**Lecture 12. Corrosion. Causes of Corrosion**

All materials or products, plants, constructions, and buildings made of such materials are subject to physical wear during use.

A general overview of different kinds of wear caused by mechanical, thermal, chemical, electrochemical, microbiological, electric, and radiation-related impacts is shown in Figure 12.1.

The technical and economic mastering of physical wear is difﬁcult, since several causes are intertwined and mutually inﬂuence each other. The interaction with certain media of the environment results in undesired reactions of the materials that trigger corrosion, weathering, decaying, embrittlement, and fouling.

While mechanical reactions lead to wear, chemical and electrochemical reactions cause corrosion. Such processes emanate from the materials’ surfaces and lead to modiﬁcations of the material properties or to their destruction. According to X, corrosion is deﬁned as:

“Physical interaction between a metal and its environment which results in changes of the metal’s properties and which may lead to signiﬁcant functional impairment of the metal, the environment or the technical system of which they form a part.”

**Corrosion system:** A system consisting of one or several metals and such parts of the environment that affect corrosion.

**Corrosion phenomenon:** Modiﬁcation in any part of the corrosion system caused by corrosion

**Corrosion damage:** Corrosion phenomenon causing the impairment of the metal function, of the environment or of the technical system of which they form a part.

**Corrosion failure:** Corrosion damage characterized by the complete loss of operational capability of the technical system.

**Corrosion resistance:** Ability of a metal to maintain operational capability in a given corrosion system.

When unalloyed or alloyed steel without corrosion protection is exposed to the atmosphere, the surface will take on a reddish-brown color after a short time. This reddish-brown color indicates rust is forming and the steel is corroding. In a simpliﬁed way, the corrosion process of steel progresses and is chemically based on the following equation:

Fe+SO2 + O2 = FeSO4 (1.1)

4Fe + 2 H2O + 3O2 =4FeOOH (1.2)

The corrosion processes begins when a corrosive medium acts on a material. Since (energy-rich) base metals recovered from naturally occurring (low-energy) ores by means of metallurgical processes tend to transform to their original form, chemi- cal and electrochemical reactions occur on the material’s surface.

Two kinds of corrosion reactions are distinguished:

# chemical corrosion

Corrosion excluding electrochemical reaction,

# electrochemical corrosion

Corrosion including at least one anodic and one cathodic reaction.

# Types of Corrosion

Corrosion does not only occur as linear abrasion, but in versatile forms of appearance. Important variants for unalloyed or alloyed steel are:

# Uniform surface corrosion

General corrosion occurring on the entire surface at nearly the same rate.

# Shallow pit corrosion

Corrosion with locally different abrasion rates; caused by the existence of corrosion elements.

# Pitting corrosion

Local corrosion resulting in holes, that is, in cavities expanding from the surface to the inside of the metal.

# Crevice corrosion

Local corrosion in connection with crevices occurring in or immediately adjacent to the crevice area, which has developed between the metal surface and another surface (metal or nonmetal).

# Contact corrosion (aka dissimilar metal corrosion)

Occurs at contact surfaces of different metals; the acceleratedly corroding metal area is the anode of the corrosion element.

# Intergranular corrosion

Corrosion in or adjacent to the grain boundaries of a metal.

The standard mentioned above describes altogether 37 types of corrosion. These types of corrosion result in corrosion phenomena.

# Corrosion Phenomena

X deﬁnes corrosion phenomena by corrosion-causing modiﬁcations in any part of the corrosion system.

Major corrosion phenomena are:

# Uniform surface attack

A form of corrosion where the metal material is almost uniformly removed from the surface. This form is also the basis for the calculation of the mass loss (g m−2) or the determination of the corrosion rate (μm y−1).

# Shallow pit formation

A form of corrosion with irregular surface attack forming pits with diameters much larger than their depth.

# Pitting

A form of corrosion with crater-shaped or surface-excavating pits or pits resembling pin pricks. The depth of the pitting spots usually exceeds their diameter.

It is very difﬁcult to differentiate between shallow pit formation and pitting.

# Corrosive Stress

All environmental factors enhancing corrosion (see Figure 1.2).

# Atmospheric Corrosion

The corrosion rate in the atmosphere is insigniﬁcant as long as the relative humidity on the steel surface does not exceed 60%. The corrosion rate increases, especially with inadequate ventilation,

* With increasing relative humidity.
* With condensate occurring (surface temperature < dew point).
* In the presence of precipitation.
* With increasing pollution of the atmosphere which may affect the steel surface and/or be deposited on it. Pollutants are gases, including sulfur dioxide, salts, chlorides, and sulfates. In connection with humidity, deposits like soot, dusts, salts, etc., on steel surfaces accelerate corrosion.

Temperature also, inﬂuences the corrosion process. The following criteria are decisive for the evaluation of the corrosive stress:

* climatic zone;
* cold climate;
* moderate climate;
* dry climate;
* warm, humid climate;
* sea climate;
* local climate.

Local climate is deﬁned as what is prevailing within the radius of the object (up to 1000 m). The local climate and the pollutant content are the basis for the classiﬁcation of atmospheric types.

* atmospheric types;
* room atmosphere;
* rural atmosphere;
* urban atmosphere;
* industrial atmosphere;
* marine atmosphere;
* microclimate.

The microclimate is the climate immediately at an individual component part. The local conditions, such as inﬂuences of humidity, dew-point shortfalls, local humidiﬁcation and its duration, especially in connection with pollutants occurring at the location, have a signiﬁcant impact on corrosion.

Table 1.1 shows the corrosive stress of atmospheric corrosion for different atmospheric types and corrosivity categories according to X.

# Corrosion in the Soil

The corrosion behavior is determined by soil conditions and electrochemical parameters, such as element formation with other component parts and the inﬂuence of alternating and direct current.

X distinguishes between the underwater zone, the intermediate (ﬂuctuating level) zone, the splash zone and humid zone.

Special Corrosive Stress

Corrosive stress at the location, in the application area or through production- related inﬂuences is a special load that has a decisive impact on corrosion. Mainly, chemical stress is concerned, like operation-related emissions (acids, alkaline solu- tions, salts, organic solvents, aggressive gases, and dusts and others). However, special stresses may also be mechanical stress, temperature stress and combined stresses – contemporaneous presence of mechanical and chemical stress, and all enhance corrosion.

# Avoidance of Corrosion Damages

The following basic determinations are required for the avoidance of corrosion damage:

* determination of the corrosion exposure of the product, the plant, the structure or the building;
* knowledge of the service life: period in which the corrosion system

meets the requirements for functionality;

* knowledge of the protection period: expected service life of a coating system up to the ﬁrst parts replacement.

The determination of the corrosion exposure is relatively difﬁcult since both the inﬂuence of the climatic zones, the local climate, the atmospheric types and the microclimate need to be taken into account. A corrosion protection corresponding to the service life has to be determined in order to minimize the expenses for costly repetitive maintenance measures.