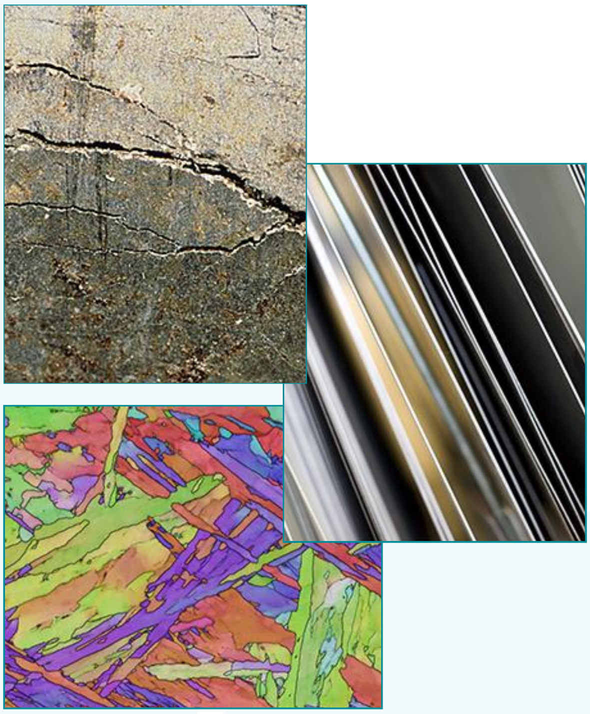

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Inspection of reference objects coated with various zinc rich coatings

Björn Tidbeck, Bror Sederholm

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Abstract

Five different coating systems have been investigated by inspection of reference objects. The emphasis has been on trying to find reference objects that are well documented and that have been coated a long time ago. The study has focused mainly on zinc-rich coatings, with special interest in zinc-rich coatings that have been used as stand-alone systems, i.e. without any topcoat. The breakdown mechanism of a coating can be very important when considering the corrosion protection of an asset from a life cycle perspective. It is evident that all the zinc rich coatings studied deteriorated from the outside and in rather than via under-rusting and flaking. This mode of breakdown can be very advantageous, it means that the assets can be spot repaired to a higher extent than if they were protected with a coating system that deteriorates via flaking and loss of adhesion. A relatively easy and ad hoc maintenance protocol for single layer zinc rich coating systems can reduce the need for downtime and secondary cost for maintenance of the asset.

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1 Introduction

In this study, five different coating systems have been investigated by inspection of reference objects. The emphasis has been on trying to find reference objects that are well documented and that have been coated a long time ago. The study has focused mainly on zinc-rich coatings, with special interest in zinc-rich coatings that have been used as stand-alone systems, i.e. without any topcoat. As such, the coating systems investigated comprise alternative coating systems that do not meet the specification requirements in AMA-anläggning. AMA-anläggning is commonly used to specify anticorrosion works within Swedish industry, infrastructure and building sector. The coating systems covered in this study have been selected from a list of alternative systems that was compiled as a part of a previous literature study performed within the RISE KIMAB Membership Research Consortium (MRC) Corrosion protection [1]. The selected systems could potentially offer better solutions for protecting various assets in industry, infrastructure and the building sector. The potential benefits and a short description of each alternative coating system is described under section 2 through to section 6. All inspections in this study have been complemented by accelerated corrosion tests and field testing at the RISE field station Kvarnvik Väst at Bohus-Malmön. [2]

2 Fontezinc HR

The first inorganic zinc silicates were discovered in the 1940's in Australia by Nightingall. The Nightingall silicates were heat cured and required baking in temperatures of about 120-230 °C, [3]. During the mid-1960´s through to the late 1970`s NASA published a series of patents related to the development of a waterborne silicate that cure quickly at ambient temperatures [4] [5] [6] [7]. The NASA patents describe various inorganic zinc silicates based on water soluble potassium silicate. Generally, the reactivity of this type of coating depends on the molar ratio between the silicate and the alkali counterion of the silicate solution. The molar ratio affects the viscosity, the pH and the curing rate of the coating. Simplified, the molar ratio can be viewed as a degree of pre-polymerization, where a higher molar ratio is analogous to a higher degree of pre-polymerization. The Nasa patents [7] describe a zinc silicate coating with an unusually high molar ratio of; $K_2O:SiO_2 = 5,3:1$. During the late 1970`s the production of a silicate coating formulated according to the NASA patents was licensed to Polyset and was sold by Inorganic Coatings under the trade name IC531. Inorganic Coatings has now been deconstructed and Tikkurila OY owns an exclusive agreement with Polyset to sell the original IC531 formulation in Europe under the new trade name Fontezinc HR. Fontezinc HR is very interesting for the following reasons: the coating is completely free from VOC, it contains no sensitizing chemicals such as epoxy or isocyanates; it is made without petroleum-based raw materials; it is extremely fast curing; has antifouling properties and gives excellent corrosion protection. A drawback of the coating is that it is waterborne, and as such, it requires more careful pretreatment: all surfaces must be completely free from oil and dirt for the coating to be able to wet the substrate. Another drawback is that there is no available topcoat that is compatible with Fontezinc HR. The following sections 2.1 to 2.4 report our findings from inspections of some reference objects coated with Fontezinc HR/ IC531.

2.1 The Statue of Liberty

The Statue of Liberty was refurbished during 1981 through to 1986. The refurbishment included a renovation of the protective coating on the supporting steel structure inside the statue. Prior to the renovation, the steel structure was coated with various paints including; coal tar, aluminum pigmented paint, and 4-5 layers of lead-based paints. During the renovation, the old paint was stripped by vacuum blasting with aluminum oxide, the steel was then recoated with Fontezinc HR/ IC531 and a waterborne two-component polyamide epoxy topcoat [8]. The coating on the steel inside the statue was inspected by Björn Tidbeck, RISE KIMAB, Lennart Björk, Tikkurila AB and Earl Ramlow, Polyset on the 23rd of May 2019, about 33 years after the coating work was finished.

2.1.1 Results

The inside air of the statue was controlled by an air conditioning system that was installed 2012. Before 2012 the statue was not open to the public and the air inside was not conditioned. The topcoating had started to flake and peel off from the zinc silicate. However, the supporting steel structure was virtually free from corrosion and the underlying zinc silicate was intact. The general film thickness of the zinc silicate was about 60-90 µm. In some places excessive amounts of coating had been applied, certain areas had been coated to a DFT in excess of 400 µm without any signs of mudcracking.

Figure 1. Overview of the Statue of Liberty and Ellis island

Figure 2. Overview of the supporting steel structure, light gray in the picture. In the middle of the picture is the spiral staircase leading to the top of the statue. The copper cladding of the statue was black on the inside.

Figure 3. Supporting steel structure with rivets, the top coat (light gray in the picture) was flaking and peeling off from the underlying silicate (blueish gray in the picture).

Figure 4. A steel beam in the supporting structure that had been subjected to wear from bypassing visitors. The coating on the edge of the steel beam had been scraped off leaving the underlying steel exposed to the air.

Figure 5. Generally, the film thickness of the silicate coating was between 60-90 µm.

Figure 6. Two Bresle tests were carried out, the amount of soluble salts was equivalent to about 600-800 mg Cl^{-}/m^{2}*. According to the warden of the statue, there had previously been quite a lot of holes in the copper cladding and the high salt content could be a result of rainwater seeping through the cladding. The high salt content on the surfaces could also have been obscured by zinc salts and hydroxides from the silicate coating.*

2.2 US Army Causeway Systems

Both the US Army and the US Navy have used Fontezinc HR/ IC531 to protect their causeway systems. The US Army and US Navy causeways are modular floating pontoons used to establish temporary docks for moving cargo between different ships, or to land troops and supply onshore in remote places where no harbor is available. The causeway modules are thus used partly immersed in sea water, exposed to the atmosphere hanging along the sides of warships or stored at a harbor. It is therefore impossible to say how and where each module has been exposed, it is however clear that they all have been exposed in marine environments, probably ranging from C3 up to CX. Because the causeways are modular systems, each module will be assembled and disassembled many times during its life cycle. Therefore, each module is also exposed to heavy wear and tear.

2.2.1 Results

The coating of about six US Army causeway modules was inspected on the 24th of May 2019 by Björn Tidbeck, RISE KIMAB, Lennart Björk, Tikkurila AB and Earl Ramlow, Polyset. During the time of inspection, the modules were located at Metal Trades Inc. steel workshop near Charleston, South Carolina. All inspected modules had been taken out of service due to various damage, such as holes or damage to the structural steel. Despite a lot of mechanical abuse, the coating was intact on most surfaces and generally the coating was in surprisingly good condition. At places where the coating had been damaged down to the bare steel, no apparent spreading of rust could be seen. This observation includes pinholes where extensive corrosion in the pinholes had taken place without any spread of rust or under paint corrosion around the pinholes, see Figure 18. The coating is subjected to a slow erosion with consumption of zinc pigment as it is immersed in sea water. This can be seen in Figure 10, where the coating thickness is different above and below the waterlines. It is also evident that the coating significantly suppresses the growth of barnacles, see figure Figure 8 through to Figure 25. Generally, zinc silicates have a tendency to develop mudcracking when applied too thick. During this inspection a few areas with coating of up to 400 µm without mudcracking were found, see figure Figure 15 and Figure 17.

Figure 7. A picture illustrating an example of how the US Army and US Navy causeway systems are used.

Figure 8. Unit 0046 with an engraved sign with manufacturing month. This unit was manufactured 29 years ago. The chamfered part of these units is used to drive the modular system onto the seashore

Figure 9. Unit O224 with an engraved sign with manufacturing date. This unit was manufactured 17 years ago.

Figure 10. Unit C066FC, probably manufactured during early 1990. The DFT above the 1st waterline was about 180 µm, between water lines about 90 µm, below the 2nd water line 30µm. Below the 2nd waterline rust and barnacles were found.

Figure 11. Unit C066FC, the presence of barnacles below the second waterline could be an indication that all zinc has been consumed and as a result, the barnacles can start to grow.

Figure 12. Unit C066FC Closeup picture of the waterline.

Around the splash zone of the 1st waterline of unit C066FC some small rust spots could be seen. Probably these spots were due to micro-cracking or small imperfections in the coating during its early exposure. This behavior has been demonstrated by accelerated corrosion testing at the RISE KIMAB corrosion lab. The micro-cracks are not visible to the naked eye, but since the coating is porous, the surface can easily become discolored by the rust that forms in the cracks, and the surface appears as though it is rusting. It appears as though the coating has an ability to self-heal when it is exposed further. One explanation for this behavior could be that the micro-cracks seal by the formation of insoluble zinc salts from the coating. It is likely that these type of rust spots are mostly an aesthetical problem. In cooperation with Tikkurila Sweden, we have seen that the coating shows some tendency to form micro-cracks if the coating is applied at a too low relative humidity, (about 30%) or if the coating is applied at a too long spraying distance. These findings are also supported by research reports from NASA [9].

Figure 13. Unit L0 200, manufactured 18 years ago. This unit had been washed with a rotating high-pressure equipment, probably to remove barnacles. Most surfaces, edges and welds were essentially free from corrosion. The joints where the units are linked together have started to rust, these areas are however subjected to high mechanical wear.

Figure 14. Unit L0 200, a surface subjected to mechanical damage. The coating is relatively resilient towards impact and there was no chipping or flaking around the damaged areas. DFT in the scratches without rust was about 30 µm.

Figure 15. Unit P40 552, manufactured 13 years ago. This module was coated with a mean DFT of more than 400µm without any visible mudcracking.

Figure 16. Unit P40 552, DFT was about 90µm above the waterline, DFT was about 30 µm below the water line. The antifouling action could possibly be explained by leaching zinc salts. A change of colour in the coating below the water line suggests that all the zinc has been depleted and left a thin silicate coating where the barnacles can grow.

Figure 17. Unit Q155FC, probably manufactured during mid-1990. DFT about 350 µm above the waterline and about 260 µm below water line, no mudcracking could be found.

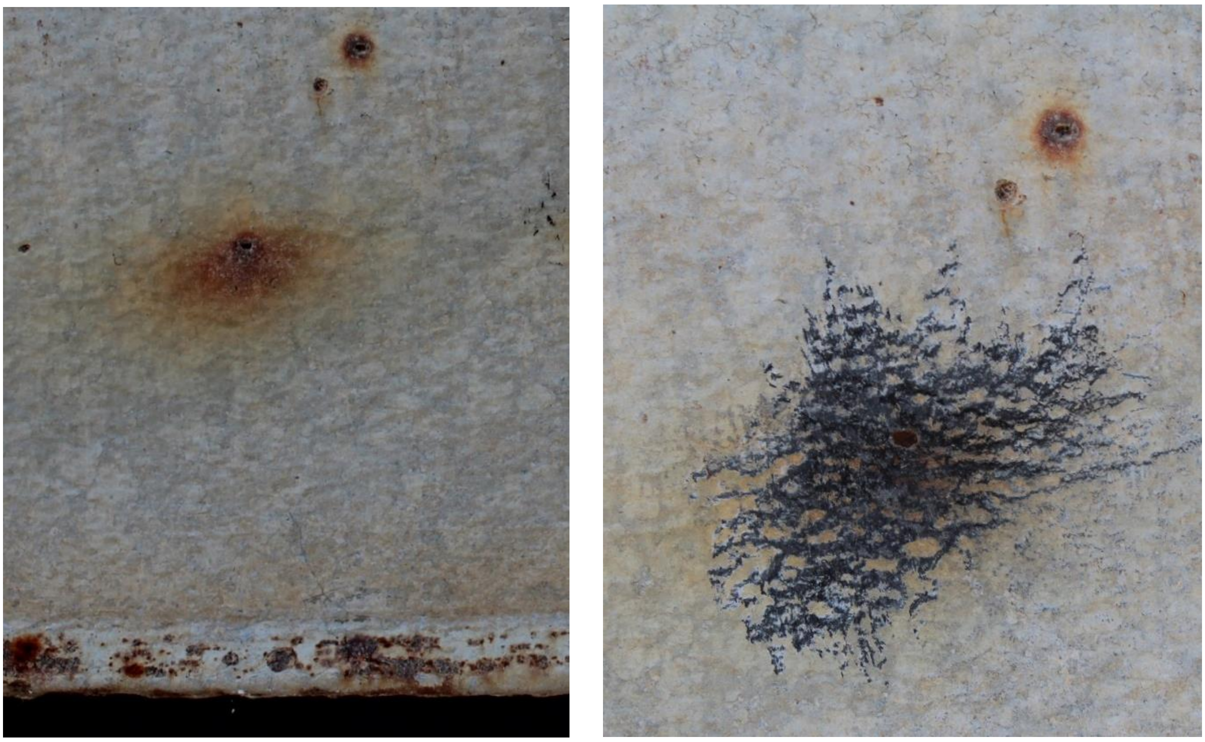

Figure 18. Unit Q155FC, to the left: pinholes and rust discoloration. To the right: The pinhole was abraded with a knife held at 90 degrees to the surface. There was no lateral rust creep from the pinholes, but intact zinc coating was found underneath the discoloration. The pit depth was approximately 2-3 mm.

Figure 19. Unit Q0254, probably manufactured during early 2000. The zinc pigment appears to be consumed under the water line and as a result the steel has started rusting, some barnacles were visible. It appears that the coating deteriorates by gradual erosion from the outside and in rather than via flaking and under rusting.

Figure 20. Unit Q0254 Barnacles under the waterline. Intact coating above the waterline

Figure 21. Unit Q0254 to the left: damage after impact. To the right: loose coating was removed with a screwdriver, no rust creep under the intact coating was observed.

Figure 22. Reference units coated with 400µm epoxy. The coating had started to break down under the waterline.

Figure 23. Reference unit coated with 400 µm epoxy. Under rusting and flaking was found beneath the waterline.

Figure 24. Reference unit coated with epoxy. Corrosion on welds around manhole. Significant growth of barnacles under the waterline.

Figure 25. Reference unit coated with 400 µm epoxy. Barnacle growth under the waterline. Welds with insufficient pretreatment around the manhole had begun to rust and the coating had started to under rust.

2.3 Tempe Lake hydro dam in Phoenix, Arizona

Tempe Lake is a man-made lake that was built around the Salt River between 1997 and 1999. The goal with the lake was to prevent floods, support economic development and recreational activity in and around central Phoenix. The gate system is composed of 8 dam gates, each gate is about 5 m high, 32 m long and weighs about 117 tons. The gates have been coated with Fontezinc HR/ IC531. Each dam gate was constructed and coated in two halves at a steel work shop a couple of miles away from the lake. During the installation of the gates, the two halves of each gate were welded together at the construction site. The welding of the two halves was done without removing the coating on the edges to be welded. After joining, the welds were pretreated with a flap-wheel grinding machine and coated with one layer of Fontezinc HR/ IC531 using a brush. The dam gate project was finished in 2016 and is the largest hydraulically operated steel gate dam system in the USA. The Salt River got its name because it flows through a salt (NaCl) rich area in northern Arizona called the Luke Salt Dome. According to the central Arizona salinity study [10] the water in Salt River contains about 480 mg/L salt, measured as an average at the Granite Reef Diversion Dam just outside of central Phoenix. Studies performed at RISE KIMAB [11] have shown that the corrosion rate of immersed carbon steel does not vary significantly with chloride concentration. In the RISE KIMAB study, the corrosion rate of immersed carbon steel was approximately the same for chloride concentrations ranging from 150 mg/L, (65 µm/y) to 1500 mg/L, (68 µm/y). This result indicates that the corrosion is not limited by the conductivity of the electrolyte or the corrosivity of the chloride ions, what determines the corrosion rate is instead the supply of oxygen.

2.3.1 Results

The Dam gates were inspected by Björn Tidbeck RISE KIMAB, Lennart Björk, Tikkurila and Earl Ramlow, Polyset on the 25th of May 2019. Generally, the coating was found to be in good condition. Despite apparent poor welding quality, low DFT (60-70 µm) and minimum pretreatment, welds that had been coated with a brush looked surprisingly good, see Figure 29. A few areas with dry spray/ incomplete coverage were found, see Figure 31. The coating on a few of the welds had started to crack and fall off, see Figure 32. This behavior is typical to Fontezinc HR on welds that have not been pretreated to give a sufficient blasting profile of the weld seam surface. Due to the heat input during the welding process, welds often get harder than the bulk steel. It can therefore be beneficial to use harder abrasives than steel grit for welds. A good workflow can be to use hard abrasives (for example garnet) on the welds alone before the welds are inspected for imperfections by the welding inspector.

Figure 26. Overview of the Tempe Lake dam gates with surroundings.

Figure 27. Overview of one out of eight dam gates. The brownish surfaces in the pictures are not rust but have been fouled by running water or dirt from the surroundings.

Figure 28. A picture of the wet side of a dam gate, notice the absence of corrosion around the hydraulic cylinder attachment points.

Figure 29. Welds between the two halves of dam gates. No signs of corrosion despite apparent poor pretreatment and low DFT. According to Earl Ramlow who was inspecting the installation of the dam gates, the weld has been laid through the coating and the resulting weld has been ground with a flap disc and painted with a brush to a DFT of about 60µm

Figure 30. Irregular weld profiles with deep undercuts. To the left: generally, this type of weld was free from corrosion. To the right: a few poor welds had started to rust.

Figure 31. An area with rust spots. This could be a result of poor coverage or dry spray. Or it could be foreign matter from a disc grinder.

Figure 32. Rust on a weld with adequate smoothness. The premature coating failure on this weld is probably due to an inadequate blasting profile on the weld, which in turn had led to loss of adhesion.

2.4 Bathing ramp in Varberg

Varberg municipality have constructed a ramp for the walking disabled to be able to enjoy a cool dip in the sea on the Swedish west coast. The installation is located on the beach near Varberg harbor/ train station. The ramp starts on the beach and leads down in the sea to a depth of approximately 1 m, (depending on the tide). In essence, almost all of the structure can be considered to be in a splash zone. The two far ends of the ramp will (for most of the time) be under and above the water line respectively. The ramp was coated with Fontezinc HR/ IC531 with a DFT of about 180 µm and was put into service during late March 2019.

2.4.1 Results

The ramp was inspected by Lennart Björk, Tikkurila, Björn Tidbeck and Bror Sederholm, RISE KIMAB on the 18th of September 2019. The coating appeared to be in very good condition. No corrosion could be found, not even at the places where the coating was damaged. There was no corrosion in connection to the stainless-steel bolts used to assemble the ramp. It will be interesting to follow how this reference object will evolve. A new inspection is planned for the autumn of 2020.

Figure 33. Overview of the ramp in Varberg with surroundings.

Figure 34. Overview of the ramp after a few days of windy weather.

Figure 35. The ramp can become covered by sand. The lower part of the ramp is subjected to constant abrasion by beach sand moving with the waves.

Figure 36. Close up of the ramp floor: there are lots of crevices and the design is not ideal for coating work.

Figure 37. The ramp has been assembled with stainless steel bolts.

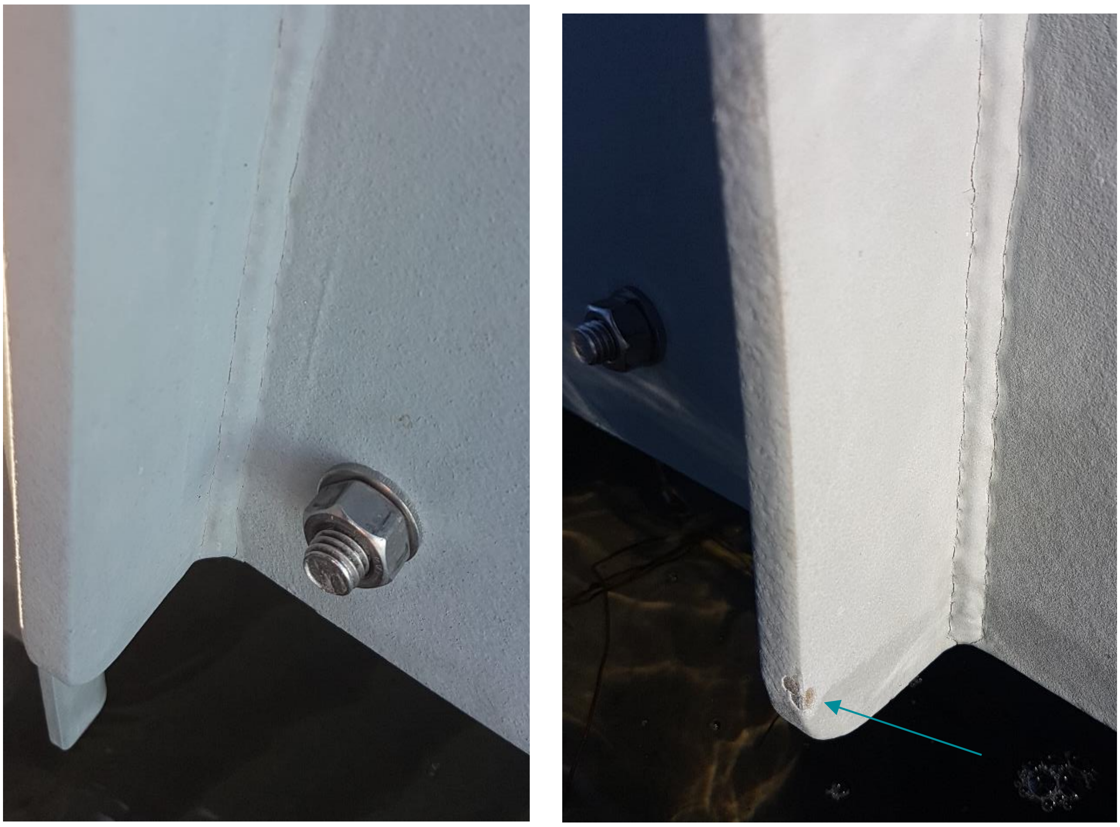

Figure 38. Cracks in the coating along an involute weld seem. It is likely that the cracks penetrate through the first coat but not the coating layer closest to the steel. To the right: A damage in the coating, no corrosion.

Figure 39. Mudcracking around a weld joining the girder of the ramp with one of the fencing poles.

Figure 40. The coating had chipped around this stainless allen bolt. There was however little or no corrosion. One reason for this could be that the silicate binder creates a passivating silicate layer on the steel. Another explanation could be that the coating is protecting the steel cathodically.

Figure 41. To the left: some craters on a pile for the fencing. To the right: support leg bolted in the girder of the ramp.

Figure 42. A damage in the coating was introduced by throwing a rock at the outside girder of the ramp. The impacts tended to create indentions in the coating rather than chipping it. Some zinc got stuck on the stone. The DFT in the indentations was about 40µm.

3 Zinga

Zinga is a zinc-rich coating with high zinc content, 97% by weight in the dry film. According to the manufacturer, the zinc pigment in the product is produced by an atomization process which provides high purity and tailored morphology of the zinc particles. Zinga is a physically drying coating with unlimited pot life and very short drying times, 1-4h depending on the ventilation and temperature. Application is possible in a wide temperature range, -10 °C to 45 °C. It is also relatively insensitive to moisture during curing as it is possible to apply in relative humidity of up to 90%. The product is relatively high in VOC but with a specified nominal dry film thickness of 120-180 µm the total amount of VOC per square meter can be lower than traditional C5 systems with specified nominal dry film thickness of 320 µm. One advantage of Zinga is that the degradation of the coating in moderately corrosive atmospheres appears to progress from the outside and in, rather than via flaking and undercutting. Maintaining an aged Zinga coating can be done simply by a high-pressure wash followed by application of a new coating layer. The new layer will then (in part) dissolve the old paint and reload the coating with new zinc. This results in a coating that can be comparatively easy to maintain, especially on assets such as ships, oil platforms and in industry where a frequent and ad hoc maintenance procedure can be utilized.

3.1 Ro brua

Ro brua, a road bridge owned by Statens Vegvesen (the Norwegian Road Administration) is located in Gol municipality, Norway. The bridge leads over the Hemsil river and is composed of a riveted steel construction and a roadway made of concrete. The bridge was refurbished during 2018 by blasting and recoating with Zinga, 2x 60µm DFT.

3.1.1 Results

The bridge was inspected on the 18th of June by Thor Smette/ Zinga, Björn Stam/ St Control, Björn Tidbeck and Bror Sederholm/ RISE KIMAB. The anti-corrosion works had just been finished at the time of inspection and no damage or breakdown of the coating could be found. The bridge was well coated without any apparent application issues.

Figure 43. Ro Brua, under the late stages of refurbishment 2018.

Figure 44. Ro Brua is composed of a riveted steel structure and a roadway of concrete

Figure 45. The coating refurbishments appeared good. All rivet heads had been painted by brush before a final layer of sprayed Zinga was applied. No sags, running or cracking could be found.

3.2 Granli brua

Granli brua is a pedestrian bridge owned by Statens Vegvesen. It is located in Gol municipality, Norway. The bridge leads over the Hemsil river and is composed of a riveted steel construction and a walkway made of wood. The bridge was refurbished during 2016 by blasting and recoating with Zinga, 2x 60µm DFT.

3.2.1 Results

The bridge was inspected on the 18th of June by Thor Smette/ Zinga, Björn Stam/ St Control, Björn Tidbeck and Bror Sederholm/ RISE KIMAB after about two years in service. After the visual inspection, some conclusions could be drawn. Generally, the coating appears to be in good condition, however, the coating had started to flake and fall off on some surfaces. Where flaking was observed, both white rust from the zinc in the coating and red rust from the substrate was found. The affected surfaces were only horizontal or near horizontal surfaces. It is therefore likely that these damages are the result of a poor surface cleaning/ vacuuming after blasting or due to rain/ condensation during curing. Some areas were uneven and had a rough surface, which had resulted in an uneven coating layer. See figures from the inspection below.

Figure 46. Granli bru with surroundings, the bridge is located in Gol municipality, Norway

Figure 47. Granli bru, an overview of the steel structure. The bridge is composed of I-beams connected with riveted steel plates.

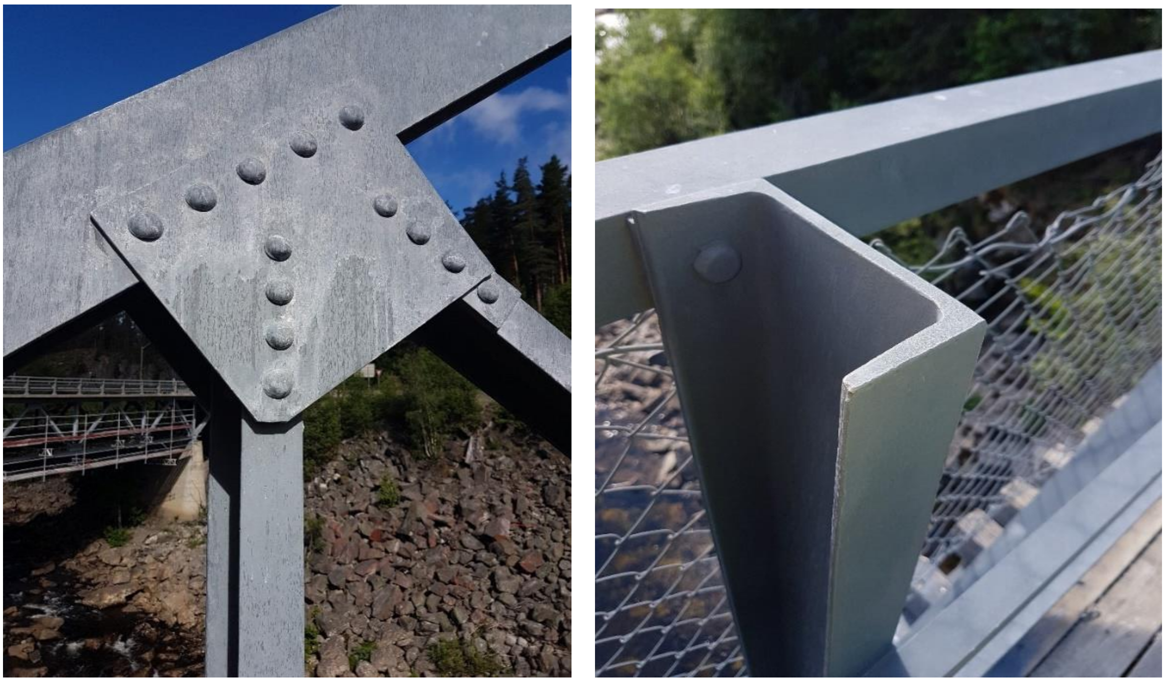

Figure 48. The steel beams of the structure have sharp edges. The design is not optimal for corrosion protection since there are many crevices and surfaces where dirt and debris can collect. No corrosion was observed.

Figure 49. Surfaces with rough surface profile, probably a result from overcoating steel with rust grade C or D.

3.3 Seimsbrua

Seimsbrua, owned by Statens Vegvesen is a road bridge that leads over the Holsfjord, located in Hol municipality in the Norway inland. It is a steel beam bridge with a roadway made of concrete. The maintenance of the bridge has been appointed to Tunhovd Mekaniske AS. According to Tunhovd Mekaniske, the bridge was blasted and coated with Zinga (2 x 60 µm) during 1991.

3.3.1 Results

The bridge was inspected on the 18th of May 2019 by Thor Smette/ Zinga, Björn Stam/ St Control, Björn Tidbeck and Bror Sederholm/ RISE KIMAB, 27 years after the last renovation. The inspection showed that the bridge was in good condition. The DFT varied between 22µm and 140µm. Some surfaces with low film thickness had started to rust. The intact coating had an adhesion of 11Mpa according to the pull of method ISO 4624. No blistering, flaking or cracking could be observed.

Figure 50. Overview of Seimsbrua with surroundings.

Figure 51. The bridge is made of three steel beams and a concrete roadway.

Figure 52. A few surfaces with red rust were found. To the left: the square steel beams were located under a gap in the roadway between the road and the concrete roadway. To the right: The DFT of the square beams was about 20µm thick. The breakdown mechanism of the coating appears to be a slow erosion from the outside and in, rather than a through blistering and flaking.

Figure 53. A few surfaces with red rust were observed. Unfortunately, these locations were inaccessible for DFT measurements at the time of inspection.

3.4 Kalvøya bru

Kalvøya bru is a small pedestrian bridge that leads out to the small iland Kalvøya in the archipelago of Oslo, Norway. The bridge is composed of two I-beam girders with a supporting cross-sectional lattice in the deck and supporting stay cable hangers. The walkway is made of wood. The Bridge was first coated with Zinga in 1985. The steel was cleaned and blasted to a cleanliness of Sa 2½ according to ISO8501-1, after blasting a 2 x 60 µm coat of Zinga was applied with a brush on the steel beam members and with an application glove on the stay cables. During 2014 after 29 years in service the bridge was refurbished by a high-pressure wash and a light sweep blast. The steel/ coated steel was then overcoated with Zinga 2 x 60 µm.

3.4.1 Result

The bridge was inspected by Thor Smette/ Zinga, Björn Stam/ St Control, Björn Tidbeck and Bror Sederholm/ RISE KIMAB on the 17th of February 2017 about three years after the refurbishment. Below are pictures from the inspection 2017, some archive pictures of the bridge before the refurbishment have been included for the purpose of reference. The inspection found that the bridge coating was in excellent condition. No blistering, flaking rusting or cracking could be found.

Figure 54. Kalvøya bru with surroundings, (2017).

Figure 55. The underside of the bridge. Steel beam girders with support lattice and hanger beams. The distance from the steel structure to the salty water is about 2,5 meters. As there are many crevices and sharp edges on the steel beams, the structure is not optimal for coating

Figure 56. To the left: archive picture from 2014 after 29 years in service. To the right: stay cable attachment in 2017, three years after refurbishment

Figure 57. To the left: archive picture of a stay cable after 29 years in service. To the right: Stay cable in 2017, three years after the refurbishment.

Figure 58. One or two spots with red rust could be found, these were most probably areas where the coating application for some reason had failed.

3.5 Rånosfoss bru

Rånofoss bru is a pedestrian bridge owned by Statens Vägvesen. It leads over the fjord Glomma, one of Norway's longest and most voluminous fjords. The bridge is a suspension bridge with concrete pillars and a stay cable system with four cables on each side of the walkway. During 2014 all structural steel including the cables were coated with Zinga, 2 x 90 µm. The pretreatment used was a high-pressure wash followed by blasting to Sa 2½ according to ISO 8501-1. The cables were coated using an application glove for the cables and using a brush for the cable fasteners.

3.5.1 Result

The bridge was inspected on the 17th of February 2017 by Thor Smette/ Zinga, Björn Stam/ St Control, Björn Tidbeck and Bror Sederholm/ RISE KIMAB. During the inspection there was no crane available, therefore the inspection was limited to the surfaces that could be inspected from the walkway and at the cable anchoring points. After three years in service there was no corrosion or damage in the coating. No blistering, flaking cracking or coating defects could be seen.

Figure 59. Owerview of Rånofoss bridge with surroundings

Figure 60. Close up picture of the cable linkages. These parts are not optimal to coat, there are a lot of crevices, sharp edges and areas where it is hard to get good coverage. No corrosion was observed.

Figure 61. Clamp joining the cable bundles together. The coating has been applied with a brush, some red-rust had formed inside the crevice between the U-profile and the plate.

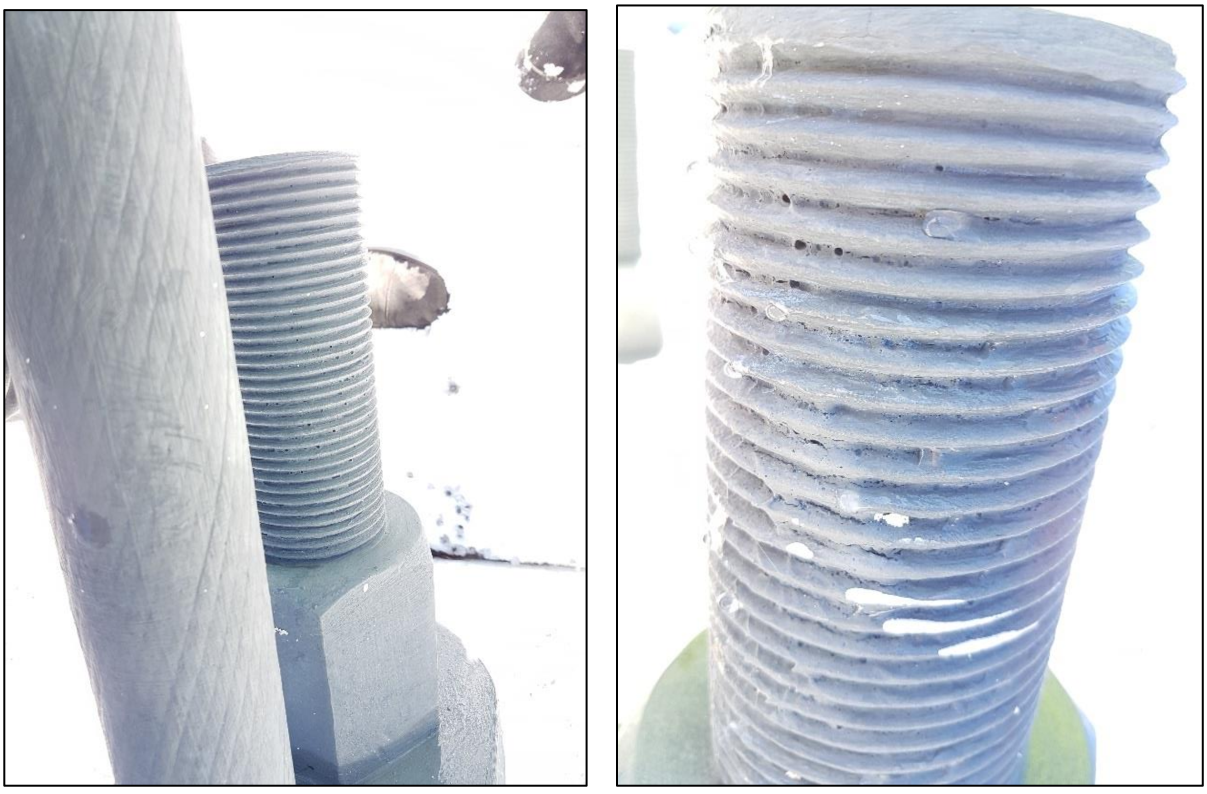

Figure 62. To the left: cable at the anchoring point. To the right: Coating on a bolt thread at the anchoring point, some pinholes were visible in the thread. There were however no signs of corrosion.

Figure 63. A cable near the anchoring fundament. No corrosion was observed on the part of the cables that were accessible during the inspection.

3.6 Hausmanns bru

The Hausmanns bridge is located in central Oslo. The original bridge is a construction in cast iron and was constructed in 1892. Since then, the bridge has been rebuilt and broadened by inserting a modern steel beam construction between the old riveted steel and cast pillars. The bridge was refurbished during 2014 by a complete repainting program: all surfaces were washed and blasted to a cleanliness of Sa 2½ according to ISO 8501-1. The bridge was then painted with 80 µm of Zinga as a primer, a 1-component polyurethane (Zingalufer) as a midcoat and finally it was top-coated with an acrylic polyurethane (Zingaceram PU2).

3.6.1 Resultat

The bridge was inspected on the 22nd of February 2017 by Thor Smette/ Zinga, Björn Stam/ St Control, Björn Tidbeck and Bror Sederholm/ RISE KIMAB, about three years after the refurbishment. Generally, the bridge coating was in very good condition. At places red rust had started to seep out from crevices in the old part of the bridge. However, it should be noted that it was impossible to coat the steel inside these crevices. Furthermore, since the top coating was white it is very easy to spot all the rusting joints. In the pictures below, some archive pictures of the bridge before the restoration have been included.

Figure 64. Overview of the Hausmann bridge, the bridge is composed of old cast iron and the center of the bridge is made from modern steel I-beams.

Figure 65. Joint between support arch and fencing post in cast iron. At some joints, discolorations from corroding steel inside crevices could be seen

Figure 66. discoloration from crevice corrosion under rivets.

Figure 67. Some rust between the pavement and the cast iron pillars could be seen under the bridge.

Figure 68. An archive picture of the Hausmann bridge before the restoration in 2014.

Figure 69. An archive picture of the Husmann bridge before the restoration in 2014.

4 Thermally sprayed coatings

Thermally sprayed aluminum, zinc or aluminum/zinc alloys are well proven technologies that gives excellent corrosion protection in most atmospheric applications. Thermally sprayed coatings are the only economically viable method to metallize steel structures that are too big to be dipped. According to the standard ISO 1461, thermally sprayed pure zinc or 85 % zinc and 15 % aluminum, Zn/Al (85/15) a is the preferred method for repairing damages in hot dip galvanized coatings. According to the ISO 2063-1, coatings of Zn/Al (85/15) are described as giving better corrosion protection in marine environments than the corresponding pure zinc coatings. RISE KIMAB have studied thermally sprayed aluminium, zinc and Zn/Al (85/15) without sealer in marine atmosphere and in seawater [12]. After 16 years atmospheric exposure at Bohus-Malmön, none of the sprayed samples showed any red-rust. The zinc and the Zn/Al (85/15) appeared to give a good cathodic protection whereas the sprayed aluminium appeared to give a slightly inferior cathodic protection with red rust forming in the scribe of the sample specimens. After 8 years of exposure in seawater, samples coated with thermally sprayed aluminium and aluminium/ magnesium showed no signs of red rust. Samples with zinc and Zn/Al (85/15) coatings had however started to show red rust. Statens Vegvesen, (the Norwegian road authority) have used thermally sprayed zinc and aluminium as primer on bridges since the 1960´s. From 2007 all new bridges in Norway are coated with thermally sprayed zinc 100 µm followed by 25-50 µm epoxy tie coat, 100-125 µm epoxymastic as a midcoat and a 80-100 µm polyurethane as a topcoat [13]. Statens Vegvesen no longer allow thermally sprayed aluminium on their bridges. The reason being that the North Sea offshore industry have experienced problems with overcoating thermally sprayed aluminium.

4.1 The Åsbobridge

The Åsbo bridge is a 400m combined roadway/ pedestrian bridge that leads over Dalälven, just outside of Avesta, Sweden. The bridge connects Avesta with the E4 freeway. It is relatively well used and the road over the bridge is treated with deicing salt during winter. The bridge is made of concrete, with a bridge railing that was originally hot dip galvanized. The bridge was built in 1972 and by 1999 the railing was in need of a new corrosion protection. During 1999 the railing of the bridge was renovated with thermally sprayed Zn/Al (85/15). The refurbishment was done by removing the fencing and transporting it to a workshop where it was cleaned, blasted and sprayed with Zn/Al (85/15). The lower parts of the railing post were treated with an epoxy sealer followed by a polyurethane topcoat. [14]

4.1.1 Results

The bridge fencing of the Åsbo bridge was inspected on the 27th of March 2019 by Björn Tidbeck RISE KIMAB, about 20 years after the renovation. Generally, the fencing was in very good condition. The coating of the lower part of the fencing poles had deteriorated completely, however, the sprayed Zn/Al (85/15) underneath the damaged coating was intact on most of the railing posts, only on a few railing posts, red-rust had started to appear, see Figure 71. Generally, the welds between the fencing poles and the handrail was very badly prepared. A railing posts with flaking and blistering coating could be found, see example in Figure 74. Some crevice corrosion could be seen in the gaps of the expansion joints of the handrail, see Figure 72. At one place there was a mechanical damage in the coating, there was however only limited corrosion creep around the damage, see figure Figure 75.

Figure 70. Overview of the Åsbo brige

Figure 71. To the left: fencing pole with lower parts coated with epoxy and polyurethane. To the right: Fencing post with completely deteriorated coating, The TSZ under the coating was largely intact, although some spots of red rust had started to emerge.


Figure 72. Two examples of crevice corrosion in the expansion joints of the handrail.

Figure 73. Apparently poorly prepared welds around the expansion joints

Figure 74. The welds between the fencing poles and the handrail was not optimally prepared. On a few poles some blistering and flaking of the TSZ could be seen.

Figure 75. Mechanical damage on the handrail. Only limited rust creep from the damages was observed.

5 Zinc Ethyl Silicate

Alkyl zinc silicates were developed in the 70-80´s. This type of paint is cured by transesterification of alkoxy silicates. The silyl alkoxides react with moisture from the atmosphere to form polymeric zinc silicate. In the process, alcohol is liberated and the final paint film is in theory completely inorganic. [3] This type of coating has previously been used extensively in the offshore and shipping industry. Combined with a chlorinated rubber topcoat it has also been used as part of a bridge system in Swedish infrastructure. A few reasons that it no longer is used for bridges is that the chlorinated rubber has high VOC content, and that the curing requires high humidity which means that the application is a little bit more complicated compared with zinc rich epoxy primers. Some research reports claim [15] that all zinc ethyl silicate, and most zinc rich coatings generally show better corrosion protection when used as a stand-alone system, i.e. without any topcoat. It is therefore interesting to evaluate zinc ethyl silicates as a single coat system. This could provide a cost-effective coating for assets or surfaces that have no aesthetical requirements. The use of ethyl zinc silicate as a stand-alone system could also reduce the amount of VOC and limit the use of sensitizing chemicals such as epoxy or isocyanates.

5.1 The crown crucifix on Uppsala Dome church

In a practically challenging project, the crown crucifix of Uppsala Dome church is being refurbished. The crucifix was made during the late 1800's and is composed of both wrought iron in the cross as well as ornaments in cast iron. The complete structure is about 10 meter tall, about 3,5 meters wide and weighs about 4,2 tons. The crucifix is situated at 114 meters above ground level. Initially the crucifix was coated with red lead lineseed oil. The crucifix was then refurbished during the early 1970´s when the red lead was removed by blasting, and the cross was repainted with zinc ethyl silicate, Carbozinc 11 with a DFT of about 200 µm followed by a thinner coat of dark grey chlorinated rubber.

5.1.1 Results

The coating on the crown crucifix and ornaments was inspected by Björn Tidbeck on the 24th of September 2019, about 45 years after the refurbishment. The coating on the cross and ornaments have been well preserved during the last 45 years. The zinc silicate is largely intact, only a few spots with under rust could be seen. At the places where under-rust had started to show, the DFT was about 40 to 60 µm. Generally, the DFT was between 180-200 µm. By scraping the zinc silicate with a knife edge and treating it with copper chloride it was apparent that the zinc silicate still has metallic/ active zinc pigment beneath the surface layer. The adhesion between coating and substrate was tested on two places of the cast iron ornaments. The pull-off values according to ISO 4624 was more than 20 MPa (outside the scale of the meter). The coating was also tested with the cross-cut test ISO 2409 that revealed a zinc coating with good adhesion but a topcoat that was brittle and not adhering well to the zinc coating. Generally, the chlorinated rubber topcoat was completely deteriorated exposing the underlying zinc coating to the atmosphere. Investigations of the coating using SEM-EDS showed that the zinc coating contained about 1-2% chromium. The chromium content might have affected the corrosion protection of this installation.

Figure 76. Uppsala Dome Church with scaffolding.

Figure 77. The top of the spire is constructed around a steel cone made from galvanised sheet metal, on the outside it has been painted with red lead linseed oil.

Figure 78. An example of an ornament in cast iron, largely an intact zinc coating, a small spot with under rust was visible. The grey chlorinated rubber has deteriorated completely.

Figure 79. Cast iron ornaments, To the left: a crevice that has been successfully coated without any signs of corrosion. To the right: some under-rusting near edges and rivets/ bolts could be seen.

Figure 80. Under-rust on the edge of a cast iron ornament

Figure 81. Cast iron ornament, to the left: apparent coating damage on the object before the coating was fully cured. The zinc was about 200 µm thick, the coating/ rust layer was about 20 µm thick. Notice the year 1974 painted on the right ornament. To the right: the foot of the cross. Some rust on the edges and in the crevice.

Figure 82. The top of the wrought iron cross, it appears as if the bolt holding the assembly together is made of stainless steel. Probably these parts have been disassembled so that the surfaces in the crevices could be coated, at some point during the early 1970´s.

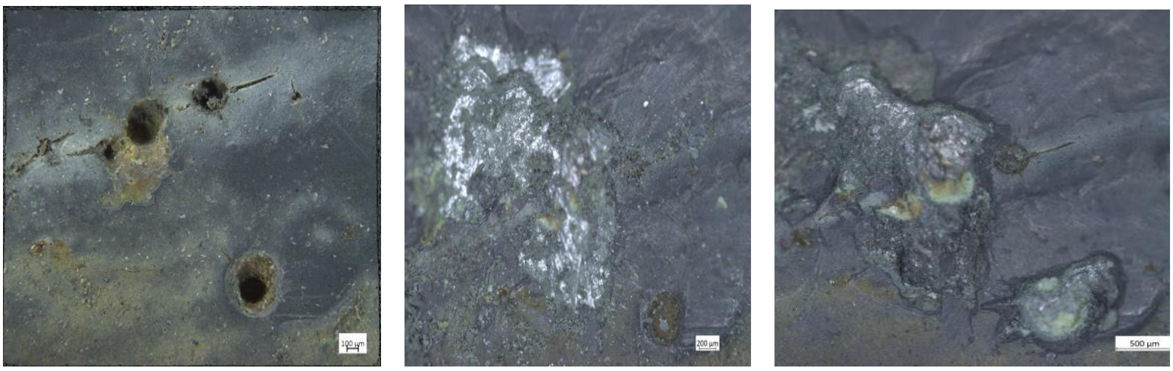

Figure 83. Some pinholes were found in the coating. To the left: pinholes as found. In the middle: The coating was scraped with the edge of a knife, revealing metallic zinc under the surface of the coating. To the right: the scraped surface reacted instantly with copper chloride to form black corrosion products, that indicate corrosion of the metallic zinc.

6 Eon coat

EonCoat is a product that could be an alternative for coating bridges. According to the manufacturer, only one layer is necessary, and the product is not as susceptible to flash rust as normal coatings. The product is interesting from an environmental standpoint because it contains no organic solvents or sensitizing hardeners. The product consists of Wollastonite which is a naturally occurring mineral. The mineral comprises a calcium-silicate with the chemical formula $CaSiO_3$. The product also contains magnesium hydroxide and phosphoric acid. EonCoat is a by-product of a development project conducted by NASA that aimed to produce a rapid-curing concrete. The concrete was to be used as a safety precaution for containment of meltdowns in the nuclear industry. The product has shown good corrosion resistance in accelerated tests and field tests conducted by NASA. [16] As the product is a ceramic, it has somewhat different properties than organic coatings.

6.1 Railway bridge in Varberg, Sweden

Trafikverket, the Swedish Transport Administration, has conducted a field test with Eon-Coat on a railway bridge in Varberg, Sweden. The bridge was coated during the autumn of 2015.

6.1.1 Result

The Railway bridge was inspected by Björn Tidbeck and Bror Sederholm on the 18th of September 2019, about 4,5 years after the refurbishment. The railway bridge in Varberg is in relatively poor condition. The coating had started to flake, see Figure 85, at some areas the coating was cracked and had started to flake, see Figure 87. There was rust in the joints between the fencing poles and the support beams. On many places the coating was very thick and uneven. It is impossible to say whether the poor condition is a result of an insufficient pretreatment or if the product itself is not giving a sufficient corrosion protection.

Figure 84. Overview of a railway bridge coated with Eon Coat, the bridge is located near the sea. The coating had started to flake on the main I-beams.

Figure 85. Corrosion in the joints between the bridge fencing and the support lattice. The picture is from the side facing the sea.

Figure 86. The brown color is not coming from corrosion but from the wooden sleepers of the train tracks.

Figure 87. The coating was in some places very thick and had started to flake

7 Conclusions

Reference objects with various zinc rich coatings and Eon Coat have been inspected. The topcoat on the structural steel of the statue of liberty was flaking, but the underlying zinc silicate showed no signs of deterioration. The US army causeway modules looked good considering their use, exposure and age. The coating on the gates of Tempe Lake was largely in good condition although the coating on some badly prepared welds showed signs of premature failure. The bathing ramp in Varberg looked very good, there was no signs of corrosion, not even around damages where the coating had been chipped during assembly. Six bridges in Norway coated with Zinga have been inspected. Generally, the coating on all bridges apart from Granli brua looked very good, the premature failure on Granli brua was most probably due to an inadequate pretreatment or bad conditions during application. The Seimsbrua was inspected after 27 years, despite some spots with corrosion, the general condition was surprisingly good. The adhesion of the coating was excellent, 11 MPa. The zinc ethyl silicate coating on the crown crucifix of Uppsala dome church was in very good condition 45 years after application in a coating system with a chlorinated rubber topcoat. The adhesion of the zinc was higher than 20MPa. The thermally sprayed Zn/Al 85:15 on the Åsbo bridge was in relatively good condition after 20 years in service, the corrosion damage was limited to areas around inadequately prepared welds. Some blistering of the coating was observed. The coating on the Åsbo bridge indicates that topcoating a thermally sprayed Zn/Al 85:15 coating may not be necessary. The Eon Coat bridge in Varberg was in poor condition, it was however not possible to deduce a clear reason to why the coating had deteriorated prematurely.

The breakdown mechanism of a coating can be very important when considering the corrosion protection of an asset from a life cycle perspective. From the inspections it is evident that Zinga and Carbozinc 11 have higher adhesion to the steel than when they were new, typically the adhesion of unexposed coatings ranges from 4 MPa (Zinga) to 8 MPa (ZnEtSi). [2] It is also evident that all zinc rich coatings studied deteriorate from the outside and in rather than via under-rusting and flaking. This mode of breakdown can be very advantageous, it means that the asset can be spot repaired to a higher extent than if it were protected with a coating system that deteriorates via flaking and loss of adhesion. A relatively easy and ad hoc maintenance protocol for single layer zinc rich coating systems can reduce the need for downtime and secondary cost for maintenance of the asset.

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