THE ADVANCES AND BARRIERS IN APPLICATION OF NEW CONCRETE TECHNOLOGY

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Abstract

Numerous advances in all areas of concrete technology including materials, mixture proportioning, recycling, structural design, durability requirements, testing and specifications have been made. Throughout the world some progress has been made in utilizing these innovations but largely these remain outside routine practice.

The high performance concrete (HPC) for transportation structures, e.g., bridges and pavements, is gaining wider acceptability in routine practice. HPC provides enhanced strength and durability properties and contributes towards long lasting structures and pavements. The constructability can also be enhanced by proper mixture proportioning and testing. Most HPC mixture include recycled materials e.g. fly ash, ground granulated blast furnace slag (GGBFS) or silica fume.

The use of recycled materials in construction is an issue of great importance in this century. Utilization of fly ash and GGBFS in concrete addresses this issue. The replacement of portland cement by fly ash or GGBFS reduces the volumes of portland cement used is a major benefit. The reduction of portland cement production will reduce carbon dioxide (CO_2) emissions, reduce energy consumption and reduce the rate of global warming. Utilization of fly ash and GGBFS usually provides cost savings as well as improved concrete properties.

The case histories discussed demonstrate the practical uses of supplementary cementitious materials—e.g., fly ash, GGBFS, and silica fume—for various types of bridges and pavements in wide ranging environmental conditions. The successful utilization of supplementary cementitious materials requires proper mixture proportioning, testing, placement and curing.

Lack of widespread transfer of developed and available new concrete technology is a major problem in most countries. The practicing engineer's (user) involvement through research, development and technology transfer stages is a key to successful application of new concrete technology in routine design and practice. The past experience has shown that successful technology transfer occurs when there is a pressing national need, champions of technology are created, champion and organizations involved persist, practical demonstrations of technology are conducted to demonstrate benefits, and regulatory requirements are implemented. The new concrete technology must fulfill a need to be successful. The user (owner, designer, construction engineer) involvement is vital to success. The user starts and ends technology process. Examples of successful concrete technology transfer efforts are discussed.

1. Introduction

Developing and maintaining world's infrastructure to meet the future needs of industrialized and developing countries is necessary to economically grow and improve the quality of life. The quality and performance of concrete plays a key role for most of infrastructure including commercial, industrial, residential and military structures, dams, power plants and transportation systems. Concrete is the single largest manufactured material in the world and accounts for more than 6 billion metric tons of materials annually. In the United States, federal, state, and local governments have nearly $1.5 trillion dollars in investment in the U.S. civil infrastructure. The worldwide use of concrete materials accounts for nearly 780 billion dollars in annual spending.

The industrialized and developing world is facing the issues related to new construction as well as repair and rehabilitation of existing facilities. Rapid construction and long term durability are requirements on most projects. Initial and life-cycle costs play a major role in today's infrastructure development.

There have been number of notable advancements made in concrete technology in the last fifty years. Some of these advances have been incorporated in routine practices. But, in general the State-of-practice has lagged far behind the state-of-art. This is particularly true for public sector projects. There is an increasing concern in most of the world that it takes unduly long time for successful concrete research products to be utilized in practice. Even though some advances have been made in quick implementation of new concrete technology, significant barriers to innovation and implementation remain. Continued coordination of ongoing international research and educational programs is needed.

This paper shares Federal Highway Administration's (FHWA) experience with regard to incorporation of new technology for concrete bridges and pavements. FHWA's experience in concrete research and technology transfer is described in the following sections.

2. Advances in Concrete Technology

Numerous advances in all areas of concrete technology including materials, mixture proportioning, recycling, structural design, durability requirements, testing and specifications have been made. Innovative contracting mechanisms have been considered, explored and tried. Some progress has been made in utilizing some of these technology innovations, but largely these remain outside routine practice. The following sections describe some of the innovations.

2.1. Concrete materials

The development of chemical admixtures has revolutionized concrete technology in the last fifty years. The use of air entraining admixtures, accelerators, retarders, water reducers and corrosion inbitititors are commonly used for bridges and pavements. The use of self-consolidating concrete is beginning (mostly used for precast elements). Shrinkage reducing admixtures are rarely used for bridges and pavements. Supplementary cementitious materials e.g. fly ash, ground granulated blast furnace slag (GGBFS) and silica fume are routinely used.

2.2. Use of recycled materials in concrete

The use of recycled materials generated from transportation, industrial, municipal and mining processes in transportation facilities is a issue of great importance. Recycled concrete aggregates and slag aggregates are being used where appropriate. As the useable sources for natural aggregates for concrete are depleted utilization of these products will increase. Utilization of fly ash and GGBFS in concrete addresses this issue in addition to improving concrete properties. The replacement of portland cement by fly ash or GGBFS reduces the volumes of cement utilized which is a major benefit since the cement manufacture is a significant source of carbon dioxide emissions worldwide. Silica fume is a comparatively expensive product and it is added in smaller quantities in concrete mixture rather than as a cement replacement.

2.3. Concrete mixture proportioning

Continuous gradation and consideration of workability during laboratory testing are slowly gaining acceptance in practice. The utilization of laboratory as well as full-scale trial batches are used on major projects.

2.4. Concrete mechanical properties

Higher strength concrete for bridges are commonly used for columns and beams. Higher strength concrete usually provide higher abrasion resistance and where appropriate this is considered in the bridge deck and pavement designs.

2.5. Concrete durability properties

Concrete durability requirements are specified on most major bridge and pavement projects. Typically the requirements are based on "Rapid Chloride Permeability

Test." This is a surrogate procedure which measures flow of electrical current. The lack of better laboratory and field tests has hindered progress in this area.

2.6. Concrete tests

The utilization of advanced test procedures e.g. various shrinkage tests, air-void analyzer and non-destructive tests have become widespread. The non-destructive tests including maturity test are gaining wider acceptability. Workability test for stiff concrete mixes is being evaluated by several organizations.

2.7. Concrete construction control

In-situ concrete testing, effective curing practices and utilization of computer software to monitor concrete strength development as well as minimizing cracking potential are used on major transportation projects.

2.8. Specifications

Performance related specifications rather than prescriptive specifications for concrete have been developed but not widely used. The use of incentive/disincentive clauses in specifications tend to improve concrete quality.

3. Advances in Application of New Concrete Technology

The advances in applying new concrete technologies in transportation facilities are numerous. The following case histories will provide a good overview of the state-of-practices for concrete bridges and concrete pavements.

3.1. High performance concrete (HPC) bridges

In 1993, FHWA initiated a national program to implement the use of HPC in bridges. The bridges are located in different climatic regions of the United States and use different types of superstructures. These bridges demonstrate practical applications of HPC. The concrete mixtures utilized for the superstructure elements (deck and girders) and substructure elements (piers and abutments) included supplementary cementitious materials (fly ash, silica fume, GGBFS). The cementitious materials were used to provide required durability and/or strength characteristic. Following are characteristics:

- Specified design strengths. For prestressed concrete girders range from 8,000 psi to 14,700 psi (55 to 101 Mpa).
- Specified rapid chloride permeability for bridges decks range from 1,000 to 2,500 coulombs.
- Specified compressive strength for deck concrete range from 4,000 to 8,000 psi (28 to 55 Mpa).
- Required strength and/or durability requirement was met or exceeded.

- Total cementitiious materials contents range from 765 to 1000 lb/cu. yd. (454 to 593 kg/cu.m).
- Fly Ash content range from 200 to 316 lb/cu.yd (231 to 59 kg/cu.m).
- The water–cementitious materials ratio ranges from 0.24 to 0.35.

New York State Department of Transportation, Florida Department of Transportation, and Virginia Department of Transportation utilize HPC in routine practice.

3.2. High performance concrete pavements

The goal of the FHWA High Performance Concrete Pavement Program is a develop an integrated system for the design and construction of portland cement concrete (PCC) pavements that will perform better under the traffic conditions today and in the future. Improved durability, better designs and the innovative materials will help to minimize and extend pavement service life.

Fly ash is routinely use in pavement concrete mixes for jointed plain concrete and continuously reinforced concrete pavements. Both Class C and Class F ashes are used and typically the amount of fly ash used may vary from less than 5 to more than 40 percent by mass of the cement plus fly ash. The percentage depends on fly ash and cement properties and desired concrete properties. Many fly ashes reset with available alkalies in concrete which makes them less available to react with aggregate. The state DOTs of Virginia, Illinois, Iowa, Indiana, Nebraska, Texas, Wisconsin and Kansas are among those which encourage the use of fly ash in concrete pavements.

GGBFS is utilized for paving mixes by several state DOTs including North Carolina, Ohio, Delaware and Virginia. GGBFS preblended with portland cements or added separately in the concrete mix is used. Preblended GGBFS with portland cement is available in proportions of 25%-70% of the total cementitious materials.

Silica fume is rarely used on the paving projects because of cost considerations. In the past, Maine Department of Transportation has utilized silica fume for medians and sidewalks on urban roads. Silica fume provides excellent abrasion resistance and a few northern States are consisting its use on roads with significant winter usage by vehicles employing chains and/or studded tires.

Concrete pavement can be designed with two lifts with wet on wet construction. In such a design, the lower lift can be designed economically with higher volumes of fly ash or/or GGBFS.

3.3. Implementation of pavement research projects

HIPERPAV—In 1993, FHWA recognized the industry concern with the potential for early-age cracking on fast track paving projects. This was a result of projects built in the mid-1980s and reported in the joint industry FHWA Special Project Report SP –201 (1). There was similar concern at the time of maintaining the bond of bonded concrete overlays (BOLs). To respond to this concern, a research project was formulated to develop information on factors that had the potential to influence both early-age uncontrolled full depth cracking and the effect of early traffic on the bond of BOLS. This project had the object o the developing a set of guidelines for mixture proportioning, pavement design ad construction of enable to user to avoid these early-age problems. Since temperature was envisioned as the primary influencing factor, the project was entitled "Fast- Track Paving: Temperature control and Opening to Traffic of bonded Concrete Overlays".

FHWA's Mobile Concrete Laboratory (MCL) was involved in the field testing and monitoring of fast track paving projects and the MCL staff identified the need for concrete temperature monitoring and "opening of traffic criteria. "FHWA's MCL engineers approached FHWA's research and development engineers and a research project was initiated. The practitioners were included on the technical panel and participated throughout the research and development stages. When it became apparent that written guidance would be too voluminous and impractical and a computer software approach was must, the practitioners readily agreed to this approach. This lead to successful deployment and delivery by the practitioners. The practitioners and researchers continue to collaborate on further refinements of the software.

Workability—Workability of fresh concrete depends on its rheological properties. This rheological behavior is defined by two characteristics of the concrete, i..e yield stress and plastic viscosity. Yield stress is the effort needed to initiate movement of the fresh concrete, and correlates well with slump. Plastic viscosity is the flow characteristics of the concrete while moving, and for low stiffness concretes can be determined by various rheometers currently available. However, for higher stiffness mixes (such as used with slipform paving) there are currently no laboratory or field devices available for measuring plastic viscosity, Therefore, the FHWA formulated a project to develop a test for measuring plastic viscosity, in order that workability of slipform paving concrete could be determined and controlled. The objective of this project was develop a practical, reliable test for measuring paving concrete workability in the laboratory or in the field.

FHWA's researchers discussed the research feasibility for such a test for stiff concrete paving mixes prior to project initiation. The practitioners have remained engaged through the research and prototype development state. In fact, the practitioners have suggested further modifications to the test apparatus (e.g. weight reduction for field use). The modifications have been included in three prototype units being used for deployment.

Air Void Analyzer—In the mid 1980s, researchers in Europe were challenged to improve quality assurance in concrete construction by innovation testing of plastic concrete. The efforts in Denmark resulted in the development and evaluation of the fresh concrete air void analyzer (AVA). This device can characterize the air void structure (volume, size and spacing) of fresh concrete. The clear advantage of the AVA is its ability to characterize the air void structure on fresh concrete in less than 30 minutes. With this information, adjustments can be made in the production process during concrete placement. Since 1995, the AVA has been used commercially in a number of European countries.

The FHWA first purchased an AVA test unit in 1993. Field trials and comparisons with standard ASTM test procedures (ASTM C457) were made. The results compared well. FHWA has been actively promoting the technology since 1993. The implementation was difficult and slow till 1999 when a number of State Departments of Transportation as well as industry recognized inadequate air entrainment in several newly built transportation facilities and inadequacies of traditional test procedures e.g. pressuremeter . This recognition has prompted several State highway agencies and industry to purchase the equipment. The American Association of State Highway and Transportation Official have listed AVA technology as a priority item for implementation. This case history demonstrates the importance of having a champion (FHWA) promote the technology with persistence and the necessity of perceived need on the part of intended user.

4. Barriers in Applications of New Concrete Technology

In order to improve the durability of concrete buildings, bridges, pavements and other structures, not only must the technology or state of the knowledge be advanced, but in addition, that knowledge must of transferred to those doing the work, so that the advancement becomes state of the practice. This “technology transfer” or implementation of the results of research into routine use in concrete mixtures, structural design and construction practices is a challenge that has often lagged considerably behind the actual technical advancements. Research projects need to be developed and conducted with implementation of the results in mind. It is of vital importance to involve the practitioners and users of the research projects in all the activities from formulation of research ideas and plans through product development, delivery and deployment. This involvement and resultant buy-in from the future users of the technology from the time of research project initiation leads to quicker technology transfer and implementation.

Once the research has been completed, a number of possible implementation mechanisms need to be considered in order to select the right approach for successful transfer of the technology to the practitioner. The best approach will depend on the form of the research results. The processes used to bring techniques for improvement in concrete performance and durability through research to practice were discussed in previous sections. Innovation cycle begins and ends with user involvement.

Other barriers in the successful implementation of new concrete technologies are as follows:

- No perceived need on the part of the intended user.
- Inadequate Research and Development
- No Champion
- Too complex
- Poor economics
- Institutional opposition
- Lack of persistence

5. Conclusions and Recommendations

- Significant advances have been made in concrete technology during the last fifty years.
- Many of the innovations have been incorporated in the routine practice.
- Some of the successful examples are discussed in this paper.
- Major barriers in application of new concrete technology remain.
- Technology transfer is not easy.
- In order to speed implementation, research project objectives and scope should fully consider the potential end-use of the research results.
- Practitioner's input into the formation and conduct of research project is critical to the transition to practice.
- User participation from the early research project stage results in quicker product implementation in routine concrete design and construction practice. The practitioners become "technology champions" through early and continuous involvement in the project.
- Researchers, implementers, and users must be a cohesive team in order to convince others to try new technology.
- Multiple strategies including information dissemination, training workshops, field demonstration projects, hands-on training, equipment loan programs, technical support and educational courses should be considered for research product implementation.
- Adult education and marketing techniques play a major role in technology implementation. This is particularly true for civil engineering design and construction technologies.

- Delivery and full implementation is a long-term process and may require several years of effort. The researchers and implementation team need to continue to be involved in the technology transfer efforts with enthusiasm and confidence for a sustained period.

References

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