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Role of steel and zinc coating thickness in cut edge corrosion of coil coated materials in atmospheric weathering conditions; Part 2: Field data and model

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ABSTRACT

Paint delamination from cut edges of model coil coated hot dip galvanized materials exposed at a marine test site for 5 years increased with steel thickness and decreased with zinc coating thickness. It was larger in sheltered locations than for openly exposed cut edges whereas red rust protection was more efficient on sheltered edges due to higher electric conductivity of deposits. The rate of paint delamination increased or decreased in time depending on the relative amount of zinc ions available for formation of the protective film on steel controlled by the initial steel substrate and zinc coating thicknesses.

1. Introduction

Coil coated steel sheets are widely used in building and appliance industries. Their superior corrosion stability is explained by the synergetic protection provided by metallic and organic coatings. Although the product quality is generally high and stable due to advanced production methods and quality control used in the coil coating industry, defects such scratches appear during transport, processing, installation and product service life. In addition, cut edges of pre-painted panels are usually not treated and can be considered as defects as well [1,2]. Galvanic protection by zinc not only limits any detrimental effect of defects on the product lifetime but also ensures good visual appearance. This is particularly important at cut edges where a relatively large area of bare steel and a small area of zinc and organic coating are exposed to corrosive media.

Coil coaters are looking for product optimization with regard to specific applications and environments while keeping high product quality and sustainability levels. The aim of this study was to investigate the role the metallic coating thickness can play in long-term cut edge protection of coil coated products. In Part 1 devoted to the mechanism of cut edge corrosion [3], it was shown that paint delamination from cut edges progressed by the anodic undermining mechanism independently of exposure conditions and steel and zinc coating thicknesses. The cathode surface area and its ability to reduce oxygen controlled the rate of zinc dissolution and paint delamination. In agreement with earlier works of other authors [4–10], zinc corrosion products deposited over steel proved to inhibit oxygen reduction and reduce galvanic current and further zinc dissolution and paint delamination. Presence of iron corrosion products on steel caused an increase in galvanic current between steel and zinc during drying phases because of presence of additional oxidizers, Fe^{3+} species and adsorbed oxygen. Zinc corrosion products formed under polymeric coatings introduced additional resistance to galvanic current that decreased the rate of zinc anodic dissolution but increased a risk of red rust formation on steel cut edges.

It was proposed that the rate of paint delamination from cut edges in atmospheric exposure conditions would change in time due to an increase in size of steel area to be protected, effect of zinc and steel corrosion products on the rate of oxygen reduction and changing ohmic resistance of the surface film. The rate is expected to decrease or increase in time depending on the relative amount of zinc ions available for formation of the protective film on steel controlled by the initial steel substrate and zinc coating thicknesses. In Part 2 of this study, the proposed mechanism is verified on data collected in a 5-year exposure programme in marine climate for series of pre-painted hot dip galvanized materials differing in zinc coating and steel substrate thicknesses.

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Table 1
Sample denomination; steel substrate/zinc coating thickness [μm].

Substrate thickness [mm]	Coating weight, both sides [g/m^2] (coating thickness, each side [μm])		
	100 (7)	140 (10)	275 (20)
0.2	200/7	–	–
0.35	–	–	350/20
0.5	500/7	500/10	500/20
0.7	700/7	700/10	700/20
1	1000/7	1000/10	1000/20
1.5	1500/7	1500/10	1500/20
2.5	2500/7	2500/10	2500/20

2. Experimental

2.1. Materials and sample preparation

Line-produced hot dip galvanized (HDG) panels differing in substrate and zinc coating thicknesses are listed in Table 1. All zinc coatings contained about 0.2 wt.% Al. The thickness of steel substrate varied from 0.2 to 2.5 mm and the zinc coating weight from 100 to 275 g/m^2 (both sides). It corresponds to 7–20 μm of zinc on each side of a steel panel. The materials are denominated as steel substrate thickness/zinc coating thickness in μm. For example, 700/10 corresponds to 700 μm (0.7 mm) steel with 10 μm zinc coating on each side. All panels were non-passivated and except for 2500/20, skin-passed. They were painted in the laboratory following a procedure applied in coil coating lines. Details on the paint application are given in Part 1 [3].

Painted panels were cut with the top side facing up using identical mechanical cutting tool. At least 15 mm from each side were disposed. ECCA panels formed of two overlapped single panels of 300 × 200 mm with a variable radius bend from 1T to 3T were prepared according to EN 13523-19. The panels were scribed with a 0.5-mm Elcometer 1538 scribing tool down to steel and down to metallic substrate. Schematic drawing of the ECCA panel is shown in Fig. 1. In addition, flat samples of 110 × 80 mm were prepared for all materials except 2500/7, 1500/20 and 2500/20 with edges cut using the same procedure.

2.2. Field exposure and evaluation

Three parallel samples per material have been exposed at a marine weathering site in Brest in France since April 2009. The ECCA panels were oriented at 90° to horizontal facing north under an overhang (further denominated as 90°N) and smaller flat samples at 45° facing south (45°S). The site is characterized by high chloride deposition due to strong wind and close vicinity of sea. From 2009 until 2014, the chloride deposition was in average about 1 g/m^2 day. The region has mild winter with temperatures generally above zero and mild summer with temperatures typically not exceeding 20 °C. The average annual temperature was 12 °C, relative humidity 84 % and time of wetness 505 h/month. The corrosivity at the site according to ISO 9223 was C5 and C3 for carbon steel and zinc, respectively.

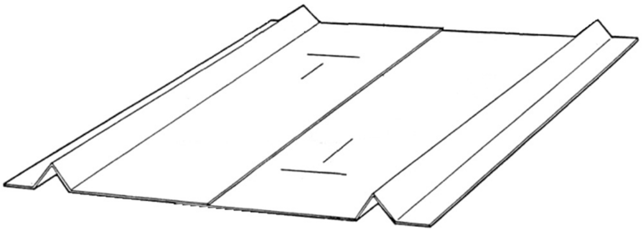

Fig. 1. Schematic drawing of an ECCA panel, size 300 × 380 mm.

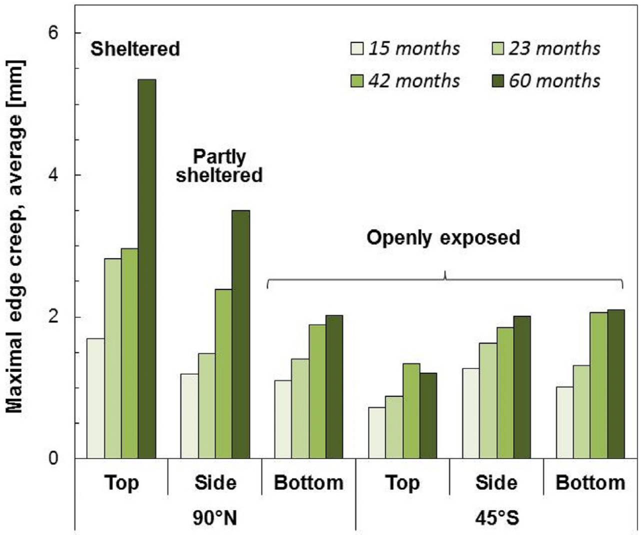

Fig. 2. Maximal paint delamination for different cut edges as a function of exposure duration; samples 1500/20, 2500/20 and 2500/7 not exposed at 45°S are excluded.

The maximum and mean paint delamination distance from top, side and bottom cut edges and extent of red rust were measured after 15, 23, 42 and 60 months of exposure. The extent of red rust was quantified according to Renault 01-72-000 standard. Transparent foil with a grid was placed over red rusted edge and the extent of red rust calculated as percentage of squares with red rust appearance. It must be noted that the procedure gives somewhat exaggerated results compared to image analysis. However, it is rapid and sufficiently precise for a comparative study. Other evaluated parameters such as delamination from scribes to steel and metallic coating, blister size and density and degradation on bend are not reported.

3. Field exposure results

3.1. Paint delamination from cut edges

As seen in Fig. 2, large differences in paint delamination were observed from particular edges of 90°N and 45°S panels. The creep was elevated from top and side cut edges of the 90°N panels protected with an overhang simulating conditions on sheltered facades with limited rinsing of aggressive deposits with rain fall. The average maximal creep distance reached 5.4 and 3.5 mm for top and side edges after 60 months, respectively. For openly exposed 45°S panels, the delamination distance somewhat increased from top to down with the average maximal creep of 1.2, 2.0 and 2.1 mm for top, side and bottom edges. Side and bottom edges were more delaminated because of water accumulation and prolonged time of wetness. The bottom edge at 90°N was delaminated similarly to the same edge at 45°S. This shows on a limited effect of panel