

Materials Science
in Design
and Engineering

Materials Science in Design and Engineering

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VSSD

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First edition 2012

Published by VSSD

Leeghwaterstraat 42, 2628 CA Delft, The Netherlands

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internet: <http://www.vssd.nl/hlf>

URL about this book: <http://www.vssd.nl/hlf/m017.htm>

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Printed version ISBN 978-90-6562-301-0

Electronic version ISBN 978-90-6562-302-7

NUR 971

Key words: materials science

Preface

Human activities will always rely on the availability of materials. It can be expected that in view of the increasing complexity of products the range of materials will become larger and larger. This not only applies to the modern materials, but also to the classical materials still in use since the very start of human activities: ceramics and biomaterials. Moreover, modern products are assemblies of different materials. Materials science and materials selection therefore become more and more important and are integrated parts of product development. This process often starts with design sketches on the basis of a more or less explicit list of requirements and iteratively runs *via* materials selection, selection of the manufacturing process, manufacturing and market introduction until scrap processing. In a sustainable world this chain should be a cradle-to-cradle concept. In each part of the chain, materials and materials science play their role. So, for designers and engineers it is of great importance to have knowledge of materials.

This book is an introduction to the very broad range of materials that is relevant for modern designers and engineers when designing and manufacturing new products or improving existing ones. The book provides designers and engineers with basic knowledge and insight in order to better cope with problems and questions arising when designing and manufacturing specific products. One may wonder if in an era dominated by an abundance of free internet information, textbooks like this one still play a role. In our opinion the answer is affirmative. The designers' or engineers' knowledge and insights are essential in the search for suitable materials, as they form the framework in which new information can be judged.

In many cases, materials selection starts with the translation of product requirements into material properties. Hence, properties play a key role in materials selection. As a matter of fact, a designer is often more interested in certain material properties than in the material as such, since the material is only bearer of the required product properties. Then the following questions arise: what is a property and which properties are important? These questions are dealt with in Chapter 2. In the subsequent chapters the structure of materials and the material classes are discussed. The book ends with chapters devoted to the manufacturing processes and materials selection. The latter issue is highlighted from different points of view and illustrated with a practical example.

For the present (and first English) edition a new co-author, prof. dr. S.J. Picken, has strengthened the team. This new cooperation has led to innovations related to his personal expertise: functional polymers. Prof. em. dr. B.M. Korevaar made a useful contribution to the present text by reviewing

Chapters 2 to 5. Materials of biological origin have served mankind from the earliest days of human activities. They still play an important role in modern life (textiles, leather and wood). In principle, biological materials offer the possibility of an endless supply and as such they are fully compatible with the demands of sustainability. Therefore it was decided to devote a new Chapter (8) to this class of materials. The inspiring discussions with dr. J. van Dam (Wageningen University) are gratefully acknowledged, whereas the scientific director of the Botanical Garden of Delft University of Technology, drs. W.N.J. Ursem, critically reviewed this chapter. The Section about concrete in Chapter 9 was rewritten in close collaboration with dr. M. de Rooij and dr. A. Fraaij (both from the Faculty of Civil Engineering and Geosciences of Delft University of Technology). Chapter 10 about processing and manufacturing was completely rewritten after fruitful discussions with ir. C.A. van Luttervelt (retired from the Faculty of Mechanical, Maritime and Materials Engineering of Delft University of Technology) and dr. A. Hoogstrate (TNO, Eindhoven, The Netherlands). Finally, the Appendix on Standardization and nomenclature was updated in collaboration with drs. H. van der Hoek (Dutch Normalization Institute NEN) and dr. H. de Vries (Erasmus University of Rotterdam, The Netherlands).

We hope that designers and engineers will benefit from the new features of this book. We are indebted to the publisher, mr. J. Schievink, for his involvement and enthusiasm.

Delft, Spring 2012

Pieter van Mourik, Jaap van Dam, Stephen Picken

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Chapter 1

Introduction

Matter transforms into a material when it is applied in a lasting solid product. Hence, materials selection is an integral part of the whole designing process. For all materials, there is a strong relation between the composition, the method of production and the final resulting properties of the product. This will be discussed, in different contexts and on different occasions, throughout the course of this textbook. This discussion does not start from scratch as everybody has, at least some, knowledge of common materials. In the field of industrial design and engineering, the following classes of materials are important:

1. Metals
2. Biomaterials
3. Synthetic polymers
4. Ceramics

Metals and metal alloys can be lustrous, are often ductile and when touched, feel cold. Everybody knows iron and steel. The applications of iron and steel are so dominant that metals are divided into ferrous and non-ferrous metals. On a mass basis, the annual worldwide production of iron and steel is fifty times larger than that of the second-ranked metal: aluminium and its alloys. This dominant position is especially related to the low cost of mining and refining, and the enormous variation in properties of iron and steel alloys.

Biomaterials are all materials from natural origin, like wood, leather, wool, and the fibres of vegetable origin (hemp, flax, cotton and jute). Natural rubber occupies a position in-between: its origin is biological, but as far as structure and processing are concerned it resembles a synthetic polymer.

Synthetic polymers are generally derived from mineral oil. They are of paramount importance for the designer: from use in simple domestic appliances and low-cost packaging materials to advanced fibres that are stronger than steel, and for insulating materials and protective coatings that can withstand years of exposure to harsh conditions.

Ceramics form the oldest class of materials used in human civilization. Ceramic pots were already in use 15,000 years ago and glass dates back to about 50 centuries BC. For the designer and the engineer these materials are important because of their wide range of properties: good conductors or good insulators for heat and electric currents, high heat resistance, often in combination with sustainability in a wide variety of environments. Often, the

ceramic material is formed during the manufacturing process of a certain product. Here again, the link between composition, the manufacturing process and the resulting properties of the product is crucial.

Generally, the designer is asked to design a whole product, which is mostly an assembly of different parts, each in turn consisting of a variety of materials. The whole product has to meet the demands specified by the list of requirements. Performing a rational materials selection in relation to the total design will thus be complicated. In a successful industrial design, all the aspects: engineering, materials selection, cost and sustainable manufacturing, are balanced. To obtain this balance, the importance of industrial design for mass production has to be acknowledged in an early stage of product development. For example, a long time ago the Dutch United Glassworks at Leerdam started producing a series of glasses designed by Copier, which combines artistic functionality with the demands of mass production. This resulted in a well-known *interbellum* design, the so-called tulip glass, which is still in production at the beginning of the 21st century. However, here the materials selection is traditional: as wine is to be drunk from a glass, this product is entirely made of glass – not out of polymers or metals. Alternatively, the use of polymers for packaging of beverages has become widespread in recent years and this is based on a rational rather than a traditional choice.

For a rational materials selection, and hence for a good design, knowledge of materials and their properties is essential. Also, from a practical point of view, an overall insight in costing (cost effectiveness), availability, processing and environmental impact of materials use is necessary. In view of the above, the Faculty of Industrial Design of Delft University of Technology listed the following requirements for Materials Science Education (Marinissen *et al.* (1992)):

1. Knowledge of materials, especially metals and polymers; their physical and chemical properties in relation to function, their manufacturing, and the environmental impact of goods obtained by mass or series production.
2. Knowledge of the availability of materials: forms, types and quantities.
3. Ability to understand and evaluate materials data from handbooks.
4. Understanding the relevance of materials for industrial design and for mass and series production.
5. Knowledge and understanding of the application of metals and polymers in relation to requirements on function, manufacturing and cost effectiveness.
6. Knowledge and understanding of the process of materials selection.
7. Insight in the trends and modern developments in materials science.

Chapter 2

Properties and testing

2.1 Introduction

A tree is known by its fruit. Similarly, products are designed to perform certain desired functions. The performance of the product is related to the underlying material properties, the production process and, of course, the design. The 'fruit' of a material are its properties. A material property is any aspect of the material that links a material with functional or processing requirements. The following may serve as an example. Suppose, the product is a bar used to convey a certain tensile force. Then, the ultimate force per unit of cross-section that the bar can withstand is a relevant property. This property is called strength. This link between material properties and requirements of the product may seem obvious, and indeed often is. However, there is no general theory to connect properties and performance. In each design, the designer and the engineer have to examine what essential functions the product has to fulfil and which material properties are then required.

Many material properties can be measured and expressed quantitatively. However, some can only be observed by one of the senses and described qualitatively, e.g. colour, touch and smell. As said previously, some properties of substances and materials are related to functional requirements, others are related to their processing. Sometimes such properties are called the 'abilities'. Examples are the weldability, the castability and the machinability. This chapter does not deal with these abilities. Some of the factors concerning the processing of materials will be discussed later in this book (see Chapter 10).

As stated before, the designer and the engineer should be focused on that combination of properties that copes with the essential functional product requirements. Hence, to a large extent design and engineering can be traced back to the link between material properties and functional requirements. Table 2.1 gathers the properties frequently encountered in design and engineering (see Ashby (2005)).

Chapter 3

Structure of materials

3.1 Introduction

Materials can be studied from a phenomenological point of view: which materials are found in modern society, which resources are used to make them and which features are important for their applications in real products? In many cases, the mechanical properties (how strong is a material?) are decisive. However, other properties may play a role, for instance surface and corrosion characteristics can determine the success or failure of a product. The strength of steel is usually higher than that of aluminium alloys, but steel often shows severe corrosion compared to aluminium alloys. Or, as another example, the density of polymers is lower than that of most metals, which can be an important factor in designing lightweight constructions.

This chapter will provide further insight into the structure of materials. With the word structure we mean the way the atoms or molecules are assembled to form the substances commonly known as materials. This insight may help to explain the relation between properties and the processing route by which products are manufactured. It is important to understand that a material is a substance processed into a real final product or a semi-finished product. Material properties and characteristics should be considered together with the intended product and its manufacturing route. Product (design), Material and Manufacturing are closely related *via* the **PMM** triangle (see Figure 3.1).

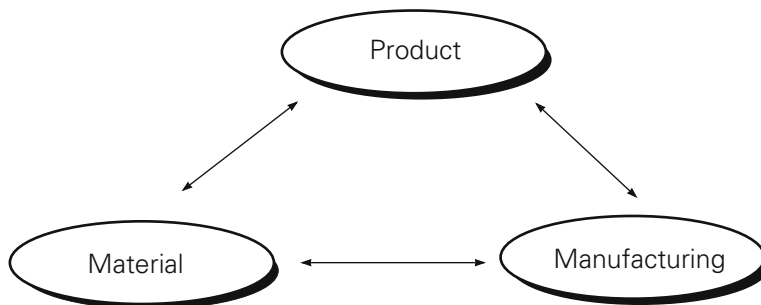


Figure 3.1. The triangle Product, Material and Manufacturing.