Environmental Deterioration of Materials

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Environmental Deterioration of Materials

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WIT*PRESS* **Southampton, Boston**

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Published by

WIT Press
Ashurst Lodge, Ashurst, Southampton, SO40 7AA, UK
Tel: 44 (0) 238 029 3223; Fax: 44 (0) 238 029 2853
E-Mail: witpress@witpress.com
http://www.witpress.com

For USA, Canada and Mexico

WIT Press
25 Bridge Street, Billerica, MA 01821, USA
Tel: 978 667 5841; Fax: 978 667 7582
E-Mail: infousa@witpress.com
http://www.witpress.com

British Library Cataloguing-in-Publication Data

A Catalogue record for this book is available
from the British Library

ISBN-10: 1-84564-032-2
ISBN-13: 978-1-84564-032-3
ISSN: 1368-1435

LOC: 2006929309

The text of the chapters of this book were set individually by the authors and under their supervision.

Printed in Great Britain by Athenaeum Press Ltd, Gateshead

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Preface

The increasing level of pollution in the environment not only harms the natural world, but also accelerates the deterioration and corrosion of materials used in technical work as well as materials of objects with historical or artistic value. It is not possible to eliminate the numerous sources of this negative effect, so there is a currently an increased effort at better preservation, which requires a thorough knowledge of the causes of the degradation of individual materials.

The purpose of this book is to evaluate various natural and anthropogenic factors, to better understand the conditions that cause the decay of selected construction materials, and to show conservation approaches and application methods allowing for their improved preservation. The chapters of the book offer an overview of the newest information regarding the causes of material and object deterioration and its prevention for a wide specialized readership. The authors of these chapters have based their work on knowledge gained from years of research and practical experience during the assessment of damaged objects. The content of the book is relatively wide but some topics are not involved. Topics such as flood damage, seismic effects, mechanical vibrations due to transportation, and indoor building environments, among others, are not covered, or are given limited attention. Only those construction materials that are used most often or to the greatest extent have been selected. Nevertheless, the book offers the specialized reader a general introduction to many facets of material preservation, and may be a good supplement to the limited publications pertaining to this field.

I would like to express my thanks to all of the contributors for their patience, their cooperation and their support over an extended period of time. I would also like to thank the publishers for their support and cooperation. I believe that the final result of our efforts is a worthwhile contribution to the better understanding of the environmental deterioration of materials.

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2006

Introduction

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This book deals with the basic principles underlying the environmental deterioration of commonly used construction materials and metals, as well as the available prevention and protection techniques that may be adopted to protect and conserve them. Building and construction materials, such as natural stones and timber, man-made composite materials, such as bricks and concrete blocks, and construction metals, namely, cast iron, steel, aluminium, zinc and copper and their alloys, are included in this book. The individual chapters include brief information about some types of polymer composites and paints. Taking into consideration the wide range of these materials used in construction, more detailed information on the factors influencing the failures of individual types of polymeric materials is beyond the scope of this book.

This book briefly reviews the basic knowledge on the environmental deterioration mechanisms of materials and corrosion of metals and the information on the meteorological and climatic factors, the effects of pollutants and biological action affecting degradation. This also includes information about ISO standards relating to the classification of atmospheric corrosivity, the classification system of low corrosivity of indoor atmospheres and corrosivity categories of atmospheres for several construction metals. Dose–response functions describing the corrosivity of outdoor atmospheres for these metals are also briefly discussed. The book gives several examples of how this knowledge may be applied to the protection and conservation of buildings, industrial facilities and culturally important objects in order to reduce damages and economic impact.

The deterioration of buildings and the corrosion of metallic constructions due to natural environmental effects and anthropogenic pollution lead to shortening of the service life and usefulness of structures, demand the use of more valuable and expensive materials, give rise to higher costs of surface protection or replacing damaged segments, thus having serious economic impact. The depreciation of construction materials has a severe effect on the national economies. A number of reports focusing on the corrosion costs in several countries were written in the last century. They indicated that the total annual corrosion cost varies between 1.5% and 5.2% of the gross national product of the respective economies. In the last American study, the total direct cost of corrosion was estimated to be 3.1% of the 1998 US gross domestic product (GDP), the indirect cost of corrosion was estimated to be equal to the direct cost and the sum of both represents approximately 6% of GDP. In the industrially polluted regions, indirect losses may be considerably higher than the direct cost and give rise to significantly higher economic losses. Air pollution also has a considerable impact on the deterioration of stone and concrete buildings in polluted industrial areas. The degradation of slab blocks in the large housing estates built in the extremely polluted cities of Central and Eastern Europe has been noted over the past 40 years. The economic impact of the deterioration of construction timber is also serious and requires a considerable investment to maintain or replace parts of damaged timber. Annually, the global losses incurred by the decay of wood through biological processes have been estimated at US$ 10 billion.

Irreplaceable losses may result when air pollution affects historical sites, stone statuary and other works of art. This deterioration is related not only to physical damage but also to the aesthetic appeal of the material surface. Air pollution damage to artefacts has been known since the Middle Ages. Concerns about these effects on materials were raised as early as 1284, when a Royal Commission was appointed to study air pollution from fuel used for kilns in London. By the 17th century, many references were made to the degradation of materials and products in polluted atmosphere; however, it was only in the 20th century that attention began to be paid to the better understanding of the causes of deterioration and to the effective prevention and protection of culturally important artefacts and monuments against deterioration.

1 Chemical, physical and biological factors affecting the deterioration of materials

The degradation of materials is the result of different physical, chemical and biological effects. Deterioration also depends on the type of materials and products used and is influenced by specific conditions of processing and use. Physical degradation takes place due to mechanical attrition of the material surface, embrittlement, failure of the component by breaking due to fatigue stress or other irreversible changes of the shape; a specific example of physical degradation is the interaction of radioactive radiation with material in a nuclear power station. For example, sorption of the well-known pollutant sulphur dioxide on a stone surface induces physical changes such as water retention and change in porosity. The repeated freezing and thawing process may result in non-porous layer generation and consequently in blistering and splitting-off of the layer. Materials deteriorate due to chemical attack through exposure to different aggressive chemical compounds. The presence of anthropogenic pollutants in the environment can accelerate this deterioration. The interaction of physical and chemical factors can significantly increase the degradation of materials. The effect of condensation of moisture on the surface of materials and the absorption of acidic gases in generating aqueous film with subsequent formation of aggressive compounds during chemical reactions and the effect of the volume change due to chemical reactions with contaminants in concrete pores are examples.

It is assumed that damage to stone and concrete is predominantly associated with natural environmental factors and, to a lesser extent, with pollution. Timber degrades due to chemical and physical exposure and the effect of various types of biological agents including insects, bacteria and fungi. Corrosion of metals is affected by the nature of the substances present in the environment including moisture and oxygen and also by biological agents. In a dry atmosphere, the corrosion of metals is negligible at normal temperature; it progresses only in the presence of moisture on the metal surface, where the generated moisture layer provides a medium for water-soluble air pollutants and is a conducting medium for corrosion process reactions. Many metals form a protective corrosion layer that guards against corrosion, but higher concentrations of pollutants decrease this protective effect. The properties of the protective corrosion layer differ with the type of metal. Long-term corrosion resistance of some metals such as steel appears to depend on changes in the structure and composition of the protective corrosion layer.

Deterioration of building materials and corrosion of metals occur not only in the natural environment, e.g. in air, water and soil, but also in environments polluted by industrial, agricultural and municipal wastes in the form of gases, solutions and solids. This damage may be very unfavourable with respect to the service life of structures and their reliability in operation.

Materials also undergo degradation in the absence of external factors through the effects of the structure failure of the material and changes in the physical and chemical properties of the material. The characteristics and properties of the material are as equally important as the environmental factors in the process of deterioration. The principal characteristics of most material damage mechanisms are the texture of the material surface, the chemical properties of the surface, the specific surface of the exposed area and the medium in which the material is found. Especially important is the roughness of materials; rough surfaces permit easier mass transfer across the quasi-laminar air film close to the surface. The rate of delivery of gases to the surface is largely determined by the mutual chemical affinity of the material of the surface and the particular gas. Irregularities in the structure significantly influence level of weathering of the material surface. The corrosion of metals also depends on, besides other factors, the properties of surface electrolytes. The most important property of stones is porosity, in terms of the number, size and extent to which pores are connected. It can in turn determine, for example, the amount of salt solution that can be absorbed and the rate of its migration through the stone. In this manner, the material's sensitivity to deterioration will be enhanced. For instance, the presence of several interconnecting microspores that can carry moisture into the stone make it susceptible to frost and pollution attack. Other material properties such as permeability and absorbability may affect its resistance considerably. The permeability of a building material is conditioned by its porosity – the absorbability may decrease the material's resistance to frost and influence the weathering of materials such as stone, concrete, brick and plaster; however, it can also be utilised for protection, e.g. in the empty-cell process used for the treatment of timber. Generally, the properties and structure of a material may not only significantly affect its quality but also influence its extent of damage. The extent of the effects depends on the quality of the raw materials used to produce the product and the mode of processing. It is associated with the way in which the material is incorporated into the final product, the correct preservation and maintenance of the product, and the way it is designed and used.

The knowledge of the impact of natural environmental and anthropogenic factors together with the effects of non-external factors on construction and building materials is important for the better understanding of deterioration mechanisms and for the optimal selection of materials, and is also a basis for the design of materials and for the proper selection of prevention and protection measures.

Principal sources and literature for further reading

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