Edited by Peter Maass
and Peter Peissker

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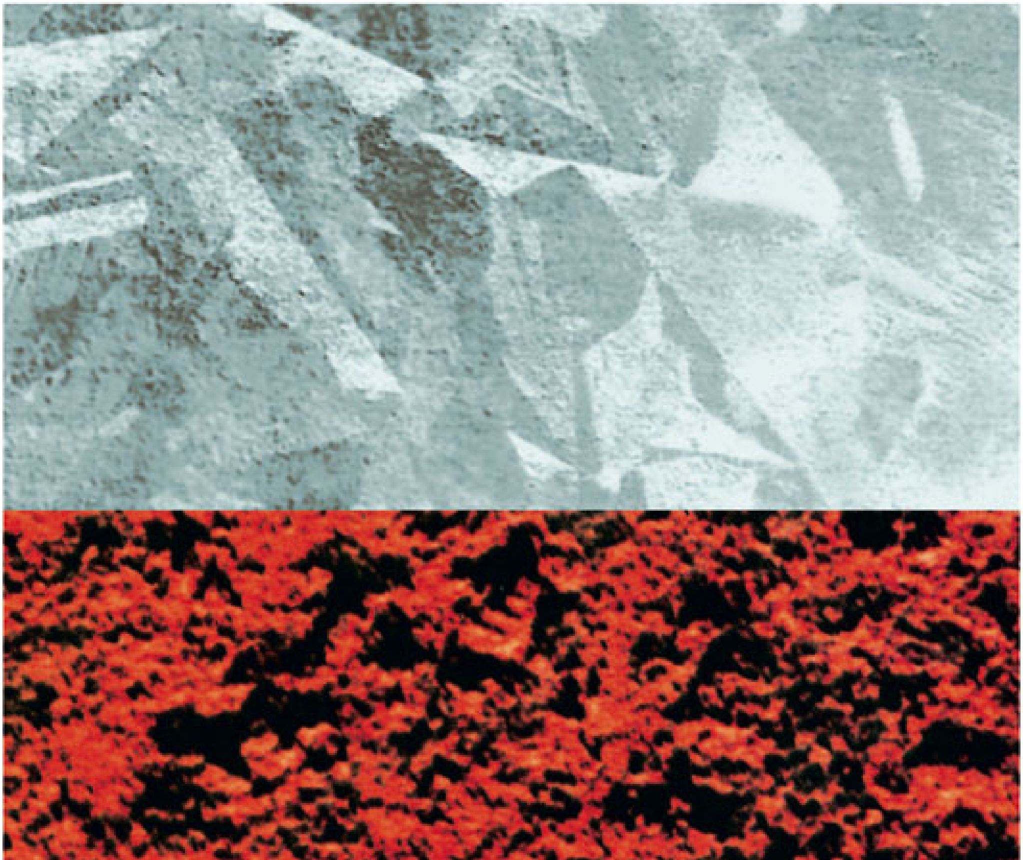
Handbook of Hot-dip Galvanization



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Handbook of
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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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Contents

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.

Leipzig, December 2007

Peter Maaß
Peter Peißker

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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.

Leipzig, July 1993

Peter Maaß
Peter Peißker

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
Dortmand (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.

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.

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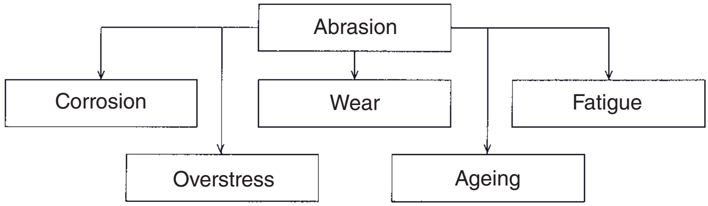

Figure 1.1 Types of wear of materials.

- **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:

$$Fe + SO_2 + O_2 \rightarrow FeSO_4 \quad (1.1)$$

$$4Fe + 2\ H_2O + 3O_2 \rightarrow 4FeOOH \quad (1.2)$$

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

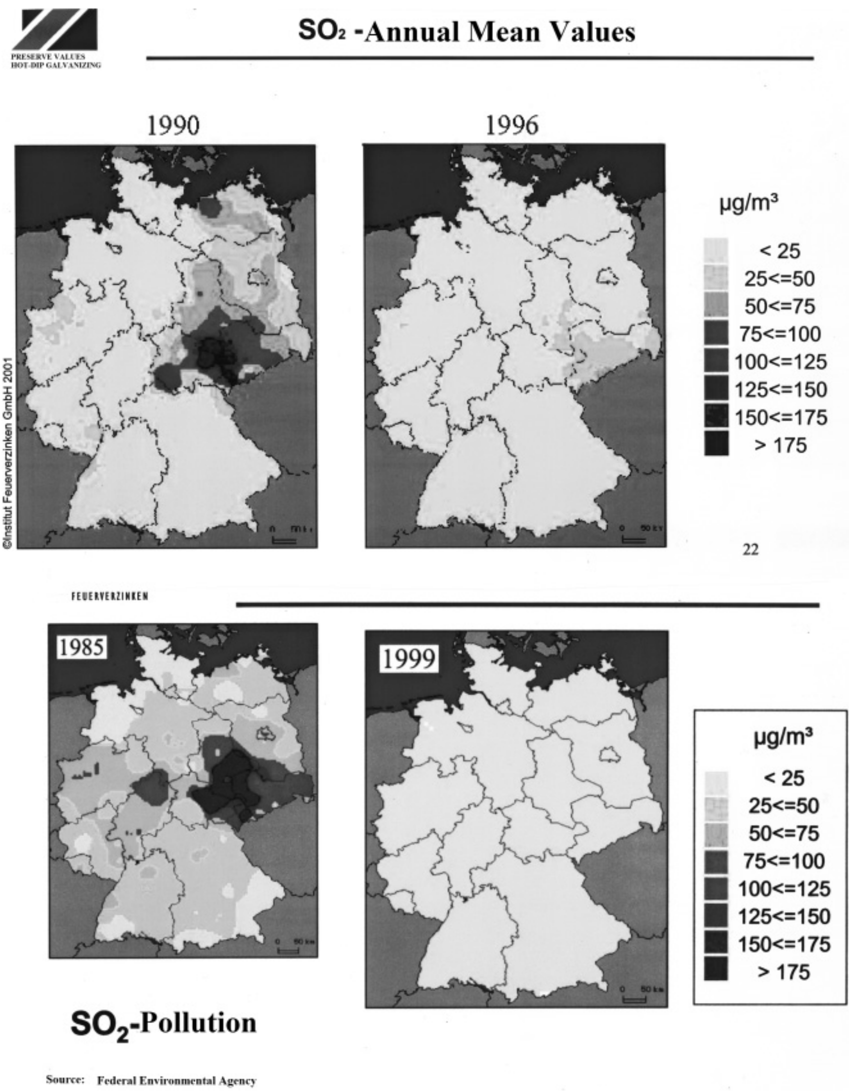

Figure 1.2 The reduction of SO_2 pollution in Germany over the last 20 years led to decisive reductions of the zinc-removal values (cf. Table 1.1).