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Handbook of Ceramics Grinding and Polishing

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Chapter 1

Properties of Ceramics

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1.1 INTRODUCTION

Although ceramic materials for technical application have been known for more than two hundred years, especially-designed synthetic ceramics, unlike traditional materials in composition, microstructure, and properties, have been developed since approximately 1970. Whereas silicate ceramics and refractory materials are basically derived from natural minerals and manufactured by comparatively simple processing steps, this new class of materials, the "advanced", "high-tech," or in Japanese terms "fine" ceramics require an entirely different fabrication route starting from chemically well-defined, fine, highly-purified, and artificial raw materials. These materials have been created for distinct applications in which other conventional materials like metals or polymers have failed. Due to the large variety of chemical, electrical, biological, and mechanical properties that ceramics presently exhibit, there is almost no social and industrial application without ceramics (Table 1.1). In the electronic and manufacturing industries, as well as in technologies that require materials sustaining extremely high temperatures and corrosive environments, high-tech ceramics play the role of key materials; novel technologies, processes, and machines are finally made possible only by means of especially tailored ceramics.

Surprisingly, this development was initiated by metal scientists or -more precisely - by powder metallurgists rather than by traditional ceramists. The reason for this is that the manufacturing route used for the production of metallic parts by powder molding and compaction followed by subsequent consolidation by a heat treatment, i.e. sintering, was investigated fundamentally since the turn of the century for steel, refractory metals, and since 1920, for hard metals which could not be casted or molded otherwise. With regard to natural multicomponent raw materials and comparatively simple chemical systems, the basic understanding of these originally "ceramic" processing procedures was much easier than in the case of traditional ceramics. Thus, the break through in the science of sintering was achieved in 1970 to 1980 yielding knowledge on the reproducible production of high-performance powder and metallurgically-prepared

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TABLE 1.1 Classes of Ceramics and Fields of Application

Materials Group	Properly	Application
	Compressive Strength	Bricks
Traditional	Density + Strength	Ceramic Hollow Ware
Ceramics	Density + Wear Resistance	Structural Clay Products
	Heat and Corrosion Resistance	Refractories
Structural	Hardness	Grinding Grits and Disks
Ceramics	Strength + Toughness	Engineering Ceramics
	Biocompatibility, Bioactivity	Bioceramics
	Nuclear Properties	Nuclear Ceramics
	Corrosion Resistance	Chemoceramics
	Catalytic Properties	
Functional	Electric Resistivity	Electroceramics
Ceramics	Dielectric Properties	
	Magnetic Susceptibility	Magnetoceramics
	Diaphaneity, Anisotropic	Optoceramics
	Optical Properties	

parts. Being easily transferred to ceramics of "simple" composition, the foundation for the development of tailored microstructures with as-desired properties was created. The simultaneous development of high-toughness zirconia and highly wear-resistant silicon nitride ceramics indicated a promising way to overcome the most important disadvantage of traditional ceramics: their brittleness. The capability of the entire control of residual porosity together with the so-called transformation toughening by zirconia as well as the science of phase relationships in multicomponent systems that yielded the opportunity to synthesize silicon nitride -based high-temperature materials initiated a world wide boom in ceramic research and development. Figure 1.1 shows one of the many predictions for future markets and turn-over opportunities related to the various branches of application. To further the collaboration between industry and research institutes, large investments in ceramic development and research programs by industrial countries have been implemented. As a consquence of these efforts, a novel understand of matter was achieved in the field of fracture mechanics yielding insights in toughening phenomena and reinorcing strategies for static and dynamic load. Models for the prediction of the long-term behavior of complex parts have been derived, and the term "fatigue" was described in respect to brittle fracture originating from microstructural defects which have been quantified by means of statistics. High-resolution electron transmission microscopy gave information about the internal structure of grain boundaries

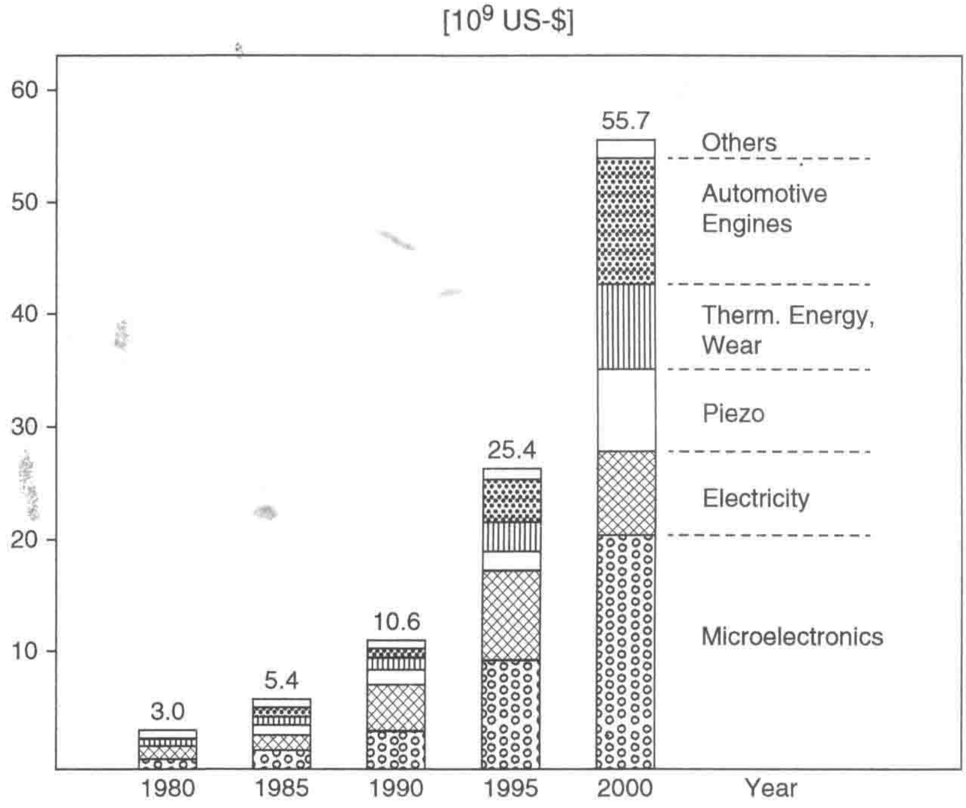

FIGURE 1.1 Market forecast for high-performance ceramics. *(Courtesy, Hoechst 1988)*

and thus enhanced the development of creep resistant high-temperature silicon nitride based monoliths. Micro- and nanoscaled molding techniques brought about new possibilities to manufacture electrically and electronically active ceramics: ubiquitous components of modern electronic devices. Additionally, the invention of the ceramic high-temperature superconductors contributed to the tremendous increase in materials research.

Not in all cases, however, have ceramics been able to meet the sometimes extraordinarily high demands of the applying industry. The progress in understanding the particular influence of the manufacturing procedures to the microstructure and mechanical properties was slower than expected. The market did not develop as projected due to the lack of reliability of the ceramic parts and due to problems in its acceptance by construction engineers. Furthermore, the request for high quality products led to high-cost raw materials and products which had some time to compete with metals or even with polymers. Thus, some strategic investments by big companies came too early and turned out risky, especially in Europe, but the competition with Japan and the United States, as the two most important providers of advanced ceramics, was severe. Imports from Japan where part development and production was strongly supported and funded by the government, were sometimes preferred to imports from the European providers.