# CHAPTER SEVEN

# RECENT MATERIALS DEVELOPMENTS

## INTRODUCTION

Research and development for new materials and improvements in existing materials are of vital importance to our Nation's infrastructure, yet U.S. efforts lag far behind needs. This has not always been the case. In the first half of the 20th century, for example, U.S. research in cement and concrete provided the basis for developments in concrete technology throughout the world. Today, Europe and Japan have assumed the leadership role in some areas of cement and concrete research and development (e. g., kiln technology and concrete admixtures), and the U.S. has taken the "back seat." A brief description of some of the more recent developments in R&D for cement and concrete, asphalt, and plastics and other synthetics follows. Potential economic and performance benefits of using these new and improved materials could not be quantified within the scope of this brief survey, However, a few examples of research areas with potentially big "payoffs" are given in chapter one.

## CEMENT AND CONCRETE

Cement[7] is the "glue" in the most widely used composite material--concretes Concrete is used in larger quantities than any other man-made material, and is the preferred material for civil engineering construction.

---

[7] Portland cement is a dry powder composed of compounds of silica, alumina, lime, and iron oxide, which forms a hardened paste when mixed with water; it generally is used as a binder with aggregate to form mortar or concrete, but also may be used in its paste form as a structural material.

[8] Concrete is a mixture of aggregate, water, and a binder (usually portland cement) which hardens to a stone-like condition. The more water used in mixing, the higher the porosity of the hardened concrete. Pores act as crack nuclei, the consequence of which is that the tensile strength and fracture toughness of concrete are usually low. To improve its usefulness, concrete must be reinforced with steel and/or its porosity reduced.

The primary advantages of using cement and concrete are that they are durable, versatile, inexpensive and easy to produce. Despite the importance of these materials and their advantages, however, U.S. investments in cement and concrete research have been minimal. According to a 1980 report on the Status of Cement and Concrete R&D in the U.S., Federal and private funding for basic research are inadequate, and only a few universities are involved in R&D efforts. Furthermore, research efforts are fragmented, and the flow of scientific and technological information among cement producers and users and the related governmental, academic and industrial establishments is inadequate.[9]

The same report recommended that government agencies with responsibilities for energy, materials, the environment, and construction should increase their support of long-range fundamental research on the manufacture and use of cement and concrete. It also recommended that efforts should be made to devise an improved mechanism for transferring research results to development and practice. The report further suggested that special attention be paid to studies of: a) basic mechanisms, such as hydration and crystal-phase development in cement, and hardening and strength development in concrete; b) long-term behavior and durability in extreme environments; c) use of energy and resources in producing cement and utilizing concrete products; and d) the interaction of experiment, theory and modeling.

Perhaps one of the greatest challenges facing the cement and concrete industry is to produce materials that are both highly durable and economical. Some of the latest developments in cement and concrete materials used for infrastructure are cement-based composites, concrete admixtures, fiber-reinforced concrete, polymer concretes, and high-strength concrete.

---

[9] Frohnsdorff, G. and J. Skalny, Cement in the 1990s: Challenges and Opportunities, Phil. Trans. R. Soc. Lend., Volume 310, 1983, p. 18.

## Blended Cements

Blended cements, which have been introduced within the last decade, combine portland cements with one or more different types of reactive byproducts, such as blast-furnace slag, fly ash, or silica fume. The addition of these particulate to portland cement can enhance its strength and increase the durability of steel-containing cement composites used in highways and bridges. Use of these materials, however, depends on local availability. For example, silica fume is a byproduct of the metallurgical operations in the production of silicon metal or ferro-silicon alloys and is available only in limited quantities. The Bureau of Reclamation has conducted field tests of silica fume concrete at American Falls Dam; and the Army Corps of Engineers, Concrete Technology Division, has evaluated and tested concrete containing silica fume and fly ash.

## Fiber-Reinforced Concrete

Fiber-reinforced concrete is concrete made of hydraulic cements containing fine, or fine and coarse, aggregate and discontinuous discrete fibers. Some of the fibers used to reinforce concrete include steel, glass, carbon, nylon, polyethylene, and polypropylene, Fiber-reinforced concrete has the potential to improve the strength and durability of pavements, bridges, dams, and buildings. Also, fiber-reinforced concrete has been used to stabilize rock slopes, armor jetties, and line mine tunnels. Several examples of field applications of fiber-reinforced concrete include: paving applications of steel fiber-reinforced concrete at McCarran International Airport (aircraft parking area), Cannon International Airport (new taxiway), and Fallen Naval Air Station (aircraft apron); dam repair to stop erosion of plunge pool bedrock at May field and Alder Dams, and construction of spillway deflectors on Lower Nionumental Dam and Little Goose Dam on the Snake River.[10]

---

10 AC I Committee 544, "State-of-the-Art Report on Fiber Reinforced Con Crete, Con Crete International, May 1982.

The addition of small fibers to concrete continues to be researched by both the Federal and private sectors. The National Science Foundation (NSF) is currently funding work in this area, and the Portland Cement Association is doing some R&D on glass fiber-reinforced concrete for use in parking lots to control cracking.

Polymer Concretes

Polymer concrete is a composite material formed by incorporating a polymer[11] as a binder in a mixture of fine and coarse aggregate; no other cement is used. Many different polymers can be used: acrylics, polyesters, vinyl esters, polyurethane, styrene-butadiene, and polyvinyl acetate and epoxy resin. Current polymer concrete uses include patching and reconstruction of concrete structures; rehabilitation of pre-cast panels on bridges; and application of thin, waterproof, and saltproof overlays on roads. One of the main advantages of using polymer concrete is that traffic is disrupted for shorter periods of time during construction.

Thus far, polymer concretes have not found extensive application because the technology has not been perfected and production is costly. Consequently, the polymer concrete industry has not grown in recent years. DuPont, for example, stopped manufacturing this material because the concrete was cracking. Companies like duPont are watching the industry closely so that if a sufficient market develops, they could restart their operations.[12] On the Federal side, the Army Corps of Engineers, through its Repair, Evaluation, Maintenance and Rehabilitation Research Program (REMRR) and its Waterways Experiment Station, has conducted demonstrations of polymer concrete use in repairing concrete structures (e.g., dams). The Bureau of Reclamation also is funding a "concrete materials systems" research project, that will include polymer concrete development and evaluation.

---

11 A polymer is a substance made of giant molecules formed by the union of simple molecules (monomers); for example, polymerization of ethylene forms a polyethylene chain.

12 Business Communications Company, Inc., Strategies of Advanced Materials Suppliers and Users, Contractor Report to OTA, 1986.

Roller Compacted Concrete

Roller compacted concrete (RCC) requires less cement and lower quality aggregates than conventional concrete. Compaction is used to reduce pore space, thereby decreasing permeability and enhancing durability,[13] The in-place cost of RCC is about one-third 1ower than that of conventional concrete. Also, RCC pavement takes less time to spread than conventional concrete. Roller compacted concrete is suitable for dams and pavements. The Army Corps of Engineers built the world's first RCC dam (Willow Creek) in the early 1980s; now there are RCC dams under construction all over the world. The first commercial RCC pavement was built in Houston in 1985 for the Burlington Northern Railroad's intermodal hub facility.[14] The NSF, Army Corps of Engineers, Bureau of Reclamation and the Portland Cement Association have funded research and demonstration projects on RCC technology.

## ASPHALT

Asphalt[15] is most commonly used as a paving material. Of the 32 million short tons of asphalt produced in 1986, about 70 percent was used for paving. Generally, asphalt R&D efforts have concentrated on improving the performance and workability of the material. According to the Asphalt Institute, some of the activities undertaken by the private sector have focused on several areas:

- development and evaluation of asphalt additives to control pavement rutting, thermal cracking, and load-associated fatigue;
- improvements in asphalt cement specifications for low temperature behavior, oxidative hardening, and compatibility with aggregates, and environmental and safety concerns;

13 Halpin, supra note 5, at p. 12.

14 "New Ways With Concrete," Civil Engineering, May 1985.

15 Asphalt is a brown t. black bituminous substance found in natural beds and, more importantly, obtained as a residue in petroleum refining. It consists chiefly of hydrocarbons.

- refinements in production processes at refinery;
- development of mix design methods for aspha t concrete under various climate and traffic conditions;
- evaluation of the effect of changes in external ~actors (truck weights, new types of hot mix production, compaction equipment and techniques, etc. ) on the asphalt concrete;
- field performance evaluation of asphalt pavements;
- development of new uses for asphalt cement, such as in construction of asphalt concrete roadbeds for railroads; and
- investigation of the chemistry of asphalts.[16]

On the Federal level, the Strategic Highway Research Program (described in chapter eight) proposes to investigate asphalt as it relates to pavement performance, qnd ultimately will develop performance-based specifications for asphalt and asphalt-aggregate mixtures.

## PL,4STICS

Radically different pipe production methods provide the greatest potential for plastics use in infrastructure. Up until recently, polyvinyl chloride (PVC) pipe has only modestly penetrated the sewer and water supply pipe market, because it is costly to manufacture and has not met American Society for the Testing of Materials (ASTM) specifications for compression resistance, flexural strength, and other loading parameters. Two recent major breakthroughs in pipe production methods have made it possible to manufacture heavy-duty PVC pipe in bores from 27-60 inches and larger-- big enough to compete with concrete in sewer and water pipes. One of the new production methods was developed in Greece by A.G. Petzetakis S.A. and is marketed in the U.S. by Aim International. The pipes manufactured using this process are

16 OTA staff meeting with Asphalt Institute executives, March 17,1987.

equivalent in compressive strength and stiffness to solid-wall pipe. The Petzetakis system also cuts materials use by as much as 50 percent.[17]

The Ultra-Rib system is the other new breakthrough for making heavy-duty large-bore, vinyl pipe. This system was developed by Corma, Inc., a Canadian pipe corrugation equipment manufacturer, and Oy Uponor AB, a Finnish pipemaking and equipment company. In the Ultra-Rib system, the pipe is extruded from a specialized die, and then enters a forming unit developed by Corma that puts radial stiffening ribs in the pipe at rates more than twice as fast as for solid pipe. Extrusion Technologies Inc. has entered into the first Uponor process license agreement in the U. S.; they plan to make and sell Ultra-Rib sewer pipe up to 18 inches in diameter by Spring 1987.[18]

## GE OTEXTILES

Geotextiles[19] are woven and nonwoven fabrics used in drainage, erosion control, materials separation, and soil reinforcement. The Pennsylvania Department of Transportation (DOT) was one of the first agencies to use geotextiles, and to evaluate their strength and permeability after one-, two- and six-year intervals. Their test results showed that, while fabric permeability and strength decreased somewhat over time, the geotextiles were still performing satisfactorily after six years. These test results in part influenced the Pennsylvania DOT to include geotextiles as a standard part of drainage system design in locations where open-graded aggregate

---

17 "The Pipe Business Gets a New Shake from Advanced Technology," Modern Plastics, February 1987, pp. 42-43.

18 Ibid p42. and personal communication to OTA from Mr. Eckstein, Uni-Bell, March Lo, 1987. ' " '

19 Geotextiles consist of long chain polvmeric filaments or yarns, such as ProPY1ene, PolYethJ'~-ene, polyester, polyamide, or polyviny]idene- chlor ide formed into a stable network such that filaments or yarns retain their relative position to each other. The fabrics are inert to commonly encountered chemicals.

backfill requires protection from adjacent, low-plasticity fine soils that transport easily .20 The Texas State Department of Highways also evaluated the use of geotextiles as a separator between pavement base and subgrade. The evaluation showed that geotextiles are cost-effective in stabilizing lightly-traveled, thin pavements over difficult subgrade.

Geotextiles can also be used in drainage systems and wastewater treatment facilities. For example, in Muskogee, Oklahoma, geotextile liner panels were used to repair concrete walls at a water treatment plant.

In addition, the Army Corps of Engineers, Waterways Experiment Station, has used geotextiles for streambank protection, and the Bureau of Reclamation has funded a multi-year program to line all of its canals with geotextiles. The fabric linings are used to prevent water loss, erosion, and contamination in arid areas.

The geotextile industry has shown tremendous growth. Sales increased from $10 million in 1980 to $250 million in 1985.[21] In 1985, the amount of geotextiles used in Europe and North American reached about 300 million square meters.

## ANTICORROS1ON METHODS[22]

The deterioration of steel-reinforced concrete bridge decks and structural steel members is a serious national problem. A major cause of the concrete deterioration is the corrosion of embedded black steel reinforcing bars by chloride ions that permeate the concrete cover. These chloride ions are derived from de-icing salts applied directly to the bridge decks, or from marine environments.

---

ZO Materials and Testing Division, Bureau of Construction Quality Control, Pennsylvania Department of Transportation, Lone-Term Insitu Prot)erties of Geotextile~, January 1983, pp. 22-23.

21 “Engineering with Fabric,” Civil En~ineerinq, December 1985.

22 This section is based on infornlation received from the Federal Highway Administration, Office of Research, Development and Technology, May 22, 1987.

New construction provides the best opportunity to protect bridges against corrosion. According to the Federal Highway Administration (FHWA), a number of protective systems have proven effective. These include epoxy-coated rebars, corrosion inhibitors incorporated in the steel, and concrete coatings such as epoxies, polymer overlays, and sealers. Epoxy-coated rebars are the most effective bridge corrosion protection, followed by corrosion inhibitors and coatings. Two methods commonly used to rehabilitate older salt-contaminated concrete bridges are overlays and cathodic protection.

EDox~-Coated Rebars

Epoxy-coated rebars, first used in 1973, became a FHWA-approved protective system in 1976. Forty-six States use epoxy-coated rebars for new bridge deck construction. The fusion-bonded epoxy coating forms a protective barrier against the corrosive action of chloride ions. The FHWA is funding research to evaluate epoxy-coated rebars for substructure and superstructure members, as well as epoxy-coated seven-wire strands for prestressed concrete bridge components.

Corrosion Inhibitors

Corrosion inhibitors such as calcium nitrite are being considered for use in concrete bridge components that cannot be built with epoxy-coated rebars. The FHWA reported that, in the laboratory, these materials effectively reduced corrosion of black steel rebars when chlorides were present in the concrete. A number of structures currently are using this system,

CoatinPs

A number of States coat non-traffic, non-abrading concrete surfaces with either sealers, penetrants, epoxies, or polymer overlays. These coatings reduce the penetration of chloride ions and water, protect the embedded reinforcing steel, improve the properties of hardened concrete against freeze-thaw deterioration, seal cracks, and strengthen concrete. When used in combination with quartz aggregate, these types of coatings also can reduce slipperiness on wet or icy surfaces.

## Overlays

According to FHWA, a relatively large number of bridge decks have no built- n protective systems, but still contain sufficiently few chloride ions that they do not yet need to be replaced. These bridges can be rehabilitated effectively with a good quality overlay that is impermeable to, and thus will prevent additional contamination by, chloride ions and water. A variety of overlay materials, such as latex-modified concrete, high-density low-slump concrete, silica fume concrete, and polymer concrete, can provide 15-20 years of additional bridge deck life with a smooth riding surface.

## Cathodic Protection

Cathodic protection is another technique that has been used to stop corrosion of reinforced concrete components if the concrete is durable and has not already deteriorated significantly. The technique involves forcing a low-level electric current through the concrete to the rebars to counteract the corrosive current that flows naturally between steel and salt contaminated concrete. Cathodic protection technologies require regular monitoring and maintenance. The Federal Highway Administration recommended the use of cathodic protection in 1982, and this technology now is gaining acceptance by transportation officials, engineers, contractors, etc.

The technology for cathodic protection of bridge *decks* has matured enough that a number of durable systems are available today. About 150 systems have been installed, most of which are on bridge decks. Systems for *substructure* bridge components are still under intense development. None of the available cathodic protection technologies has been installed for a sufficient period to evaluate long-term durability, however.

As part of its research on cost-effective methods for combating corrosion, the Construction Engineering Research Lab, Army Corps of Engineers, developed a breakthrough in cathodic protection -- the ceramic anode. This anode makes corrosion protection available at one-fourth the cost of previous technologies, and in a size that permits installation in areas previously considered too small. One ampere of current supplied to the ceramic anode will stop corrosion on 500 square feet of uncoated steel. An exclusive license for the ceramic anode patent was awarded to APS Materials, Inc., of Dayton, Ohio, in May 1984.[23]

23 Telephone conversation with Paul Howdyshell, Construction Engineering Research Laboratory (CERL), Army Corps of Engineers, March '16, 1987; and CERL Fact Sheet, September 1986.