests.

Photo 12: Test plates before and after the cleaning using the selected chemical stripping product

The test plates cleaned with this method seem to be visually unchanged after the removal of the coating system. Taking into account the recorded mases of the test plates before the application of coating system and after its removal, it can be concluded that the mass has increased in average about 0,049g. The same conclusion can be reached by looking at the images taken by SEM.

Test plate nr.	Mass before paint (g)	Mass after paint removal	Change in mass (g)	Average change (g)
2	351,269	351,330	+ 0,061	+ 0,049
11	352,083	352,135	+ 0,052	
20	344,880	344,930	+ 0,050	
29	353,259	353,291	+ 0,032	

It is also visible in the SEM and light microscope images that there are some remains of paint in the crevices of the sandblasted surface. These images can be found in the WP 4 analysis report by METRIS.

The full reports on cleaning of these test plates can be found in the Appendix 6.

6.3 Testing of sandblasting with aluminium oxide

This set of test plates was sandblasted with pure aluminium oxide (corundum) of granulation 150 mesh. The working pressure of the sandblasting unit was around 7 bar. The question wit this method was not if it will be possible to remove the coating system from the surface of the test plate, but how efficiently and how much will the surface be damaged by the procedure.

Photo 13: Test plates before and after the sanblasting with aluminium oxide

Given that the test plates were initially sandblasted by the same method, the visual change vas negligible, but the main factor for evaluation of the degree of damage done to the surface was the change in mass. In average the mass was decreased by 0,417g.

Test plate nr.	Mass before paint (g)	Mass after paint removal	Change in mass (g)	Average change (g)
3	347,728	347,417	- 0,311	- 0,417
12	351,414	350,819	- 0,595	
21	346,337	345,975	- 0,362	
30	352,365	351,966	- 0,399	

The detailed reports on cleaning with this method can be found in the Appendix 6 and the results of analysis performed by METRIS in their WP4 report.

6.4 Testing of sandblasting with glass beads

This set of test plates was cleaned of coating system by sandblasting with glass beads (glass microspheres, glass microbaloons) of the granulation 400-200 mesh and the working pressure of the sandblasting unit was around 7 bar.

Given that this technique of sandblasting is, among other uses, used for the so called condensation of the surface of metal, the results are interesting both in macroscopic visual examination and microscopic visual examination, even more so in comparison with the test plates sandblasted by aluminium oxide.

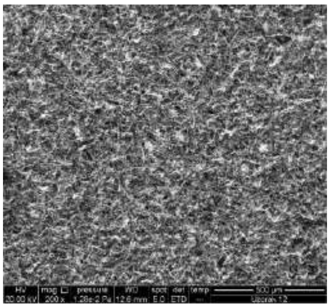
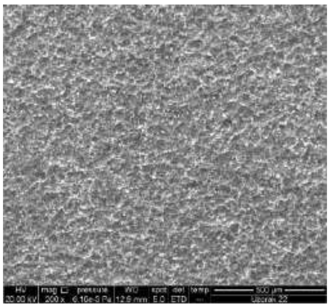
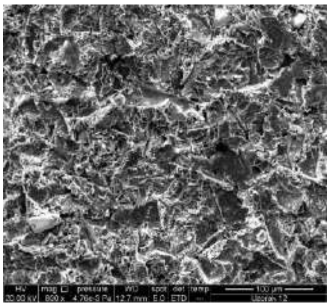
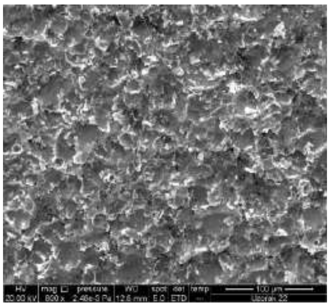
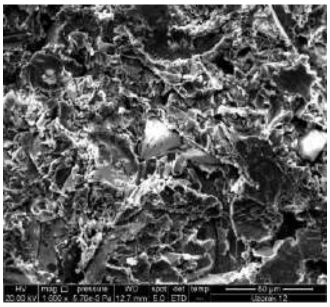
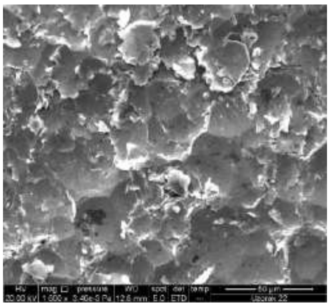
SEM P=200X side-by-side test plates 12 and 22		
SEM P=800X side-by-side test plates 12 and 22		
SEM P=1600X side-by-side test plates 12 and 22		

Photo 14: Comparison of surface after sanblasting with aluminium oxide and glas beads

The surface after cleaning is visually much shinier and smoother than on the test plates sandblasted with aluminium oxide, but there are some shadows left on the surface from the base coat of the coating system.

Photo 15: Test plates before and after the sanblasting with glass beads

The mass of the test plates is decreased by 0,593 g in average.

Test plate nr.	Mass before paint (g)	Mass after paint removal	Change in mass (g)	Average change (g)
4	348,172	347,650	- 0,522	- 0,593
13	352,678	352,081	- 0,597	
22	344,170	343,633	- 0,537	
31	353,337	352,620	- 0,717	

The detailed reports on cleaning with this method can be found in the Appendix 6 and the results of analysis performed by METRIS in their WP4 report.

6.5 Testing of sandblasting with nutshell granulate

The set of test plates cleaned by this method was sandblasted with nutshell granulate in mesh 60-40 granulation and working pressure of the sandblasting unit around 7 bar. The results of cleaning with this method were not excellent. After extensive sandblasting lasting in average around 43 minutes per test plate (average duration of sandblasting with aluminium oxide was around 7 minutes and

Before test cleaning				
After test cleaning				

Photo 16: Test plates before and after sanblasting with nutshell granulate

with glass beads around 23 minutes) there were visible residues of the base coat that could not be removed completely and shadows on the whole surface of the test plate.

The residues on the surface are also apparent from the recorded mass of the test plates before application of the coating system and after its removal – the mass increased in average 0,137 g.

Test plate nr.	Mass before paint (g)	Mass after paint removal	Change in mass (g)	Average change (g)
5	349,646	349,762	+ 0,116	+ 0,137
14	355,712	355,868	+ 0,156	
23	350,159	350,297	+ 0,138	
32	353,621	353,757	+ 0,136	

The detailed reports on cleaning with this method can be found in the Appendix 6 and the results of analysis performed by METRIS in their WP4 report.

6.6 Testing of heat gun stripping

This set of test plates was cleaned by means of heating the surface with a heat gun (industrial blow drier) producing the heat of nominal values 350/550°C. The higher setting was used. After the coating system layer were softened, they were removed using a small flat spatula.

The method is not ideal, because it is hard to heat up the surface enough for the coating layers to soften to a point of removal without the use of large force with the spatula. It is to be expected that this problem would be even more prominent on a large scale artwork, especially in an outdoor setting.

This method also produces a lot of fumes from heating up the coatings.

Also, even though the force used for scraping the coatings was not large, there are visible scrapes on the metal surface from this, along with ample base coating residues.

Photo 17: Test plates before and after clenaning with heatgun

The mass of the test plates has also increased from the measured values before the application of the coating systems, in average 0,131 g.

Test plate nr.	Mass before paint (g)	Mass after paint removal	Change in mass (g)	Average change (g)
6	348,601	348,751	+ 0,150	+ 0,131
15	352,446	352,606	+ 0,160	
24	346,555	346,663	+ 0,108	
33	352,054	352,160	+ 0,106	

The detailed reports on cleaning with this method can be found in the Appendix 6 and the results of analysis performed by METRIS in their WP4 report.

6.7 Testing of cleaning with composite brushes

This set of test plates was cleaned of the coating system by use of the rotating composite “wire” brush. These brushes do not use steel wire as the conventional wire brushes, but instead they use fibres made out of hard plastic material that also contain abrasive particles. They can be mounted on drills, grinders and other tools with rotating axis.

The method showed as very inefficient and labour intensive, with significant drawbacks such as creation of large quantities of very fine dust made out of the removed coating layers and also very significant change in the aspect of the test plates. The surface became shiny with noticeable scrapes and scores as a result of the need to apply force to the brush in order for it to remove the coatings.

For these reasons, the testing was interrupted after the cleaning of two out of four test plates in this set.

Before test cleaning		
After test cleaning		

Photo 18: Test plates before and after the cleaning with rotating composite brushes

The mass of the test plates has also decreased after the process of cleaning, compared to the recorded masses before the application of the coating system, an average 1,477 g.

Test plate nr.	Mass before paint (g)	Mass after paint removal	Change in mass (g)	Average change (g)
7	348,869	347,403	- 1,466	- 1,477
16	352,651	351,163	- 1,488	

The detailed reports on cleaning with this method can be found in the Appendix 6 and the results of analysis performed by METRIS in their WP4 report.

6.8 Testing of cleaning by dry ice blasting

Given that the Sisak Municipal Museum does not possess the equipment necessary for application of this cleaning method, several private companies were contacted in order to execute this part of the testing. Only one of these companies was willing to participate in the testing – ICEsonic from Nova Gradiška, Croatia.

Four test plates were sent to the in order to be completely cleaned by dry ice blasting. After a few days we were contacted by them because it was impossible for their workers to completely remove the coating system from the test plate by only using dry ice as abrasive. Their proposition was to introduce around 15% by weight of glass beads to the dry ice in order to be able to remove the coatings.

The test was conducted so that each of the four test plates was cleaned as well a possible by dry ice blasting from the one side, and completely cleaned by the aforementioned mixture of dry ice and glass beads from the other side.

Photo 19: Teste plates before and after the cleaning using dry ice and dry ice with the adition of glass beads

Feedback from the company performing the cleaning was that, from their point of view, it would be very inefficient and in some cases impossible to remove the old coatings from the sculptures by using only dry ice pellets for blasting and also that this method probably would not be able to remove potential corrosion products from the metal substrate, and that they would advise us to use the mixture of dry ice and glass beads for this type of work.

The mass of the test plates is greater after the removal of coating systems and it was to be expected because of the uncomplete removal on one side of the test plates. For this reason this part of the collected data cannot be considered as relevant.

Test plate nr.	Mass before paint (g)	Mass after paint removal	Change in mass (g)	Average change (g)
8	349,425	352,124	+ 2,699	+ 1,884
17	354,274	356,445	+ 2,171	
26	349,677	351,382	+ 1,705	
35	354,126	355,088	+ 0,962	

The detailed reports on cleaning with this method can be found in the Appendix 6 and the results of analysis performed by METRIS in their WP4 report.

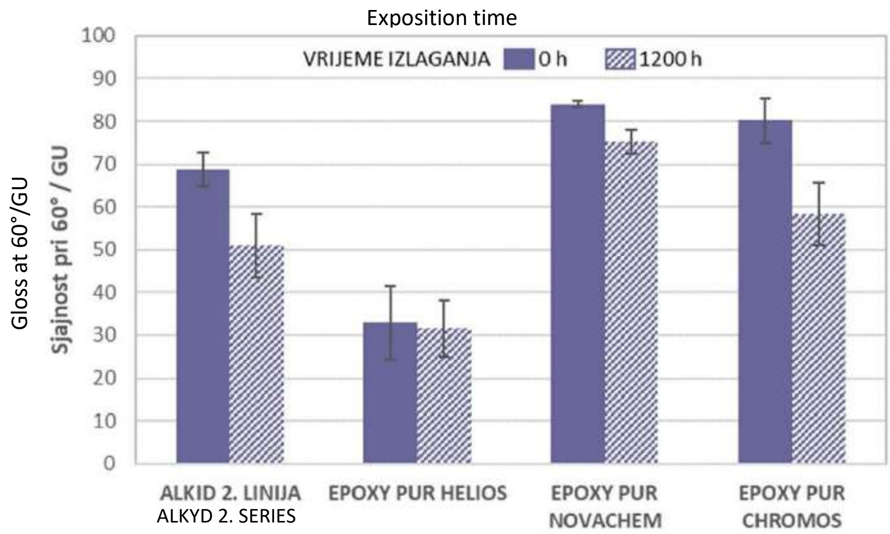
7. Testing of the selected epoxy + polyurethane coating systems for application on the sculptures

As previously mentioned, this part of testing was performed on 60 test plates in total, including the reference test plates. Part of the test plates was aged in the salt spray chamber, and the other part was aged by natural exposition. The tests and analysis used to quantify and describe the ageing of the test plates will be explained bellow.

7.1 Gloss measurement

Measurement of the gloss value at 60° was executed on each test plate in triplicate (3 measurement points, 5 measurements in each point) both before and after exposition in the salt spray chamber / natural exposure.

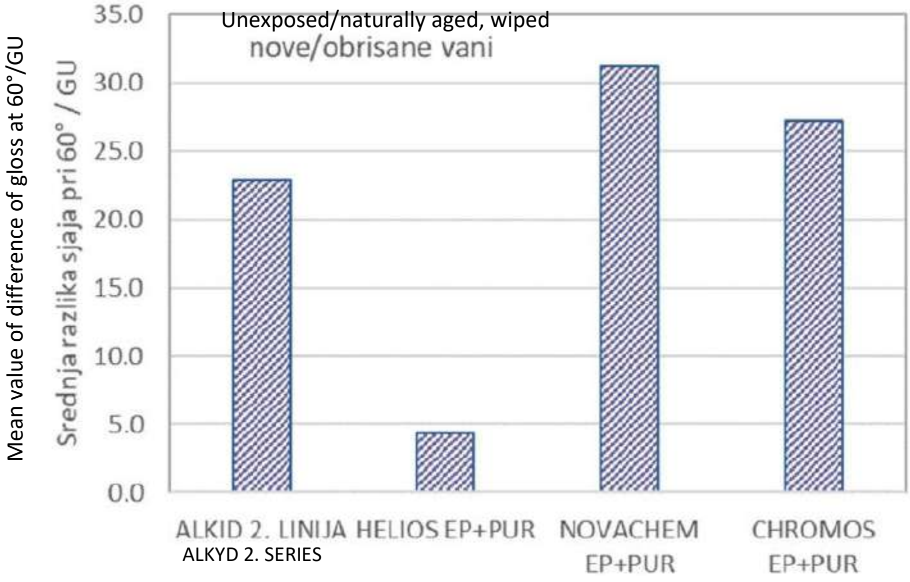
The following graph depicts the difference in gloss for each set of test plates, before and after the exposition to the salt spray chamber.[5]



Graph 1: Results of gloss measurement on unexposed tesplates and after exposition in the salt spray chamber

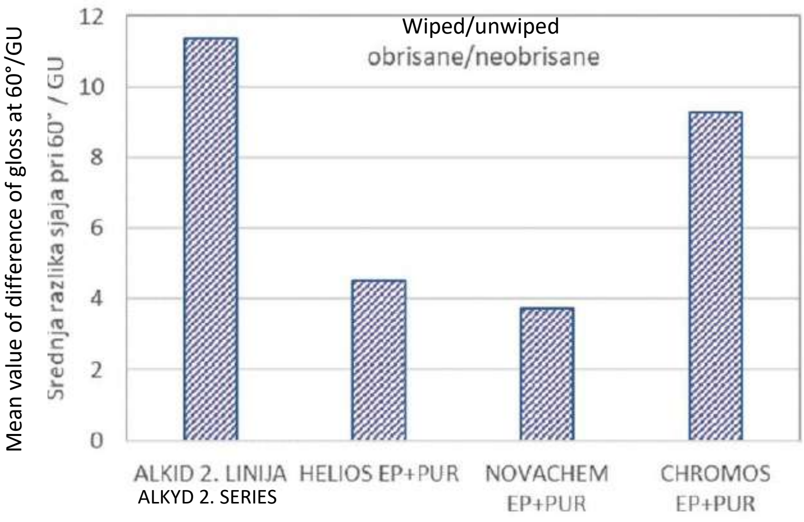
[5] The graph is taken from the report produced by ReCorr Tech for Sisak Municipal Museum which is available in Appendix 4.

Another very interesting graph[6] is the one showing the difference between measured values of gloss between the unexposed test plates and naturally aged test plates that were wiped clean before measurement.



Graph 2: Difference in measured values of gloss between the unexposed and naturally exposed test plates

Also, it is interesting to mention that there was a measurable difference in gloss on the naturally exposed test plates from the residues on the surface (mentioned in part 5.1 of this report) which is shown in the following graph[7] cumulatively for each set of test plates.



Graph 3: Difference in measured gloss before and after wiping of the residue from the surface of the naturally exposed test plates

[6] The graph is taken from the report produced by ReCorr Tech for Sisak Municipal Museum which is available in Appendix 4.
[7] The graph is taken from the report produced by ReCorr Tech for Sisak Municipal Museum which is available in Appendix 4.

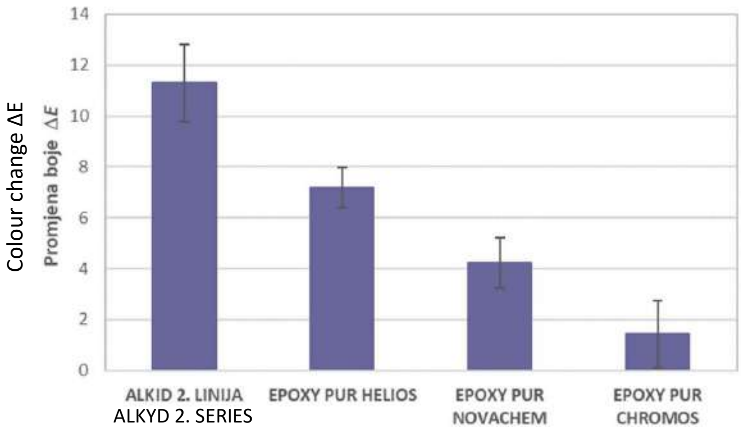
The full report by ReCorr Tech is available in the Appendix 4.

7.2 Measurement of the change in colour

Measurements were performed on unexposed test plates after the exposition, both to the salt spray chamber and natural.

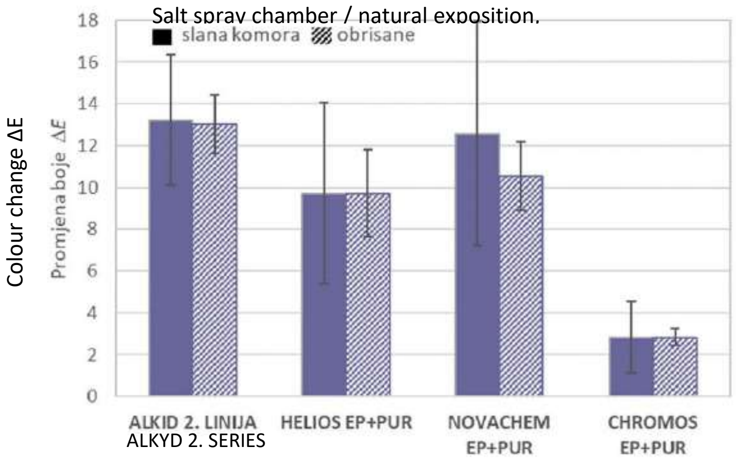
The values were recorded in L*a*b* and RGB systems and from those values ΔE (the change in colour) was calculated.

The following graph[8] depicts the change in colour for each test plate between the unexposed test plates and the ones aged in the salt spray chamber.



Graph 4: Colour change between unexposed test plates and test plates exposed to the salt spray chamber

Another interesting set of data is the graph[9] (below) depicting the difference of ΔE between the test plates aged in the salt spray chamber and the ones aged naturally.



Graph 5: Comparison of colour change between the test plates exposed in salt spray chamber and naturally exposed test plates

8 The graph is taken from the report produced by ReCorr Tech for Sisak Municipal Museum which is available in Appendix 4.

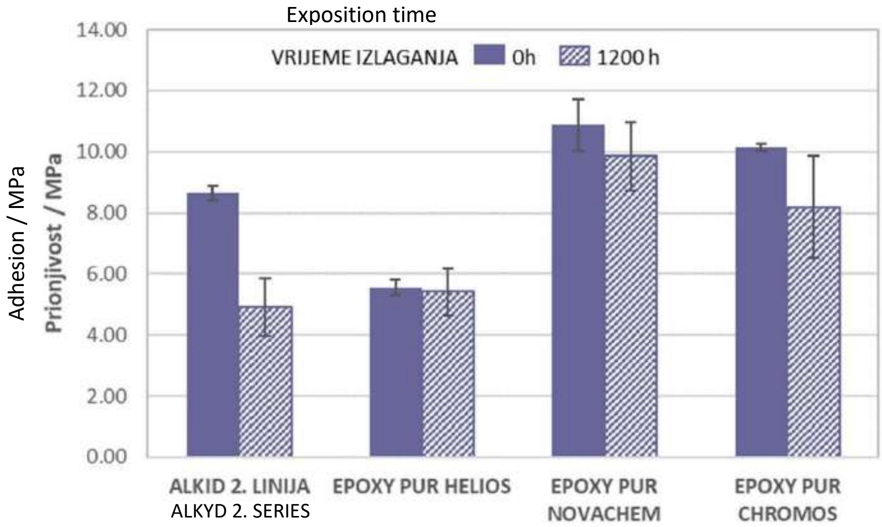
9 The graph is taken from the report produced by ReCorr Tech for Sisak Municipal Museum which is available in Appendix 4.

The full report by ReCorr Tech is available in the Appendix 4.

7.3 Testing of adhesion according to ISO 4624

This type of measurement of adhesion is performed by an electronic or hydraulic device that pulls off a dolly glued to the surface by applying and recording constant force.

The following graph[10] shows the recorded values of pressure (MPa) needed to separate the dolly from the surface of the test plate both on unexposed test plates and the test plates after the exposition in the salt spray chamber.



Graph 6: Measured values of adhesion before and after the exposition in the salt spray chamber

The full report by ReCorr Tech is available in the Appendix 4.

7.4 Testing of adhesion according to ISO 2409

This method of testing uses a special tool that cuts a lattice of lines into the coating layers in order to evaluate the adhesion of the coating. After the lattice is cut, a visual evaluation is performed according to the ISO 2409 standard.

All of the unexposed test plates from all four sets have passed the test (score for all of the test plates was ≤2). After the exposition, the following test plates have failed the test (score >2):

[10] The graph is taken from the report produced by ReCorr Tech for Sisak Municipal Museum which is available in Appendix 4.

Set	Number of test plate	Score
Alkyd 2. series	43 (blue)	4
Epoxy+PUR Novachem	69 (blue)	3
	73 (black)	4
Epoxy+PUR Chromos	81 (blue)	4
	85 (yellow)	4

The full report by ReCorr Tech is available in the Appendix 4.

7.5 Testing of the porosity according to ISO 29601

Testing was performed both on the unexposed test plates and on the test plates aged by exposition in the salt spray chamber. The test is performed by connecting the base metal of the test plate to one electrode and then using the second electrode inserted into a sponge soaked with electrolyte solution to pass over the surface. The device uses two voltage settings 9V and 90V in order to measure the porosity of the coatings.

The only set of plates that showed porosity of the coating at 90V (but not at 9V) is the unexposed set of test plates coated with epoxy+pur system by Helios. The same set of test plates after the ageing in the salt spray chamber does not show porosity, except for one spot on the test plate number 50.

The full report by ReCorr Tech is available in the Appendix 4.

7.6 Measurement by EIS ReCorr QCQ test according to ISO 16773

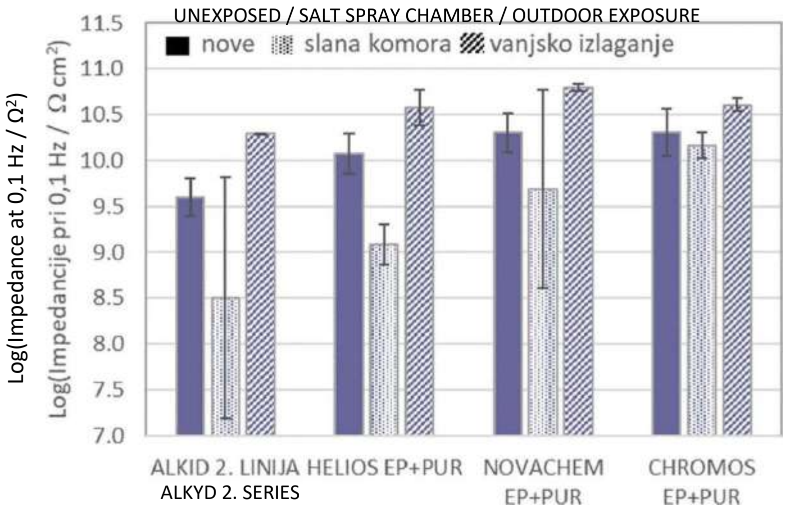
Measurement by electrochemical impedance spectroscopy (EIS) was performed both on the unexposed test plates and on the test plates aged by exposition in the salt spray chamber and natural exposition.

Generally speaking, the measurement of impedance enables us to assess the protective barrier properties of a coating applied to metal surface. Also, with different types of measurements it is possible to make estimates concerning the problems with a coating that will appear in the future.

As for the test plates aged in the salt spray chamber, as expected, the set of test plates coated with alkyd binder based system has had the biggest drop in impedance value after the ageing, while the sets of test plates coated with epoxy+pur systems had better results.

With the test plates exposed to the natural ageing, another phenomena occurred – the impedance values have increased. This type of occurrence is possible because of two main reasons: either the coatings were further polymerised by exposure to sunlight, wind etc. or the open-air conditions impacted the measurements to this extent.

The results are shown in the graph[11] below.



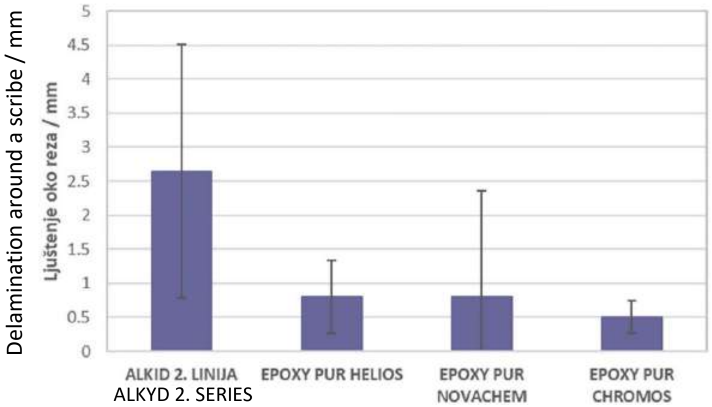
Graph 7: Comparative results of EIS measurement

The full report by ReCorr Tech is available in the Appendix 4.

7.7 Testing of delamination around a scribe according to ISO 4628-8

Testing of the delamination around a scribe is performed by cutting of a scribe into the coating layers on a test plate before the exposure in the salt spray chamber. Evaluation is performed by visual inspection after the exposure by applying different criteria from ISO standards.

Acceptable mean value of delamination is ≤ 1,5 mm. According to the standards, at least two out of three test plates with the same type of coating system have to meet the criteria in order for a system to meet the criteria. This is the case with all of the tested epoxy+polyurethane systems, but the alkyd binder based systems did not meet the criteria (the mean value was higher than 1,5 mm). The results are visible in the graph[12] below.



Graph 8: Measured values of delamination around a scribe

[11] The graph is taken from the report produced by ReCorr Tech for Sisak Municipal Museum which is available in Appendix 4.

[12] The graph is taken from the report produced by ReCorr Tech for Sisak Municipal Museum which is available in Appendix 4.

The full report by ReCorr Tech is available in the Appendix 4.

7.8 Visual evaluation according to ISO 4628

The visual evaluation with application of criteria form ISO 4628, ISO 12944 and ISO 23944 standard was performed both on the unexposed and the salt spray chamber aged test plates.

Defects such as bubbling, corroding, breaking and peeling are graded according to the pictorial standards and criteria given in the aforementioned standards.

The results of the aged test plates along with the remarks are shown in the table[13] below.

Name of the sample group	Norm of evaluation	Condition by the norm	Remarks
ALKYD 2. SERIES	HRN EN ISO 4628-2, bubbling	0S(0)*	* On the plate 46 bubbling is visible under and on 1 cm from the scribe on the same hight, under the scribe and by the lower edge of the plate. The maximum diameter of the bubbles is 4 mm. System MEETS the requrements of the norm HRN EN ISO 12944-6.
	HRN EN ISO 4628-3, corroding	Ri0	
	HRN EN ISO 4628-4, breaking	0S(0)	
	HRN EN ISO 4628-5, peeling	0S(0)	
EP PUR HELIOS	HRN EN ISO 4628-2, bubbling	0S(0)	System MEETS the requrements of the norm HRN EN ISO 12944-6.
	HRN EN ISO 4628-3, corroding	Ri0	
	HRN EN ISO 4628-4, breaking	0S(0)	
	HRN EN ISO 4628-5, peeling	0S(0)	
EP PUR NOVACHEM	HRN EN ISO 4628-2, bubbling	2S(3)*	* On the plate 69 one bubble 4 mm in diameter is visible 1 cm from the edge of the plate and several small bubbles in the midle of the plate. On the plate 65 one bubble 3 mm in diameter is visible in the midle of the plate and also several small bubbles. System DOES NOT MEET the requrements of the norm HRN EN ISO 12944-6.
	HRN EN ISO 4628-3, corroding	Ri0	
	HRN EN ISO 4628-4, breaking	0S(0)	
	HRN EN ISO 4628-5, peeling	0S(0)	
EP PUR CHROMOS	HRN EN ISO 4628-2, bubbling	0S(0)	System MEETS the requrements of the norm HRN EN ISO 12944-6.
	HRN EN ISO 4628-3, corroding	Ri0	
	HRN EN ISO 4628-4, breaking	0S(0)	
	HRN EN ISO 4628-5, peeling	0S(0)	

The only system that did not meet the requirements of ISO 12944 standard was epoxy+pur system by Novachem d.o.o.

The full report by ReCorr Tech is available in the Appendix 4.

[13] The table is taken from the report produced by ReCorr Tech for Sisak Municipal Museum which is available in Appendix 4.

8. Results and comparative analysis

In this part of the report, a comparative analysis will be given for each of the testing methods with proposition of the best material/method according to that test. The final proposition will be made in the Conclusion.

8.1 Results of the testing of removal methods

The results of testing of different methods of removal of aged coating systems will be given in this part.

8.1.1 Testing of the chemical stripping products

A total of six chemical products were tested on two sets of four test plates coated with alkyd binder based coating system (AGROHEL ES primer +REZISTOL enamel A) by Helios Hrvatska d.o.o. in four shades (RAL 3024 - Luminous red, RAL 5002 - Ultramarine blue, RAL 1026 - Luminous yellow, RAL 9005 - Jet black).

On the first set all six products were tested on each test plate in order to decide on the most efficient product for further testing.

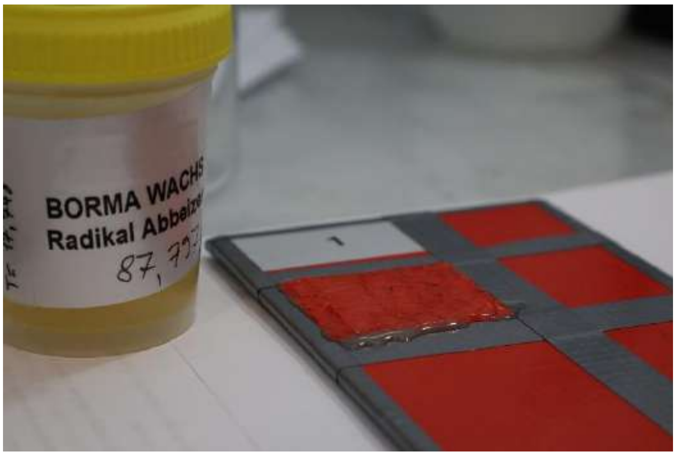


Photo 20: Testing of diferent chemical striping methods

For each of the cleaning tests the time of application of the product was set to 30 min and the consumption of the product was recorded (as shown in the table below).

Consumption of products for chemical stripping of paint		
Name of the product	Consumption per test plate (g)	Mean consumption (g)
1. Radikal Abbeizer by Borma Wachs B.P.S. srl	4,394	
	4,669	
	3,476	
	2,793	3,833
2. Sverniciatore Superattivo by Saratoga INT. Sforza spa	3,562	
	6,092	
	4,838	
	4,181	4,668
3. MoTip Paint Remover by Motip Dupli b.v.	7,952	
	3,985	
	3,307	
	4,972	5,054
4. Luxal Desol by Chromos boje i lakovi d.d.	4,706	
	5,715	
	3,597	
	3,368	4,347
5. Acetone p.a.	4,510	
	2,871	
	2,932	
	2,643	3,239
6. Toluene p.a.	2,992	
	3,685	
	3,493	
	3,910	3,520

After the 30 minutes have expired, the product, along with the semi-dissolved coatings was removed from the surface with cotton wool, the surface was wiped in order to remove any of the remaining softened base coat, also, with certain products, a wooden stick or brush had to be used in order to remove the softened base coat layer in some spots. In the end the surface was wiped with ethanol in order to remove any remaining dissolved or loose fragments of paint or the product.

As for the effectiveness of the cleaning, “Sverniciatore Superattivo” by Saratoga stood out because it was the fastest acting product with the best effectiveness on the base coat. The least effective products were the pure solvents (acetone and toluene) that made the coatings rubber like and hard to remove.

Also, the price of product per unit (per mL) was calculated as shown in the table below.

Price of products used for tests of chemical stripping of paint		
Name of the product	Price per package	Price per unit
1. Radikal Abbeizer by Borma Wachs B.P.S. srl	74,81 kn / 750 ml	0,10
2. Sverniciatore Superattivo by Saratoga INT. Sforza spa	78,75 kn / 750 ml	0,11
3. MoTip Paint Remover by Motip Dupli b.v.	58,02 kn / 500 ml	0,12
4. Luxal Desol by Chromos boje i lakovi d.d.	60,65 kn / 750 ml	0,08
5. Acetone p.a.	49,14 kn / 1000 ml	0,05
6. Toluene p.a.	161,59 kn / 2500 ml	0,06

With this type of cleaning the criteria of impact to the environment and health of the person performing the cleaning can not be taken into the account because all of the products are toxic solvents or combinations of solvents and all of the by-products of the cleaning need to be disposed of accordingly. Also, the person performing the cleaning needs to be aware of the dangers of working with chemicals and use appropriate personal protective equipment.

Taking into the account all of the data listed above it can be concluded that the lowest amount of product used was with acetone (3,239 g) which is also the product with the lowest price per unit.

Unfortunately, it also had some of the worst results in the application.

Given that the maximum difference in the amount of the product used was 1,815 g, and the difference in price per unit was 0,07 kn it was decided that the criteria of effectiveness will be the key to selecting a product for further testing. Having this in mind, the “Sverniciatore Superattivo” by Saratoga was selected for further application on the second set of test plates.

After the first stage of testing, the second set of test plates were completely treated with “Sverniciatore Superattivo” by Saratoga in the same manner as in the initial tests.

In the table below the consumption of this product with application to whole test plates is shown.

Consumption of “Sverniciatore Superattivo” by Saratoga		
Name of the product	Consumption per test plate (g)	Mean consumption (g)
2. Sverniciatore Superattivo by Saratoga INT. Sforza spa	45,483	38,182
	38,395	
	34,778	
	34,073	

After the application of the product and its removal there were some residues in form of shadows visible on the surface, but after the test plates were wiped with cotton wool and ethanol they disappeared or could barely be visible in some areas. There was no visible permanent impact on the surface of the test plate.

The measurement that tells us a bit more about the impact on the surface than visual examination alone is the measurement of the surface profile or roughness with results as shown in the table below.

Change in surface profile afte the application of “Sverniciatore Superattivo” by Saratoga				
Name of the product	Profile before (μ)	Profile after (μ)	Change (μ)	Mean value (μ)
2. Sverniciatore Superattivo by Saratoga INT. Sforza spa	18,10	13,20	-4,90	-4,97
	23,27	13,60	-9,67	
	16,20	14,89	-1,31	
	18,10	14,10	-4,00	

Given that there is very little possibility of wiping with cotton wool having an impact on the surface profile of a steel test plate, we can conclude that the “valleys” created by the initial sandblasting have been filled to a certain point with the base coat and that these parts of the base coat were not completely removed by this method.

This conclusion is further confirmed by the comparison of the recorded weighting results before the application of coatings and after their removal where we can see an increase in the mass, as shown in the table below.

Test plate nr.	Mass before paint (g)	Mass after paint removal (g)	Change in mass (g)	Average change (g)
2	351,269	351,330	+ 0,061	+ 0,049
11	352,083	352,135	+ 0,052	
20	344,880	344,930	+ 0,050	
29	353,259	353,291	+ 0,032	

Another confirmation comes from the micrographs[14] taken by METRIS in which the residues of the base coat are clearly visible on these test plates.

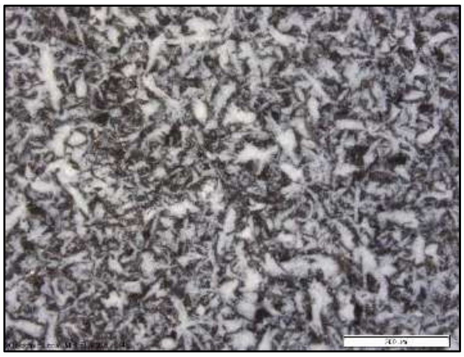


Photo 21: Micrograph of the surface of the test plate no. 2

Taking into consideration all of the data presented for chemical stripping of aged alkyd based coatings, it can be concluded that this method of cleaning, while clearly having certain drawbacks (dangers of working with chemical products, inability to remove all of the coating etc.) can still be

[14] Taken from WP4 analysis report produced by METRIS (see Appendix 5).

considered as a non-labour intensive and relatively effective method to pre-clean the surfaces of the majority of the coatings applied to the surface.

More data on the performed analysis is available in the WP4 report by METRIS.

8.1.2 Testing of sandblasting with different abrasives

As mentioned before, three types of abrasives were tested: aluminium oxide, glass beads and crushed walnut shell.

The application method was the same for all of the abrasives, as described in part 6.2, 6.3 and 6.4 of this report, but because of different effectiveness of the abrasives, the times needed to clean the test plate were different. The recorded blasting times are shown in the table below.

Time needed for sanblasting of the test plates		
Name of the product	Time per test plate	Mean time needed
Aluminium oxide (corundum)	0:06:36	
	0:07:47	
	0:07:21	
	0:07:07	0:07:13
Glass beads	0:23:56	
	0:19:39	
	0:21:30	
	0:28:12	0:23:19
Crushed walnut shell	0:38:31	
	0:30:06	
	0:55:17	
	0:47:38	0:42:53

Also, the consumption of the abrasive material was different for each used abrasive. It is also important to mention that the volumes of the same amount of aluminium oxide abrasive and the glass beads is very similar, while the volume of the same amount of crushed walnut shell is considerably larger. The recorded data on consumption of abrasives is shown in the table below.

Consumption of abrasives used for sanblasting of the test plates		
Name of the product	Consumption per test plate (g)	Mean consumption (g)
Aluminium oxide (corundum)	492,930	
	545,380	
	471,210	
	462,340	492,965
Glass beads	1138,837	
	1554,260	
	1688,910	
	2399,380	1695,347
Crushed walnut shell	2201,290	
	1372,270	
	1885,030	
	1990,290	1862,220

Another consideration is the price of the used abrasives. The aluminium oxide and the glass beads have very similar price, while the crushed walnut shell is cheaper. In the table below a comparison is given, also taking into the account the mean quantities used in this test necessary for cleaning one test plate which gives a somewhat different picture on the prices.

Price of the used abrasives				
Name of the product	Price (kn) per kilo	Price per gram (kn)	Mean quantity used (g) per test plate	Price per test plate (kn)
Aluminium oxide (corundum)	44,18	0,044	492,965	21,78
Glass beads	44,99	0,045	1695,347	76,27
Crushed walnut shell	16,39	0,016	1862,22	30,52

As can already be concluded from the time needed to clean a test plate with each of the used abrasives and the used quantities, the aluminium oxide abrasive was the most efficient in removing of the coatings, glass beads were somewhat less effective and walnut shell abrasive was the least effective. This was also clear from the visual inspection of the test plates – after the sandblasting with the aluminium oxide the surface was visually completely clean and uniform, after the glass beads blasting there were some shadows on the surface and the surface was considerably smoother and shinier, and after the sandblasting with the crushed walnut shell there were visible residues on the surface of the test plates.

This is also confirmed by the weighting of the test plates before the application of the coating systems and after the removal of the coatings with the different abrasives as shown in the table below.

Change in recorded mass of the test plates before the application of the coatings and after their removal				
Name of the product	Mass before (g)	Mass after (g)	Change (g)	Mean value (g)
Aluminium oxide (corundum)	347,728	347,417	-0,311	-0,417
	351,414	350,819	-0,595	
	346,337	345,975	-0,362	
	352,365	351,966	-0,399	
Glass beads	348,172	347,650	-0,522	-0,593
	352,678	352,081	-0,597	
	344,170	343,633	-0,537	
	353,337	352,620	-0,717	
Crushed walnut shell	349,646	349,762	0,116	+0,637
	353,712	355,868	2,156	
	350,159	350,297	0,138	
	353,621	353,757	0,136	

It is also interesting to look at the data concerning the change in the surface roughness before the application of the coating systems and after their removal by sandblasting. It can be concluded that aluminium oxide abrasive which has the sharpest edges and hardness of the used abrasives has further increased the roughness profile, in average for 2,99 µ.

The glass beads have decreased the surface profile considerably (in average for 8,45 µ), which was to be expected, given that this abrasive can be used for the so called condensing of the surface and in some instances for polishing and also from visual inspection as mentioned before (smoother, shinier surface).

The crushed walnut shell has also decreased the surface roughness, but in this case it can be assumed that given the softness of the abrasive and the residues on the surface this has more to do with the base coat being left in the "valleys" created by the initial sandblasting than with "flattening" of the surface. This will be confirmed below with the micrographs of the surface after the cleaning.

The values of the surface roughness measurements are shown in the table below.

Change in recorded surface roughness of the test plates before the application of the coatings and after their removal				
Name of the product	Profile before (μ)	Profile after (μ)	Change (μ)	Mean value (μ)
Aluminium oxide (corundum)	16,60	18,60	2,00	2,99
	18,20	16,33	-1,87	
	14,20	19,60	5,40	
	17,70	24,11	6,41	
Glass beads	15,90	10,44	-5,46	-8,45
	17,75	9,00	-8,75	
	22,90	11,80	-11,10	
	16,80	8,30	-8,50	
Crushed walnut shell	18,20	19,00	0,80	-0,55
	15,40	14,80	-0,60	
	18,50	17,10	-1,40	
	18,90	17,90	-1,00	

This is further confirmed by observing the micrographs[15] of the surface taken by METRIS after the sandblasting. From these images it is clear that on the plate sandblasted with crushed walnut shell there are residues from the base coat that were not cleaned by this abrasive.

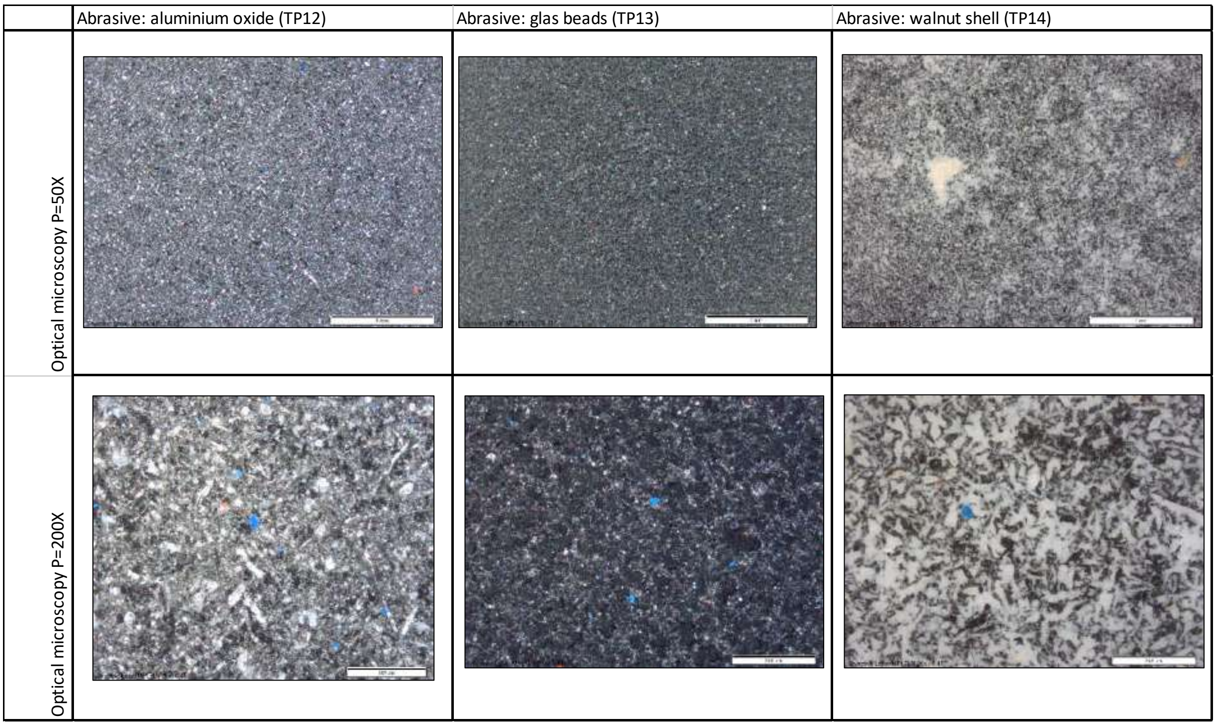


Photo 22: Comparative view of micrographs of the surface of the test plates cleaned with different abrasives

More data on the performed analysis is available in the WP4 report by METRIS.

[15] Taken from WP4 analysis report produced by METRIS (see Appendix 5).

8.1.3 Testing of heat gun stripping

The method was tested by heating up a test plate with a heat gun set to the high setting which in this case is 550°C and then, after the coating layer is softened, it was scraped away using a spatula.

Given that even in this test, where the surface that needed to be heated was quite small compared to an outdoor sculpture, it was impossible to heat up the whole surface of the test plate (10X15cm) it is questionable if this method would have any effect on an outdoor sculpture because of the heat conductivity of metal base. The time needed to heat up the test plates and scrape away the coating layers are shown in the table below.

Time needed for heat gun coating stripping		
Name of the product	Time per test plate	Mean time needed
Heat gun - 550°C setting	0:28:12	
	0:25:46	
	0:26:34	
	0:25:13	0:26:26

Even after scraping and wiping the surface with ethanol and cotton wool, the results were less than satisfactory. There were scrape marks from spatula visible on the surface and also a lot of residues from the base coat. This is also visible from the micrographs[16] taken by METRIS that are shown below.

Photo 23: Micrographs of the surface of the test plates cleaned with heat gun and spatula

The residues on the surface are also confirmed by comparing the recorded masses of the test plates before the application of the coatings and after their removal. This data is shown in the table below.

Change in recorded mass of the test plates before the application of the coatings and after their removal				
Name of the product	Mass before (g)	Mass after (g)	Change (g)	Mean value (g)
Heat gun - 550°C setting	348,601	348,751	0,150	0,127
	352,463	352,606	0,143	
	346,555	346,663	0,108	
	352,054	352,160	0,106	

[16] Taken from WP4 analysis report produced by METRIS (see Appendix 5).

The same conclusion can also be reached by comparing the surface roughness before the application of the coatings and after their removal by this method as shown below.

Change in recorded surface roughness of the test plates before the application of the coatings and after their removal				
Name of the product	Profile before (µ)	Profile after (µ)	Change (µ)	Mean value (µ)
Heat gun - 550°C setting	17,10	10,70	-6,40	-6,33
	17,70	8,30	-9,40	
	13,60	9,00	-4,60	
	15,60	10,70	-4,90	

In this case, there are no consumables, and the price of application basically depends on the energy efficiency (consumption) of the used heat gun and the price of electricity.

More data on the performed analysis is available in the WP4 report by METRIS.

8.1.4 Testing of cleaning with rotating composite brushes

This method was tested using composite "wire" brushes mounted to a pneumatic grinder. Given the results obtained by this method both in terms of base metal surface damage and inefficiency in removing the coatings from the surface, the testing was stopped after the cleaning of the first out of four test plates.

This method was very time consuming and labour intensive.

Time needed for rotating composite brush stripping		
Name of the product	Time per test plate	Mean time needed
KWB 604330	1:14:27	1:16:22
	1:18:17	

The results after such a long cleaning time were unacceptable for testing conditions given in the methodology. In order to remove the coatings from the surface it was necessary to go over certain spots many times or keep the brush in one place for longer periods of time which created considerable damage to the surface of metal of the test plates. The change from uniformly sandblasted surface to the brushed metal surface is visible by the naked eye, and even more so under magnification[17] as shown below.

[17] Taken from WP4 analysis report produced by METRIS (see Appendix 5).

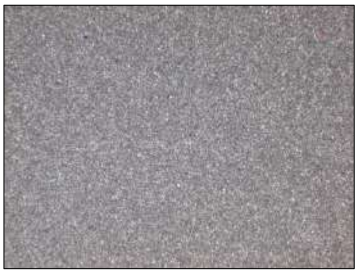
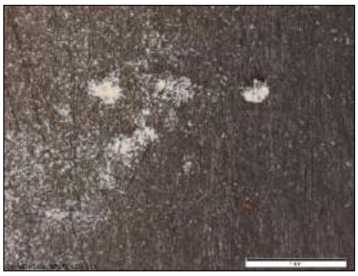
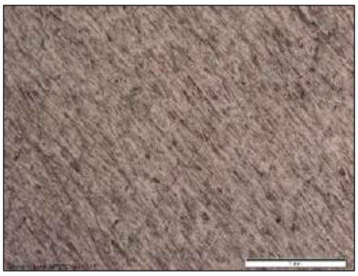
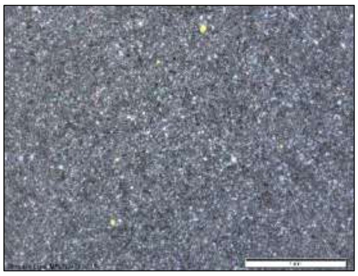
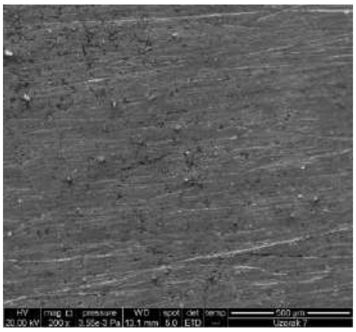
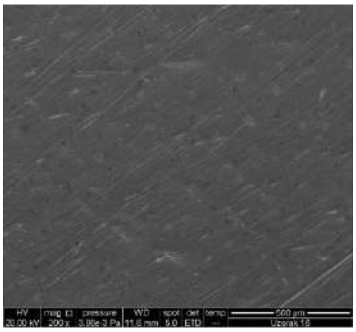
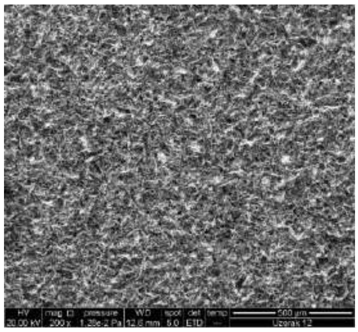
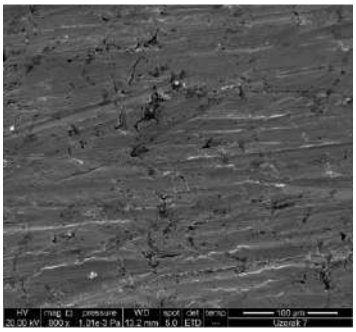
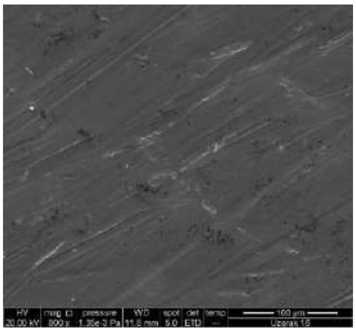
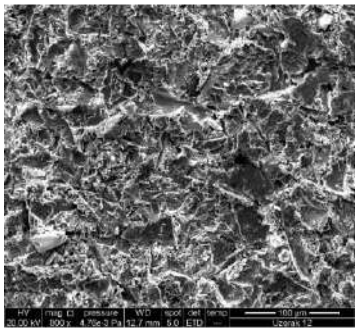
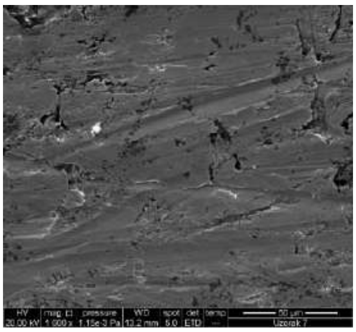
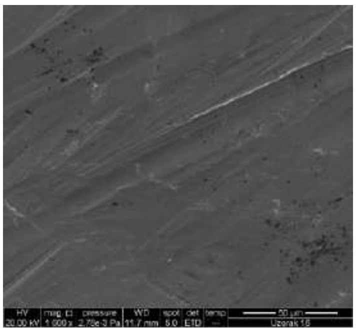
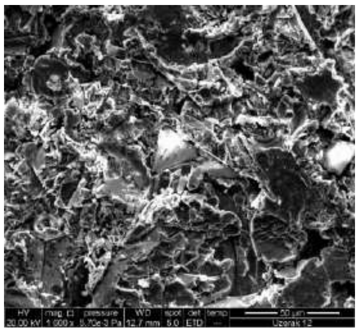
	Composite brush cleaning (TP7)	Composite brush cleaning (TP16)	Comparison: aluminium oxide blasting (TP12)
Optical microscopy P=20X			
Optical microscopy P=50X			
SEM P=200X			
SEM P=800X			
SEM P=1600X			

Photo 24: Comprison between surfaces cleaned with composite wire brush and sandblasting with aluminium oxide

The change is evident in the recorded mass change before the application of the coating system and after its removal as shown below.

Change in recorded mass of the test plates before the application of the coatings and after their removal				
Name of the product	Mass before (g)	Mass after (g)	Change (g)	Mean value (g)
KWB 604330	348,869	347,403	-1,466	-1,477
	352,651	351,163	-1,488	

The same conclusion about the change of the surface and its roughness can be drawn from the change in the recorded surface profile before the application of the coatings and after their removal as shown below.

Change in recorded surface roughness of the test plates before the application of the coatings and after their removal				
Name of the product	Profile before (μ)	Profile after (μ)	Change (μ)	Mean value (μ)
KWB 604330	17,30	11,40	-5,90	-9,10
	17,60	5,30	-12,30	

As for the price, only one brush was used and its price was 78,00 kn.

The method itself creates ample amounts of dust made primarily of the removed paint and metal particles, so a special care needs to be taken to protect the person performing the cleaning, as well as the environment in which the cleaning is performed.

More data on the performed analysis is available in the WP4 report by METRIS.

8.1.5 Testing of cleaning by dry ice blasting

As mentioned in part 6.8, two methods of dry ice blasting were tested – with and without the addition of glass beads to the dry ice pellets.

As for the blasting with pure dry ice pellets, it was reported by the company performing the cleaning that they were unable to completely remove the base coat, so it can be concluded that this method would be unable to completely remove the coating layers from a sculpture. The same occurrence was previously noticed during the conservation-restoration of “Object II” sculpture by Josip Diminić from the Sisak Ironworks Sculpture Park in 2014.

The method of dry ice blasting with the addition of glass beads was much more efficient in the removal of all layers of the coating system applied to the test plates. Also, this method changed the

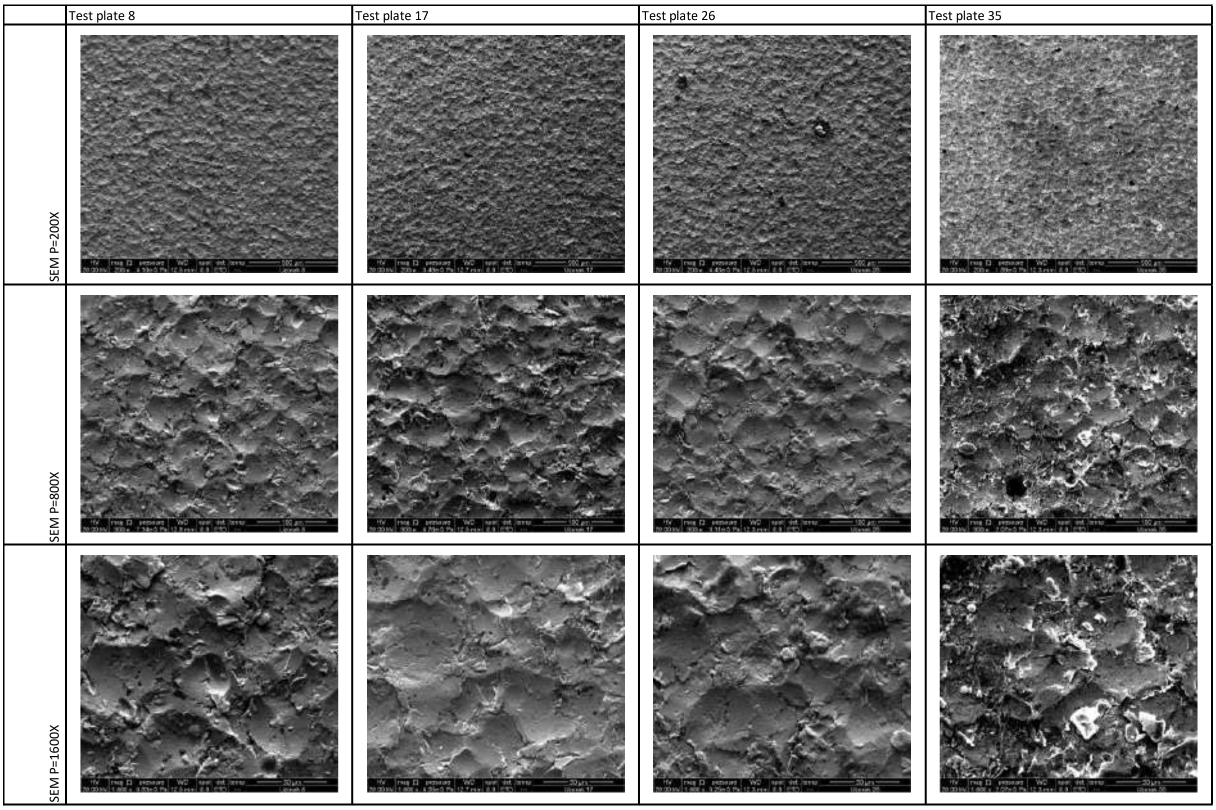


Photo 25: Micrographs of the surface of the test plates after cleaning by dry ice blasting with addition of glass beads

surface, similar to the sandblasting with glass beads as abrasive. This change is visible in micrographs[18] taken by METRIS (shown below).

As previously mentioned before (part 6.8) given that one side of the test plates was not completely cleaned, the data on recorded mass before the application of the coatings and after their removal is compromised an cannot be taken as relevant.

The surface profile or roughness was measured before the application of the coatings and after their removal (on the side cleaned by dry ice blasting with the addition of glass beads) and the results are shown in the table below.

Change in recorded surface roughness of the test plates before the application of the coatings and after their removal				
Name of the product	Profile before (μ)	Profile after (μ)	Change (μ)	Mean value (μ)
Dry ice blasting with the addition of glass beads	16,73	9,20	-7,53	-7,78
	17,10	9,00	-8,10	
	17,30	8,20	-9,10	
	17,40	11,00	-6,40	

As for the time needed to perform the cleaning, again there is a side of test plates treated with dry ice pellets alone where the time is undetermined, and the side where a mixture of dry ice and glass beads was used where the complete time necessary for cleaning of all four plates was around 6 minutes, so about 1:30 min per test plate.

[18] Taken from WP4 analysis report produced by METRIS (see Appendix 5).

The price is also unknown given that each of the companies performing this kind of cleaning charges differently – either by hour or by previously agreed on prices for the whole job. Generally speaking, the prices of this type of cleaning are still considerably higher than for the other methods of cleaning.

Concerning the impact on the health and the environment, appropriate PPE needs to be used by the operator and the material left by the procedure (either paint chips or paint chips and glass beads needs to be disposed of properly).

More data on the performed analysis is available in the WP4 report by METRIS.

8.1.6 Overview of data obtained by cleaning tests

In this part all types of the data (consumption, change in mass and surface profile, time needed to perform the cleaning and price) obtained from the cleaning tests will be summarised and compared between different methods.

8.1.6.1 Consumption of material

Consumption of materials used for clening of coatings from the test plates		
Name of the product	Consumption per test plate (g)	Mean consumption (g)
Sverniciatore Superattivo by Saratoga INT. Sforza spa	45,483	
	38,395	
	34,778	
	34,073	38,182
Aluminium oxide (corundum)	492,930	
	545,380	
	471,210	
	462,340	492,965
Glass beads	1138,837	
	1554,260	
	1688,910	
	2399,380	1695,347
Crushed walnut shell	2201,290	
	1372,270	
	1885,030	
	1990,290	1862,220
Heat gun - 550°C setting	Not applicable / no consumables used	
Composite "wire" brush	Not applicable / the wire brush is normaly slowly consumed during the cleaning but can also break apart at any moment	
Dry ice blasting with the addition of glass beads	approx.	625,000

As can be seen from the table above, the best method according to this criterion is the cleaning with the heat gun because there is no consumables used at all, but unfortunately the method had poor results in respect to the removal of the coatings and impact on the surface.

The method of chemical cleaning had a very low consumption of material, and between the different blasting cleaning methods it can be concluded that the aluminium oxide sandblasting had the lowest consumption of blasting media.

8.1.6.2 Change in recorded mass before the application of the coating systems and after their removal

Change in recorded mass of the test plates before the application of the coatings and after their removal				
Name of the product	Mass before (g)	Mass after (g)	Change (g)	Mean value (g)
Sverniciatore Superattivo by Saratoga INT. Sforza spa	351,269	351,330	0,061	+0,049
	352,083	352,135	0,052	
	344,880	344,930	0,050	
	353,259	353,291	0,032	
Aluminium oxide (corundum)	347,728	347,417	-0,311	-0,417
	351,414	350,819	-0,595	
	346,337	345,975	-0,362	
	352,365	351,966	-0,399	
Glass beads	348,172	347,650	-0,522	-0,593
	352,678	352,081	-0,597	
	344,170	343,633	-0,537	
	353,337	352,620	-0,717	
Crushed walnut shell	349,646	349,762	0,116	+0,637
	353,712	355,868	2,156	
	350,159	350,297	0,138	
	353,621	353,757	0,136	
Heat gun - 550°C setting	348,601	348,751	0,150	+0,127
	352,463	352,606	0,143	
	346,555	346,663	0,108	
	352,054	352,160	0,106	
Composite "wire" brush	348,869	347,403	-1,466	-1,477
	352,651	351,163	-1,488	
Dry ice blasting with the addition of glass beads (data not relevant - see part 6.8)	349,425	352,124	2,699	+1,884
	354,274	356,445	2,171	
	349,677	351,382	1,705	
	354,126	355,088	0,962	

When taking into the consideration the criterion of change in the recorded mass of the test plates before the application of the coatings and after their removal there are two types of results – methods with increase in mass and methods with decrease in mass. It can be concluded that the methods that had increase in mass did not in fact remove all of the applied coatings and the residues of the coatings on the surface are in fact the reason for the increase. The method with the lowest increase in the mass is the chemical cleaning by Sverniciatore Superattivo by Saratoga.

When looking at the data for the methods with the recorded decrease in mass it can be concluded that the reason for the decrease is in the fact that these methods also impact or change the surface of the base metal. The method with the lowest recorded negative change is the sandblasting with the aluminium oxide.

8.1.6.3 Change in surface profile or roughness before the application of the coating systems and after their removal

Change in recorded surface roughness of the test plates before the application of the coatings and after their removal				
Name of the product	Profile before (µ)	Profile after (µ)	Change (µ)	Mean value (µ)
Sverniciatore Superattivo by Saratoga INT. Sforza spa	18,10	13,20	-4,90	-4,97
	23,27	13,60	-9,67	
	16,20	14,89	-1,31	
	18,10	14,10	-4,00	
Aluminium oxide (corundum)	16,60	18,60	2,00	+2,99
	18,20	16,33	-1,87	
	14,20	19,60	5,40	
	17,70	24,11	6,41	
Glass beads	15,90	10,44	-5,46	-8,45
	17,75	9,00	-8,75	
	22,90	11,80	-11,10	
	16,80	8,30	-8,50	
Crushed walnut shell	18,20	19,00	0,80	-0,55
	15,40	14,80	-0,60	
	18,50	17,10	-1,40	
	18,90	17,90	-1,00	
Heat gun - 550°C setting	17,10	10,70	-6,40	-6,33
	17,70	8,30	-9,40	
	13,60	9,00	-4,60	
	15,60	10,70	-4,90	
Composite "wire" brush	17,30	11,40	-5,90	-9,10
	17,60	5,30	-12,30	
Dry ice blasting with the addition of glass beads	16,73	9,20	-7,53	-7,78
	17,10	9,00	-8,10	
	17,30	8,20	-9,10	
	17,40	11,00	-6,40	

The change in surface profile gives us information on the measured roughness of the test plate surface. The smallest decrease in the roughness happened with the use of the nutshell blasting media, but unfortunately this method had unsatisfactory results concerning the removal of base coating.

The next lower change, this time in the direction of further roughening the surface, was obtained with the use of aluminium oxide blasting media. The next lower change in the direction of reducing the initial roughness was obtained by Sverniciatore Superattiovo by Saratoga.

8.1.6.4 Time needed to perform the cleaning

Time needed to perform the cleaning		
Name of the product	Time per test plate	Mean time needed
Sverniciatore Superattivo by Saratoga INT. Sforza spa	0:30:00	0:30:00
	0:30:00	
	0:30:00	
	0:30:00	
Aluminium oxide (corundum)	0:06:36	0:07:13
	0:07:47	
	0:07:21	
	0:07:07	
Glass beads	0:23:56	0:23:19
	0:19:39	
	0:21:30	
	0:28:12	
Crushed walnut shell	0:38:31	0:42:53
	0:30:06	
	0:55:17	
	0:47:38	
Heat gun - 550°C setting	0:28:12	0:26:26
	0:25:46	
	0:26:34	
	0:25:13	
Composite "wire" brush	1:14:27	1:16:22
	1:18:17	
Dry ice blasting with the addition of glass beads (approximation from data obtained from supplier)	0:01:30	0:01:30
	0:01:30	
	0:01:30	
	0:01:30	

The most time efficient method to clean the test plates was the dry ice blasting with the addition of glass beads. One of the possible reasons for this (other than this being a very efficient method) is the fact that much higher air pressures are used for this type of cleaning.

The next method would be the aluminium oxide sandblasting.

8.1.6.5 Cost of application of the cleaning methods

Cost of application of the cleaning methods				
Name of the product	≈ Price per kg	Price per gram (kn)	Mean quantity used (g) per test plate	Price per test plate (kn)
Sverniciatore Superattivo by Saratoga INT. Sforza spa	105 kn	0,105	38,182	4,01
Aluminium oxide (corundum)	44,18 kn	0,044	492,965	21,78
Glass beads	44,99 kn	0,045	1695,347	76,27
Crushed walnut shell	16,39 kn	0,016	1862,22	30,52
Heat gun - 550°C setting	Not applicable / no consumables used			
Composite "wire" brush	Not applicable / the wire brush is normaly slowly consumed during the cleaning but can also break apart at any moment			78,00 (price of the used brush)
Dry ice blasting with the addition of glass beads	Not applicable / price is determined by each of the companies performing this type of cleaning individually			

In this part only the consumables part of the methods are taken into the account. For each of this methods a certain set of equipment is needed to perform the cleaning.

The method that uses no consumables is the heat gun stripping, but again, it did not show good results during the cleaning tests.

The lowest cost is recorded with Sverniciatore Superattivo by Saratoga.

8.2 Results of the testing of the selected epoxy + polyurethane coating systems for application on the sculptures

In this part tests, measurements and analysis concerning the selected epoxy + polyurethane coating systems will be compared. Given that all of the data of the performed analysis is available in the study obtained from ReCorr Tech that is a part of this report as Appendix 4, the raw data will not be presented here again in great detail. Instead, the comparison will be made between the three selected epoxy + polyurethane coating system in the regard of the tested parameters (change in gloss and colour, change in adhesion, change in the porosity, change in EIS measurements, testing of delamination around a scribe and visual evaluation).

The prepared test plates were aged in two manners – by exposure in the salt spray chamber and by outdoor exposure in the real conditions in the Caprag neighbourhood where the sculptures are also located. Given that the selected coating systems have a very long predicted lifespan, the test plates that were exposed to the natural ageing did not show significant changes when non-destructive tests were performed on them, so it was decided that the destructive tests will not be performed at this time because they were not expected to show significant change in the results obtained on the unexposed test plates.

8.2.1 Gloss measurement

As shown in the part 7.1 there are several factors influencing the measured gloss values[19] and the perception of that gloss. The first factor is the initial gloss value of the unexposed test plates which is noticeably different between different producers as shown in the table below.

Coating applied	Unexposed test plates		
	Test plate number	Mean gloss value	Average per set
ALKYD 2. SERIES	38	68,1	68,683125
	41	65,8325	
	44	74,3675	
	47	66,4325	
EPOXY+PUR HELIOS	50	42,1	33,016875
	54	30,8675	
	58	37	
	62	22,1	
EPOXY+PUR NOVACHEM	66	83,4325	84,06625
	70	84,9	
	74	84,5325	
	78	83,4	
EPOXY+PUR CHROMOS	82	75,0675	80,20875
	86	85,7675	
	90	83,5325	
	94	76,4675	

According to multiple sources (on-line and from personal communication with paint producers), generally speaking a paint can be considered semi-gloss if the measured GU values at 60° are between 35 and 70. If we take this information into consideration, none of the tested coating systems, except for the alkyd based system, are in the semi-gloss region. The epoxy+PUR system by Helios would be considered as satin finish, while the coatings by Novachem and Chromos would be considered as glossy finish. Of course, given that this data is not official (it is not prescribed in ISO standards) it cannot be considered an eliminatory criterion.

[19] Data is taken from the report produced by ReCorr Tech for Sisak Municipal Museum which is available in Appendix 4.

After the exposition either in the salt spray chamber, the values[20] have changed as shown in the table below.

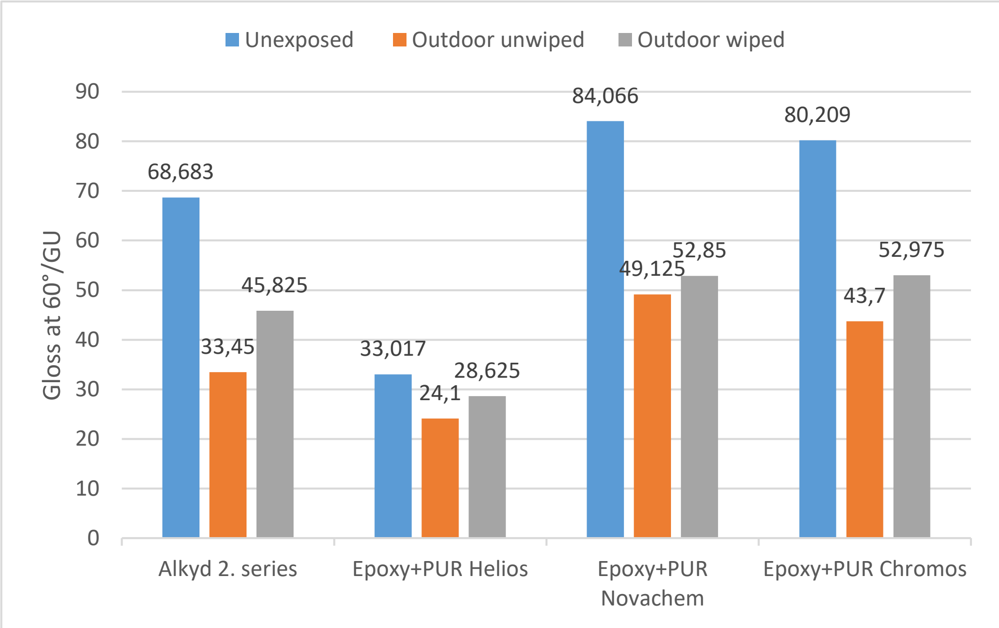
Coating applied	Test plates after salt spray chamber		
	Test plate number	Mean gloss value	Average per set
ALKYD 2. SERIES	37	54,4325	
	40	40,4675	
	43	57,4325	
	46	51,4	50,933125
EPOXY+PUR HELIOS	49	40,1675	
	53	31,1675	
	57	31,2	
	61	23,9675	31,625625
EPOXY+PUR NOVACHEM	65	72,3675	
	69	73,2675	
	73	77,7675	
	77	77,3325	75,18375
EPOXY+PUR CHROMOS	81	49,1325	
	85	59,5675	
	89	66,9675	
	93	58,3	58,491875

The most realistic change in gloss can be observed with the test plates that were exposed in the real outdoor conditions. The measured values[21] are shown in the table below.

Coating applied	Test plates after outdoor exposition (unwiped)			Test plates after outdoor exposition (wiped)		
	Test plate number	Mean gloss value	Average per set	Test plate number	Mean gloss value	Average per set
ALKYD 2. SERIES	39	40,8		39	48,4	
	42	28,4		42	42	
	45	35,4		45	45,2	
	48	33,2	34,45	48	47,7	45,825
EPOXY+PUR HELIOS	51	29,4		51	35,5	
	55	24,4		55	28,5	
	59	25,2		59	30,8	
	63	17,4	24,1	63	19,7	28,625
EPOXY+PUR NOVACHEM	67	46		67	54,3	
	71	41,2		71	44,3	
	75	41,3		75	47,1	
	79	68	49,125	79	65,7	52,85
EPOXY+PUR CHROMOS	83	46,7		83	56,7	
	87	42,5		87	53,4	
	91	39,6		91	47,4	
	95	46	43,7	95	54,4	52,975

[20] Data is taken from the report produced by ReCorr Tech for Sisak Municipal Museum which is available in Appendix 4.
[21] Data is taken from the report produced by ReCorr Tech for Sisak Municipal Museum which is available in Appendix 4.

The reduction in gloss values after outdoor exposure is shown on the graph[22] below. Provjeriti jel to



Graph 9: Comparison of measured gloss values

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As can be noticed in the graph and data, the highest drop in measured gloss (between unexposed and outdoor exposed and wiped) happened with epoxy+PUR coating system by Novachem (approx. 37,13%), then Chromos (approx. 33,95%) and the lowest drop in gloss was measured with epoxy+PUR coating system by Helios (approx. 13,30%).

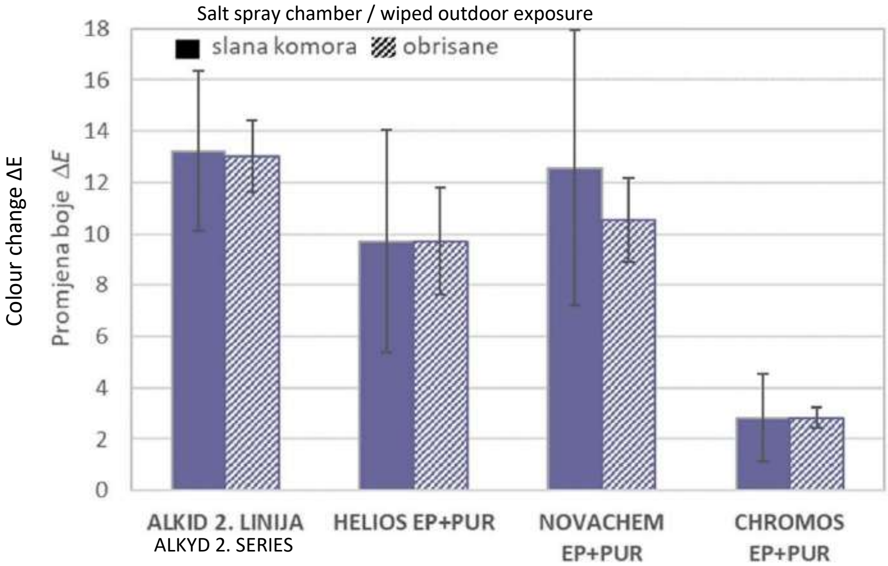
The full report by ReCorr Tech is available in the Appendix 4.

8.2.2 Measurement of the change in colour

There are two ways to show the results of the change in colour that occurred because of exposition of the test plates either to the salt spray chamber or to the outdoor environment. The first one is ΔE and it shows the change in data recorded by the machine and the other one is ΔE2000 according to the algorithm CIE2000 which is more adapted to the human eye pereption of the colour.

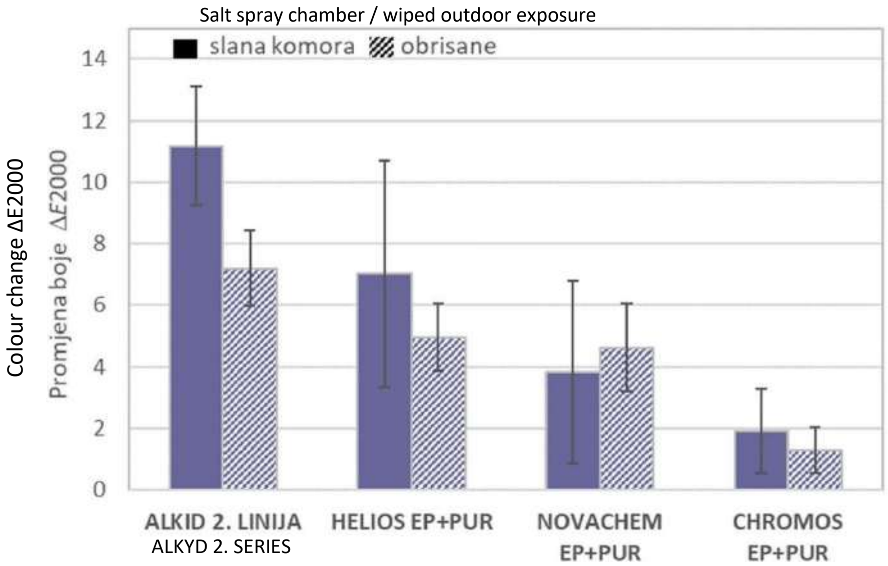
The change in is ΔE for the test plates exposed in the salt spray chamber and to the outdoor environment is shown in the graph[23] below.

[22] Graph is taken from the report produced by ReCorr Tech for Sisak Municipal Museum which is available in Appendix 4.
[23] Graph is taken from the report produced by ReCorr Tech for Sisak Municipal Museum which is available in Appendix 4.



Graph 10: Comparison of colour change between test plates exposed to salt spray chamber and natural exposure

The change in is ΔE2000 for the test plates exposed in the salt spray chamber and to the outdoor environment is shown in the graph[24] below.



Graph 11: Comparison of colour change between test plates exposed to salt spray chamber and natural exposure

From the data shown, it can be concluded that the greatest change in colour, as expected, happened with the alkyd system, while the smallest change was measured with the Chromos epoxy+PUR coating system.

The full report by ReCorr Tech is available in the Appendix 4.

[24] Graph is taken from the report produced by ReCorr Tech for Sisak Municipal Museum which is available in Appendix 4.

8.2.3 Testing of adhesion according to ISO 4624 and 2409 (pull-off and cross-cut methods)

The results of these two types of measurements of adhesion can be compared in order to determine the best adhering coating system. A comparison is given in the table[25] below both for the unexposed test plates and the test plates exposed in the salt spray chamber.

According to the standard ISO 12944-6 two out of three test plates coated with the same coating system have to meet the criteria of adhesion in order for a coating system to meet the criteria of this standard.

	UNEXPOSED	PULL OFF	CROSS CUT		EXPOSED	PULL OFF	CROSS CUT
ALKYD 2. SERIES	38	8,05	1-2		37	3,74	1
	41	9,13	1		40	5,02	2
	44	9,99	1-2		43	6,08	4
	47	7,41	1		46	4,80	2
EPOXY PUR HELIOS	50	5,71	0		49	6,54	0
	54	5,63	0		53	5,56(A/B)	0
	58	5,30	0		57	4,67	0
	62	5,61	0		61	5,88	0
EPOXY PUR NOVACHEM	66	9,44	1		65	7,79(A/B)	2
	70	10,43	0		69	9,11(A/B)	3
	74	12,03	0		73	10,53	4
	78	11,60	0		77	9,10	1
EPOXY PUR CHROMOS	82	9,75	1		81	8,18(A/B)	4
	86	9,93	1		85	6,51(A/B)	4
	90	10,18	0		89	10,56	0
	94	10,73	0		93	8,69(S)	0

The test plates where a loss of adhesion to the base metal was noticed are marked with (A/B). The red colour marks the test plates where at least one of the three measurement of the same type did not meet the criteria of the ISO 12944-6 standard for adhesion force, although the shown mean value of adhesion from three measurements exceeds the value prescribed by the norm.

From the table above, it can be concluded that all of the systems met the conditions given by the relevant standards before the exposition to the salt spray chamber.

As for the results after the exposition in the salt spray chamber, we can say that the epoxy+PUR system by Chromos had the highest number of fails on the adhesion tests (4), Novachem had the next highest number of fails (3), while both the epoxy+PUR and alkyd based systems by Helios had the lowest number of failed tests (1).

The full report by ReCorr Tech is available in the Appendix 4.

[25] Table is taken from the report produced by ReCorr Tech for Sisak Municipal Museum which is available in Appendix 4.

8.2.4 Testing of the porosity according to ISO 29601

The porosity is tested with application of voltages of 9V and 90V. Usually, for the coatings under the 300µm of coating system thickness, only the 9V results are taken into the account.

The only set of plates that showed porosity of the coating where there are no visible damages in the coating at 90V (but not at 9V) is the unexposed set of test plates coated with epoxy+PUR system by Helios. The same set of test plates after the ageing in the salt spray chamber does not show porosity, except for one spot on the test plate number 50 again only with 90V testing voltage.

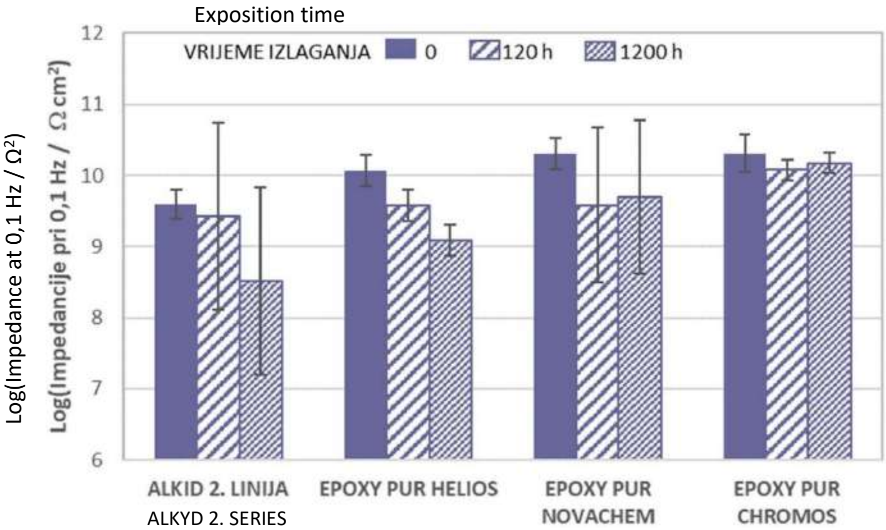
The full report by ReCorr Tech is available in the Appendix 4.

8.2.5 Measurement by EIS ReCorr QCQ test according to ISO 16773

Electrochemical impedance spectroscopy was performed using the ReCorr QCQ device according to the ISO 16773 standard.

Generally speaking, the higher value of impedance is measured, more resilient the coating used is. Basic guidelines tell us that the acceptable minimal value of impedance at 0,1 Hz is 10^6 Ω cm^2, and the value ≥ 10^8 Ω cm2 points to a coating system of excellent barrier properties[26]

The results of the testing on the test plates aged in the salt spray chamber tell us that all of the tested epoxy+PUR coating systems show excellent barrier properties with high impedances measured as shown in the graph[27] below.

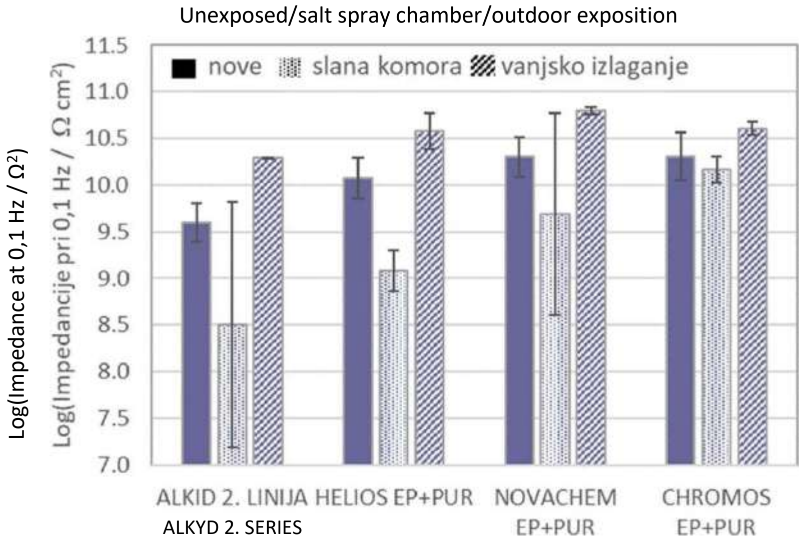


Graph 12: Results of EIS measurements

[26] Data is taken from the report produced by ReCorr Tech for Sisak Municipal Museum which is available in Appendix 4.

[27] Graph is taken from the report produced by ReCorr Tech for Sisak Municipal Museum which is available in Appendix 4.

With the test plates exposed to the realistic outdoor conditions in Caprag neighbourhood, somewhat better results were recorded. This was to be expected given the less corrosive environment for exposure than in the salt spray chamber. The results obtained are shown in the graph[28] below.



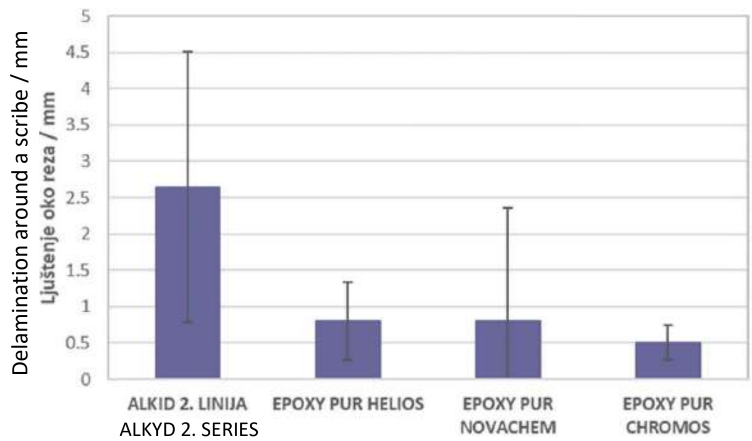
Graph 13: Results of EIS measurements

The full report by ReCorr Tech is available in the Appendix 4.

8.2.6 Testing of delamination around a scribe according to ISO 4628-8

Testing of delamination around a scribe was performed in accordance with ISO 4628-8 standard and evaluation according to ISO 4628-8 and ISO 12944-6 standards. The test was performed only on the test plates exposed to the salt spray chamber ageing.

All of the coating systems, except the alkyd binder based system, have met the criteria of the standards. The obtained results are shown in the graph[29] below.



Graph 14: Results of the delamination around a scribe test

The full report by ReCorr Tech is available in the Appendix 4.

[28] Graph is taken from the report produced by ReCorr Tech for Sisak Municipal Museum which is available in Appendix 4.
[29] Graph is taken from the report produced by ReCorr Tech for Sisak Municipal Museum which is available in Appendix 4.

8.2.7 Visual evaluation according to ISO 4628

The visual evaluation was performed according to ISO 4628-2 to 5 with application of criteria from ISO 12944-6. The results are shown in the table[30] below. Evaluation was performed on the test plates with a scribe that were exposed to the salt spray chamber ageing.

Name of the sample group	Norm of evaluation	Condition by the norm	Remarks
ALKYD 2. SERIES	HRN EN ISO 4628-2, bubbling	0S(0)*	* On the plate 46 bubbling is visible under and on 1 cm from the scribe on the same hight, under the scribe and by the lower edge of the plate. The maximum diameter of the bubbles is 4 mm. System **MEETS** the requrements of the norm HRN EN ISO 12944-6.
	HRN EN ISO 4628-3, corroding	Ri0	
	HRN EN ISO 4628-4, breaking	0S(0)	
	HRN EN ISO 4628-5, peeling	0S(0)	
EP PUR HELIOS	HRN EN ISO 4628-2, bubbling	0S(0)	System **MEETS** the requrements of the norm HRN EN ISO 12944-6.
	HRN EN ISO 4628-3, corroding	Ri0	
	HRN EN ISO 4628-4, breaking	0S(0)	
	HRN EN ISO 4628-5, peeling	0S(0)	
EP PUR NOVACHEM	HRN EN ISO 4628-2, bubbling	2S(3)*	* On the plate 69 one bubble 4 mm in diameter is visible 1 cm from the edge of the plate and several small bubbles in the midle of the plate. On the plate 65 one bubble 3 mm in diameter is visible in the midle of the plate and also several small bubbles. System **DOES NOT MEET** the requrements of the norm HRN EN ISO 12944-6.
	HRN EN ISO 4628-3, corroding	Ri0	
	HRN EN ISO 4628-4, breaking	0S(0)	
	HRN EN ISO 4628-5, peeling	0S(0)	
EP PUR CHROMOS	HRN EN ISO 4628-2, bubbling	0S(0)	System **MEETS** the requrements of the norm HRN EN ISO 12944-6.
	HRN EN ISO 4628-3, corroding	Ri0	
	HRN EN ISO 4628-4, breaking	0S(0)	
	HRN EN ISO 4628-5, peeling	0S(0)	

The full report by ReCorr Tech is available in the Appendix 4.

[30] Table is taken from the report produced by ReCorr Tech for Sisak Municipal Museum which is available in Appendix 4.

9. Conclusion

As per data presented in part 8 of this report, it can be concluded that none of the methods stood out as the “ideal” method by all of the measured criteria.

Dry ice blasting with the addition of glass beads showed itself as a very good method by all of the criteria except for the price which remains unknown because it is formed by companies performing the actual cleaning. From past experiences it can be expected that it would be the most expensive of the tested methods.

Other than this, chemical cleaning with the selected product can be used as a preliminary cleaning method to remove most of the coatings from the surface, and then the surface could be cleaned with sandblasting by aluminium oxide which showed good results with all of the criteria tested, or some other mechanical method capable of removing the coating residue left by the chemical stripping.

Although these conclusions can be indicative and used as a guidance, the method or methods that will be applied to a certain work of art need to be selected by professionals based on materials and state of preservation of that exact work of art.

The results of testing of epoxy+PUR coating systems by three producers have also shown somewhat inconclusive results as for selection of the best coating system for application on the works of art. This was to be expected given that these types of paint are intended for industrial use and have to closely adhere to different standards and legislation.

Both epoxy+PUR based systems by Helios and Chromos have met all of the tested criteria with Helios showing somewhat better results in testing of gloss and adhesion while Chromos system showed better results with the testing of colour change, porosity and delamination around a scribe.

The coating system by Novachem showed somewhat lower results than Chromos and Helios with almost all parameters and was the only system to not meet the criteria of visual evaluation given by ISO 12944-6 standard.

Given that all of the coating systems were applied by hand using a brush, it is possible that some of the results are dependent on the method of application, the achieved thickness of dry layer, formation of bubbles and brush strokes on surface etc.

Special care needs to be taken when the surface of the work of art is being cleaned and prepared for the application of coating systems that all of the residues of old coatings and corrosion are removed, that the surface is roughened to the acceptable point for each work of art, and that the surface is clean and degreased before the application. Also, the requirements concerning the thickness of the layers and conditions of application given by the producers need to be met.

In conclusion, both tested coating systems from Helios and Chromos can be used on the works of art, taking into the account the specific requirements of each work of art and the detailed results given in this report and its appendixes.