Basic Research and Emerging Technologies in Concrete

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In the past 50 years, significant changes have taken place in the properties of concrete and its materials. During the 1940s, 1950s, and 1960s, substantial basic research conducted in the United States and abroad produced a thorough understanding of the properties of concrete materials, such as cement and aggregates, and the effect of these materials on the plastic and hardened properties of concrete. Material standards and specifications, mixture design and ingredient proportions, test procedures, and construction techniques were developed on the basis of this knowledge.

In recent years, government and industry have been placing strong emphasis on high-early-strength and high-performance concrete and on shorter construction times. In response to this challenge, research has been focused on producing changes in the properties of the basic ingredients of concrete, such as cement, and on developing new ingredients to achieve better-quality, higher-strength, and more-durable concrete.

ISSUES, NEEDS, AND CHALLENGES

Several generations of concrete admixtures have been developed with the aim of altering a wide range of plastic and hardened properties of concrete to achieve high-early-strength and high-performance concrete. Use of admixtures has allowed a dramatic reduction in the water-cementitious materials ratio (w/cm) in the concrete mix, which in turn has resulted in higher-strength and more-durable concrete. Significant research has also been done on the development and use of cementitious and pozzolanic materials, such as fly ash, silica fume, and slag, to replace or supplement the cement content in the concrete mixture. These materials have significantly improved the durability of concrete by reducing its permeability.

Today it is not uncommon for five or more admixtures and cementitious and pozzolanic materials to be included in a mixture in addition to the standard concrete ingredients. Such complex concrete mixtures are significantly different from the simple mixtures produced in the 1950s and 1960s. Yet many specifications and construction practices developed in accordance with basic research of the 1950s are still being applied to today's concrete materials and construction.

In addition, there are still unresolved problems and many unanswered questions associated with today's concrete. For example, excessive shrinkage and shrinkage cracking are being observed in many of the high-performance and high-strength concretes. These unintended consequences impact the durability of the concrete and thus tend to defeat the purpose of using such mixtures. Another important set of issues with today's concrete relates to the timing, duration, and type of curing, and the balance between curing time and speed of construction.

Still another issue is the knowledge gap among many practitioners with regard to the properties of individual concrete ingredients, how the various ingredients interact in the concrete mixture, and how to arrive at the optimum mixture for the type of application and level of exposure to adverse environments. An effective technology transfer plan is needed to convey to practitioners state-of-the art information and the latest research findings on materials and concrete properties.

Current testing methods for concrete and its ingredients are another challenging issue. Some of these methods are simple but time-consuming and tend to slow the pace of construction. New or improved tests for determining the properties of concrete and its materials need to be developed. These test methods should combine speed, accuracy, and precision. Technologies from other fields, such as medicine or the military, that can be nonintrusive should be considered.

RESEARCH FOR THE NEW MILLENNIUM

The challenge to the research community in the new millennium is to promote and develop a thorough and comprehensive understanding of the properties of concrete and of its multiple ingredients. This challenge can be met through a well-planned basic research program. This program should include the development of new and improved methods for testing concrete and its materials. Another program should focus on the best and most effective means of transferring the knowledge and methods thus developed to concrete practitioners for implementation. The following are some specific directions these programs might take.

Cement

Many changes have occurred in the sources and production of cement, including the raw materials and fuel used and the grinding of the clinker. Today's cements are much finer than those of the 1950s and 1960s. Research in the basic properties of cement is needed to evaluate the effect of such properties as fineness, chemical composition on the heat of hydration, and on concrete shrinkage.

Admixtures, Fibers, and Pozzolanic/Cementitious Materials

There is a need to evaluate the basic properties of the various admixtures, fibers, and cementitious and pozzolanic materials. Issues associated with the use of these materials in concrete, including setting time, plastic and hardened shrinkage, and the need for extensive curing should be investigated. The research should produce a catalog of the types and dosage or proportion of these materials in concrete, and the specific level of performance and strength achieved with each. The research should also focus on developing a new family of admixtures that would improve the tensile strength of concrete and facilitate the construction of concrete structures. For example, new admixtures now being produced aid in the self-compaction of concrete in structures.

Curing Materials

The industry has moved away from moist curing toward the use of curing compounds that are more convenient to use. However, the use of high cement content, silica fume, and low w/cm ratio has made the concrete more prone to shrinkage and thermal cracking. Curing compounds are not effective in preventing shrinkage or cracking. New curing compounds are needed not only to prevent evaporation, but also to replenish lost mixture water. For example, the curing compound might include chemicals that could condense ambient moisture on the concrete surface to provide needed moisture.

Tests for Concrete

Tests for plastic concrete properties such as slump, air content, and unit weight have been useful in controlling the quality and consistency of concrete mixtures. However, it can be expected that stronger emphasis will be placed on shorter construction times on the nation's roads, bridges, and airports. The present tests for plastic concrete tend to cause delays in construction. New technology is needed to enable testing of the workability, air content, and unit weight of mixtures in a nonintrusive manner. For example, a nonintrusive device similar to a radar gun could be developed for measuring the concrete workability from the concrete stream during discharge.

Tests for Hardened Concrete

A better means of predicting the strength and durability of concrete is needed. Tests based on the hydration process, rate of heat development, and other physical and chemical indicators should be developed for predicting the ultimate strength and durability of concrete. The availability of such tests would allow better optimization of the concrete mixture with respect to the types and proportions of its ingredients.

In addition, the concept of 28-day strength may become obsolete as an acceptance requirement. Concrete mixtures of the future may reach their ultimate strength in less than 7 days. This accelerated development of strength may alter the microstructure of the concrete. Research is needed to better understand the physical and chemical properties of hydration products, as well as the extent of microcracking and volume change in the paste matrix.

Advances have been made in measuring the permeability of concrete to better predict its durability. Nonetheless, existing devices either are too slow or provide an indirect measure of concrete permeability. Thus a fast, accurate, and repeatable device for determining the permeability of concrete is needed. A procedure should also be developed for predicting the durability of concrete from analysis of permeability data.

Technology Transfer

Good-quality research in concrete and its materials is being conducted. This research is generating new information and technologies. However, effective means of transferring the research findings and products from the research phase to application are needed. Many practitioners do not attend conferences, workshops, or meetings. These practitioners often do not receive full information on the properties of new materials and how these materials, individually or collectively, affect the strength, durability, and volume change of the concrete. A detailed plan for transferring the knowledge and new products resulting from completed research in concrete and its materials should be developed and implemented. The Internet should be the centerpiece of this plan.

SUMMARY

The new millennium brings challenges and opportunities for research on the basic properties of concrete and its materials. New nonintrusive devices and other tests should be devised to allow faster, more accurate testing of concrete materials and construction. Performance-based specifications should be developed for concrete materials and construction. Appropriate tests should be designed to assess compliance with these requirements. An effective technology transfer plan also should be developed to translate research results and products into implementation by practitioners.