ETHZ LATSIS SYMPOSIUM 1988

HIGH-TECH CERAMICS

VIEWPOINTS AND PERSPECTIVES

edited by

GERNOT KOSTORZ

High-tech Ceramics

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Preface

Since 1986 the International Latsis Foundation, Geneva, sponsors an annual symposium to be held each fall at the Swiss Federal Institute of Technology Zurich (Eidgenössoische Technische Hochschule Zürich, ETHZ). In a series of invited lectures, a selected area of scientific research is presented and discussed. For the 1988 symposium the subject "High-tech Ceramics" was chosen because of the extraordinary attention it currently receives, not only by scientists but also by the general public. Furthermore, the ETHZ had just filled a chair in Engineering Ceramics to strengthen the faculty charged with teaching modern materials science to students of various engineering branches, and to increase the research efforts in ceramics.

At the two-day symposium attended by more than 120 participants from Switzerland and some neighbouring countries, the many fascinating and challenging aspects of high-tech ceramics were presented by some of the leading experts in the field. The present volume almost fully reflects the contents of the symposium. In eleven chapters, a broad range of topics including historical and economical aspects, problems of production and processing, improvement and control of properties and various fields of application, are covered. In such an immense and rapidly changing discipline, it is impossible to achieve encyclopaedic completeness in a single book at any given time. The authors succeeded, however, by emphasizing the basic ideas and concepts in presenting their "viewpoints and perspectives", not only to report on the "state of the art - fall 1988" but also to indicate some of the most important and challenging research goals for the years to come.

The editor is grateful to the ETHZ and the International Latsis Foundation, for making the symposium and the publication of this book possible, to the authors for accepting to come to Zurich and for their willingness to contribute to this volume, to his colleagues L. Gauckler and B. Schönfeld for their help

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Gernot Kostorz

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INTRODUCTION

The topic chosen reflects an attempt to illustrate the interplay between three entities – man, materials and technology – as a harmonious triad in which harmonies do not always prevail but rather dissonances often occur. However, harmony must drown discord: ultimately it is only the positive developments, harmonizing with man and his environment, that can count as progress. But progress is only counted as such if it is for, not against, society.

The role of new materials in setting the pace of technology is recognized today even more than in the past. Materials research is in the forefront of technologies directed towards satisfying society's needs: reducing energy consumption, improving productivity, cutting manufacturing costs and providing a safer environment.

HISTORICAL DEVELOPMENT

It can be said that 'The history of materials is the history of man'. Of course, the reverse can be stated: 'The history of man is the history of materials'. It is said that 'New materials are a prerequisite for new technologies'. Again the reverse is true. Furthermore, it is true that technology influences man and vice versa. From this viewpoint the question of pre-eminence among the three partners, man, materials, and technology, is an intellectual game;

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a controversy of the chicken and the egg type.

The basis of progress is an unalterable, interconnected three-way relationship as simplified and shown schematically in Fig. 1. This shows the evolution of mankind, his materials and technology (Petzow, 1987).

The earth's population has been continuously multiplying since early man first appeared about two million years BC. The population grew by a factor of 100 in about 500 000 years, from 100 000 to 10 million, and this was reached about 4000 BC. Despite natural catastrophes, plagues and decimating wars, by 1820 the population had grown again by a factor of 100 to 1 billion people, this time in less than 6000 years. Today there are about 5 billion people and the doubling rate is only about 33 years. Accordingly, it is possible that in not quite 200 years time there will already be 100 billion (10^9) people on Earth.

The conditions for the flourishing of the species *Homo sapiens* have improved over time such that man has made the Earth his subject. Through his materials and their use in technical devices and processes, man has made favorable living conditions which he modifies continually and to which he in turn continuously adapts.

Materials are one of our oldest cultural assets. Historical eras are named

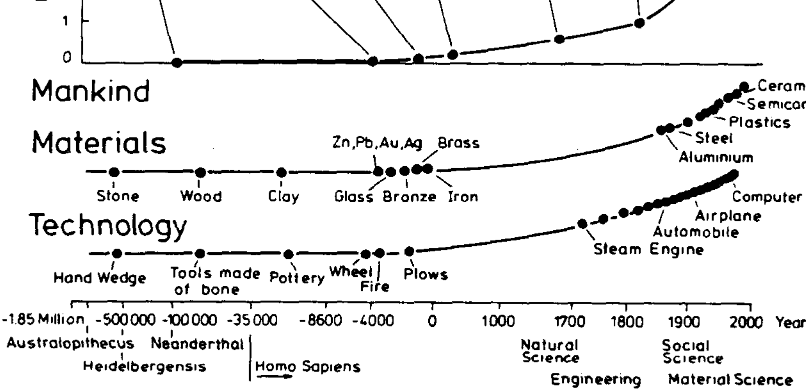

Fig. 1. The evolution of man, materials and technology.

after the materials that dominated at that time: the Stone Age, the Copper and Bronze Age and the Iron Age possibly the end of which we are living through at this time. New materials such as polymers, semiconductors and superconductors, advanced alloys and ceramics, the amorphous metals, and increasingly the composite materials, are appearing on the scene and providing an impetus for technological developments, often with far-reaching consequences.

One can expect the discovery of more materials in the future. Every chemical compound and every alloy is a material that could potentially revolutionize our lives to the extent that the first stone tools revolutionized the life of early man. Thus the name for the new era should be chosen carefully and perhaps is best left to the future; a position too close could distort the perspective.

Materials are turned into tools, devices, machines, houses and streets. Revolutionary technological developments have, as in the case of materials, followed in quick succession in modern times. Thus important developments such as printing, radar, radio, telephone, satellites, rockets etc., that enhance man's favorable living conditions, are not shown in Fig. 1 for reasons of clarity. In Fig. 1, the rise of the evolutionary curves for materials and technology includes the number of technological events.

Obviously, it is not only materials and technology that have contributed to today's high standard of living, but also discoveries in medicine, agriculture, chemistry and pharmacy. All these areas have contributed to, as well as profited from, technological progress and thus play a significant role in the interactions of the disciplines.

It has taken a long time for developments to reach their current rate. The question arises whether the steeply increasing population curve and the increasing pace of technological innovations, some of which have a great influence on society, really represent true progress. Indeed, does not a growing demand for materials imply the 'looting' of our planet of non-renewable resources? Will there come a day when we are no longer in control of our own technology and the human spirit no longer matches progress? These are questions of our times, the answers to which must come from the natural and engineering sciences, especially from their interdisciplinary branch materials science, as well as the social sciences.

The relation between man and technology holds a prominent, often emotionally charged position, within the inter-relationship of man, materials and technology. Ever since the Industrial Revolution, or even centuries before that, there have been intense controversies, unfortunately all too often linked with violence. In this context materials were entirely ignored, even though they have frequently triggered off technological progress in the past and present, and will continue to do so in the future. Materials are mostly a means to an end and were thus considered inferior. In fact materials are taken for granted: they are self-evident to most people.

It would be appropriate to discuss the train of thought Georgius Agricola (1556) expressed in the first book of his twelve-volume work entitled *De Re Metallica Libri XII*. Figure 2 shows a picture of Georgius Agricola.

He wrote: 'If mankind ceased to use metals, all the possibilities to guard and preserve health, as well as to lead a life corresponding to our cultural values would be taken away. For, if the metals would not exist, people would lead the most detestable and most miserable life among wild animals; people would return to eating acorns and berries, they would pull out roots or herbs and eat them, they would dig caves with their fingernails and lay there at night and would roam the woods and fields during the day just as it is custom with wild animals. Since such conduct is entirely unworthy to human reason, is there anyone so foolish and stubborn not to admit that metals are necessary for sustenance and clothing, and that they serve to protect the human life?'

Even after more than 400 years this statement is relevant. Everything said about metals can be generalized to all materials. Agricola addressed the social aspects of materials: problems of public health and culture as well as general questions of standards of living. Agricola made the connection

Fig. 2. Georgius Agricola.

between materials technology and society in the context of his time. As the mayor of Chemnitz, earning a living as a town physician, he was the leading expert on the contemporary mining industry and metallurgy.

MATERIALS SCIENCE

Before and after Agricola's time, up until the present century, new materials were found fortuitously during tests or technological processes. The manufacture of these materials depended on the abilities of craftsmen and traditional methods. In these times, empirical and practical knowledge were far ahead of basic scientific understanding.

The scientific study of materials only took place at the beginning of this century, with the new understanding of the atomic structures of matter. An intensive study of engineering materials started (Fig. 3), especially of metallic, nonmetallic, inorganic and organic materials. Initially these studies were strictly separated according to these classes of materials; 40–50 years ago, however, the overlap between these classes of materials became apparent. A new descendant grew from this interdisciplinary ground of science and engineering: materials science.

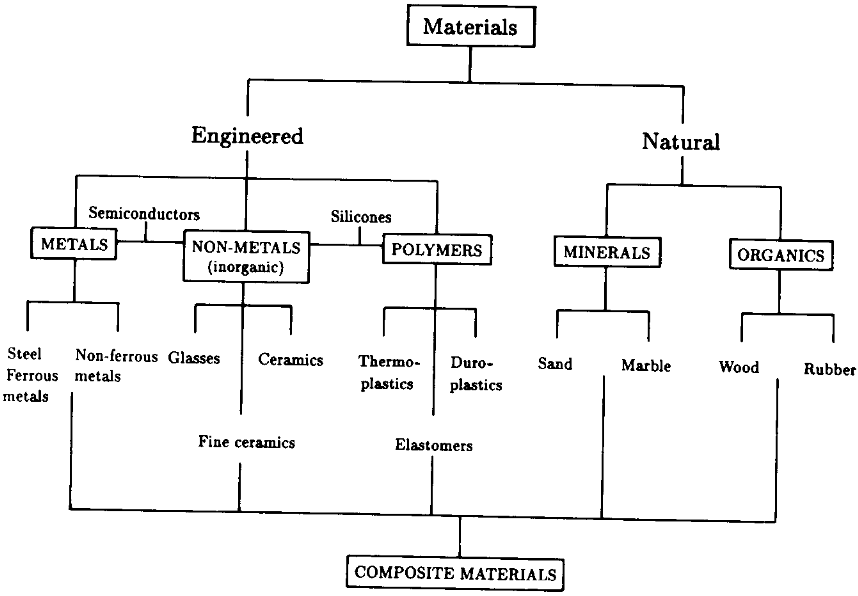

Fig. 3. Classification of materials.

Materials science, which explores the structures, properties, preparation and processing of materials, is supported in many cases by models and concepts of physics, chemistry and crystallography. The considerable initial success of materials science was its explanation of empirical findings accumulated in large numbers and the resultant improvements and extensions. The great significance of materials science in technological progress is that it can lead to a basic understanding of internal structure, so that new materials can be invented and tailor-made for specific applications.

THE MICROSTRUCTURE

The internal structure of materials is determined by the constituent atoms and their three-dimensional arrangement in a defined state of order. Many

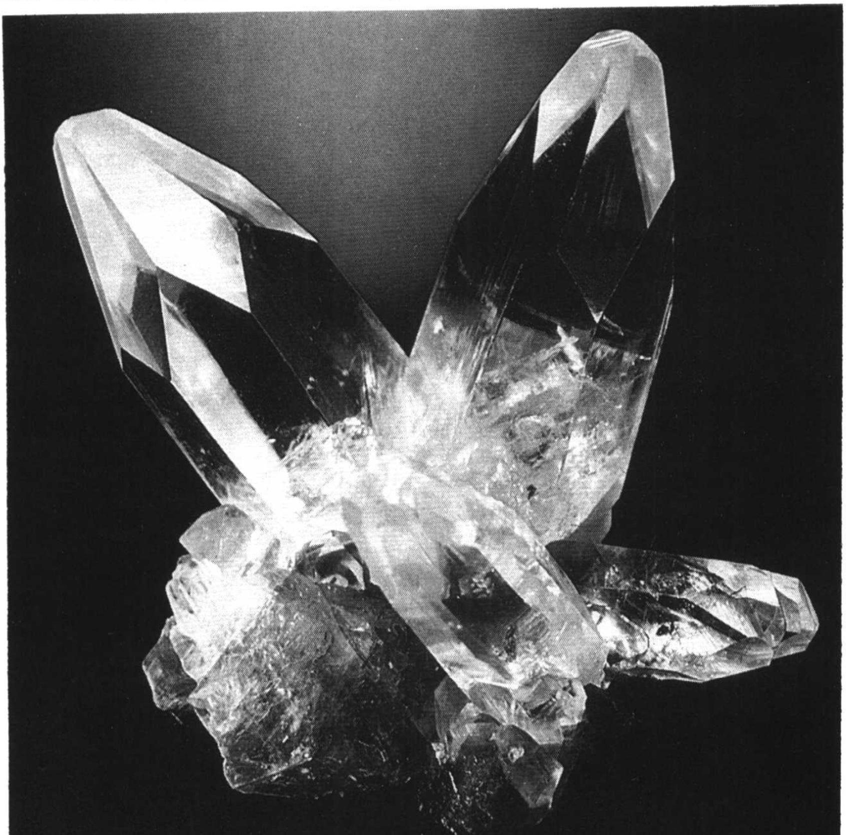

Fig. 4. Calcite crystals.

inorganic materials are crystalline and consist of an irregular multiplicity of closely packed crystals. The regular structure of larger regions is always disturbed. But also the crystallites *per se* show considerable divergence from ideal symmetry and order; this is in fact the norm. Even the most beautiful crystals, such as the calcite shown in Fig. 4, which symbolize clarity, beauty and perfection, exhibit lattice defects. In just one cubic centimeter of such a beautiful crystal there are many million defects.

The ideal crystal of perfect order, in which every atom is located on its exact site, is a dream. The symmetry plays the role of a blueprint for nature, but the deviations therefrom, the lattice defects, characterize the reality of materials. The type, size, shape and arrangement of lattice defects in a material make up what is called the microstructure. The microstructure significantly influences the properties of materials. Thus great attention is paid to the microstructure in materials science. The study of microstructure and its interaction with properties is a domain of materials science which distinguishes it from other disciplines such as physics and chemistry.

Figure 5 conveys more effectively than words an impression of the character of microstructures. It shows a sample of SiC sintered at 2220°C, a very promising high-temperature material. The secondary grain growth was investigated by optical microscopy. We can recognize, for example, the oriented growth of crystallites. The mean length of crystallites is about 200 μm. Observing shape, size, type and distribution of crystals, the materials

Fig. 5. Optical transmission micrograph of silicon carbide specimen doped with boron and carbon.