

Comparison of steel bridge coatings

K. Jyrkäs¹ & T. Harju²

¹*HAMK University of Applied Sciences, Sheet Metal Development Centre, Hämeenlinna, Finland*

²*Ruukki Construction, Infrastructure construction, Hämeenlinna, Finland*

ABSTRACT: The presently used paint systems for steel bridges approved by the Finnish Road Administration comprise several layers of paint and much solvent. New paint systems developed to meet EU's VOC Decree and facilitate painting comprise fewer layers and are low-solvent. The study analysed the weather and corrosion resistance of the new paint systems and their suitability for painting bridges. In the same connection, the suitability of a new laboratory test method as the approval test for steel bridge coatings was examined. Several new paint systems proved at least as corrosion resistant as the presently used ones approved by the Road Administration. Thus, substitute low-solvent paint systems are available. The used laboratory test proved fit for use in the evaluation of the long-term durability of steel bridge paints.

1 INTRODUCTION

1.1 *Present steel bridge paint systems*

Nordic climate is a challenge to bridge building due to the rather long and cold winter period. Not only the construction of bridges suffers from cold weather, but the structures are also exposed to heavy use of de-icing systems. Hence long term durability and life cycle costs are important issues in Nordic bridge building today.

Present paint systems for bridges enable very long repair intervals. Painting conditions in workshops have improved considerably in the last few years, and the risk of moisture condensing on the surface of steel before painting can be eliminated completely. Presently used paint systems – zinc epoxy primers + iron mica or aluminium-pigmented epoxy intermediate coats + polyurethane top coats – have proven their durability over the last 25 years. Painting is, however, time consuming and costly since, for instance, the paint system (TIEL 4.12) presently used for new steel bridges in Finland comprises 5 layers of paint (Fig. 1). (Finnra 1996).

The paint systems used today to protect steel bridges do not meet the requirements of the EU VOC Directive (VOC = volatile organic compound) since they contain too much solvent (EU Parliament 2004). Solvent-free paints and paint systems reduce VOC emissions significantly. A coating comparison study – which aims to come up with paint systems that meet the requirements of the VOC Decree while providing the same durability as today's paint systems with fewer paint layers – was carried out in 2007-2008. The conducted laboratory tests and outdoor test indicate that new low-emission paint systems allow at least as long maintenance intervals as presently used systems.

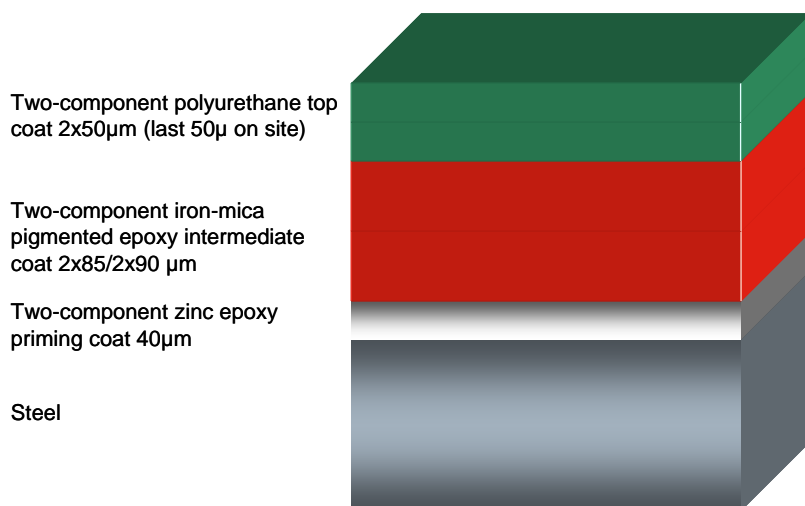


Figure 1. Paint system required by Finnish Road Administration for new steel bridges, TIEL 4.12: EPZn(R)EPPUR 310/5-FeSa2½.

1.2 Test project

The test project launched in spring 2007 examined the weather and corrosion resistance of new low-solvent paint systems of fewer paint layers and thus their suitability for protecting steel bridges. In the same connection the suitability of a new laboratory testing method based on standard SFS-EN ISO 11997-2 (Finnish Standards Association SFS 2000) as the approval test for steel bridge coatings was determined. The test differs from the earlier approval tests used by the Finnish Road Administration (Finnra 1994).

Salts, such as the sodium chloride and calcium chloride used in road de-icing, accelerate the corrosion of bridge structures. Under laboratory conditions the corrosion accelerating effect of salts is simulated by spraying a saline solution onto the surface of specimens. In accelerated corrosion tests either a sodium chloride solution, or one containing both sodium chloride and ammonium sulphate, is used (prohesion test). The latter solution simulates the corrosion conditions in an urban or industrial environment subject to acid rain.

Occasional drying of specimens often accelerates corrosion since the salt content of the cracks in the paint surface increases. A cyclic salt fog test, where the specimens are in turn sprayed with salt and dried, is believed to simulate more closely real-life conditions than the traditional continuous salt fog test.

UV radiation from the sun ages a paint coat. The impact of sunlight, temperature and humidity is simulated in a test apparatus where the UV radiation corresponding to sunlight is produced by fluorescent lamps emitting UVA radiation while the heat generated by the sun is produced with heating elements and a blower. In addition to UV radiation stress, the specimens are regularly subjected to humidity stress as water vapour condenses on the surfaces of specimens.

Temperature changes cause mechanical stresses to the paint coat due to thermal expansion, and large temperature changes are possible in Finnish climatic conditions. Thus, cold stress was also included in the testing of steel bridge coatings by incorporating it in the test of the original standard SFS-EN ISO 11997-2 by freezing the specimens for 24 hours to -20 °C after each UV and salt fog test.

The project partners were FSP Finnish Steel Painting Oy, IPC Finland Oy, Nor-Maali Oy, Rautaruukki Oyj, Teknos Oy, the Finnish Road Administration and Tikkurila Coatings Oy. Ruukki supplied the necessary steel specimens while the paint factories performed the needed surface preparation and painting. The planning, testing and specimen evaluation of the study was done by the Sheet Metal Development Centre of HAMK University of Applied Sciences.

2 TESTING OF PAINT SYSTEMS

2.1 Tested paint systems

Most of the paint systems delivered by the paint factories for testing comprised 3 paint layers. Each factory also delivered a system approved by the Road Administration comprising 5 paint layers as a reference (Table 1).

A functional primer is essential for the long-term durability of paint. It ensures good adherence of the paint layer to a metal surface. Moreover, the primer contains anti-corrosive substances, of which zinc powder is most often used with steel paints. The primer is over 90 % zinc and protects steel cathodically like a zinc coating. The intermediate coat that can be used to increase total film thickness may be of the same paint as the top coat. The top coat is dense and highly resistant to weather and sunlight. It also gives the coating the desired colour.

Table 1. Tested paint systems.

Paint system code	Primer	Internal coat	Top coat	Film thickness (µm)
1	zinc epoxy		polyurethane	160
2	zinc epoxy	polyurethane	polyurethane	160, 230, 280
3	zinc epoxy	epoxy	polyurethane	280
4	zinc epoxy	epoxy	polysiloxane	360
5	zinc epoxy	epoxy mastic	polyurethane	280
6	zinc epoxy	epoxy mastic	polysiloxane	240
7	zinc phosphate epoxy		polysiloxane	190
8	zinc phosphate epoxy	epoxy	polysiloxane	350
9	zinc phosphate epoxy	epoxy	polyurethane	450
10	1K Zinc	1K int. coat	1K polyurethane	170

2.2 Laboratory testing of specimens

Two test apparatuses were used to determine resistance to cyclic corrosion conditions according to standard SFS-EN ISO 11997-2. Corrosion stress was created in a salt fog tester while the impact of sunlight and humidity was simulated by UV test equipment. In deviation from the standard, the specimens were frozen to -20 °C for 24 hours after the corrosion and UV cycles.

2.2.1 Preparation and painting

Each paint factory prepared and painted its specimens. Grease was removed from the plates to be painted, and they were blast-cleaned to Sa 2½ so that the surface profile of the side to be painted was medium coarse (G). Dust was removed before painting. Coating thicknesses of specimens were measured after painting.

2.2.2 Preparation of specimens

Test specimens measured 100 mm x 300 mm x 5 mm. Before testing, 1 mm wide scratch lines (a vertical and a horizontal one) were cut through all paint layers to the steel substrate of the specimens as shown in Figure 1. Specimens were placed in the test apparatuses with the long side up.

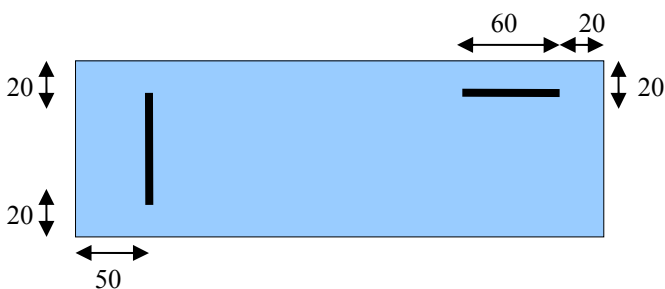


Figure 2. Test specimen used in laboratory tests. Dimensions are in millimetres.

2.2.3 Determination of resistance to cyclic corrosion conditions

A test modified from standard SFS-EN ISO 11997-2 was used with an added freezing period. The test period of two weeks and one day included a 168-hour (7 day) exposure to UV and humidity, a 168-hour exposure to cyclic salt fog (prohesion test), and a 24-hour exposure to low temperature (-20 °C). Total test duration was 2736 hours; specimens were exposed to low temperature for 216 hours. The test included one 3-day freezing period during which specimens could not be moved.

Conditions of the combined cyclic corrosion test:

- Exposure to UV and humidity (SFS-EN ISO 11507 (Finnish Standards Association SFS 2007)): four hour exposure to UV radiation (UVA 340 nm, 0.83 W/m²/340 nm) at 60 °C, and four hour exposure to condensed humidity at 50 °C. The cycles were repeated for seven days. Testing was performed by the QUV Accelerated Weathering Tester which allows adjusting the level of radiation.
- Exposure to salt fog (SFS-EN ISO 11997-2): one hour exposure to 0.5 g/l NaCl + 3.5 g/l (NH₄)₂SO₄ solution at 25 °C, and one hour drying at 35 °C (prohesion test). The cycles were repeated for 7 days. Testing was done with the Q-Fog CCT 600 corrosion testing apparatus. Specimen plates were rinsed with ion-exchanged water after each cycle of salt-fog exposure.
- Exposure to low temperature: storage in a freezer at -20 °C for 24 hours. -20 °C temperature was reached in 30 minutes.

The specimens were tested in two batches, so that half of them were either in the UV tester or the salt fog tester at any time.

2.2.4 Adhesion testing of paint coatings

The adhesion of coatings of stressed and unstressed references to a steel surface was determined by pull-off tests in accordance with standard SFS-EN ISO 4624 (Finnish Standards Association SFS 2002) using the Zwick/Roell Z050 material testing machine. In pull-off tests, a test dolly 20 mm in diameter glued to the specimens was pulled off at a speed of 1 mm/min.

Before gluing the test dolly (dia. 20 mm) to the specimens, the surface of both the dolly and specimen was roughened with sand paper and cleaned with ethanol. The dolly was glued to the painted surface with Araldite. Glued specimens were allowed to harden under light weights for at least 18 hours. Then the paint layer around the dolly was cut out with a 25 mm hole saw. The breaking strength of the used Araldite was 30 MPa. Six pull-off tests were conducted on each sample.

2.3 Accelerated outdoor test (Scab test)

The specimen plates were subjected to an accelerated outdoor test (Scab test, ISO 11474) in the test area of the Sheet Metal Development Centre in Hämeenlinna (Fig. 3). Specimens were mounted on racks at a 45 degree angle, facing south. They were sprayed with a 30 g/l saline solution twice a week. When air temperature was below -10 °C, the spraying was omitted. Testing continued for a year from 12.6.2007 to 12.6.2008. An intermediate inspection of specimens was conducted on 2.11.2007. The weather conditions during the year were quite harsh with respect to corrosion as temperature remained above 0 °C much of the time.



Figure 3. Specimens on test rack in winter 2008.

The corrosivity category of the test area was determined with and without salt spraying by mounting weighed test specimens (3 + 3 cold-rolled and 3 + 3 galvanised) on racks. Some specimens were sprayed with a saline solution the same way as the actual test specimens while the others were not sprayed and were covered for the duration of the spraying. The corrosion products of cold-rolled and galvanised test specimens were removed after a exposure period of one year using inhibited hydrochloric acid and glycine in accordance with Nordtest Method NT MAT 003. Then the specimens were re-weighed.

2.3.1 *Test area's corrosivity category*

The masses of the cold-rolled and galvanised corrosion test specimens used to determine the corrosivity category of the test area were measured before and after stress. The cold-rolled steel rusted strongly in the Scab test. Specimens that were not sprayed with a saline solution rusted clearly less. The backs of unsprayed specimens had rusted more than the fronts. The edges of hot-dip galvanised specimens subjected to the Scab test showed red rust. No red rust was observed on unsprayed specimens after the test. On the basis of weight losses due to zinc and steel corrosion, the conditions during the Scab test correspond to climatic stress class C5 (very heavy, steel corrosion 650–1500 g/m² and zinc corrosion 30–60 g/m²). The corrosivity category of the Sheet Metal Development Centre's test area without saline spraying was C2 based on steel corrosion (low, steel corrosion 10–200 g/m²) and C3 based on zinc corrosion (medium, zinc corrosion 5–15 g/m²). There was wide variation between the weight losses of unsprayed galvanised reference specimens. Some salt fog may have drifted onto some of the specimens although they were covered during the spraying of the Scab specimens.

3 TEST RESULTS

3.1 *Laboratory testing of specimens*

Specimens were photographed after testing, and deterioration of their coatings (degree of rusting, blistering, cracking and flaking) based on standards SFS-EN ISO 4628-1 to 4628-5 (Finnish Standards Association SFS 2003a,b,c,d,e) and spreading of rust around the scratch lines according to standard SFS-EN ISO 4628-8 (Finnish Standards Association SFS 2003f) was evaluated. The gloss and shade of the specimens was also evaluated.

Adhesion of one coating (zinc epoxy + epoxy + polysiloxane) to steel proved poor. The coating peeled almost completely off the steel surface already during the first test weeks. The breaking strength of the coating was low also in the case of an unstressed specimen. That coating was excluded from the following assessments.

No cracking or flaking was observed on the specimens after testing except at the scratch lines. A few rust spots and some blisters were visible on some specimens. It is possible that some of the flaws interpreted as blisters were due to defective painting of the specimen plates. No significant differences between the new paint systems and the approved ones used as references were detected. Paints layers peeled off at the scratch lines as much or less in the case of the new paint systems as with the paint factory's approved system (1–3 mm on average). The maximum peeling with some specimens was 5–7 mm. In some specimens peeling, especially in the case of the horizontal line, was quite strong but did not exceed that of the corresponding reference specimen (Fig. 4).

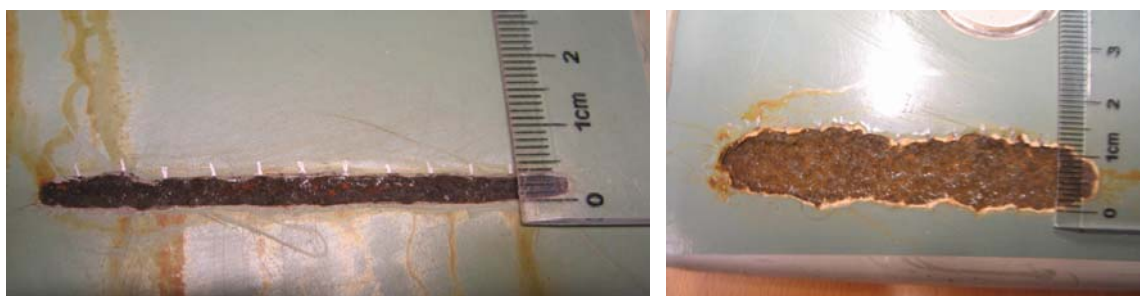


Figure 4. Corrosion at horizontal scratch line: slight peeling on left, strong peeling on right.

The gloss and colour shade measurements of specimens were done at places where no rust spots existed since there were a lot of them at places. The appearance of most specimens changed quite little. The gloss of some decreased more than that of reference specimens. Residual gloss after testing was generally 50–80 % of the original. Colour changes were also quite small (ΔE a maximum of 3.1).

The adhesion of the new paint systems to steel was good in the case of both unstressed and stressed specimens. The adhesion of most paints was not significantly weakened by exposure. With the exception of the rejected specimen, all other coatings met the requirement that the primer must not peel off the steel unless tensile force exceeds 5 MPa. Tensile strengths of coatings were in the 3.3 MPa to 12 MPa range.

3.2 *Accelerated outdoor test (Scab test)*

No cracking or blistering was observed on the specimens except around the scratch lines. Some coatings showed slight blistering. However, at least part of the blisters were probably the result of defective painting. In some specimens blistering appeared around the scratch lines beyond the area where the coating had peeled off. Corrosion and peeling off of coating around scratch lines was quite limited. That made ranking of the specimens quite difficult. Average corrosion at scratch lines was no more than 2 mm with most specimens, and the maximum was only 4 mm. In some specimens the coating peeled off beyond the rusted area. Blistering was also observed around scratch lines beyond the area where the coating could be peeled off.

3.3 *Correlation between laboratory test and Scab test*

Specimen's degree of blistering (ignoring size of blisters), average and maximum peeling off at scratch lines (mean of vertical and horizontal scratch lines of reference specimens), and gloss and change of colour shade were compared to the results of laboratory tests. The following correlation coefficients were calculated based on the results:

degree of blistering:	$r = 0.58$	$r^2 = 0.34$
average corrosion rate:	$r = 0.47$	$r^2 = 0.22$
maximum corrosion rate:	$r = 0.77$	$r^2 = 0.59$
residual gloss:	$r = 0.40$	$r^2 = 0.16$
change in colour shade (ΔE):	$r = 0.13$	$r^2 = 0.02$

There is a positive correlation between the laboratory and Scab tests. Correlation is best in the case of maximum corrosion rate and worst in relation to colour shade. Corrosion during the year-long Scab test was quite mild compared to the laboratory test which weakened the correlation. The results of Scab and laboratory tests were found to correlate quite well as to blistering and corrosion considering the difference between the tests and the many factors that contribute to corrosion. The best correlation was observed in the case of maximum corrosion rate (maximum corrosion at scratch lines). On the base of the results, the laboratory test can be considered relatively reliable. Assessments of corrosion resistance based on the laboratory test and Scab test correlate quite closely. The laboratory test produces clearer differences between specimens in a shorter time than the accelerated outdoor test.

4 PRACTICAL EFFECTS OF PAINT SYSTEMS

4.1 *Higher quality and less risks*

The presently used 5-layer systems for steel bridges are normally implemented by painting the first four layers at the workshop and the last one at the bridge construction site. However, all 5 layers of the joints of bridge sections and welded joints have to be painted on site. A reduction in the number of paint layers from five to three cuts essentially the risk of painting mistakes on site, such as painting over a wet coat of paint.

Work arrangements at the workshop also become more effective and quality improves as less time is spent waiting for various coats to dry. Yet, it should be remembered that when thicker coats are applied, sufficient drying time per coat must be ensured both at the workshop and on site.

4.2 More cost-effective paint systems

Table 2 provides a simple example of the cost effects of the new paint systems on a typical 250-metre twin girder bridge. Only labour costs at the workshop were considered in the calculation; paintwork at the site was ignored. The cost of the traditional 5-layer paint system can be estimated to be the same as that of the tested 3-layer systems. Paint costs will fall later on as use of the new types of paint becomes more prevalent. The calculation does not consider the shorter throughput time of steel components at the workshop, either.

Table 2. CASE: Twin girder bridge, length 250 m, area to be painted 4000 m².

Paint system	Layers painted at workshop	Painting work at done (h)	Hourly rate for painting	Total costs of painting	Savings
Current system	4 layers	870 h	50 €/h	43,500 €	-
New 3-layer system	2 layers	635 h	50 €/h	31,750 €	27 %

5 SUMMARY

Most of the new tested paint systems proved at least as durable in the combined cyclic corrosion test as the 5-layer systems approved by the Road Administration. The used test takes into account besides corrosion stress also the UV stress from sunlight as well as thermal and humidity stress, thus being more reliable than the traditional continuous salt fog test. The test was able to detect a specimen of low long-term durability and poor paint adhesion. The results of the test were compared to the results of the accelerated outdoor test (Scab test, ISO 11474 (International Organization for Standardization 1998)). The Scab test can be assumed to correspond reasonably well to the conditions the paint coat will be exposed to over its life cycle. The corrosivity category of the test area in the case of salt sprayed specimens was established as C5 (C5-M). Yet, the accelerating effect of the test is quite marginal. This makes it difficult to evaluate the specimens and set approval criteria. The Scab test takes 3 times longer to conduct than the laboratory test.

The study revealed that there are new low-solvent paint systems to replace the existing 5-layer paint systems which provide at least as good long-term durability as the approved systems with fewer paint layers (2 or 3). The test results are applicable also to other steel structures besides bridges. There are new low-solvent 3-layer paint systems whose long-term durability is at least on a level or better than that of the earlier approved systems.

The new paint system types proved to be competitive alternatives as to durability characteristics and costs in the selection of a paint system for steel bridges. Moreover, the new paint types are more environmentally friendly compared to the presently used ones and meet the requirements of the VOC Directive.

REFERENCES

EU parliament (2004). Directive 2004/42/CE of the European Parliament and of the Council of 21 April 2004 on the limitation of emissions of volatile organic compounds due to the use of organic solvents in certain paints and varnishes and vehicle refinishing products and amending Directive 1999/13/EC. Brussels.

Finnish Standards Association SFS (2000). SFS-EN ISO 11997-2. Paints and varnishes. Determination of resistance to cyclic corrosion conditions. Part 2: Wet (salt fog)/dry/humidity/UV light.

Finnish Standards Association SFS (2002). SFS-EN ISO 4624 Paints and varnishes. Pull-off test for adhesion.

Finnish Standards Association SFS (2003a). SFS-EN ISO 4628-1. Paints and varnishes. Evaluation of degradation of coatings. Designation of quantity and size of defects, and of intensity of uniform changes in appearance. Part 1: General introduction and designation system.

Finnish Standards Association SFS (2003b). SFS-EN ISO 4628-2. Paints and varnishes. Evaluation of degradation of coatings. Designation of quantity and size of defects, and of intensity of uniform changes in appearance. Part 2: Assessment of degree of blistering.

Finnish Standards Association SFS (2003c). SFS-EN ISO 4628-3 Paints and varnishes. Evaluation of degradation of coatings. Designation of quantity and size of defects, and of intensity of uniform changes in appearance. Part 3: Assessment of degree of rusting.

Finnish Standards Association SFS (2003d). SFS-EN ISO 4628-4. Paints and varnishes. Evaluation of degradation of coatings. Designation of quantity and size of defects, and of intensity of uniform changes in appearance. Part 4: Assessment of degree of cracking.

Finnish Standards Association SFS (2003e). SFS-EN ISO 4628-5. Paints and varnishes. Evaluation of degradation of coatings. Designation of quantity and size of defects, and of intensity of uniform changes in appearance. Part 5: Assessment of degree of flaking.

Finnish Standards Association SFS (2003f). SFS-EN ISO 4628-8. Paints and varnishes. Evaluation of degradation of coatings. Designation of quantity and size of defects, and of intensity of uniform changes in appearance. Part 8: Assessment of degree of delamination and corrosion around a scribe.

Finnish Standards Association SFS (2007). SFS-EN ISO 11507. Paints and varnishes. Exposure of coatings to artificial weathering. Exposure to fluorescent UV lamps and water.

International Organization for Standardization (1998). ISO 11474. Corrosion of metals and alloys -- Corrosion tests in artificial atmosphere -- Accelerated outdoor test by intermittent spraying of a salt solution (Scab test).

Finnra, Finnish road administration (1994). Siltojen teräsrakenteiden maalausjärjestelmät. Tielaitoksen hyväksyntä- ja laadunvalvontamenettely. Helsinki

Finnra, Finnish road administration (1996). Sillanrakentamisen yleiset laatuvaatimukset, Teräsrakenteet - SYL 4, TIEL 2210006-96. Helsinki