Concrete Durability

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The next century offers great opportunities for extending the life of the transportation infrastructure. An important focus of our vision of the future of concrete should be on the longevity of pavements and structures. The life of bridges, pavements, and supporting concrete structures should at least double in the next century. This life extension will occur through the improved quality control of materials, methods, and design and construction practices. Technical innovations in the production, transport, placement, finishing, and curing of concrete will play a role in reducing the variation of properties from one batch of concrete to another. The emphasis in the early part of the century will be on long-term performance standards, materials, optimization techniques, the science of chemical admixtures, and advances in understanding of aggregate-paste transition zones. The latter part of the century could offer affordable defect-free concrete with the durability to stand the test of time in any predictable environment.

The past century has seen the concrete industry advance from David Saylor's continuous vertical kilns and ungraded aggregates to an industry strongly supported by science and engineering of an increasing degree of sophistication. Involved in today's industry are chemical, mechanical, civil, and environmental engineers; geologists; chemists; physicists; miners; truckers; skilled craftsmen; and investment bankers. Portland cement concrete is widely available throughout the world, but the technology and skill required to proportion, mix, place, and cure it for long-term durability has not yet spread as widely as is necessary. This is the priority for the next century. The knowledge exists to select materials, proportion them appropriately, mix them thoroughly, transport and place them without segregation, and cure them to minimize cracking and optimize long-term strength development and durability. Implementing this knowledge is a major challenge, but one that will eventually result in a more permanent, low-maintenance infrastructure. As a consequence, it will be possible to spend valuable resources on improving the U.S. transportation system, instead of on replacing or maintaining a deteriorating system.

The best means of maximizing the probability that concrete will be durable is to produce concrete that will provide the desired service for the desired service life in the environment in which it will be placed and used. Every concrete mixture should be proportioned in accordance with exposure conditions, construction considerations, and structural criteria. Exposure to freezing and thawing, sulfates, deicing chemicals, acids, varying moisture conditions, and abrasive loadings should all be considered when selecting materials and proportions. In addition, available materials must be selected to prevent excessive expansion due to alkali-silica reaction (ASR), alkali-carbonate rock reaction, and thermal gradients. The fundamental factor in creating durable concrete is the use of pozzolans and ground granulated blast-furnace slag (GGBFS) and chemical admixtures in combination with portland cement, and the proper selection of aggregate (proportion, hardness, grading, shape, size, and phase composition). Nearly everywhere in the United States, locally available materials can be combined to produce durable concrete, yet the required knowledge and skills are not as widely available as necessary, either in the United States or worldwide.

Materials selection will play a large part in the improved concrete of the new century. The obsolete practice of specifying both cement content and water-cementitious materials ratio (w/cm) will be eliminated from concrete specifications. The choice of w/cm, chemical admixtures, and cementitious materials (portland cement and fly ash, silica fume, GGBFS, or natural pozzolans) will be based on exposure, strength requirements, and the need to reduce ASR or thermal gradients. The judicious selection and use of chemical admixtures will continue to enhance the durability of concrete. Air-entraining admixtures will provide resistance to freezing and thawing, and high-range water-reducing admixtures will lower w/cm. All of these changes will reduce the probability of shrinkage cracking and reduce the permeability of concrete. These benefits will in turn protect the concrete from aggressive chemical elements, reduce the rate of carbonation, improve corrosion resistance, and extend the life of transportation infrastructure. Chemical admixtures that inhibit corrosion, reduce the formation of ASR products, inhibit water penetration, and reduce shrinkage will provide important benefits as well.

Improvements in the control of concrete production in the coming century will also enhance the durability of concrete. Advances in the measurement of rheological properties, shear mixing technology, aggregate handling for greater uniformity, and cementitious materials blending will be key to improved concrete production. Each of these advances will enhance the concrete before it leaves the production facility by reducing its variability in the field.

Automation and feedback control technology may substantially improve the paving industry. Using nondestructive evaluation techniques with real-time tomography, contractors will be able to determine the adequacy of the consolidation, thickness, and density of pavement at the time of placement, when defects can be corrected. New developments in curing of concrete are on the horizon as well. In the next century, mechanization of the placement, maintenance, and removal of curing mats and covers will advance as performance-based specifications quantify curing for acceptance and payment. In addition, effective sealants and compounds that prevent the loss of water and promote moist curing conditions will be in high demand. Self-curing concrete should become available in the not-too-distant future.

The feedback of information to the maintenance divisions of highway departments is another technological benefit that will come to play an important part in the longevity of the highway system. Advances in the use of sensor technology already provide feedback on the temperature of pavements so the need for deicing measures can be determined. This capability greatly reduces the total amount of deicing chemicals—especially chlorides—used on the nation’s highways and bridges. The same sensor technology can provide feedback on the health of concrete, permitting analysis of pore water for depth of penetration of chlorides, carbonation depth, and presence of ASR or cracking from a structural overload. The piezoelectric and solar technologies being developed today will make it possible to provide bridges with affordable cathodic protection systems in the next century, further improving the durability of concrete bridges and substructures.

Performance-based specifications may drive many of the durability improvements in the concrete infrastructure. The value of the concrete will be defined in terms of maturity, permeability, air-void structure quantification, sulfate resistance, chloride penetration, strength, and in situ performance.

The knowledge needed to select materials, proportions, and practices for the production of hydraulic-cement concrete that will endure with a need for only minimal maintenance, for any desired service life, in any real environment, exists today. A major requirement is to be able to adjust the concrete to the level of attack it must resist. Too often today, concrete is produced that costs more than it should because it has properties it does not need.

In summary, advances in concrete durability for the 21st century will come from carefully selecting materials to control and optimize their properties; reducing variability in the mixing, transport, placement, and curing of concrete; and creating and using more performance-based specifications to evaluate in situ concrete. The use of real-time feedback and control from nondestructive evaluation techniques, further automation of production and placement, and improved understanding of the interaction between concrete and its environment will aid in the achievement of these advances.