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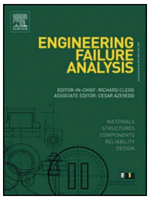

Development and failures of corrosion layers on typical surfaces of weathering steel bridges

Vit Krivy [a], Viktor Urban [a,*], Katerina Kreislova [b]

[a] VSB - Technical University Ostrava, Faculty of Civil Engineering, Ludvika Podeste 1875, 708 33 Ostrava - Poruba, Czech Republic
[b] SVUOM Ltd., U mestanskeho pivovaru 934/4, 170 00 Prague, Czech Republic

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ABSTRACT

This article introduces the program of experimental atmospheric corrosion test carried out on weathering steel bridges in the Czech Republic. Corrosion losses and average thickness of corrosion products are measured and evaluated within this program. Protective ability of corrosion products is evaluated using X-ray diffraction analysis. Special attention is paid to the surfaces exposed to leakage from a failed drainage system. The test results show that the corrosion losses on structural elements are significantly conditioned by the position and location of exposed surface within the structure. The results also indicate a high degree of correlation dependence between measured average thickness of corrosion products and corrosion loss.

1. Introduction

Structural steels with improved atmospheric corrosion resistance, so-called weathering steels, are the low-alloy steels containing a small amount of chromium, copper, nickel, phosphorus and other alloying elements. The content of alloying elements usually doesn't exceed 2 wt.%. The balance of individual alloying elements is important, especially the combination of copper, chromium and phosphorus. The protective layer of corrosion products, so-called patina, appears on the surface when suitable atmospheric conditions exist. Corrosion rates of weathering steels are considerably lower when compared with the standard carbon steel.

Historical development of weathering steels is described in detail in [1]. Specific corrosion properties of steels containing larger amounts of copper were systematically observed already in 1910 [2]. The first weathering steel was patented in the United States in 1933. Steel with trademark USS Cor-Ten was mainly used for the production of rail vehicles. Steel has found application primarily in vehicles subjected to increased abrasion, most frequently in manufacturing of wagons transporting coal [3]. In civil engineering, weathering steel was used for the first time in 1961 — architect Eero Saarinen used weathering steel for facade elements of John Deere headquarters in Moline, Illinois. The first weathering steel bridges were built in 1964 in Michigan and New Jersey [4]. In Europe, weathering steel has started to be used for load-bearing structures from the late 60s (trademarks Corten, Patinax, Coraldur, Intradur, Resist, Indaten, Atmofix).

Currently, weathering steels are used mainly in bridge constructions. In many cases the use of weathering steel is economically advantageous. The fabrication and assembly costs of weathering steel structures are typically 2–10% lower when compared with the structures protected with traditional corrosion protection systems [5–7]. The main economic advantage of using weathering steels is the elimination of costs connected with repairs or restoration of the corrosion protection systems. When using

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* Corresponding author.
E-mail addresses: vit.krivy@vsb.cz (V. Krivy), viktor.urban@vsb.cz (V. Urban), kreislova@svuom.cz (K. Kreislova).

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weathering steels there is also a significantly reduced amount of ecologically exacting manufacturing operations related to the implementation of coating systems.

The basic specific property of weathering steels is their improved corrosion resistance in atmospheric conditions. The scope of the published papers regarding the corrosion behavior of weathering steels in various atmospheric conditions is extensive and includes various characteristics of corrosion layers [8,9]. The development of weathering steels has been always accompanied by the implementation of large-scale atmospheric corrosion tests [10]. Long-term exposure of corrosion specimens was performed mainly to study corrosion processes depending on the corrosivity of atmospheres, including an evaluation of the specific effects, such as the concentration of SO_2 and chlorides deposition [11]. Atmospheric corrosion tests were also carried out to evaluate the different chemical composition of weathering steels [12].

This article presents the results of experimental measurements carried out directly on weathering steel bridges. The program of experimental atmospheric corrosion tests was mainly prepared in order to specify the prediction model for calculation of the design value of corrosion losses of weathering steels [13]. In this experimental program, the effects of various design parameters on the corrosion are tested. The following local factors affecting the creation of corrosion products are pursued:

- influence of the position and location of a surface in the structure (typical surfaces of girder bridges with the roadway above the supports are tested — upper and bottom flanges of main girders, webs of main girders, soffit areas);
- influence of the surface orientation (northward vs. southward);
- effects resulting from incorrect design, realization or neglected maintenance of structures (especially corrosion failures of surfaces exposed to leaking water).

2. Material and methods

2.1. Experimental measurement of corrosion thickness and corrosion loss

In order to evaluate the specific local factors affecting the formation of corrosion products, it was necessary to install corrosion specimens and realize the required measurements on a sufficient number of surfaces of various weathering steel structures. Towards the end of 2015, the corrosion specimens have been installed on 8 weathering steel bridges with upper deck located in the Czech Republic, see Table 1. In total, 76 specific surfaces are being tested at present.

The corrosion specimens are installed on the structure in such a way to simulate realistic behavior of the investigated structural element surface, see Fig. 1. For experimental testing were chosen standard specimens used for atmospheric corrosion tests according to ISO 9226 — test panels 100 × 150 mm with thickness of 1.5 mm. Testing specimens were made of sheets (steel grade S355J2WP) commonly used for building facades [14]. The backside of the specimens, i.e. the side adjacent to the steel structure, is masked to evaluate the corrosion attack only on the exposed side of the specimen.

Corrosion specimens are attached to the steel structure by simple pressure elements made of stainless steel, see Fig. 2. This attachment method provides tight contact between corrosion specimen and examined surface of the steel structure. The contact area between the pressure element and the corrosion specimen is minimal, so there is no influence in the development of corrosion products on the exposed surface and specimens copy the thermal inertia of structural elements [15].

Triplicate corrosion specimens have been installed on each of the examined surfaces. Statistical characteristics of corrosion products thickness were ensured on the bridge surfaces during the installation of the specimens. Rust thickness was measured with portable thickness gauge based on magnetic induction. For each surface, a total of 30 measurements were recorded. The planned duration of these experimental corrosion tests is 10 years. The thickness of corrosion products developed on specimens is measured at yearly intervals. Sampling of corrosion specimens for determination of corrosion losses is planned at 1, 3 and 10 years of exposure.

The bridge structures included in the program of experimental atmospheric corrosion tests are situated in different locations and the bridges are also of different ages. Direct comparison of corrosion quantities measured in different environmental conditions is not suitable for evaluation of corrosion processes. For this reason, the relative quantities are used for comparison and evaluation of corrosion processes on typical surfaces of the tested bridges. The outer web of main girders was selected as the reference area. The exposition time of the newly built bridges is 7 years (the bridges built in 2008) and the corrosion layers are already rather stable, though an additional moderate increase of corrosion thickness cannot be excluded during further exposition [1,8].

Table 1
Weathering steel girder bridges with the roadway above the supports included to the program of experimental testing.

Monitored structures	Year of construction	Year of specimen installation	Corrosivity category
01 — Road bridge over the river Ostravice in Frydek-Mistek	1986	2011	C3
02 — Railway bridge in Prague	1981	2012	C3
03 — Road bridge over the railway line on the road II/470 in Ostrava	2008	2013	C3
04 — Road bridge over the river Odra on the road II/470 in Ostrava	2008	2013	C3
05 — Road bridge over the railway line on the road I/56 in Ostrava	2008	2013	C3
06 — Road bridge on the Opavska St. over the highway D1 in Ostrava	2001	2014	C4
07 — Road bridge on the Opavska St. over the railway line in Ostrava	1983	2014	C3
08 — Road bridge over the river Opavice in Opava	2008	2015	C3

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