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Atmospheric corrosivity assessment on the basis of standard specimens' corrosion rates within the military air bases

Abstract: Atmospheric corrosion is one of the parameters characterizing the technical condition of the functional elements of airport pavements - it allows to determine the degree of pavement degradation, estimate the appropriate frequency of periodic inspections and take appropriate measures to keep airfield pavements in permanent technical availability. In order to determine the corrosion resistance of the cement and asphalt concrete airfield pavement, atmospheric corrosivity tests determined on the basis of standard specimens exposure and determination of corrosion rates, form and appearance of deteriorations, as well as changes in physical properties at regular intervals are carried out. The samples were exposed to atmospheric conditions at military airport facilities. The article presents the *rcorr* corrosion rate results of low-carbon steel, zinc, copper and aluminum standard specimens obtained from selected airports of the Polish Armed Forces, starting from 2015. Then, the corrosivity categories of the atmosphere were determined on the basis of the performed measurements.

Keywords: Atmospheric corrosion; Corrosion rate; Standard specimens; Military air bases

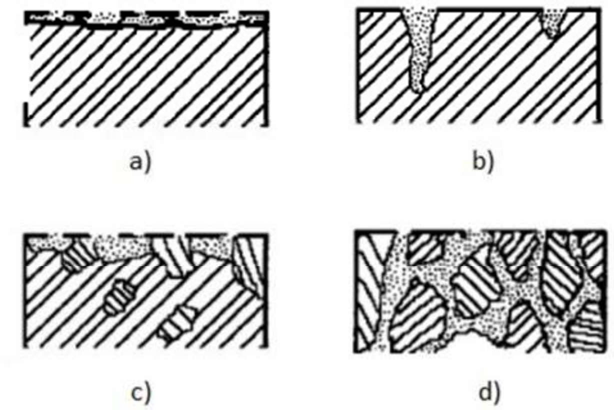
Introduction

Atmospheric corrosion is a physicochemical interaction between a metal and the environment of an atmospheric corrosion test site. During atmospheric corrosion, two processes take place simultaneously on the metal surface: anodic and cathodic. In the anode process, the metal is oxidized. In turn, the course of the cathode reaction depends on the pH of the environment - in an acidic environment, there is a cathodic reduction of hydrogen ions with the release of hydrogen, while in a neutral and alkaline environment, a cathodic reduction of oxygen in an aqueous solution takes place with the formation of hydroxide ions [5].

Determining the corrosion rate with the use of corrosion losses suggests that corrosion occurs evenly on the surface of the entire sample [15]. In the early stage of exposure, the corrosion rate is relatively high. As corrosion products accumulate on the metal surface, the corrosion rate gradually decreases and tends to remain constant [3, 7]. Corrosion tests under atmospheric exposure conditions are conducted all over the world and are a constant subject of research among researchers. The international research program ISO CORRAG (Collaborative Atmospheric Exposure Program) [6] is conducted to determine the degree of correlation between the four metals used (carbon steel, zinc, copper, and aluminum) in 13 countries around the world during 8 years of sample exposure. Temperature, relative humidity, sulfur dioxide concentration, chloride deposition rate, and other environmental factors are monitored and recorded throughout the exposure period. The exposure time of samples of 8 years was also adopted in the UN/ECE project [16], in which the corrosion rate of samples made of steel, zinc, aluminum, copper, limestone, sandstone, and other materials was assessed in 12 European countries, the United States and Canada. The authors [2] compiled and assessed the corrosion databases obtained under the ISOCORRAG, ICP/UNECE, and MICAT programs, dividing the atmospheres into marine and non-marine. Chloride deposition in coastal areas is highly dependent on factors influencing the infiltration of sea salt inland, i.e. wind direction and speed, local topography, distance from the sea. Therefore, one of the predisposed exposure of corrosive samples is in coastal areas [8, 9, 10, 17]. The atmospheric corrosion assessment system can also support the process of managing the functional elements of airports (military and civil) and support the rational management of airport pavements. The authors [20, 21, 22], having the test results of reference samples at their disposal, determining the correlations with the parameters characterizing atmospheric conditions, are aimed at limiting the collection of environmental data, and their impact is determined on the basis of the corrosion losses of the reference samples.

Types of corrosion and corrosive factors

Atmospheric corrosion can occur in two basic forms: general (uniform) corrosion and local corrosion [4]. General (uniform) corrosion occurs at a similar rate and in the same form over the entire surface of the sample. This type of corrosion is typical for atmospheric corrosion of steel and copper [19]. Local corrosion occurs selectively, in individual places on the sample surface. It can be observed on alloys of aluminum, zinc, stainless steel, nickel, and other metals in the form of pitting, crevice, and sub-sediment corrosion. This is often caused by the chloride ions that are present in the air of marine and coastal environments. The local corrosion effects of some aluminum alloys, including those containing copper, can take the form of layered corrosion and the effect of peeling or blistering. In addition, we distinguish selective corrosion, i.e. corrosion of a metal alloy (e.g. brass), the components of which react in different proportions than their proportions in the alloy or intercrystalline corrosion occurring at the metal grain boundaries or in the areas adjacent to them. Galvanic (bimetallic) corrosion occurs when two or more different metals are in direct contact in the presence of an electrolyte. The individual types of corrosion are shown in the Figure **1** [19].



1. Examples of surface corrosion occurring on the surface of metals: a) general corrosion, b) local corrosion, c) selective corrosion, d) intercrystalline corrosion

The surface of metal samples is affected by corrosive factors, i.e. air humidity, precipitation, air temperature, as well as air pollution (in particular, the concentration of sulfur dioxide (SO_2), nitrogen oxides (NO_x), PM, nitric acid (HNO_3) and pollution operational and technological microclimate, i.e. chlorine (Cl_2), hydrogen sulfide (H_2S), organic acids and de-icing agents). The corrosion process depends on the presence of an electrolyte, i.e. a medium in which electric current is transferred through ions. It can be rain, dew, melting snow, or high humidity. Atmospheric corrosion occurs under conditions of high relative humidity (so-called critical relative humidity) below which ordinary metals will not corrode because there is not enough moisture to form an electrolyte layer on the metal surface. However, according to [18], surfaces exposed to rain are characterized by better corrosion resistance than surfaces that are rarely or not washed away by rain. According to Cai, Y. K. et al. [1] the influence of various environmental factors on the corrosion rate of metals is usually non-linear.

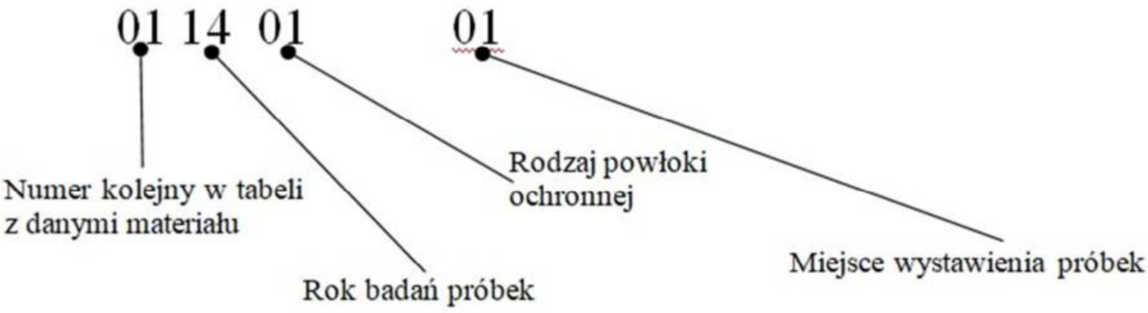
Atmospheric corrosion studies

Corrosion tests were carried out in the operating conditions of aircraft at selected airbases in order to determine the corrosion resistance of metals and the corrosiveness of the atmosphere. The samples were exposed to an open space, where atmospheric factors and atmospheric pollutants directly affect the sample surface [11]. The frames for the exposure of metal samples are located within the corrosion stations, i.e. in specially fenced places (to protect against the possibility of damage to the tested objects). The presence of buildings, any structures in the immediate vicinity of the station is unacceptable because they provide a cover for the tested samples. Therefore, the exhibition stands are located in secluded places where the sample surface is directly exposed to all weather conditions. Any vegetation around the site is cut or shortened to a height of 0.2 m. The exhibition frames are secured against undesirable displacement by attaching their bases to concrete screeds with expansion bolts. Special holders for fixing samples are used to secure the tested samples against movement. Photo **2** shows a photo of an exemplary corrosion station placed on one of the airport facilities.

Standard specimens are plates with dimensions of 50 mm x 100 mm and a thickness depending on the thickness of sheets available on the market, ranging from 1 mm to 3 mm. Standard specimens are one-year samples not protected with any anti-corrosion preparations. The test specimens were made of flat sheets. For identification purposes, a sample marking scheme was created by punching a sequence of numbers, according to the scheme shown in Figure **3**. The first two numbers indicate the material from which the sample was made (08 - carbon steel, 09 - zinc, 10 - copper, 11 - aluminum). The next two digits indicate the year of testing (exposure) of the samples to the corrosion station. Standard specimens are one-year samples, not protected with any anti-corrosion preparations, therefore the numbers 01 are embossed on the samples, which also means that they must be removed from the frame after one year of testing (exposure to weather conditions). The last two digits are the place where the samples are issued (each of the air bases on which the permanent corrosion station is located has its own individual number assigned). After the samples were labeled, a checklist was drawn up containing the identification of the samples. Photo **4** shows the reference samples after air sandblasting and their labeling.

The samples were prepared according to the PN-EN ISO 8565: 2021 standard. The employees of the ITWL Airport Department were responsible for the preparation and display of the samples to the test stands and their subsequent transport. Before the exposure, all standard specimens were degreased with organic solvents or alkaline degreasing liquids. During the removal of samples from the corrosion stations, the samples were exposed for the next research period.

2. An example of a corrosion station located at one of the airport facilities



3. Scheme of marking reference samples

4. Reference samples after air sandblasting and their labeling

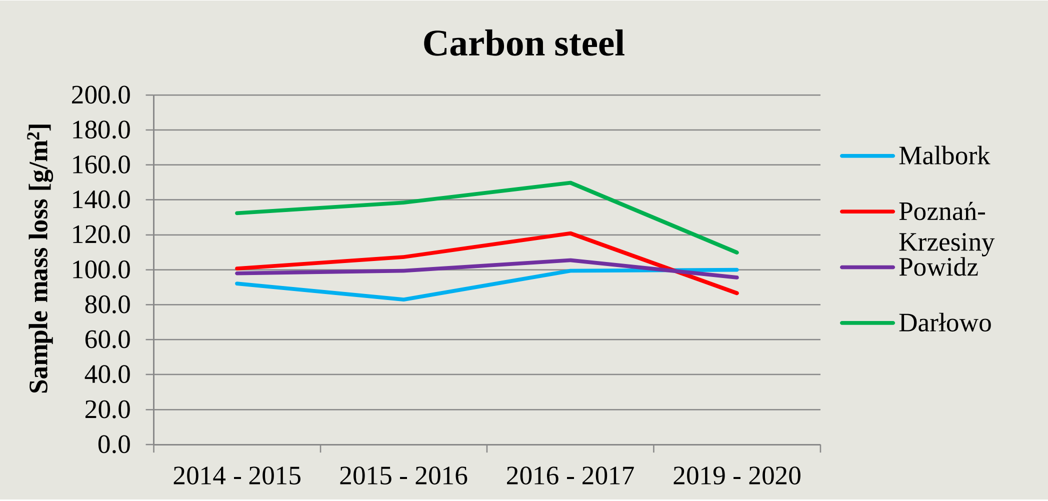
After being brought to the laboratory of the Airport Department, the samples were weighed and measured. Then, the corrosion products were removed by the chemical method according to the EN ISO 8407: 2021 standard. Corrosion of metals and alloys - Removal of corrosion products from samples for corrosion tests [20]. The next step was to weigh and measure the samples again. The samples were weighed on the balance with an accuracy of

0.001 g, while the thickness measurements were made with a micrometric screw with an accuracy of 0.001 mm. The thickness of the sample was measured at five points.

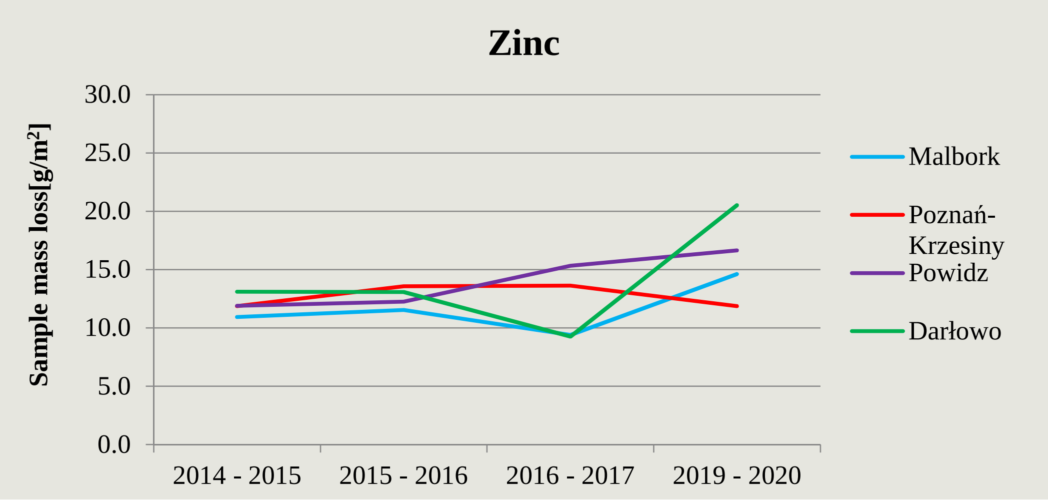
The weight loss of the sample per its surface was calculated according to PN-EN ISO 9226: 2012 Corrosion of metals and alloys - Corrosivity of atmospheres - Corrosivity assessment based on the determination of the corrosion rate in standard specimens [14].

Measurement of corrosion losses of standard specimens

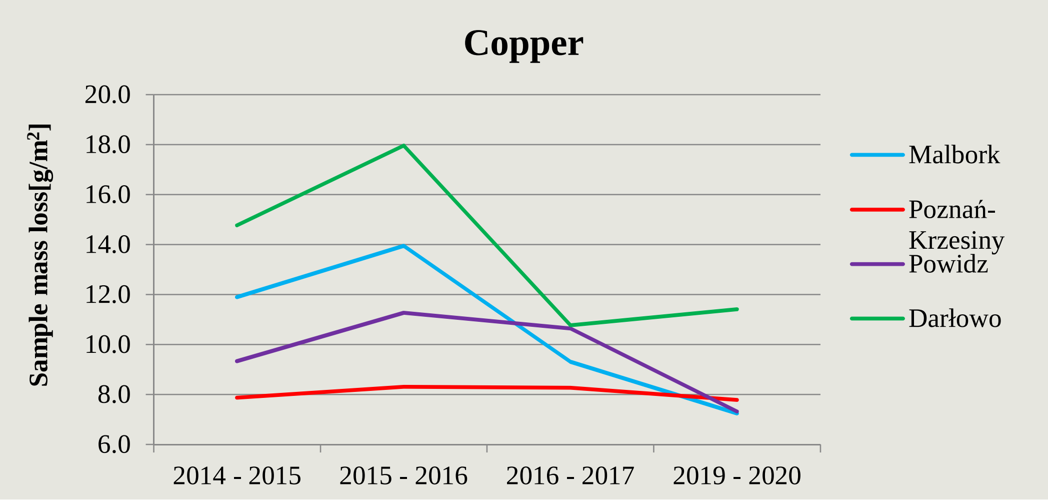
The ITWL Airport Department conducts atmospheric corrosion tests from October 2014 to the present day. The collection of corrosion data covers the annual exposure periods in 2014-2015, 2015-2016, 2016-2017, and 2019-2020, as well as one two-year exposure period in 2017-2019. The following article presents data obtained from permanent corrosion stations located in the area of 22 Tactical Aviation Bases in Malbork, 31 Tactical Aviation Bases in Poznań - Krzesiny, 33 Transport Aviation Base in Powidz, and the Aviation Group in Darłowo. The charts (Figures **5** - **8**) show specific values of the corrosion losses of standard specimens of individual metals with the division into individual objects.



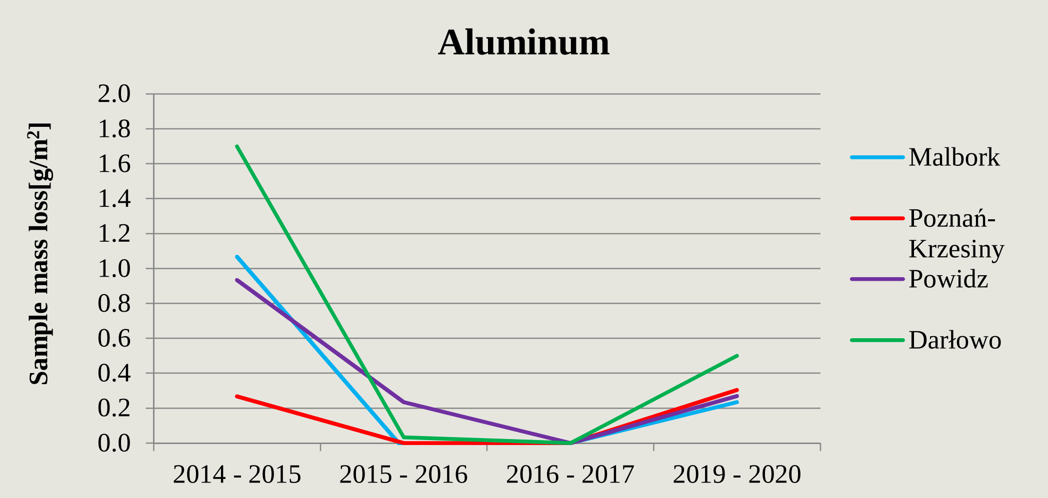
5. Mass loss of reference samples made of carbon steel in particular years



6. Mass loss of reference samples made of zinc in particular years



7. Mass loss of reference samples made of copper in particular years



8. Mass loss of reference samples made of aluminum in particular years

The above statements show that:

- the highest values of r_{corr} corrosion losses incarbon steel were recorded in 2017, the lowest - in 2020 (Poznań - Krzesiny, Powidz, Darłowo) and 2016 (Malbork),
- the highest values of r_{corr} corrosion losses in zinc were recorded in 2017 (Poznań - Krzesiny and Powidz) and 2020 (Malbork and Darłowo), the lowest - in 2017 (Malbork, Darłowo) and 2015 (Poznań - Krzesiny, Powidz),
- the highest values of r_{corr} corrosion losses in copper were recorded in 2016 at all analyzed corrosion stations, the lowest values of r_{corr} losses were recorded in 2020 (Malbork, Poznań - Krzesiny, Powidz) and 2017 (Darłowo),
- the highest values of r_{corr} corrosion losses in aluminum were recorded in 2015 at all analyzed corrosion stations, the lowest values of r_{corr} losses were recorded in 2017 (also at all corrosion stations).

Atmospheric corrosivity

The atmospheric corrosivity category is the basis for the selection of materials and measures for protection in atmospheric conditions, especially with regard to the service life, including the use of airport pavements. In this work, the atmospheric corrosivity classification system was used based on the measurement of corrosion losses of standard specimens after the first year of exposure according to PN-EN ISO 9223: 2012 Corrosion of metals and alloys -

Corrosivity of atmospheres - Classification, determination, and evaluation [13]. Tables **1-4** show the corrosivity categories determined on the basis of corrosion losses after 1 year of exposure of the samples to the effect of atmospheric corrosion.

Atmospheric corrosivity categories determined on the basis of corrosion losses (g/m^2) of standard metal samples are divergent, they indicate a close dependence of the corrosivity category on local climatic conditions and air pollutant concentrations.

Tab. 1: Atmospheric corrosivity categories determined on the basis of mass loss of samples made of carbon steel

Carbon steel								
Corrosion station	2014 - 2015		2015 - 2016		2016 - 2017		2019 - 2020	
	r_{corr} g/m^2	Corrosivity category	r_{corr} g/m^2	Corrosivity category	r_{corr} g/m^2	Corrosivity category	r_{corr} g/m^2	Corrosivity category
Malbork	92,1	**C2**	82,9	**C2**	99,5	**C2**	100,0	**C2**
Poznań-Krzesiny	100,7	**C2**	107,2	**C2**	120,8	**C2**	86,6	**C2**
Powidz	98,0	**C2**	99,4	**C2**	105,4	**C2**	95,6	**C2**
Darłowo	132,4	**C2**	138,4	**C2**	149,8	**C2**	109,8	**C2**

Tab. 2: Atmospheric corrosivity categories based on mass loss of zinc samples

Cynk								
Corrosion station	2014 - 2015		2015 - 2016		2016 - 2017		2019 - 2020	
	r_{corr} g/m^2	Corrosivity category	r_{corr} g/m^2	Corrosivity category	r_{corr} g/m^2	Corrosivity category	r_{corr} g/m^2	Corrosivity category
Malbork	10,9	**C3**	11,5	**C3**	9,4	**C3**	14,6	**C3**
Poznań-Krzesiny	11,9	**C3**	13,6	**C3**	13,6	**C3**	11,8	**C3**
Powidz	11,9	**C3**	12,2	**C3**	15,3	**C4**	16,6	**C4**
Darłowo	13,1	**C3**	13,1	**C3**	9,3	**C3**	20,5	**C4**

Tab. 3: Atmospheric corrosivity categories based on the mass loss of copper samples

Copper								
Corrosion station	2014 - 2015		2015 - 2016		2016 - 2017		2019 - 2020	
	r_{corr} g/m^2	Corrosivity category	r_{corr} g/m^2	Corrosivity category	r_{corr} g/m^2	Corrosivity category	r_{corr} g/m^2	Corrosivity category
Malbork	11,9	**C3**	13,9	**C4**	9,3	**C3**	7,2	**C3**
Poznań-Krzesiny	7,9	**C3**	8,3	**C3**	8,3	**C3**	7,8	**C3**
Powidz	9,3	**C3**	11,3	**C3**	10,6	**C3**	7,3	**C3**
Darłowo	14,8	**C4**	18,0	**C4**	10,8	**C3**	11,4	**C3**

Tab. 4: Atmospheric corrosivity categories based on mas loss of aluminum samples

Aluminum								
Corrosion station	2014 - 2015		2015 - 2016		2016 - 2017		2019 - 2020	
	r_{corr} g/m^2	Corrosivity category	r_{corr} g/m^2	Corrosivity category	r_{corr} g/m^2	Corrosivity category	r_{corr} g/m^2	Corrosivity category
Malbork	1,1	**C3**	0,0	**C2**	0,0	**C2**	0,2	**C2**
Poznań-Krzesiny	0,3	**C2**	0,0	**C2**	0,0	**C2**	0,3	**C2**
Powidz	0,9	**C3**	0,2	**C2**	0,0	**C2**	0,3	**C2**
Darłowo	1,7	**C3**	0,0	**C2**	0,0	**C2**	0,5	**C2**

Summary

The article presents the types of corrosion occurring on the surface of metals, as well as corrosive factors that have a direct impact on the corrosion rate. Next, the requirements for the exposure of standard metal samples within permanent corrosion stations located at the airbases of the Polish Armed Forces are described, as well as the procedure for the preparation and handling of standard metal samples (carbon steel, zinc, copper, and aluminum). The results of research on r_{corr} corrosion losses recorded at corrosion stations in 2015-2020, located at selected air bases, are also presented. Atmospheric corrosivity categories were also determined based on the value of corrosion losses r_{corr} after one-year exposure of samples.

The results of the conducted research indicate the need to conduct regular corrosion tests in field conditions in order to obtain real data on the durability of metals and their degradation in various types of environment, extended by laboratory tests of metals and their alloys, i.e. corrosion tests in sprayed brine. Moreover, it is recommended to increase the sample size of the available corrosion data in order to increase the interpretability of the obtained results.

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