

Assessment of Paint Layers Quality

1. Field investigations on a railway bridge

EMESE VARGA¹, LASZLO FORTUNA², DANIEL LINGVAY³, ADRIANA MARIANA BORS^{4*}, NICOLETA OANA (BUTOI) NICULA⁵, IOSIF LINGVAY⁵

¹Hungarian Railways Co., Regional Infrastructure Directorate of Szeged, Regional Management Support, 6720 Szeged, Tisza Lajos krt. 28-30, Hungary

²FORCORR Ltd, 3700 Kazincbarcika, Vajar utca 33. Hungary

³Sapientia Hungarian University of Transylvania, Faculty of Sciences and Arts, Cluj-Napoca 400193 Calea Turzii no. 4 Romania

⁴ICPE SA, Splaiul Unirii 313, 030138, Bucharest, Romania

⁵National Institute for Research and Development in Electrical Engineering INC DIE ICPE-CA, Splaiul Unirii 313, 030138, Bucharest, Romania

*By electrical determinations, digital microscopy and visual observations, the anticorrosive insulation capacity of the paint layers applied to the three sections of a bridge over the Tisza River was assessed. The visual observations have highlighted the fact that on the Eastern section repainted in 2013, biofouling increases are significant (covers up to 10 % of the surface) - both ferns have been identified (*Hypogymnia physodes* and *Xanthoria parietina*), filamentous molds (*Aspergillus fumigatus* and *Aspergillus niger*) as well as algae and moss (green - capable of photosynthesis). On paint applied in 1986, no bio fouling was visible but the painting material is aged and shows rust traces (5-10 % of the surface) and exfoliation between the paint layers (10-20 % of the surface). No bio fouling and/ or exfoliation/ degradation of the paint layer have been observed on the paint applied in 2014. Determinations of electrical insulation resistance correlated with those of the paint layers' thickness are closely related to the visual observations. The values obtained for the specific resistivity of the paint layers applied in 2013 (with bio fouling increases) are approx. 38 times lower than those applied in 2014. These findings suggest that the painting material used in 1983 for the top coat realization, showed major qualitative vices.*

Keywords: painting, fouling, electrical resistivity, filamentous fungi, ferns, algae, moss

Sustainability and safety in a building works exploitation, especially bridges, is a complex issue with practical, economic and ecological implications [1]. From a sustainable development point of view - with accent on acceptable life in a clean and healthy environment - ensuring an increase durability of building works is a particular priority [2-4].

The bridges strength structures - both the metallic and reinforced concrete [5-9] - during operation in addition to specific mechanical stresses are exposed to a number of stress factors which by their simultaneous action with synergic effects lead to their degradation (especially by corrosion).

Corrosion control of metallic structures exposed to atmospheric weather - atmospheric corrosion - is usually achieved by suitable coatings layers, by painting.

The applied paint layers to perform the corrosion control function must be [10-22]:

- with a low permeability (diffusivity) to aggressive agents in the atmosphere, such as: CO₂, O₂, SO₂, NO_x, humidity etc.;
- adherent, compact and continuous - prevent the formation of local micro and macro corrosion cells;
- with a low electrical conductivity, or high resistivity, to disable any local micro- and macro-corrosion cells formed;
- with a high chemical stability- resistance to action of climatic stressors (including solar radiation in the IR and UV spectrum), high thermal stability;
- with a resistance to the action of microbiological factors, especially filamentous molds.

Polymer based composites materials (often epoxy, polyurethanes, etc.) with add of the various ingredients (CaCO₃, BaSO₄, TiO₂, ZnO, etc.) and colorants (pigments) are used for painting building works. Under these conditions, the paint layers durability is primarily determined by the resistance to the atmospheric and environmental factors of the polymer used. Under the atmospheric oxygen action, polymers undergo thermooxidation processes, that can be initiated and accelerated by UV and IR solar radiation [10, 16]. Microorganisms - especially filamentous mold - can contribute substantially to polymer degradation by carbon metabolism, that can be accelerated by existing mineral salts on the surface (dust) or in the polymer volume (the mineral ingredients).

It is noted that metabolism - the development and multiplication of microorganisms, can be substantially stimulated by electric fields of anthropogenic origin (such as those generated by high voltage power lines near building works) [23-39], including by modifying the membrane potential and / or activation energy of membrane - level processes and / or photosynthesis for microalgae and / or moss [40-46].

The filamentous molds penetrate into the polymer of paint layers, where they retain moisture and thereby increase the permittivity (diffusivity) of aggressive agents in the atmosphere (O₂, CO₂ etc.), and thus lower the polymer electrical resistivity (which leads to the activation of corrosion cells), so microorganisms and bio fouling contribute substantially to the degradation of anti-corrosion protection capacity of paint layers.

* email: adrianambors@gmail.com : +0773917319

In view of these considerations, the purpose of the work is to assess the state of the paint layers applied on a railway bridge using an original method (recently applied patent) based on the electrical resistivity measurement of the paint film.

Case presentation

The paint layers from a metallic railway bridge put into operation in 1986 were analysed. The bridge analysed ensures the railway link across the Tisza River between the towns of Csongrad and Szentes (Hungary). The Eastern section (towards the town of Szentes) - above the flood area - 167.9 m long is made in the weak bridge structure and was repainted in 2013 (fig. 1). The Western section (over the flood area) of 182.2 m length is made in the lattice-girder bridge structure and was repainted in 2014 (fig. 2). The central section (above the river basin) 154.2 m is also made in the lattice-girder bridge structure and still has the original paint applied in 1986 (fig. 3 and fig. 4).



Fig. 1. Slab bridge (the Eastern section) and further on lattice-girder bridge (central section)



Fig. 2. West Bridgehead-lattice-girder structures



Fig. 3. Detail of the merger of the Western sector (repainted in 2014) and the central section (the original paint in 1986)



Fig. 4. The merger of the Eastern sector (repainted in 2013) and the central section (the original paint in 1986)

The electrical continuity (electrical safety) between the metal elements of the investigated bridge is adequately ensured (fig. 5). The bridge is located in a protected area Natura 2000 with a special biodiversity (flora and fauna)

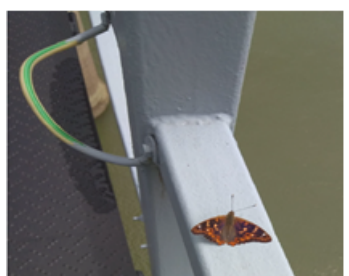


Fig. 5. Ensuring electrical continuity between the metallic elements of the bridge

specific to the area –which requires minimal interventions, namely the use of corrosion resistant materials as well as environment-friendly technologies for their application.

Experimental part

Materials

Experimental field measurements consisted of:

- Visual evaluation - photographic recordings;
- Digital microscopy (USB);
- Non-destructive determination of the thickness of the paint layers;
- Determination of the electrical resistivity of the paint layers

The digital recording of microscopic images was done with a USB Digital Microscope type USB-025 made in China.

The thickness determination of the paint layers was performed non-destructively with an eXacto FN - produced by ElektroPhysik.

In order to determine the electrical resistivity (assessment of anti-corrosion protection capacity of the paint layers/ anticorrosive protection rating) was measured a resistance R of the paint layer with a FLUKE 1550B MegOhmmeter, between the metal support and an electrode saturated with 1 % NaCl solution. The electrode is a circular disc from cork, of about 50 mm - with area of 20 cm².

From the values thus measured, with relation (1), the resistivity of the paint layer (a complex indicator of the quality) and the anticorrosive insulation capacity of the painting material, was calculated.

$$\rho = R \cdot d/s \quad (1)$$

where:

- ρ = the electrical resistivity
- d = the paint layer thickness,
- s = the contact surface of the measuring electrode
- R = resistance of the paint layer.

Results and discussions

Following the visual assessment of the paint layers on the three sections of the bridge, it was found that:

- on the West section, (lattice-girder structures), repainted in 2014, the paint layers are continuous, do not show exfoliations and / or bio fouling traces;
- on the central section (lattice-girder structures) the paint layers applied in 1986 show rust traces (5-10 % of the surface) and exfoliation between the paint layers (10-20 % of the surface);
- on the Eastern section, (slab bridge structures), repainted in 2013, does not show exfoliation between layers but has relatively large areas (5-10 % of the surface) covered with bio fouling (fig. 6, fig. 7 and fig. 8).

It is important to note that bio fouling was not formed on the area repaired as a result of adhesion testing in 2014 (pull-off test), with the top coat used to paint the Western section until the date of field investigations (July 2018), no bio fouling has been formed (fig. 9).

In figure 10 shows representative images captured with the USB microscope on a Southern-facing surface covered with bio fouling.



Fig. 6. Extensive areas of bio fouling on slab structures and on handrail



Fig. 7. Detail - area mainly covered by ferns (gray - *Hypogymnia physodes* and yellow - *Xanthoria parietina*) and molds



Fig. 8. Areas mainly covered by molds, algae and moss



Fig. 9. Area repainted after the pull-off test (2014) without bio fouling



Fig. 10. Images captured with the USB microscope at X50 (up) and X500 (bottom). The surface is completely covered with microorganisms (1 - expanded colonies of *Aspergillus fumigatus*, 2 - *Aspergillus niger* colonies, 3 - green algae and moss bio fouling)

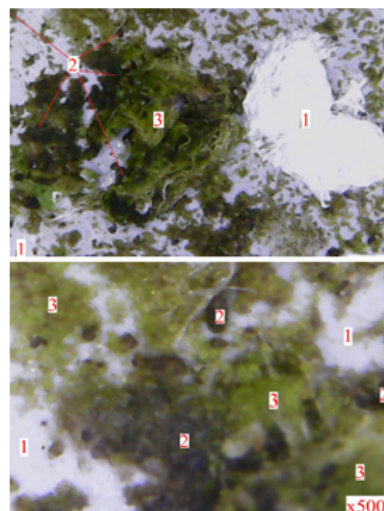


Fig. 11. X50 image captured with USB microscope on cleaned and washed paint. 1 - traces of *Aspergillus niger*, 2 - traces of *Aspergillus fumigatus*

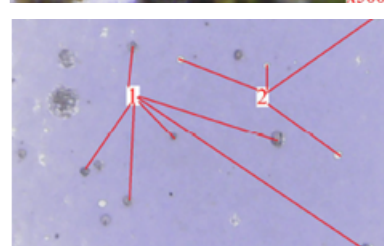


Fig. 12. X500 image captured with USB microscope on cleaned and washed paint - surface with orange peel depressions (white - traces of *Aspergillus fumigatus*, black - traces of *Aspergillus Niger* and green - traces of algae / moss)

To assess the damage degree of the paint layer, the surface was cleaned by intensive rubbing with a hard textile material and washing with water, after which the cleaned area was analyzed microscopically - the results are shown in figure 11 and figure 12.

By analyzing figure 11 and figure 12 it is observed that due to the action of microorganisms, especially of filamentous molds, the paint layer surface became as orange peel and in recesses are fixed both filamentous fungi and micro-plants capable of photosynthesis (alge and moss).

This observation suggests that the dyeing material was inhomogenetically metabolized by filamentous fungi and that in the recesses formed conditions for the growth of algae and moss.

Determinations of thickness and strength / electrical resistivity of the paint layers were made both below (at 20

Table 1

THE DETERMINATIONS RESULTS OF **d** - THICKNESS AND THE STRENGTH **R** MEASUREMENTS, ELECTRICAL RESISTIVITY **p**

The determination place			Thickness	Resistance	Resistivity	Average values of resistivity [MΩ·m]	Remarks
No.	bridge section	place	d [μm]	R [MΩ]	ρ [MΩ·m]		
1	Slab bridge (the eastern section) repainted in 2013	below	602	0.4	12.04	888	extensive bio fouling
		above	515	8.0	206		without bio fouling
2		below	610	8.38	255.59		extensive bio fouling
		above	605	71	2147.75		without bio fouling
3		below	530.1	19	503.595		little bit bio fouling
		above	297.9	50	744.75		without bio fouling
4	Lattice-girder bridge (the central section). painted in 1986	below	451.6	62	1399.96	33,566	little bit bio fouling
		above	374.2	98	1833.58		without bio fouling
5		below	395	2000	39500		without bio fouling
		above	290	1500	21750		without bio fouling
6		below	390	2100	40950		without bio fouling
		above	631	1000	31550		without bio fouling
7	Lattice-girder bridge (the western section). repainted in 2014	below	390	2100	40950	8,047,808	without bio fouling
		above	281	1900	26695		without bio fouling
8		below	628.2	260000	8166600		without bio fouling
		above	415.3	250000	5191250		without bio fouling
9		below	609.5	208000	6338800		without bio fouling
		above	481.6	190000	4575200		without bio fouling
10		below	631	500000	15775000		without bio fouling
		above	515	320000	8240000		without bio fouling

cm of the floor usually covered by bio fouling) and above (at 150 cm of the floor (usually clean, without bio fouling).

The recorded results are summarized in table 1.

By analyzing the data in table 1 it is found that the average electrical resistivity of the paint layers is strongly dependent on the dyeing material type and the exposure time to atmospheric stressors. The highest average values - approx. $8 \times 10^6 \text{ M}\Omega\text{m}$ were recorded on the paint layers applied in 2014. Lower values - approx. $3.4 \times 10^4 \text{ M}\Omega\text{m}$ were recorded on the paint layers applied in 1986 (after 32 years of exposure to climatic stressors) and surprisingly low values of approx. $8.9 \times 10^2 \text{ M}\Omega\text{m}$ on the paint layers applied in 2013.

According to [47], a polymer having the molecular weight of the usual order 10^6 has a specific resistivity of the order $10^{11} \text{ M}\Omega\text{m}$ - with decreasing trend at the decrease of the degree of polymerization (increase the mobility of the charge carriers). In view of these considerations it is found that the ρ value recorded at the paint layers applied in 2014 is normal for the usual composite polymers ($10^6 \text{ M}\Omega\text{m} < \rho$).

The average value of $3.4 \times 10^4 \text{ M}\Omega\text{m}$ at the layers applied in 1986 can be explained by degradation of the polymer under the influence of climatic stress factors (UV, humidity, thermal stress, etc.).

Particularly small values of approx. $8.9 \times 10^2 \text{ M}\Omega\text{m}$ recorded on the paint layers applied in 2013 may be due to several factors such as: low degree of polymerization / low molecular weight, polymer with low thermal stability, poor quality ingredients - with minerals impurities (dissociate salts - electroconductive species. The low molecular weight and / or the dissociated salt content may explain the low strength of the paint used in 2013 for the top coat.

Conclusions

By electrical determinations, digital microscopy and visual observations the anticorrosive insulation capacity of the paint layers applied on the three sections of a bridge in total length of 504.3 m over the Tisza River, which was put into operation in 1986, was evaluated.

Visual observations have highlighted the following:

- on the Eastern section repainted in 2013, bio fouling increases are significant (covers up to 10 % of the area),
- on the paint applied in 1986 (the central section) there is no visible increase in bio fouling, but due to climatic stress factors, the painting material ages and shows rust traces (5-10 % of the surface) and exfoliation between the paint layers (10-20 % of the area),
- on the paint applied in 2014 (Western section) no increases in bio fouling and / or exfoliation / degradation of the paint layer have been observed.

Determinations of electrical insulation resistance correlated with the paint layers' thickness are in agreement with the visual observations, so the specific resistivity of the paint layers applied in 2013 (with bio fouling increases) is approx. 38 times lower than that of the original paint applied in 1986, respectively over 9,000 times lower than those applied in 2014.

These findings suggest that the painting material used in 1983 for the top coat realization, showed major qualitative vices.

Acknowledgment: The authors thank Hungarian State Railways Co. and FORKORR Ltd Hungary for access to the objective and logistical support in carrying out the work. The contract type D, no.11384/18.06.2018, (internal release 10.3-626), Advanced recovery and valuation of technological waste resulting from the manufacturing processes of electric servomotors - transfer of knowledge, project Eco-Nanotechnologies for Water Pollution and Waste Recovery, acronym ECO-NANO-ECO.

References

- 1.ROBERTSON, N., MEZZOFIORE, G., VONBERG, J., <https://edition.cnn.com/2018/08/14/europe/italy-genoa-bridge-collapse-intl/index.html>
- 2.STERE, E.A., POPA I., Environment, modeller of the mankind existence (Part 1), Electrotehnica, Electronica, Automatica (EEA), **vol. 65** (1), 2017. pp. 97-102.
- 3.STERE, E.A., POPA I., Environment, modeller of the mankind existence (Part 2), Electrotehnica, Electronica, Automatica (EEA), **vol. 65**, (2), 2017. pp. 163-170.
- 4.STERE, E.A., POPA I., Environment, modeller of the mankind existence (Part 3), Electrotehnica, Electronica, Automatica (EEA), **vol. 65**, (3), 2017. pp. 213-220.
- 5.LINGVAY, I., Rev. Chim. (Bucharest), **57**, no.3, 2006, p. 261-265.
- 6.LINGVAY, C., COJOCARU, A., VI^aAN, T., LINGVAY, I., U.P.B. Sci. Bull., ISSN 1454-2331, Series B, **vol. 73**, Iss. 4, 2011, pp. 143-152.
- 7.OLLERER, K., LINGVAY, J., Korrozios figyelo, **vol. 45**, no. 4, 2005, pp. 133-135.
- 8.LINGVAY, J., KOVÁCS J., Korrozios figyelo, **vol. 45**, 3, 2005, pp. 88-91.
- 9.LINGVAY, I., LINGVAY, C., HOMAN, C., CIOGESCU, O., Rev. Chim. (Bucharest), **57**, no. 12, 2006, p.1279-1282.
- 10.RUS, T., CARAMITU, A., MITREA, S., LINGVAY, I., IEEE Xplore 2016, pp. 60-65, DOI: 10.1109/DEMISEE.2016.7530466.
- 11.HU, J., LI, X., GAO, J., ZHAO, Q., Progress in Organic Coatings, **vol. 65**, 2009, pp. 504-509.
- 12.RUS, T., BORS, A.M., CARAMITU, A.R., LINGVAY, I., VAIREANU, D.I., Mat. Plast., **55**, no. 2, 2018, p. 167-175.
- 13.HUA, J., LI, X., GAO, J., ZHAO, Q., Mater. Des, **vol. 30**, 2009, pp. 1542-1547.
- 14.YANG, X.F., TALLMAN, D.E., BIERWAGEN, G.P., CROLL, S.G., ROHLIK, S., Polymer Degradation and Stability, **vol. 77**, 2002, pp. 103-109.
- 15.BRIA, V., CIRCIUMARU, A., BIRSAN, I.-G., Mat. Plast., **48**, no. 2, 2011, p. 189.
- 16.RUS, T., LINGVAY, I., CARAMITU, A.R., BORS, A.M., VAIREANU, D.I., Mat. Plast., **54**, no. 4, 2017, p. 720-725.
- 17.RAVIKUMAR, H.R., RAO, S.S., KARIGAR, C.S., Indian Journal of Science and Technology, **vol. 5** (1), 2012, pp. 1977-1987.
- 18.RUS, T., RADU, E., LINGVAY, I., LINGVAY, M., CIOBOTEA-BARBU, O.C., CAMPUREANU, C., BENGHA, F.M., LAZAR, G.C., VAIREANU, D.I., U.P.B. Sci. Bull., Series B, **vol. 79**, (4), 2017, pp. 167-180.
- 19.RUS, T., CARAMITU, A.R., UNGUREANU, L.C., MARINESCU, V., BORS, A.M., VAIREANU, D.I., Mat. Plast., **55**, no. 1, 2018, p. 28-32.
- 20.LINGVAY, I., BORS, A.M., UNGUREANU, L.C., STANOI, V., RUS, T., Rev. Chim. (Bucharest), **69**, no. 5, 2018, p. 1139-1144.
- 21.CARAMITU, A., BUTOI, N., RUS, T., LUCHIAN, A.M., MITREA, S., Mat. Plast., **54**, no. 2, 2017, p. 331-337.
- 22.ASHWINI R., ANCHANA D.C., International Journal of Biology Research, **vol. 3** (1), 2018, pp. 180-184.
- 23.LINGVAY, I., LINGVAY, C., VOINA, A., Revue Roumaine des Sciences Techniques série Électrotechnique et Energetique, 2008, Tome **53** (2bis), pp. 85-94.
- 24.LINGVAY, I., RUS, G., STOIAN, F., LINGVAY, C., UPB Sci. Bull, Series B, 2001, **vol. 63** (3), pp. 263-270.
- 25.LINGVAY, I., RUS, G., BURUNTEA, N., UPB Sci. Bull, Series B, 2001, **vol. 63** (3), pp. 29-36.
- 26.LINGVAY, J., GROZA, C., LINGVAY, C., CSUZI, I., Korrozios Figyelo, 2009, **vol. 49** (3), pp. 31-38.
- 27.BORS, A.M., BUTOI, N., CARAMITU, A.R., MARINESCU, V., LINGVAY I., Mat. Plast., **54**, no. 3, 2017, p. 447-452.
- 28.LINGVAY, J., SZATMARI, I., LINGVAY, M., TUDOSIE, L., Korrozios Figyelo, 2013, **vol. 53** (3), pp. 71-80.
- 29.LINGVAY, I., OLLERER, K., LINGVAY, C., HOMAN, C., CIOGESCU, O., Rev. Chim. (Bucharest), **58**, no. 7, 2017, p. 624-627.
- 30.SZATMARI, I., LINGVAY, M., TUDOSIE, L., A COJOCARU, A., LINGVAY, I., Rev. Chim.(Bucharest), **66**, no. 3, 2015, p. 304- 311.
- 31.YOKUS, B., AKDAG, M.Z., DASDAG, S., CAKIR, D.U., KIZIL, M., International Journal of Radiation Biology, 2008, **vol. 84** (10), pp. 789-795.

32. LINGVAY, M., STANCU, C., SZATMARI, I., LINGVAY, I., *Electrotehnica, Electronica, Automatica (EEA)*, 2013, **vol. 61** (1), pp. 43-47.
33. STANCU, C., LINGVAY, M., SZATMARI, I., LINGVAY, I., The 8th International Symposium on Advanced Topics in Electrical Engineering, Bucharest, Romania, 2013, May 23-25, pp.1-4.
34. HUANG, Y.J., SAMORAJSKI, J., KREIMER, R., SEARSON, P.C., *PLoS ONE*, 2013, **vol. 8**, (3).
35. SANDU, D., LINGVAY, I., LANYI, S., MICU, D.D., POPESCU, C.L., BREM, J., BENCZE, L.C., PAIZS, C., *Studia Universitatis Babes-Bolyai, Chemia*, 2009, **vol. LIV** (4), pp.195-201.
36. KWEE, S., RASKMARK, P., VELIZAROV, S., *Electro- Magnetobiol.*, 2001, **vol. 20**, pp. 141.
37. LINGVAY, I., RADU, E., CARAMITU, A. R., MITREA, S., OPRINA, G., VOINA, A., Patent: RO 132117 A2, 2016.
38. RADU, E., LIPCINSKI, D., TANASE, N., LINGVAY, I., *Electrotehnica, Electronica, Automatizari (EEA)*, 2015, **vol. 63** (3), pp. 68-74.
39. BLANK, M., GOODMAN, R., *Pathophysiology*, 2009, **vol. 16** (2-3), pp. 71-78.
40. GOLTISOV, A.N., *Bioelectrochem. Bioenerg.*, **vol. 48**, pp. 311-316, 1999.
41. HAJDU, K., SZABO, T., SARRAI, A.E., RINYU, L., NAGY, L., *International Journal of Photoenergy*, p. 9128291, 2017.
42. BRESSAN, M., DALL'OSTO, L., BARGIGIA, I., ALCOCER, M.J.P, VIOLA, D., CERULLO, G., D'ANDREA, C., BASSI, R., BALLOTTARI, M., *Nature Plants*, 2018, **vol. 2** (9), p. 16131.
43. AKHTAR, P, LINGVAY, M., KISS, T., DEAK, R., BOTA, A., UGHY, B., GARAB, G., LAMBREV, P.H., *Biochimica et Biophysica Acta-Bioenergetics*, 2016, **vol. 1857** (4), pp. 462-472.
44. YOKONO, M., AKIMOTO, S., *Current Opinion in Biotechnology*, 2018, **vol. 54**, pp. 50-56.
45. SZABO, T., MAGYAR, M., HAJDU, K., DOROGI, M., NYERKI, E., TOTH, T., LINGVAY, M., GARAB, G., HERNADI, K., NAGY, L., *Nanoscale Research Letters*, 2015, **vol. 10** (1), pp. 1-12.
46. SCHWARZ, E.M., TIETZ, S., FROEHLICH, J.E., *Photosynthesis Research*, 2018, **vol. 136** (1), pp. 107-124.
47. DONALD, A., Seanor, *Electrical Properties of Polymers*, Academic Press, New York 1982

Manuscript received: 17. 06. 2018