# CORROSION BEHAVIOUR OF WEATHERING STEELS IN THE CZECH REPUBLIC

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**Abstract:**
The corrosion behaviour of weathering steel Atmofix had been tested at atmospheric test sites in various localities in the Czech Republic in 1980ties and in 2008. The corrosion rate decreased significantly according to lower atmospheric corrosivity, but the corrosion rate may be relative high in specific polluted areas. The corrosion behaviour of weathering steel was evaluated on ca 20 long-term exposed constructions (bridges, poles, etc.) which showed the typical corrosion effects conditioned by design of structure or by contamination of surfaces. The effect of chlorides on patina forming was tested by laboratory and modified atmospheric tests. The patina was evaluated by appearance, thickness measurement and by chemical and structural analysis.

**Keywords:**
Weathering steel, steel structure, atmospheric corrosion, field test, patina analysis.

## 1. Introduction

Atmospheric corrosion resistant steel, or weathering steel, is a low alloy steel with Cu, Cr, Ni, P and other metalloids added to strengthen the corrosion resistance quality. Weathering steel is 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 (max yearly average 100 µg $SO_2.m^{-3}$). The optimal conditions for protective rust layer forming are open outdoor exposure.

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 | Chemical composition (wt. %) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | C | Si | Mn | P | S | Cu | Ni | Cr | Al | Nb |
| Atmofix 52A | 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 | 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 |

## 2. Atmospheric field tests

Guidelines and standards give data of corrosion behaviour of weathering steel based on results of atmospheric field tests performed according to ISO 8565. The basic information about corrosion behaviour of Czech weathering steel Atmofix 52A and Atmofix 52B are derived from the results of long-term atmospheric exposures in various environmental conditions performed in periods 1968-1978, 1975-1986 and 1986-1995 [2]. Since 90ties of the last century the decreasing sulphur dioxide levels in most Europe and mainly in the Czech Republic and the increasing car traffic causing elevated levels of nitrogen compounds, ozone and particulates has created a new multi-pollutant situation which also affected the corrosion rate of structure metals including weathering steels.

In period 2008-09 the atmospheric exposure program of weathering steel had been realised on 3 permanent SVUOM´s test sites (rural, industrial, urban environments) and on 2 temporary test sites located at Ostrava as locality with specific high air pollution (in 2000-2005 the 5 new highway bridges from weathering steel had been built in this region). At SVUOM´s test sites the samples had been exposed at open atmosphere and under the shelter, too. The environmental data had been measured during the exposure of samples (see Table 2). The corrosion loss of samples was estimated according to ISO 8407.

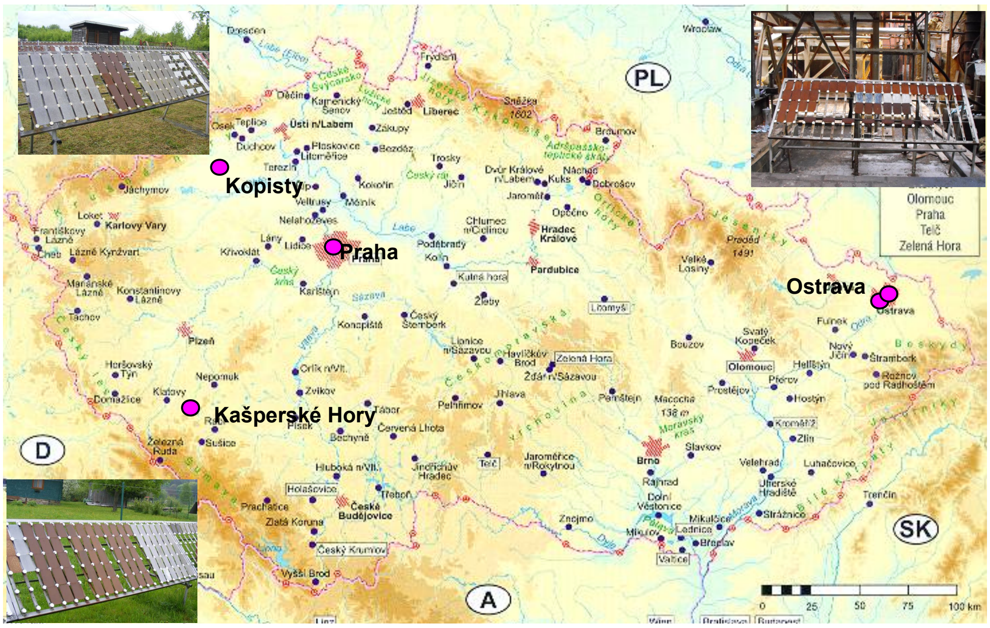


*Figure 1 – Atmospheric test sites in the Czech Republic*

Table 2: Average yearly environmental data in period 2008/2009

| test site | temperature ($^0$C) | RH (%) | amount of precipitation (mm) | pH | $SO_2$ ($\mu g.m^{-3}$) | $NO_2$ ($\mu g.m^{-3}$) |
|---|---|---|---|---|---|---|
| Praha - urban | 10,0 | 68 | 521,9 | 6,9 | 7,0 | 33,9 |
| Kopisty – industrial | 9,4 | 79 | 503,5 | 5,4 | 14,4 | 24,1 |
| Kašperské Hory - rural | 7,0 | 67 | 995,9 | 4,6 | 6,4 | 8,9 |
| Ostrava 1 – urban | 9,8 | 80 | 695,9 | - | 7,6 | 21,3 |
| Ostrava 2 – heavy industrial | 9,8 | 80 | 695,9 | - | 16,7 | 38,1 |

## 3. The change of weathering steel corrosion rate

The comparison of yearly corrosion losses of weathering steel in various environmental situation in 1988 and 2009 – Figure 2 – shows the effect od decreasing $SO_2$ pollution on it. In all these localities the yearly corrosion loss of weathering steel significantly decreased during the last 20 years as a result of $SO_2$ air pollution decreasing. The similar decreasing was evaluated for open atmospheres and for shelter exposures.

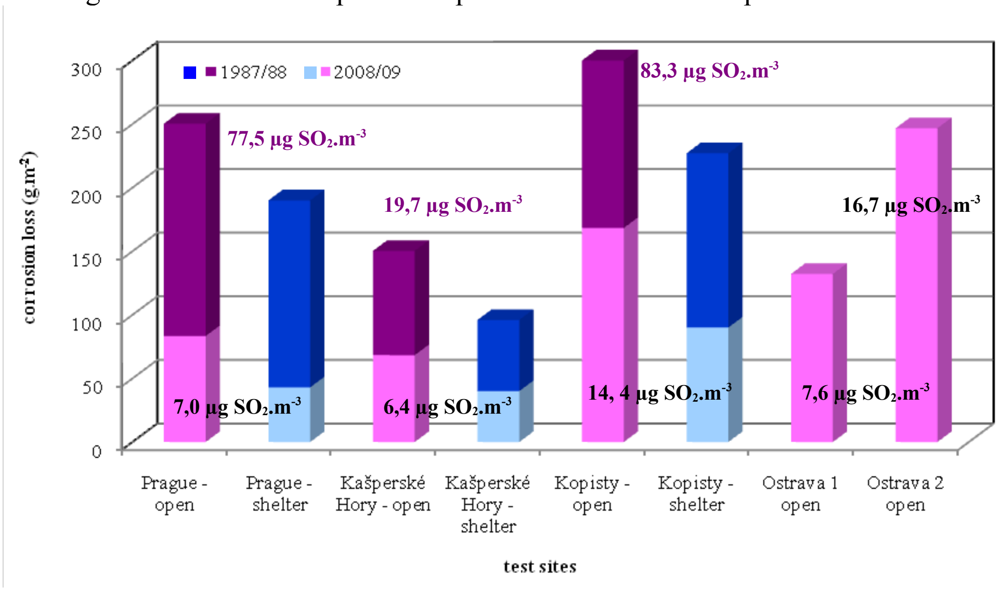


*Figure 2 – The comparison of weathering steel corrosion loss*

From this point of view is interesting the corrosion loss of weathering steel in industrial localities in Ostrava. This very specific polluted environment (steel plants, plate mills, etc.) contains high $SO_2$ and particle pollution and other type of air pollution which was not measured but affected the corrosion rate of weathering steel. After all in these industrial polluted atmospheres the one-year corrosion rate of weathering steel is significantly lower than for carbon steel (ca 250 $g.m^{-2}$ for weathering steel versus ca 550 $g.m^{-2}$ for carbon steel). On Figure 3 the comparison of one-year corrosion loss of weathering and carbon steels are given - the difference in corrosion behaviour is more evident for atmospheres with higher $SO_2$ pollution.

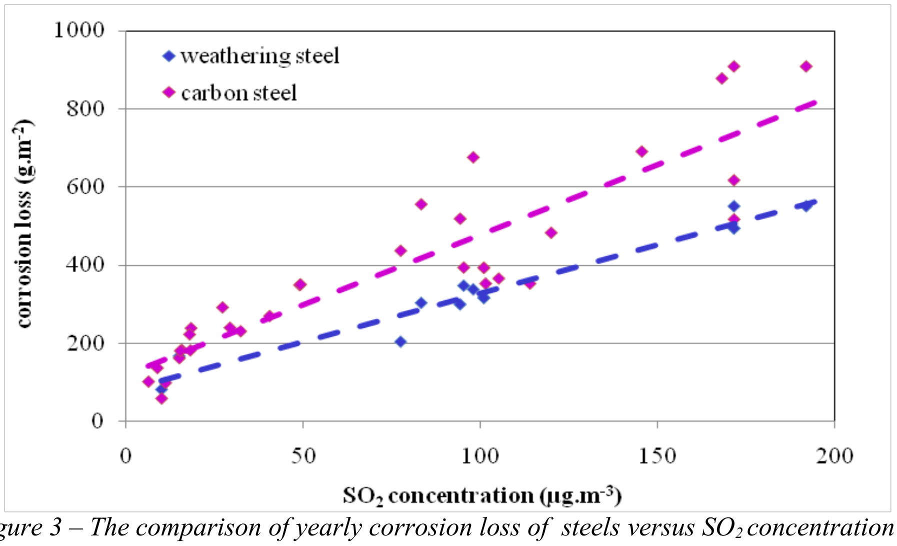


*Figure 3 – The comparison of yearly corrosion loss of steels versus $SO_2$ concentration*

Long-term exposure realized at 80ties showed the trend of decreasing of corrosion rate to steady state rate after ca 5 years of exposure. On Figure 4 there is long-term corrosion behaviour of weathering steel according to field test performed in period 1970-1995 in CR with extrapolation to 30 years. Into Figure 4 the actual one-year corrosion loss of weathering steel in typical environments in CR is included for various environments.

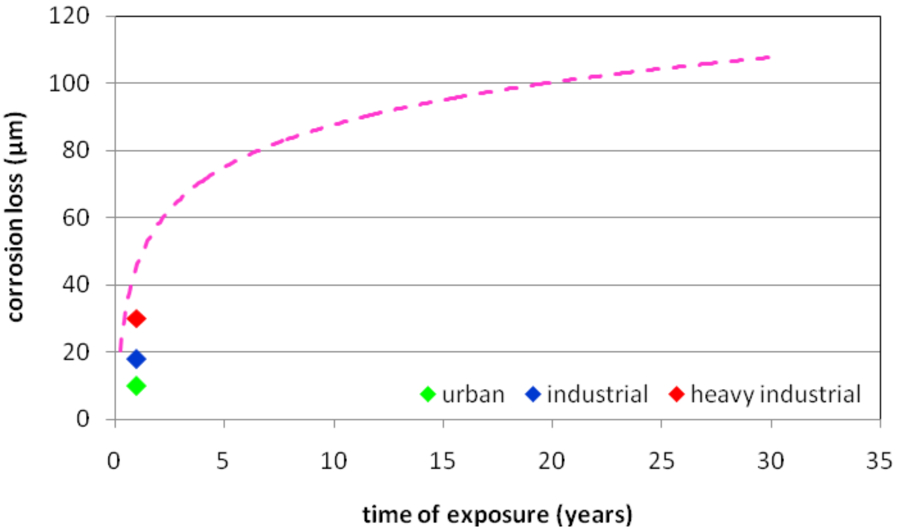


*Figure 4 – The long-term and actual one-year corrosion loss of weathering steelAtmofix 52A in CR environments*

**4. Corrosion behaviour of weathering steel under service conditions**

The service environments in which weathering steels on real structures are exposed do not fulfil all conditions defined as requirements for effective patina forming. The main specific effects in service conditions are sheltering, orientation, angle of exposure and specific pollutants and debris.

The tests studying the effect of orientation performed in 80ties shoved that the eastward exposure was the most aggressive (lower drying time). Southerly exposure was the most favourable orientation for weathering and carbon steel and greatest corrosion resistance for weathering steel relative to carbon steel was found [3].

Weathering steel surfaces on real objects show always some level of sheltering. The effect of sheltering is not unambiguous, the main characteristic for these exposure conditions is given by lower or absence of rain washing and possible accumulation of pollutants and debris in industrial and marine environments. In order to describe the corrosion behaviour of weathering and carbon steel on structures with various surface shielding degrees long term corrosion tests in open air exposure and louver box exposure were performed on test sites with different atmospheric corrosivity [4]. In rural and urban atmospheres remarkable decreasing of short term and long term corrosion rates was evaluated. In industrial and marine environments the accumulation of pollution on corroding surfaces accelerated the corrosion rate during time of louver exposure. The very low steady state corrosion rate was not found. The contemporary lower atmospheric corrosivity will minimalise this effect unless specific service conditions or defects will intensify the effect of local pollution.

The effect of sheltering can be generalized as follows:

- lower time of wetness causes decreasing of corrosion rate, but in heavy polluted and marine environments the absence of rain washing leads to accumulation of pollution on surfaces and acceleration of corrosion rate for longer exposures,
- rust layers are less compact with higher part of non-adherent particles.

Special attention had been given to indoor condition in bridge box section. The measurement of temperature and relative humidity together with carbon and weathering steel sample exposure was realised in two bridges at Ostrava (bridge Svinov, 25 years old and bridge Odra, 5 years old). The temperature measurement shows the same values for outdoor and indoor exposure conditions but for relative humidity is evident that the values at indoor bridge box environments are significantly lower, mainly in winter season (Figure 5). This lower relative humidity resulted into very low corrosion loss of exposed samples (Figure 6).

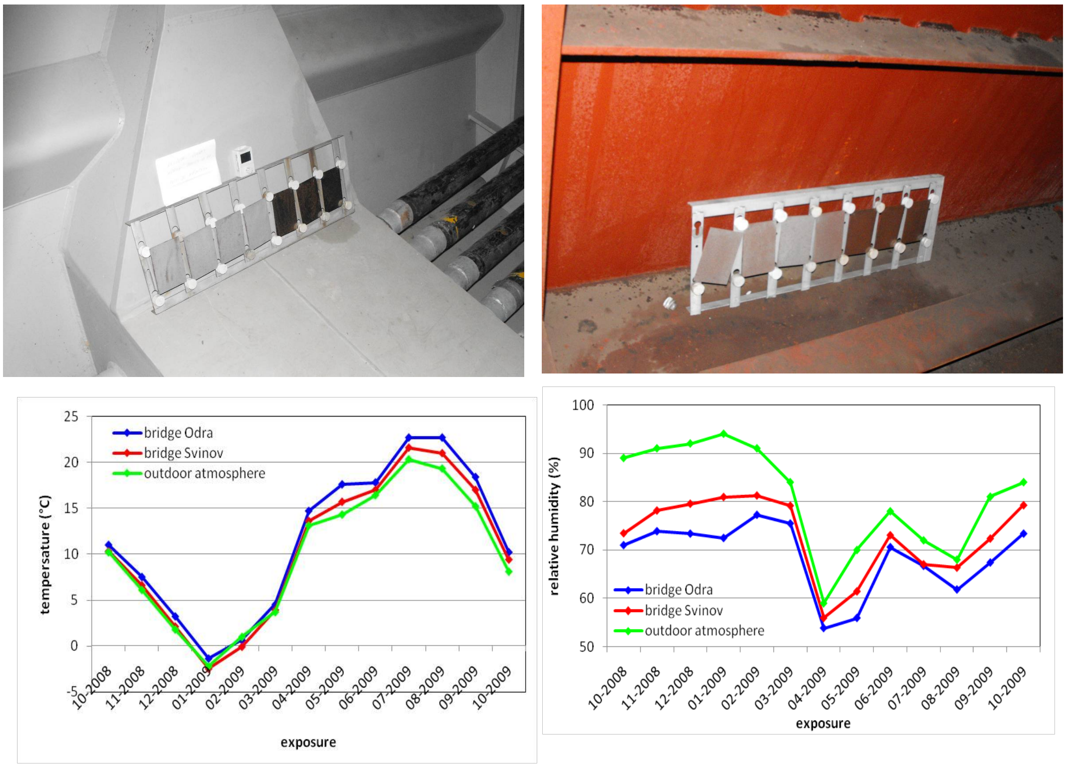


*Figure 5 – The measurement and exposure of samples in indoor conditions of bridge box*

One-year corrosion losses reflect the actual atmospheric corrosivity and are not fully applicable of long-term corrosion behaviour, but give the important information for prediction of it. The most important for corrosion is amount and frequency of leakage passing into indoor space of bridge structure.

## 5. Patina layer forming on real structures

Bridge structures, framed and box bridge structures, have areas with various orientations toward affecting agents and with various sheltering levels [5]. The structure design of detail element (nook, corona, void, etc.) evokes the additional effects of outdoor environment influences on protective rust layer forming.

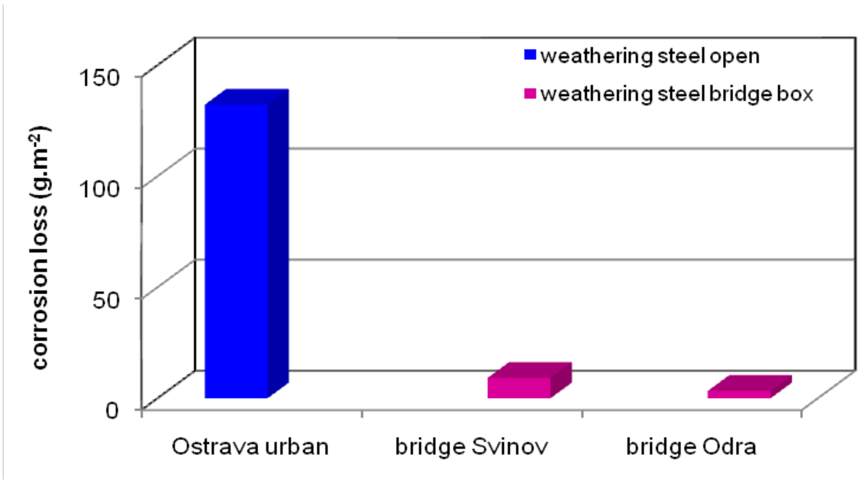


*Figure 6 – The comparison of one- year corrosion loss of weathering steel Atmofix 52A at open atmosphere and in bridge boxes*

Evaluation of 11 long-term exposed bridges proved that the non-suitable construction design may have negative effect on protective layer forming (detail as deck drainage system, scuppers, troughs, etc.) [6]. During the inspection of bridges there were found many defects caused by these functionless, blocked or trimmed elements. In these cases precipitation containing de-icing salts leaked on weathering steel surface and destroyed the protective ability of patina layer. The effected areas are strongly limited and represent only minor areas of construction.

Realised tests with corroded samples with 25 years stable, protective patina (50 µm thickness, goethite) showed the layer is quickly destroyed by chloride contamination – after one-year of atmospheric test with spraying of de-icing salts in winter season (ISO 11474 modification) the layer thickness increased for 90 µm and akaganeite had been found in patina layer with dominating phase goethite. The patina layer is living system reflecting the actual exposure condition and on the other hand it may recover again and has protective properties. From evaluation of construction it was found that the recovery of patina is relative slow procedure and takes more than 5 years.

The effects of the non-suitable design or secondary elements defects appeared very quickly on patina layers – mainly on the macroscopic structure of patina (more voluminous, less adherent layer) – Figure 8.

**Conclusion**

Weathering steels are economical and ecological solution of some types of steel structures with fair assumption of long-term service life and durability but they need periodic control and maintenance, firstly the secondary construction elements which are made from other materials.

The bridges evaluated after 25 – 30 years of exposure in CR show some defects mainly caused by insufficient basic maintenance but even in the worst case the bridge may serve for next years after repair of them.

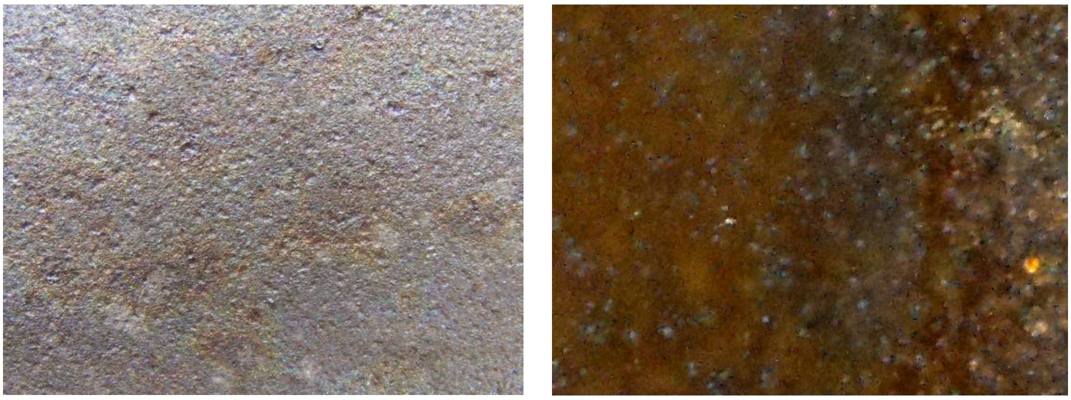

*Figure 7 – The patina layer before and after the 1-year atmospheric test with salt spraying*

*Figure 8 – The negative patina appearance in bridge areas affected by leakage due to non-suitable design and missing gutter after 2 years of exposure*

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