The effect of differentiated exposure conditions on corrosion behaviour of weathering steel on bridges

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Abstract
Application of weathering steels for structures of highway and other bridges represents a typical suitable choice of this material for long term service lifetime. In the Czech Republic after year 1980 about 20 weathering steel bridges were built, SVUOM and IOK performed periodical evaluation of the corrosion effects, causes of defects were defined. Investigation had as aim to consider the specific differentiated exposure conditions in relation to the well-known requirements for forming of the protective patina layers. Variation of exposure conditions depends above all from level of sheltering (lowering of the open air effects) and complementary environmental effects caused by design of the structural elements.

Marked differences in the corrosion effects and the corrosion rates for open air and sheltered exposure proved at atmospheric test site experiments is brought down by the intensive ventilation effect typical for spacious steel bridges. Results of long term corrosion tests of samples exposed on different positions of steel bridges are presented. Conditions for protective patina layer forming were achieved in most situations, unless the structure of the rust layer was modified by the exposure conditions.

The protective ability of the rust layer was more damaged at structural details with unsuitable design causing cumulation of contamination and falling rust or detain and penetration of water (sheltered horizontal surfaces, cavities, surroundings of waste pipes).

Corrosion attack on differentiated steel surfaces was quantified and properties of the patina layer evaluated. The contribution introduces examples of corrosion defects on weathering steel bridges initiated by both causes (effect of sheltering or design).

Key words: “weathering steel”, “bridge structure”, “corrosion loss”, “exposure conditions”, “sheltering effect”, “design of structure”,

Introduction

Weathering steel without corrosion protection are used for structures of highway and other bridges as material with long-term durability and service life and relative low cost for maintenance [1]. This presumption should be fulfilled only in case the suitable conditions for protective rust layer (patina) forming will be created. The basic presumption for patina forming is cyclic wetting and drying of steel surface in acceptable level of air pollution. The optimal conditions for protective rust layer forming are open outdoor exposure.

Guidelines and standards give data of corrosion behaviour of weathering steel based on results of atmospheric open air tests where the samples are placed in 45º angle. Bridge structures, framed and box bridge structures, have areas with various orientations toward affecting agents and with various sheltering levels [2]. The structure design of detail element (nook, corona, void, etc.) evokes the additional effects of outdoor environment influences on protective rust layer forming.

In the Czech Republic many exposure programmes had been performed and more than 30 bridges were built from weathering steel Atmofix 52B (S 355W), with parts from Atmofix 52A (S355). Weathering steel Atmofix 52 meets the specification EN 10025-5 and the basic characteristic of this steel is given in Table 1.

Table 1: Characteristics of weathering steel Atmofix 52A and Atmofix 52B

Steel	$R_{p0,2}$ (MPa)	R_m (MPa)	A (%)	Chemical composition (wt. %)									
				C	Si	Mn	P	S	Cu	Ni	Cr	Al	Nb
Atmofix 52A	345	470-590	22	0,12	0,25-0,75	0,30-1,00	0,055	0,04	0,30-0,55	0,30-0,60	0,50-1,25	0,01	0,00
Atmofix 52B	335-355	470-620	22	0,10-0,17	0,20-0,45	0,90-1,20	0,30-0,55	0,04	0,30-0,55	0,30-0,60	0,40-0,80	0,00	0,04

The effect of sheltering levels

The effect of sheltering level on corrosion rate and protective ability of rust layer of weathering steel was studied in standard atmospheric test sites exposures and in real conditions on existing bridge structures.

The basic information about corrosion behaviour of Czech weathering steel Atmofix 52A are derived from the results of long-term atmospheric exposures in various environmental conditions performed in periods 1968-1978, 1975-1986 and 1986-1995 (Table 2) [3]. The low steady state corrosion rate as result of protective function of rust-patina layer had been obtained in case the corrosion mass loss after 3 exposure years was lower than 500 $g.m^{-2}$ (ca 60 µm) [4]. Comparison of long-term exposure in the open and shelter conditions in atmospheres with high air pollution (industrial, marine) showed high corrosion rate of weathering steel in shelter conditions after longer exposures due to cumulation of corrosion stimulators on steel surfaces. In shelter conditions the non-homogenous rust layer formed which obtained higher concentration of corrosion stimulators (sulphates, chlorides) – Figures 1 and 2.

Table 2: Corrosion loss of weathering steel in different exposure conditions (µm)

Test site	Time (years)	SO_2 ($\mu g.m^{-3}$)	Corrosion loss	
			open	shelter
Prague (1987-1995)	8	53,3	50,5	93,9
Prague (1968-1978)	10	101,6	66,4	152,7
Prague (1975-1986)	12	82,6	70,0	184,5
Ústí nad Labem (1968-1978)	10	176,6	118,4	142,4
Kopisty (1987-1995)	8	67,0	55,6	170,2

On bridge structures the partly sheltered surfaces are situated mainly under bridge deck. In Table 3 the results of specimens´ exposure in real bridge conditions are presented.

Table 3: Corrosion loss of weathering steel in different bridge exposure conditions (µm)

Position	1 year	4 years	9 years
under plate	9,9	26,3	35,5
outside, south	16,8	19,3	17,5
outside, north	21,6	43,6	58,5

open atmosphere shelter

Figure 1: Cross section of weathering steel rust layer after 8 years of exposure

open atmosphere shelter

Figure 2: Distribution of sulphates and chloride nests in rust layer after 8 years of exposure

The effect of surface orientation

The exposure of weathering steel specimens with different orientation (south, east, west) had been performed by SVUOM. The different orientation may affect mainly time of wetness of steel surface. The results of the corrosion mass loss given in Figure 3 showed that the effect of surface orientation is significant on limited level only, the eastward exposure was the most aggressive. The reason for this behaviour was attributed to the slower drying time of the specimens facing east (wind blowing direction is preferably west). Southerly exposure was the most favourable orientation (the most intensive sun radiation).

The similar results had been obtained from specimens exposed on bridge structure (Table 3). On real bridge structures this effect is difficult to evaluate, effect of surface orientation is combined with effect of sheltering.

The effect of structure design

This effect may develop only on real bridge structures. Corrosion of vertical and horizontal surfaces of bridge structures is slightly different. Critical areas are horizontal surface of bottom flange and narrow strip of web approximately 15 cm above this bottom flange where time of wetness of surface is longer and deposition of non-adherent rust, dust and other pollutions occurred there (Figure 4). On narrow strip above bottom flange the rust layer is less adherent than on typical open surfaces but it does not means that this rust layer has not protective ability. The most critical is this effect on bridge surface located under plate where it is combined with sheltering effect [5].

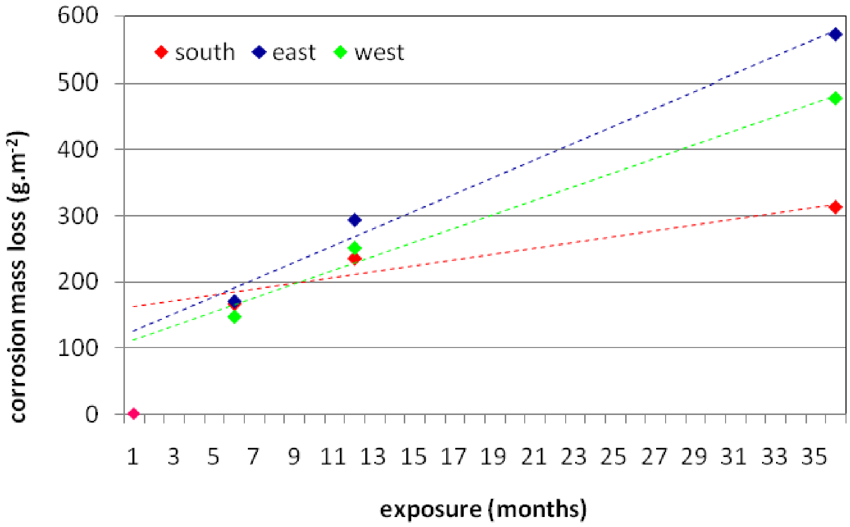

Figure 3: Effect of surface orientation on corrosion loss of weathering steel

The above mentioned areas had been evaluated on 3 bridges exposed for 25 – 30 years. The thickness of rust layer was measured (Table 4). Difference of residual thickness of steel profiles in vertical surface and surface 5 cm above bottom flange was detected as 5%.

Table 4: Thickness of corrosion layers on bridges´ surfaces (µm)

Surface area	Average corrosion layer thickness (µm)
vertical surface	150
vertical surface -5 cm above bottom flange	250
horizontal surface – bottom flange	400

To eliminate this negative effect the application of special element was use to overlap critical surface of low flange (Figure 5). This slopping strap was used around bridge supports to prevent entrance of unathorized persons onto bridge structure. The structure design element is now used alongside the low flange for new planned high-way bridges in the Czech Republic [6].

Negative effect on protective layer forming has such detail as deck drainage system (scuppers, troughs, etc.). During the inspection of bridges it were found many defects caused by these functionaless, blocked or trimmed elements (Figure 6). In these cases precipitation containing de-icing salts leaked on weathering steel surface and destroyed the protective ability of patina layer.

3 – 5 years exposed bridges

25 – 30 years´exposed bridges

Figure 4: Examples of rust layer above bottom flange

Figure 5:New design of low flange element

Figure 6: Effect of leaked precipitation with de-icing salt containt

Conclusions

The use of weathering steel for bridges ensures cost-effective performance over the expected service life of the structure. In a number of cases the corrosion of weathering steel bridges and other strucutres is affected by design details. There is necessary to respect the specific conditions for protective patina forming and to make suitable design of steel stuctures.

For existing weathering steel structures, where proper guidelines have not been followed, the supplementary protection means had to be used (e.g. paint application on specific surface areas). In cases, bridges, light poles and guardrail have experienced excessive corrosion damage, and some have ultimately experienced loss of section and/or localized structural failure because of improper applications of this material. A more precise technical evaluation of the suitability of weathering steel may be obtained from a corrosion consultant, from conducting standardized environmental tests, or from both.

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