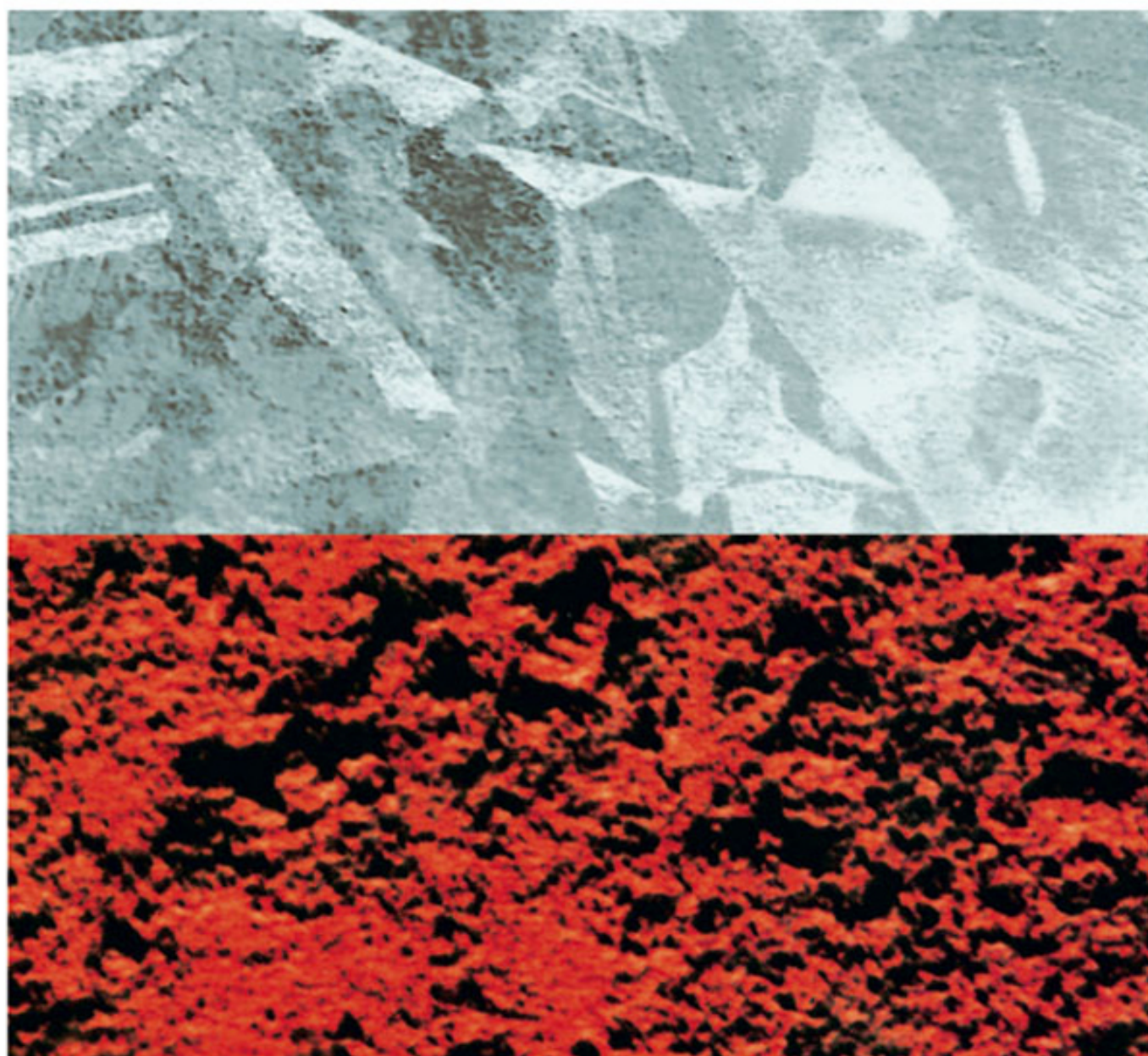


Edited by Peter Maass  
and Peter Peissker

 WILEY-VCH

# Handbook of Hot-dip Galvanization



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**Corrosion Handbook - Corrosive Agents and Their Interaction with Materials**

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2009

ISBN: 978-3-527-31217-7

Heimann, R. B.

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Ghali, E., Sastri, V. S., Elboujdaini, M.

**Corrosion Prevention and Protection Practical Solutions**

2007

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**Verbundwerkstoffe**

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*Edited by Peter Maafß and Peter Peißker*

## **Handbook of Hot-dip Galvanization**



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## **The Editors**

***Dr. Peter Maaß***

Fabrikstr. 17a

04178 Leipzig

Germany

***Dr. Peter Peißker***

Dahlienstr. 5

04209 Leipzig

Germany

## **Translation**

***Christine Ahner***

Translate Economy

Freiherr-von-Eichendoff-Str. 8/l

88239 Wangen

Germany

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# ***Preface to the Third German Edition***

As the second German edition of the “Handbuch Feuerverzinken”, published in 1993, has been out of print for some time, a third, completely revised edition became necessary. With its publication we would like to thank all authors, some of them new to this edition, for their valuable contributions.

The following modifications and additions have been made:

- In the revision the new Euro- and ISO standards are considered, in particular DIN EN ISO 1461.
- The chapter on surface preparation technology now covers new processes that take into account the trend towards environmentally friendly technologies.
- The layer formation technology is explained on an entirely new footing, based on the investigations of the Institute for Corrosion Protection, Dresden, and the Institute for Steel Engineering, Leipzig, and includes high temperature galvanization.
- The chapters on technical equipment, design and manufacturing according to hot-dip galvanizing requirements as well as on occupational safety and quality management have been updated.
- The commercially important method of powder coating is now covered in the sections on the post-treatment of zinc coatings.
- All chapters take into account the vastly expanded range of hot-dip galvanized products, e.g., truck frame parts.
- After eight years of intense discussions with the responsible government departments, trade associations and the IG Metall (Industrial Union of Metal



Workers) the method of hot-dip galvanization, since August 2005, has been integrated into the job description of a Surface Coating Specialist. Therefore, for the first time, a Germany-wide recognized trade for hot-dip galvanization specialists exists.

We hope that the third edition of the “Handbuch Feuerverzinken” will continue to meet interest in the professional circles and will constitute a ready reference for the hot-dip galvanization industry.

Critical remarks conducive to the book’s content will be much appreciated. We would like to thank the publisher Wiley-VCH, notably Dr. Ottmar and Dr. Münz, who sympathetically supported us in our wish to publish this third edition and unbureaucratically also undertook some of the editors’ work.

Peter Maaß

Peter Peißker

Leipzig,

December 2007

# ***Acknowledgment***

The publisher wishes to thank Philip G. Rahrig, Executive Director of the American Galvanizers Association (AGA), USA, Werner Niehaus, former President of Voigt & Schweitzer, Inc., USA, and Barry P. Dugan of Horsehead Corp., USA, for their support in reviewing the translation. Philip G. Rahrig and Murray Cook, Director of the European General Galvanizers Association (EGGA), UK, kindly provided the lists of the AGA and EGGA member associations that are reproduced in Appendix D.

# ***Preface to the Second German Edition***

Hot-dip galvanization was invented in 1742 by the French chemist Paul Jacques Malouin, but first found wide-spread use in 1836 after a patent on its practical application was issued to the French chemist Stanislas Sorel. Decades of alchemy and chemistry combined with craftsmanship led the way to a productive, efficient and modern industry.

The increasing importance of structural engineering with its varied application fields on the one hand and the demands for low-maintenance or maintenance-free corrosion protection on the other hand have spurred the development of process technology and installation engineering of hot-dip galvanization.

The essential groundwork on the topic was laid in the landmark publication “Das Feuerverzinken” (Hot-dip Galvanization) by Prof. Bablik, the eminent expert of process technology, published in 1941. The book “Das Feuerverzinken”, the first German edition of “Handbuch Feuerverzinken” by the editors, published in 1970, and its second edition will provide readers and practitioners with the possibility to gain an understanding of the historical and technological development of hot-dip galvanization and will hopefully help to bring it to fruition in practical applications.

Corrosion and corrosion protection, notably hot-dip galvanization, are nowadays integral parts of quality management of products and of environmental protection because corrosion is caused by environmental influences. By limiting and preventing corrosion, hot-dip galvanization as a prime method of corrosion protection helps to

- protect natural resources
- conserve values
- increase the quality of living
- enhance security.

If reference books could be written by few individual authors in the past, the sheer complexity of process technology and installation engineering necessitates a joint effort of an assembly of experts from various disciplines. Critical remarks conducive to the book's content will be much appreciated. We thank the publisher which supported us in every respect.

Peter Maaß

Peter Peißker

Leipzig, July 1993

# ***List of Contributors***

***Dipl.-Ing. Hans-Jörg Böttcher***

Düsseldorf (Chapters 4 and 9)

***Ing. Werner Friehe***

Mühlheim (Chapter 9)

***Dr. Gunter Halm***

Dorsten (Chapter 8)

***Dipl.-Chem. Lothar Hörig***

Leipzig (Chapter 3)

***Dr. Dietrich Horstmann***

Erkrath (Chapter 9)

***Dipl.-Ing. Mark Huckshold***

Düsseldorf (Chapter 7)

***Dipl.-Ing. Jens-Peter Kleingarn***

Düsseldorf (Chapter 11)

***Dr. Rolf Köhler***

Haan (Sections 6.1 to 6.3)

***Dr. Carl-Ludwig Kruse***

Dortmund (Chapter 9)

***Dr. Peter Maaß***

Leipzig (Chapters 1, 2, 11, 12, and 13)

***Dipl.-Ing. Jürgen Marberg***



Düsseldorf (Section 6.4 to 6.7, and Chapter 7, 8 and 12)

***Dipl.-Ing. Rolf Mintert***

Hagen (Chapter 5)

***Dr.-Ing. Peter Peißker***

Leipzig (Chapter 3 and 5)

***Ing. Gerhard Scheer***

Rietberg (Chapter 7)

***Dipl.-Chem. Andreas Schneider***

Leipzig (Chapter 10)

***Dr. Wolf-Dieter Schulz***

Leipzig (Section 3.6, and Chapters 4 and 9)

***Prof. Dr. Wilhelm Schwenk***

Duisburg (Chapter 9)

***Dipl.-Chem. Marc Thiele***

Dresden (Chapter 4)

***Dr. Christian Kaßner***

Hattingen (Chapter 6)

***Dipl.-Ing. Rolf Mintert***

Halver (Chapter 5)

# 1

## ***Corrosion and Corrosion Protection***

**Peter Maaß**

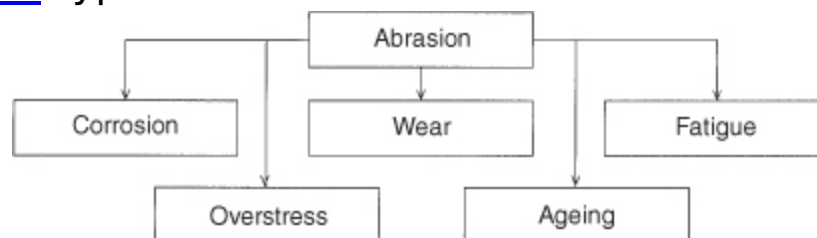
### **1.1 Corrosion**

#### **1.1.1 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 [1.1](#).

**Figure 1.1** Types of wear of materials.



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 DIN EN ISO 8044, 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.”

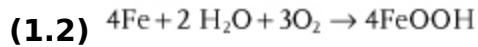
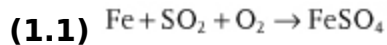
Note: *This interaction is often of an electrochemical nature.*

From this definition, included in the standard, further terms are derived:

- *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:



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, chemical 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.

## 1.1.2 Types of Corrosion

Corrosion does not only occur as linear abrasion, but in versatile forms of appearance. According to DIN EN ISO 8044, 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.

### 1.1.3 Corrosion Phenomena

EN ISO 8044 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 ( $\text{g m}^{-2}$ ) or the determination of the corrosion rate ( $\mu\text{m y}^{-1}$ ).
- *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.

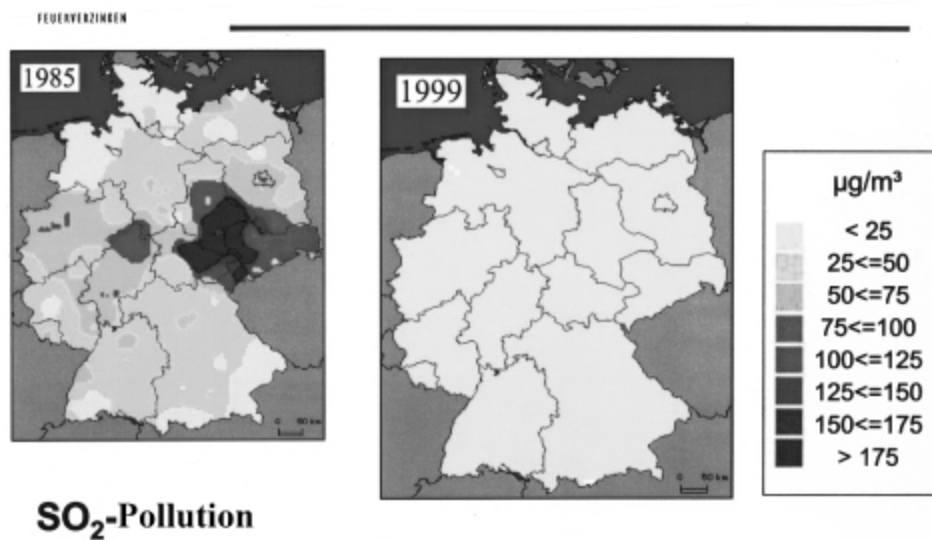
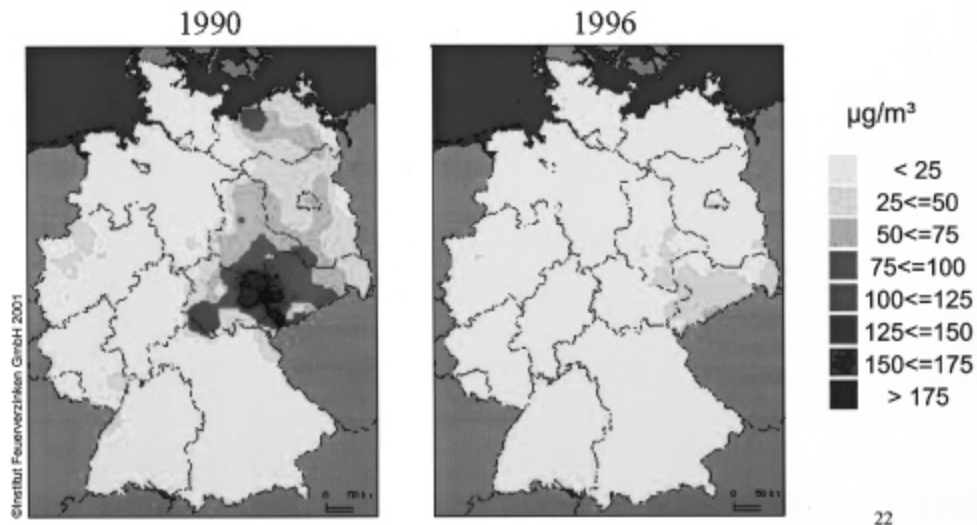
It is very difficult to differentiate between shallow pit formation and pitting.

### 1.1.4 Corrosive Stress

According to DIN EN ISO 12944-2: All environmental factors enhancing corrosion (see Figure [1.2](#)).

**Figure 1.2** The reduction of SO<sub>2</sub> pollution in Germany over the last 20 years led to decisive reductions of the zinc-removal values (cf. Table [1.1](#)).





Source: Federal Environmental Agency

### 1.1.4.1 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 DIN EN ISO 12944-2.

**Table 1.1** Corrosive stress – classification of environmental conditions acc. to DIN EN ISO 12944-2.

Corrosivity Class	Thickness loss <sup>a)</sup> in the 1st year (µm)		Examples of typical environments	
	C-Steel	Zinc	Outdoors	Indoors
C 1 insign.	≤1.3	≤0.1	–	Insulated buildings ≤ 60% rel. humidity
C 2 low	>1.3–25	>0.1–0.7	Slightly polluted atmosphere, dry climate, e.g., rural areas	Uninsulated buildings with temporary condensation, e.g., store rooms, gymnasiums
C 3 moderate	>25–50	>0.7–2.1	S- and I-atmosphere with moderate SO <sub>2</sub> -pollution or moderate coastal climate	Rooms with high rel. humidity and minor pollution, e.g., breweries, laundries, dairies
C 4 heavy	>50–80	>2.1–4.2	I-atmosphere and coastal atmosphere with moderate salt pollution	Chem. production halls, swimming pools
C 5 very heavy I	>80–200	>4.2–8.4	I-atmosphere with high rel. humidity and aggressive atmosphere	Buildings or areas with almost permanent condensation and heavy pollution
C 5 very heavy M	>80–200	>4.2–8.4	Coastal and offshore areas with high salt pollution	

a) Also reported as mass loss.

### **1.1.4.2 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.

Corrosive stress is decisively determined by:

- the composition of the soil;

- changes of the soil condition at the object due to deposits present in the soil;
  - additional electrochemical factors.
- For further details, see EN 12501-1.

### ***1.1.4.3 Corrosion in Water***

Major conditions for corrosive stress in water are:

- the composition of the waters, such as oxygen content, kind and amount of dissolved substances in fresh water, brackish water and salt water;
- mechanical stress;
- electrochemical factors.

DIN EN ISO 12944-2 distinguishes between the underwater zone, the intermediate (fluctuating level) zone, the splash zone and humid zone.

### ***1.1.4.4 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 solutions, 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.

### ***1.1.4.5 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 of time in which the corrosion system meets the requirements for functionality (EN ISO 8044);
- knowledge of the protection period: expected service life of a coating system up to the first parts replacement (EN ISO 12944-1).

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.

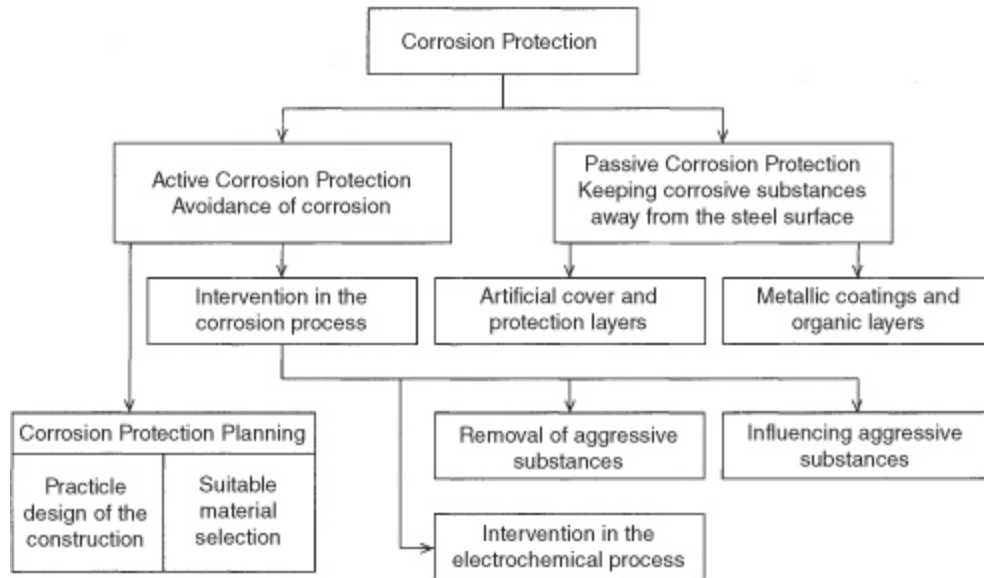
## **1.2 Corrosion Protection**

### **1.2.1 Procedures**

All methods, measures, and procedures aimed at the avoidance of corrosion damages are called corrosion protection. Modifications of a corrosion system in so far as corrosion damages are minimized.

Figure [1.3](#) gives an overview.

**Figure 1.3** Methods, measures, and procedures of corrosion protection (*von Oeteren, Korrosionsschutz-Fibel*).



### ***1.2.1.1 Active Procedures***

Active corrosion protection helps reduce or avoid corrosion by means of manipulation of the corrosion process, corrosion protection-related material selection, project engineering, design and manufacturing. But it is also a significant precondition for the effectiveness of passive corrosion-protection procedures. The following aspects are surveyed in this respect:

#### ***Design-Engineering Requirements***

The basic design-engineering requirements of the corrosion-protection-related design of steel structures are defined in the DIN EN ISO 12944-3:

- corrosion protection of steel structures by protective paint systems;
- basic rules for protective coating;
- EN ISO 14713;
- protection of iron and steel structures against corrosion – zinc and aluminum coatings.

In the figurative sense, they also apply to other products, unless these contain precise requirements determined in