Inorganic Cementitious Materials — A Neglected Area of Materials Research

J. Francis Young

Familiarity breeds contempt. This old saw applies nowhere better in the materials world than to concrete and other cement-based materials. Concrete is ubiquitous in everyday life. We walk on it, drive on it, and live and work in structures made of it. It forms much of the material fabric of the modern world. And yet it has not captured the imagination of the scientists and engineers engaged in materials research, or the attention of those involved in materials education. This despite the fact that the volume used annually is greater than for any other material.

History

Cementitious materials have a long history—their antiquity rivals that of metals and ceramics. The oldest dated concrete is estimated at 7000 B.C., and many ancient monuments were constructed using masonry with cementitious mortars. Recently it has been suggested that the pyramids were made from blocks of limestone concrete cast in place. While this hypothesis may well be disproved it was certainly within the technical capabilities of the Egyptians to use concrete. The Greeks and the Romans made widespread use of cementitious materials. The Romans in particular extended and improved the technology, and it could be said that the might of the Roman empire depended as much on its concrete infrastructure as it did on the force of arms. The Pantheon in Rome, built in 100 A.D. and the Pont du Gard at Nimes in the south of France are excellent examples of Roman concrete technology. How many of our modern structures will be standing 2,000 years from now?

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Perhaps herein lies the key to neglect. The examples given above are utilitarian structures. We admire them for their technology and engineering, but give little thought to the materials of which they are made. In addition, their constituents are made of common materials abundantly available from the earth. In contrast metals and ceramics used technology to create objects of beauty and hence of value. The materials became valuable in their own right because of this fusion of art and technology, and the scarcity of their occurrence.

Development of the Science of Cements

The scientific study of inorganic cements and their reactions began to emerge in the late 19th century along with other materials science, and some distinguished scientists have conducted research in the field. Henri Le Chatelier studied the chemistry and hydration of Portland cement for his doctoral thesis. The National Bureau of Standards had an active program in the early decades of the 20th century with an emphasis on phase equilibria, and much of our knowledge of calcium silicate and aluminate systems stems from this work. In the 1930s Prof. Brunel (London, England) applied the new technique of x-ray diffraction analysis to the structures of cementitious compounds, and this was extended in the 1950s and 1960s by Prof. Guinier (Paris, France). Electron microscopy was first used in the 1950s, while Dr. Brunauer (of BET fame) spent much of his professional career studying the surface chemistry and pore structures of cementitious materials.

It is fair to say that up to the 1950s cement science was on a comparable footing to metals and ceramics in terms of the knowledge that was being generated. But since then progress has lagged behind. Why is this? The answers are probably varied and it is not the purpose of this article to explore this question in depth. Suffice it to say that the major factors range from the chemical and physical complexity of the Portland cement system, which has made it difficult to develop elegant theoretical models (such as dislocation theory which revolutionized metallic science), to the lack of large numbers of scientists working in the field, due, in part, to its neglect in university curricula; and to the shift of research emphasis to civil engineering applications with a reduction in funding opportunities for fundamental research.

Science Opportunities

Materials science may well have been the loser in this drift into obscurity because cementitious materials have many features whose study could have applications to other materials. Cement-based materials can be considered as ceramics whose microstructures are developed by chemical reactions taking place at or near ambient temperatures. This makes it much easier to create desired composite structures using a variety of different types of fillers and fibers without the concerns of thermal stability and compatibility. However, as presently constituted, most of these materials are limited by high intrinsic porosity. The presence of a continuous pore system extending from the millimeter to the nanometer range is a unique feature of these materials. Characterizing and modeling this has been a formidable challenge that is only slowly being met. Modeling of diffusion and moisture migration phenomena derive from these studies. The chemical complexity of many cementitious systems combined with a tendency to form poorly crystallized reaction products has created further challenges, but has provided knowledge that could be relevant to sol-gel processing. Studies of the fracture of cementitious composites could be relevant to ceramic composites, where similar concerns of microstructural influence on fracture properties exist.

New Directions

It is to the credit of the Materials Research Society that it provided an opportunity for this small and unfashionable branch of the discipline to discuss in depth various aspects of the materials science of cement-based materials. MRS has thus played its part in helping to reverse the "low-tech" image that has dogged cementitious materials for so long. The 1984 symposium devoted to recent developments in attaining (comparatively) very high strengths in cementitious materials highlighted some innovative approaches to processing and microstructural control. This attracted the attention of program managers in the National Science Foundation (NSF) and the Air Force Office of Scientific Research (AFOSR), and contributed to the creation of a Materials Research Group on "chemically bonded ceramics" at Pennsylvania State University and the formation by the Air Force of a Center of Excellence for Cement Composite Materials at the University of Illinois. These two groups have been looking beyond the confines of civil engineering and exploring the potential of using cements to create new materials with properties comparable to other ceramic materials. These university programs have been developing the science base for a small group of industries that have been using cements for novel applications.

Cement-based materials with mechanical properties comparable to aluminum, mild steel, or fiber-reinforced plastics are now possible. Along with the development of improved materials for repair and rehabilitation of the nation's infrastructure, the new cement-based materials may well become a material of choice for many manufactured articles where low cost and high volume are important. Opportunities also exist for developing such specialized critical applications as blast-resistant structures, encapsulation of hazardous wastes, abrasion-resistant components, EMP shielding, etc.

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The recent establishment by NSF of a Science and Technology Center for Advanced Cement-Based Materials further consolidates the renaissance that appears to be occurring in cements research. Materials science and engineering has become an integral part of the new initiatives, taking its place alongside chemistry and physics. We are moving toward the recognition that cements represent a new class of materials that have unique and challenging properties. Their future may now be limited only by our imagination.

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