Materials, Degradation and its Control by Surface Engineering 2nd Ed

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Degradation and its Control by Surface Engineering

2nd Edition

Dedicated to

Mrs. Valli Boobal Batchelor

Mrs. Yong Foon Loh

&

Sri. Comal Neelakantan Margam and Srimathi Rajeswari Margam.

PREFACE

In this second edition, the authors have included information about recent developments, such as the degradation of medical implant materials and provided some photographic illustrations of corrosion and surface coating technologies. The purpose of the book remains the same, i.e. to provide a comprehensive view of subjects that are traditionally treated as separate, i.e. the various forms of materials degradation and protective coating technologies. While the established subjects of aqueous electrode theory for corrosion and mechanical causes for wear are given adequate coverage in this book, less familiar problems such as liquid metal corrosion are also covered. An applied approach to the problem of materials degradation is offered to help engineering students to appreciate the significance of materials degradation. The wide variety of materials degradation that is found in practice, e.g. damage to polymer and ceramics is discussed here to enable students to recognize potential materials degradation problems in any given situation.

In industry, materials degradation of components and equipment comes in the form of wear caused by materials processing and handling, corrosion from process chemicals and natural water and fracture from fatigue and shock loading. In some industries, thermal and radiation damage may also be significant. In the absence of premature technical or economic obsolescence, the lifetime of any mechanical device is determined by which is the faster process, wear, corrosion or fracture. Engineering students therefore need a comprehensive view of corrosion, wear, fracture and their preventive technologies. In most courses on corrosion, electrode theory has been emphasized at the expense of detailed discussion of painting and other important coatings. Most practicing engineers need to know more about polymeric coatings and their effective use than the fine details of electrode theory. This book on materials degradation (or corrosion, wear and fracture) and its control is intended to help students to achieve a balanced knowledge of materials degradation and how to control it. They should then be able to either solve basic problems in materials or interact effectively with specialists. The lack of awareness of materials degradation by many engineers belies its importance. It has been known for an engineer to replace a zinc sacrificial anode with a stainless steel anode because the zinc anode required frequent replacement. As a consequence of this action, a large mineral processing tank became severely corroded necessitating replacement.

The authors aim to provide the reader with a readable and generously illustrated guide as to what is materials degradation and how it can be controlled. The nature of corrosion, wear and fracture is first described. Methods of materials conservation are then discussed and followed by examples of actual applications. The book is intended for final year students of an undergraduate mechanical or materials engineering course. Postgraduate students and professional engineers may also find the book useful.

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CONTENTS

CHAPTER 1

Introduction

Accumulated human experience over several millennia in the adaptation of natural materials for useful purposes has caused the notion of materials degradation to be firmly embedded in language and culture. The familiarity of such words as 'fracture', 'wear out', 'burn up' or 'rot' are evidence of the close relationship between human civilization and materials degradation. An instinctive appreciation of surface engineering is present in almost all civilized peoples where the quality of a surface controls much of the value of the object enclosed within. Common examples of this association of value with effective surface engineering are the emphasis given to the polishing or to the painting of mechanical equipment. A single scratch on some new article often causes depreciation in its financial value that is much greater than the cost of mechanical damage caused by the scratch.

Whereas lay persons usually give priority to the subjective significance of materials degradation and surface engineering, it is the task of technologists to evaluate the true costs of materials degradation and balance this against the costs of surface engineering necessary to prevent such materials degradation.

1.1 Definition of materials degradation

Before proceeding into a subject, which depends on an enormous variety of information from many diverse sources, some pertinent questions would have to be asked: What is materials degradation? How does it affect an engineering system? What is the significance of materials degradation in terms of engineering performance?

From the moment that any material is released from the point of production, it is in theory subjected to some form of materials degradation although such degradation may not be readily observed or measured. The rapid rusting of freshly machined steel surfaces is a common example of immediate materials degradation. Such damage continues throughout the lifetime and materials degradation of any component be a limiting factor. No known service environment provides perfect immunity from materials degradation. Under atmospheric conditions, electrochemical corrosion is the most significant degradation process in economic terms. In outer space, although the absence of atmosphere precludes corrosion, radiation damage can be severe. Corrosion, radiation damage and many other mechanisms all have a shared feature of reducing the performance of engineering materials to cause premature failure of components and devices. A simple definition of materials degradation is that it is the consequence of a wide range of physical processes; it is almost universal in occurrence and is a major engineering problem.

Materials degradation imposes a cost penalty on all engineering systems. For instance, a mechanical structure has to be constructed with extra metal or concrete to allow for corrosion-induced loss of strength. If such corrosion did not occur, the extra metal could be dispensed with and the structure could carry more weight. The corrosion ensures that a more expensive structure is required for any given load. Wear between pistons and cylinders inside an internal combustion engine causes leakage of combustion gases from inside the cylinders and the engine becomes less efficient. Piston-cylinder wear causes a vehicle to consume more fuel per distance travelled than would otherwise be the case. The risk of sudden fracture of an aluminum structure necessitates frequent and expensive preventive repair of aircraft fuselage. Further examples of loss of performance are discussed below in this chapter.

Materials degradation can be defined in terms of loss of performance of an engineering system. Loss of performance can relate to many parameters, e.g. loss of reflectivity in optical equipment caused by fungal attack. A more common example might be the loss in mechanical strength of a structural component exposed to a corrosive medium. For any item of equipment, there is a critical minimum level of performance, e.g. whether a useful image is obtained from the optical system or whether the mechanical structure will collapse due to corrosion damage. For the engine with worn cylinders, wear can increase the clearance between piston ring and cylinder to such an extent that there is no compression of combustion gases. In this case the engine can be considered to have failed, as it will no longer be able to pull the car or truck up the hill. A mechanical degradation proceeds at a rate that varies with local conditions and failure occurs if the performance declines to below the critical level. Loss of efficiency occurs if performance declines but remains above the critical level during the service lifetime. Referring to the previous examples of the optical system and mechanical structure, loss of efficiency could involve a progressive distortion of the image for the optical system and load restrictions for the mechanical structure. This view of mechanical degradation is illustrated schematically in Figure 1.1

Some loss of performance is inevitable unless very expensive control measures are implemented, e.g. constructing a car from stainless steel instead of plain steel. The objective of surface engineering is to ensure that performance remains far above the critical level for the entire service lifetime of the system. The scientific study of degradation of engineering materials can be summarized as predicting the rate of decline of performance; this is the gradient on the graph shown in Figure 1.1. Engineering analysis of materials degradation is directed at finding the factors controlling this gradient and how to reduce it.

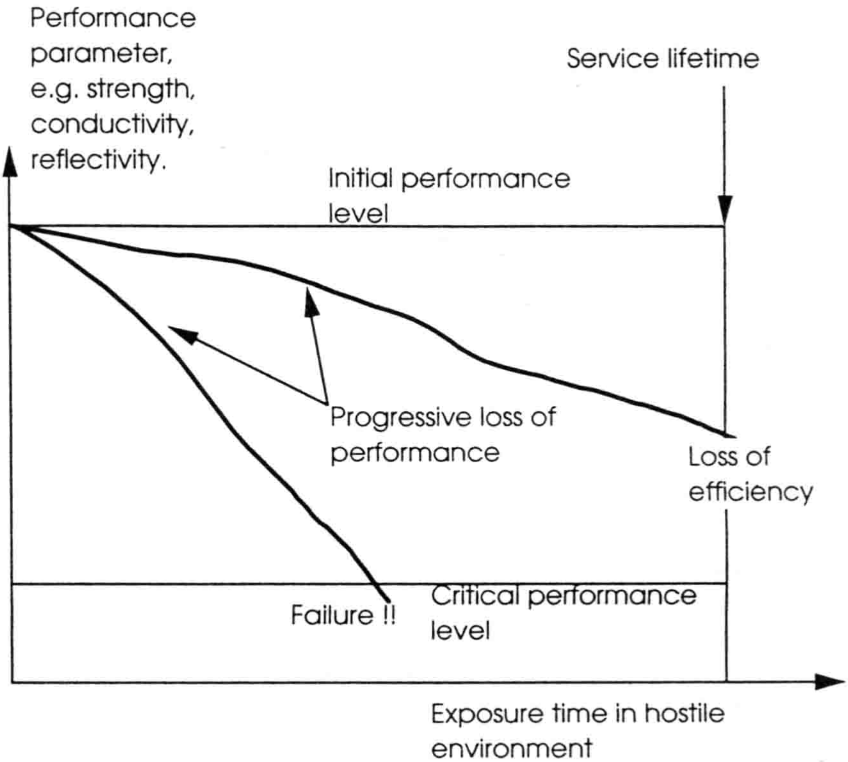

Figure 1.1. Graphical definition of materials degradation as loss of performance of an engineering system.

1.2 Definition and significance of surface engineering

Surface engineering is a comparatively recent term that refers to control of problems originating from the surface of engineering components. It is generally considered that the surface of a component is much more vulnerable to damage than the interior of the component and that surface originated damage will eventually destroy the component. Most types of materials degradation such as, wear, corrosion and fracture are usually located at the surface of a component. As a result of this concentration of damage processes at the surface of a component, surface engineering is essential to control these damage processes.

A time-honored solution to the problem of materials degradation is to try and shield the material from the hostile agent. For example,