

History of ACI Committee 548: The Past Thirty Years

by J. T. Dikeou

Synopsis: The paper reviews the historical development of polymers in concrete, and the history of ACI Committee 548, and its sister organization, the International Congresses on Polymers in Concrete. Polymer concretes and polymer modified concretes have been studied and used since the 1940's and 1950's; polymer impregnated concretes have been studied starting in the mid 1960s.

Three categories of concrete that contain polymers are: (1) polymer concrete (PC), (2) polymer modified concrete (PMC), and (3) polymer-impregnated concrete (PIC). Committee 548 was started in 1971, and from the start has been one of the most active and productive committees in ACI. The committee has produced seven documents, most of which have required committee action to reaffirm or revise over the years. The committee has also organized and conducted nine technical sessions at ACI Conventions, which have produced Special Publications (SP), and has organized two National ACI Seminars.

Keywords: ACI Committee 548; historical development; international congresses; properties of polymers in concrete

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INTRODUCTION

Before reviewing the history of ACI Committee 548, I'd like to first discuss a little about the historical use of polymers in concrete.

HISTORICAL DEVELOPMENT

Improvement of the properties of hardened concrete by the addition of polymers is now into its sixth decade. In the 1940's and 1950's, both polymer concrete and polymer-modified concrete were studied and used. Polymer concrete was being used in the mid 1950's in the production of prefabricated wall panels and floor tile (figure 1). Polymers used included both methyl methacrylate and polyester styrene based systems. The products were successful and continue to be used up to the present time.

Polymer concrete using polyester resins was also being considered in the 1950's for use in road and bridge overlays, pothole repairs, and airfield runway repairs. However, early formulations of polymer concrete for highway work, although relatively easy to mix and place, were found to be porous and not resistant to chloride deicing salt penetration, which permits corrosion of reinforcing steel to occur. The early products therefore did not have wide acceptance in the highway industry.

Polymer modified concrete that was developed in the 1950's was actually a mortar rather than a concrete. It was found that by introducing the polymer in the form of a latex, it could be made compatible with portland cement in the fresh mortar. Polymer modified mortars were initially used as overlays for industrial floors and later were used in the construction of prefabricated wall panels and as an admixture for shotcrete. Their use also expanded into the highway field in the production of bridge overlays. However, refining of the materials remained necessary, both in terms of the polymeric component and in terms of modification of the mixture from a mortar to a concrete.

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In 1966, U.S. Government sponsored research was initiated to develop methods for impregnating hardened portland cement concrete with liquid monomers, which are subsequently polymerized in place to form the polymer impregnated concrete composite. Initial tests showed that the structural and durability properties of this new composite could be quite remarkable, prompting the U.S. Government to spend several millions of dollars over the next few years to identify suitable monomers for impregnation, develop impregnation processes, evaluate structural and durability properties of polymer impregnated concrete, and study and develop applications for polymer impregnated concrete.

However, because of the complexity and cost of the treatment process commercial applications for fully impregnated polymer impregnated concrete have not emerged. Nevertheless, the high level of worldwide interest in polymer impregnated concrete stimulated accelerated interest in polymer concrete and polymer modified concrete development, and it was from this point in time that worldwide studies and applications of these composite materials started to rapidly evolve.

ACI COMMITTEE 548, POLYMERS IN CONCRETE

Following approval by the ACI Technical Activities Committee, ACI Committee 548, Polymers in Concrete, held its organizational meeting at the spring 1971 ACI Meeting in Denver, Colorado. The first Chairman of Committee 548 was George B. Wallace, then Head of the Polymer Concrete Group at the Bureau of Reclamation's Engineering and Research Center in Denver (figure 2). George was a wonderful visionary and organizer who set the Committee on the course which it still follows 30 years later. One of the more interesting procedures that George initiated was that, following the Committee's business session, George went "around the table" and invited all attendees to present a brief discussion of the particular work with polymers in concrete that they were involved in. This procedure has been and is still followed today. Another procedure George initiated and is still followed today is that document preparation is accomplished in Task Groups and Subcommittees, and presented to the Committee for letter ballot or at Conventions for final action. So, time is not wasted at Committee meetings with boring time consuming activities such as crossing T's and dotting I's on Committee documents, as is done at so many other committee meetings.

The first undertaking of the Committee was to prepare a State-of-the-Art Report on Polymers in Concrete. The Committee membership was assigned to one of five task groups, and work was begun. Through George's initial push, the report was approved and published in some sort of record time for an ACI document.

At the same time that work was started on the State-of-the-Art Report, work was

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started on organizing Technical Sessions on Polymers in Concrete for the Fall ACI Convention in 1972 in Hollywood, Florida, and for the Spring 1973 Session in Atlantic City, New Jersey. Both sessions were quite successful.

Because of a change in employment and professional interests, George Wallace gave up the Chairmanship of Committee 548 at the end of his first 2-year appointment, and I became Chairman at the spring 1973 ACI Meeting, continuing as Chairman until Spring 1979. I was followed by David Fowler, who was Chairman from spring 1979 through spring 1985. The next Chairman was Jack Fontana who served from spring 1985 until Spring 1991, and Jack was succeeded by D. Gerry Walters who was Chairman from Spring 1991 until Fall 1996. And this brings us to our current Chairman Albert O. Kaeding who started his term at the fall 1996 ACI Convention (figure 3).

In my mind, Committee 548 has continued its initial impetus of busy activities started in 1971. Over all the years, it has consistently had one of the largest memberships of all ACI Committees, including voting, associate and consulting members from around the world. I can just about guarantee you that no other ACI Committee has been more productive. Let me back this up with the following data regarding published documents, sponsorship of Technical Sessions at ACI Conventions, and organization of ACI Seminars.

PUBLICATIONS

Published Committee Reports

- ACI 548 Polymers in Concrete, State-of-the-Art Report
- ACI 548.1R Guide for the Use of Polymers in Concrete
- ACI 548.2R Guide for Mixing and Placing Sulfur Concrete in Construction
- ACI 548.3R State-of-the-Art Report on Polymer Modified Concrete
- ACI 548.4 Standard Specification for Latex Modified Concrete (LMC) Overlays
- ACI 548.5R Guide for Polymer Concrete Overlays
- ACI 548.6R Polymer Concrete Structural Applications - State-of-the-Art Report

Along with other Committee work, numerous updates and revisions have been made, approved, and incorporated in the above documents.

SPONSORSHIP OF TECHNICAL SESSIONS AND PUBLICATION OF ACI SP'S

Committee 548 has regularly sponsored Technical Sessions at ACI Conventions,

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and has published proceedings of such sessions as ACI SP's. Following is a listing of the proceedings:

ACI SP-40	Polymers in Concrete	1973
ACI SP-58	Polymers in Concrete	1978
ACI SP-69	Applications of Polymer Concrete	1981
ACI SP-89	Polymer Concrete - Uses, Materials, and Properties	1985
ACI SP-99	Polymer Modified Concrete	1987
ACI SP-116	Polymers in Concrete: Advances and Applications	1989
ACI SP-137	Polymer Concrete	1993
ACI SP-166	Properties and Uses of Polymers in Concrete	1996
ACI SP-169	In-Place Performance of Polymer Concrete Overlays	1997

ACI SEMINARS

At the request of ACI Local Chapters and the ACI Education Department, Committee 548 organized and conducted two ACI Seminars on Polymers in Concrete. The first was held in Denver, Colorado in 1973, in cooperation with the ACI Rocky Mountain Chapter, and the second was held in Albany, New York in 1978, in cooperation with the ACI New York Chapter. Both involved speakers from the Committee 548 membership, and were received with much enthusiasm.

ICPIC ACTIVITIES

I'd like also to say a few words about an offspring of Committee 548, which is the International Congresses on Polymers in Concrete (ICPIC). The first international meeting on polymers in concrete was held in 1975 in London. About 300 persons from over 30 countries attended the First Congress. This Congress proved to be extremely useful. For the first time representatives from around the world gathered to present and exchange information on incorporation of these relatively new synthetic polymer materials into concrete. Much new information was presented on research and development of materials, processes, and properties of a variety of polymer-concrete composites. In addition, the latest information on the technological and economic feasibility of numerous applications was presented and explored. It became apparent that these materials could be used advantageously for many applications.

Following the success of the First Congress, it was decided that such meetings should be held at regular intervals, and I, as current Chairman of Committee 548 was asked if I could find a home for ICPIC-II in the United States. Following the

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Second ICPIC Congress, Committee 548 gave its endorsement of this activity, and the ICPIC Organization became a reality.

The meetings, with dates and locations for ICPIC Congresses, are as follows. Ten Congresses have now been held, as shown below (figures 4, 5, and 6):

	DATE	LOCATION	ORGANIZED BY
ICPIC-I	May 1975	London, England	The Concrete Society
ICPIC-II	Oct 1978	Austin, USA	University of Texas
ICPIC-III	May 1981	Koriyama, Japan	Nihon University
ICPIC-IV	Sept 1984	Darmstadt, Germany	Technische Hochschule Da
ICPIC-V	Sept 1987	Brighton, England	Brighton Polytechnic
ICPIC-VI	Sept 1990	Shanghai, China	Tongji University
N.A. Workshop	Sept 1991	San Fransisco, USA	American Concrete Institut
ICPIC-VII	Sept 1992	Moscow, Russia	Research Institute of Concr Reinforced Concrete
IBRACON Workshop	Oct 1993	Salvador City, Brazil	Instituto Brasileiro do Con
ICPIC-VIII	July 1995	Oostende, Belgium	Katholieke Universiteit Lei
Central European Workshop	Sept 1996	Bled, Slovenia	Institute for Research-Mate Applications
ICPIC-IX	Sept 1998	Bologna, Italy	Universita di Bologna
ICPIC-X	May 2001	Honolulu, USA	ICPIC

CONCLUSIONS

From the time that Committee 548 was formed in 1971 (30 years ago) to the present, many advances have been made in the commercial and practical applications of polymers in concrete. Many refinements have emerged, as a result of efforts of both researchers and commercial producers, which have converted laboratory processes into commercially and economically feasible products. From a review of what has happened to date, it is evident that much future progress will be made with these "new construction materials." Time will tell where the economics will balance with the increased costs. But, it is very exciting to view the progress in improvement in properties that are possible.

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12. Polymers in Concrete, Proceedings of the Third International Congress on Polymers in Concrete, Koriyama, Japan, May 1981.
13. Polymers in Concrete, Proceedings of the Fourth International Congress on Polymers in Concrete, Darmstadt, Germany, September 1984.
14. Polymers in Concrete, Proceedings of the Fifth International Congress on Polymers in Concrete, Brighton, England, September 1987.

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15. Polymers in Concrete, Proceedings of the Sixth International Congress on Polymers in Concrete, Shanghai, China, September 1990.
16. Polymer Conference, American Concrete Institute SBM –1, 1991.
17. Polymers in Concrete, Proceedings of the Seventh International Congress on Polymers in Concrete, Moscow, Russia, September 1992.
18. Polymers in Concrete, Proceedings of the IBRACON Workshop, Salvador City, Brazil, October 1993.
19. Polymers in Concrete, Proceedings of the Eighth International Congress on Polymers in Concrete, Oostende, Belgium, July 1995.
20. Polymers in Concrete, Proceedings of the Central European Workshop, Bled, Slovenia, September 1996.
21. Polymers in Concrete, Proceedings of the Ninth International Congress on Polymers in Concrete, Bologna, Italy, September 1998.



Figure 1: Precast Wall Panels (courtesy of Prusinski).



Figure 2: George B. Wallace.



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Walters



Fontana



Fowler



Kaeding

Figure 3: Committee Chairmen.

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Figure 4: The Third International Congress.



Figure 5: The Sixth International Congress.



Figure 6: ICPIC Workshop in Salvador City, Brazil.

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Fifty Years' History of Polymers in Concrete in Review

by W. S. Wahby

Synopsis: Polymer concrete materials stand today as a very promising group of new building materials. This paper presents a brief overview of the use of polymers in concrete in various industrial applications over the past fifty years. Classification, production, and main advantages and disadvantages of polymer concrete materials are presented. Their physical, mechanical, and chemical properties are reviewed and compared to those of the conventional portland cement concrete. Hazards involved in handling, transporting, storing and mixing the chemicals used to produce polymer concrete materials are discussed, and safety consideration are presented.

Keywords: polymer concrete; polymer-impregnated concrete; polymer-modified concrete; polymers

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RESEARCH SIGNIFICANCE

Polymer concrete materials stand today as a very promising group of new building materials. They possess a remarkable potential through quite a wide variety of interesting features, properties and applications. Although still considered expensive as compared with conventional materials on the basis of the monetary cost per unit weight, yet they compares extremely favorable when judged on parameters like cost-effectiveness, durability, and low maintenance requirements. The need is still there to shed the light on this family of building materials in order to gain new markets that would lead to lowering its cost.

INTRODUCTION

Historical Background

The improvement of properties of hardened concrete by the addition of synthetic polymers is well into its fifth decade (ACI 548.1R-97). Different concrete-polymer materials have proved themselves as reliable construction materials, (DePuy, 1998), especially over the last decade.

The concept of using organic polymers in construction materials is not new. There are indications that people in the early history of mankind have had the experience of combining natural polymers with inorganic materials in order to produce a high-strength and durable construction materials (Okada, 1967). It is believed that as early as the second century BC, the glutinous rice paste-lime mortar was used to build the Great Wall of China (You-Yun, 1981).

Bricks impregnated with vegetable oil, and binding materials mixed with natural polymers were widely used in the ancient construction of palaces, temples, and graves, which are still preserved to the present day (Bares, R., 1967). It is also interesting that one of the recent theories suggests that ancient Egyptians might have known some sort of technology for producing the huge stones used in building the Pyramids using polymeric binders with medium, fine, and very fine

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fillers (Davidovits, J. 1987). However, it was not until the 1950's when synthetic polymers were applied to concrete.

Polymer concrete was first used commercially in the United States in the 1950's (Kaeding, 1998). "Ar-Lite Panelcraft" polymer concrete building panels were manufactured then by Architectural Research Corporation and were marketed worldwide by the 1970's. (Prusinsky, 1999). Much research work on polymer impregnated concrete and polymer concrete was performed under the auspices of the U.S. Department of Energy at Brookhaven National Laboratory during the 1960's to 1980's (Fontana, J., Kakacka, L.E., Steinberg, M., Dikeou, J.)

Concrete

The general definition of concrete is "an aggregate bound with a binder". Ordinary "concrete", or conventional portland cement concrete (CPCC) is a man-made rock, manufactured by binding together fine and coarse aggregates (sand and gravel or crushed stones), by means of a gel that is formed by portland cement and water. In certain situations, special additives or admixtures may be incorporated as need be.

CPCC is one of the most important and versatile building materials in the world, with quite a good range of mechanical properties, and with no equally economic alternative. On the other hand, however, and in spite of the many improvements over the years, CPCC still has some deficiencies such as relatively high permeability, vulnerability to attacks by seawater and organic and inorganic acids, especially at elevated temperatures.

In addition, CPCC also has many undesirable engineering characteristics, such as: low tensile strength, brittleness, low impact resistance, low modulus of elasticity, insufficient insulating properties, heavy weight, and difficulty of shaping into some special tiny or complicated shaped forms.

Researchers in various countries engaged themselves in investigations to improve concrete's shortcomings. In the process, concrete polymer materials emerged as a possible solution to most of the problems associated with traditional CPCC, and were developed to reduce its deficiencies.

Polymers

Polymers, commonly called "plastics", are nonmetallic materials, which have undergone tremendous technical developments during the last few decades. A "poly"- "mer" ("many"- "parts") is formed from a "mono"- "mer" ("one"-

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“part”), or simply a “mer” through a chemical process called polymerization. An example is the monomer vinyl chloride, which is formed into the commonly known polymer, polyvinyl chloride (PVC).

The first modified natural polymers, namely: cellulose nitrate and casein-formaldehyde, were commercially produced about 150 years ago, while the first fully synthetic polymer, phenol-formaldehyde, was made 50 years later, in 1910. Following the tremendous progress of the petrochemical industry, it was only forty years ago, in the late 1950's, that a booming production and development of synthetic rubber latexes, resin emulsions, and monomers were started.

Today, industries associated with polymeric materials in this country employ more than half of all chemists and chemical engineers, while the annual production of polymeric materials has grown from a few million pounds to several billion pounds.

POLYMER CONCRETE MATERIALS CLASSIFICATION

There are three main types of polymer concrete materials: Polymer-Modified Concrete (PMC), Polymer Impregnated Concrete (PIC), and Polymer Concrete (PC).

PMC has at times been called polymer-portland cement concrete (PPCC) and latex-modified concrete (LMC). It is defined in ACI 548.3R as portland cement and aggregate combined at the time of mixing with organic polymers that are dispersed or redispersed in water. As the cement hydrates, coalescence of the polymer occurs, resulting in a “co-matrix” of hydrated cement and polymer film throughout the concrete.

PIC is a hydrated portland cement concrete that has been dried to remove moisture and free water from its pores, and then impregnated by either atmospheric or pressure soaking with a monomer that is subsequently polymerized in situ. There are two levels of impregnation: partial impregnation (sometimes called surface impregnation) and full impregnation, depending on the degree to which the available space in the concrete is filled with monomer.

PC is a composite material in which the aggregate is bound together in a matrix with a polymer binder. The composites do not contain a hydrated cement phase, although portland cement can be used as an aggregate or filler but not as a binder.

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PRODUCTION

Polymer-Modified Concrete (PMC)

Selecting the proper polymer depends a great deal on the exposure and service life requirements. Amongst the wide variety of polymers investigated for use in PMC, the latex polymers, epoxies, and acrylics are the three most successful types that have been investigated, accepted and widely used for different applications.

The specific mix proportions selected for any particular application depend on the specific need of the application and the type of polymer used in PMC. For optimum performance, in general, polymer levels of 10 to 20% (based on the weight of polymer solids in the latex solution to the weight of portland cement) will be required.

Polymer Impregnated Concrete (PIC)

In general, all types of aggregates, cements, and admixtures that are used in old and modern concrete technology can be used for PIC. Moreover, almost any shape, size, configuration, orientation and quality of nearly all existing types of hardened CPCC can be impregnated with monomer, to some degree, provided the monomer has access to the void space within the concrete. The main factor in producing high quality PIC is in achieving a high degree of impregnation, and complete polymerization.

Polymer Concrete (PC)

Polymer concrete (PC) is a composite material in which the aggregate is bound together solely with a polymer binder of 8-15 % by weight. This is different than using 1 to 5% by weight of cement as admixtures or additives to a fresh CPCC mix.

Generally, PC has many of the advantages of PIC, though its processing techniques are much easier and simpler than those of PIC. Meanwhile, the term PC should never suggest only one product, but rather a family of products. In contrast to PMC and PIC, PC can be made with a wide range of monomers, and the material is suitable for both precast and in-situ applications. Processing techniques depend on the finished product desired, and the required performance.

PROPERTIES

A range of properties for PMC, PIC, and PC is presented in Table (1) (Kakacka, 1975).

INDUSTRIAL APPLICATIONSPolymer Modified Concrete (PMC)

PMC applications have included, but are not limited to relatively large prefabricated panels of masonry curtain walls, overlays of bridge decks, parking garages and floors, precast operations, and patching any concrete surface.

Polymer Impregnated Concrete (PIC)

The potential applications of PIC include treatment of existing concrete structures and precast concrete elements, protection of concrete bridge decks and spillways from damage, improvement of the structural stability of roof and wall structures in mines, restoration of deteriorated structures and monuments, and repairs of badly fractured concrete, and developing chemically resistant PIC.

Unfortunately, it seems that the excellent structural performance and the enhanced durability of PIC in general could not in themselves, economically, justify its commercial use on a large scale. The complicated techniques and the industrial hazards involved in producing PIC halted the anticipated progress for such materials and led to the obvious dramatic decrease in the rate of its development and production in the last decade.

Polymer Concrete

The use of polymer concrete is equally distributed between load-carrying elements, aggressive media-protecting elements, and decorative or aesthetic elements. Many PC products can be plant-precast more efficiently and economically than site-cast.

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PC is used in the manufacture of overlays and floorings, structural and decorative housing elements, sewer pipes, bricks and building panels, grouting, swimming pool and patio decking, machine parts and tools, PC thermal and insulator panels, electric insulators, shotcreting, and street furniture. PC can also provide a fast-curing, high-strength patching material for repair of CPCC deteriorated highway structures.

MAIN ADVANTAGES OF USING POLYMERS IN CONCRETE

As shown in Table (1), most concrete mechanical properties are improved with polymer inclusion. PC and PMC generally have lower moduli of elasticity than CPCC. The most significant improvements are those related to durability. In certain tests of freeze-thaw resistance, PIC is reported to have a weight loss of almost zero after 3650 cycles, while the corresponding CPCC specimens lost 26% of their weight after only 690 similar cycles. Improvement in erosion and abrasion resistance is remarkable. Chemical resistance for concrete-polymer materials is much better than that of CPCC. High cost of polymer concrete materials can be justified when considering factors like cost-to-strength ratios, mass-to-strength ratios, chemical resistance, time saving or durability.

MAIN DISADVANTAGES OF USING POLYMERS IN CONCRETE

The main disadvantages of polymer concrete materials include high cost, creep behavior and stress relaxation, poor performance under dynamic loads, polymer degradation and the effect of oxidizing agents, handling hazards, some difficulty in mixing and placing, and the lack of perfectly suitable polymers for use with concrete.

SAFETY

Safety is a wide-ranging subject that includes aspects of normal construction practices, special construction practices arising from the use of concrete polymer materials, the intrinsic properties of the chemicals, and the codes and regulations of governmental regulatory agencies, and various groups and associations. (ACI 548.1R-97).

CONCLUSION

Polymer concrete materials stand today as a very promising group of new building materials. They possess a remarkable potential through quite a wide variety of interesting features, properties and applications. Although still considered expensive as compared with conventional materials on the basis of the monetary cost per unit weight, they compare extremely favorably when judged on parameters like cost-effectiveness, durability, and low maintenance requirements.

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Table: 1 TYPICAL PROPERTIES OF CONCRETE-POLYMER MATERIALS

Properties	Conventional Portland Cement Concrete	Polymer Modified Concrete	Polymer Impregnated Concrete	Polymer Concrete
	CPCC	PMC	PIC	PC
Compressive Strength, psi (kg/cm ²)	4000-5000 (280-350)	4000-8000 (280-560)	14143-21286 (990-1490)	5572-21286 (390-1490)
Tensile Strength, psi (kg/cm ²)	300-357 (21-25)	571-929 (40-65)	1214-1643 (85-115)	1000-2000 (70-140)
Modulus of Rupture, psi (kg/cm ²)	471-529 (33-37)	1429-1786 (100-125)	1714-2000 (120-140)	1214-3000 (85-210)
Modulus of Elasticity x 10 ³ psi x 10 ³ (kg/cm ²)	2800-3600 (196-252)	1400-2100 (98-147)	5000-5700 (350-399)	1000-5000 (70-350)
Water Absorption, %	5-6	-	0.3-0.6	-
Resistance to Acids, Factor Of Improvement Over Control	-	1-6	5-10	8-10
Abrasion Resist- ance, Factor Of Improvement Over Control 5-10	-	10	-	2-5

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Development and Applications of Various Polymer Concrete Engineering Materials

by J. J. Fontana

Synopsis: A wide variety of advanced construction materials have been developed to meet certain needs and solve specific problems. These materials have all come under the umbrella title of “Polymer Concrete”(PC). Using different types of resins and fillers, composites can be formulated having totally different physical properties.

This paper will review several different PC formulations that were developed at Brookhaven National Laboratory (BNL) and installed at operating facilities by construction contractors. The three materials selected for this review are: A) Insulating Polymer Concrete (IPC) for dike insulation at Liquefied Natural Gas (LNG) facilities; B) Electrically Conductive Polymer Concrete Overlays used in conjunction with a cathodic protection system on a deteriorated bridge deck and C) Precast PC vaults for natural gas regulator stations.

Keywords: electrically conductive polymer concrete; insulating polymer concrete; precast polymer concrete

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Jack J. Fontana graduated from Adelphi University in 1963 and has conducted research and development work on polymer concrete materials for the past 38 years. Has developed PC materials for the Federal Highway Administration, for the geothermal energy industry and for the liquified natural gas industry. Most of the materials developed has been implemented for commercial applications. Currently a consultant to the polymer concrete industry.

INTRODUCTION

During the past three decades, a wide variety of advanced construction materials have been developed for different industries to solve specific problems. These materials have generally come under the umbrella title of “Polymer Concrete”. The stigma of trying to compete with low cost Portland cement concrete (PCC) products has restricted the use of many of these engineered composites. It is the opinion of the author that the industry would have been best served if these materials would have been promoted as “Polymer Composites”. Polymer Composites are sophisticated materials that can be formulated for a wide variety of applications with no apparent limits to their use.

Polymer Composites generally consist of three ingredients: resin, aggregate/filler, and additives. Varying one, two, or all three, of these ingredients, can change specific chemical or physical properties in the composite. In general, the type of resin used will mostly influence the chemical properties of the composite, such as, corrosion resistance. Changing the aggregate and fillers will generally change the physical properties of the composite, such as, conductivity (thermal or electrical) or insulating (thermal or electrical). The addition of additives, such as, silanes, will improve the bond between the aggregate and the resin, thereby increasing the strength properties and reducing degradation due to moisture.

Three Polymer Composites will be reviewed to show how different formulations will fulfill different composite requirements. The first composite, to be discussed, was used to insulate the dike areas surrounding LNG storage tanks. The second composite, an electrically conductive material, used as a bridge deck overlay, uniformly distributes the anode current from a cathodic protection system. The third composite was a high strength, highly ductile material used to cast vaults for underground natural gas regulator stations.

INSULATING POLYMER CONCRETE

The natural gas industry has always been concerned with accidental spills of LNG from storage tanks into surrounding impounding dike. The LNG stored in

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these tanks is at a temperature of approximately -260°F . The dikes are generally constructed of tamped soil or of Portland cement concrete slabs over the soil. The LNG, which is leaked to the dike area, boils off very rapidly and the vapors mix with the atmosphere forming a hazardous explosive mixture in the surrounding region. (1,2,3) Analysis of the problem has indicated that the rate and quantity of LNG evaporation are primarily dependent on the rate of heat transfer from the dike surfaces to the spilled LNG in the dike. If the rate of heat transfer is reduced, the total quantity of LNG vapor, per unit time, will also be reduced. Studies by the natural gas industry indicate that insulating the dike areas surrounding these tanks could markedly reduce the hazards associated with accidental spills of LNG from storage tanks. The insulating material is used to construct a thermal barrier between the walls and floor of the dike and the spilled LNG. This will significantly reduce the rate of evaporation in a given time period after an accidental spill.

The insulating composite, designed to meet the criteria, required a very low thermal conductivity to reduce the rate and quantity of LNG evaporated. In addition to the thermal properties, strength and durability were also important. Strength, because the insulated surfaces would have to carry light transient loads, such as, workmen and maintenance vehicles. Durability, because the insulating material will have to withstand atmospheric weathering for several decades. The insulating composite must have a good bond to a concrete surface and must not support combustion. Last but not least, the composite must lend itself to field applications and should be easy to handle by experienced construction personnel.

Insulating Polymer Concrete (IPC) (4,5,6) is a composite that meets all of the requirements specified for dike insulation. A typical composite consists of lightweight multicellular glass nodules bound together in a dense matrix with a polymer binder. Low thermal conductivity is characteristic of organic polymers and lightweight hollow structure aggregates. The composite formed, by these materials, is a closed-cell structure, with low thermal conductivity, low density, low water absorption, good durability, and relatively high strengths. These composites can be cured in-situ at ambient temperatures, with workability properties similar to Portland cement concrete. The IPC formulation used at the Long Island Lighting Company (LILCO) LNG is given in Table 1.

The physical and thermal properties of IPC formulations were measured using ASTM standards wherever possible. The measured properties, of several different IPC formulations, are given in Table 2.

A thermal shock test was simulated on a small field installation of an IPC overlay. Liquid nitrogen (N_2), at a temperature of -320°F was poured over the IPC overlay which was at a temperature of 60°F . Wooden sides, glued to the overlaid slab, prevented the liquid N_2 from pouring over the sides. Within a few minutes, a liquid level remained on the surface and slowly evaporated without the boil-off normally associated with cryogenic liquids. There was little, if any,

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indication that the IPC overlay had cracked or disbonded. The test was repeated two additional times, on the same slab, with the same results.

In addition to the flammability test, reported in Table 2, another, more severe, burn test was conducted with IPC panels. The panel surface was covered with approximately 0.25 inches of gasoline and then ignited. Since the gasoline did not absorb into the low porosity IPC, the fire self-extinguished as soon as the fuel was consumed. The IPC surface was charred but did not crack or lose its structural integrity.

Specialty construction contractors made several full-scale installations of IPC overlays. In 1984, the first IPC overlay was placed on a dike owned by the Brooklyn Union Gas Company (BUG). The contractor was Polymer Construction Specialties (PCS).

There were two impounding dikes, side by side, located in Brooklyn, NY, near the East River and less than 2-3 miles from downtown New York City. Each dike had approximately 80,000 square feet of surface area that had to be overlaid. The ratio of floor to walls was approximately 3:1. The walls of these dikes were approximately 25-30 feet high and severely sloped. The overlay was placed in vertical sections approximately 6-8 feet wide. Ladders were constructed on both sides of the area to be overlaid, as shown in Figure 1. The materials were mixed in a Respecta continuous mixer. Each batch was transported, in wheelbarrows, to the appropriate area. The composite mixture was applied to a tack-coated surface and leveled with a vibrating screed to a thickness of 0.5 to 0.75 inches. The floors of the dike were much easier to overlay and much larger sections could be done at one time (Figure 2). The second dike, at BUG, was overlaid in 1986. The Taisei Corporation, from Tokyo, Japan, placed this overlay. They had introduced a "Shot Rem System", at the ICPIC conference in Darmstadt, Germany, in September 1984. (7) The author visited the company in May 1985 and had them try several IPC mix designs with their shot-crete machine. Samples were returned to BNL and their physical and thermal properties were evaluated. The physical and thermal properties of the samples provided by Taisei Corp. were within the standards set by BNL. Upon the author's recommendation, BUG contracted with Taisei to place the IPC overlay on the second dike, in 1986, using their shot-crete machine (Figure 3,4) with BNL's composite mix design. The physical and thermal properties of the IPC were monitored several times a week by BNL. These properties were found to be within the limits set throughout the construction phase.

In the summer of 1987, the Long Island Lighting Company (LILCO) proceeded to insulate their dike with a new formulation designed by BNL. New, lightweight spheres, from the 3M Company, made it possible to refine the IPC formulation without interfering with the one used at BUG. The PCS construction company was awarded the contract and, with its previous experience, completed the installation without any problems.

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For several years, after the IPC installations, BNL monitored all three applications. Both visual and physical tests were made to monitor the bond strength of the overlay and its durability. Some repairs were required on the overlays, but these were considered minor since they were less than 1 % of the total area placed. There have been some minor spills of LNG, both in the BUG and LILCO facilities. Both companies have been impressed at the slow boil-off of LNG from the IPC surface.

ELECTRICALLY CONDUCTIVE POLYMER CONCRETE OVERLAY

The use of impressed current, cathodic protection (CP), to prevent the corrosion of embedded reinforcing steel, in chloride contaminated bridge decks, received much attention from 1970-1990 (8,9,10). Electrically conductive composites have played a significant role in advancing the use of CP systems installed in highway bridge decks and other concrete structures. In 1984, the Federal Highway Administration (FHWA) contracted BNL to develop an electrically conductive bridge deck overlay and a sprayable conductive coating (11). The non-sagging, sprayable, conductive coating developed has a very low electrical resistivity, 1.6-3.5 ohm-cm, with excellent bonding characteristics to concrete. The mix design, of the coating, combined 60-wt % of calcined coke breeze (an electrically conductive aggregate) with 40-wt % vinyl ester resin containing 3.5-wt % of a thixotropic agent based on modified bentonite clay. Some physical and electrical properties, of the coating, are given in Table 3.

A field demonstration was performed on a bridge substructure near Norfolk, Virginia. The conductive coating was sprayed on the concrete surfaces using a conventional pneumatic spray machine and a fan-jet gun (Figure 5). The permeability of the coating is about one-half that of concrete. This allows any formation of chlorine, hydrogen or oxygen gas, formed by the impressed cathodic protection (CP) current, to permeate through the coating and escape into the surrounding atmosphere. If the coating were not permeable, the gasses would be trapped in the concrete substrate-coating interface. Moisture in the concrete could combine with the chlorine gas and form an acid thus deteriorating the concrete surface and adversely affect the bonding of the conductive coating.

The coatings were monitored for several years by an independent corrosion-engineering firm. They reported that the conductive coating had less than one-percent deterioration.

The second system developed was an electrically conductive composite overlay (12) to uniformly distribute the CP current across the bridge deck surface while providing a skid and wear-resistant surface for the bridge deck. The overlay,

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approximately 1/2-inch thick, will not increase the dead load significantly. Ramps on the slabs will provide a smooth transition to the bridge deck.

A low electrical resistivity composite was obtained with an aggregate mixture of 50-wt % calcined coke breeze and 50-wt % crushed basalt or silica sand with a binder content of 15-20-wt % unsaturated polyester resin. The electrical resistivity of this composite was 2-5 ohm-cm. An overlay of this composite was cast on a concrete slab and tested on BNL's wear test machine. Tests representing 0.84 to 2.1×10^6 -tire passes, on the overlay, indicated there was no measurable wear on the surface. A British Pendulum Tester (ASTM E 303) was used to determine surface texture changes from the wear resistant tests. There was some decay in the BP number however; it was not deemed significant.

A field installation, of a conductive overlay, was made on a two-lane bridge, on Route 99, over Peak Creek, near the town of Pulaski, Virginia. The three span bridge deck had a surface area of 4,400 square feet. The chloride content, of the Portland cement concrete bridge deck, ranged from 1.4 to 5.56 lb.-Cl⁻/yd³. Chloride contents of 1.3 lb.-Cl⁻/yd³ are considered high enough to corrode the reinforcing steel.

About 2,000 square feet (>45 % of total surface) of the bridge deck, was so highly deteriorated that it had to be removed and replaced before the CP system, with the conductive overlay, could be installed. Repairs were made, as per the specifications, of the Virginia Department of Transportation, for Type B repairs.

The deck repairs were cured for a minimum of 30 days before the conductive overlay was placed. The bridge deck surface was prepared for overlay placement by shotblasting. Oil-free compressed air was used to remove residual cement dust. An engineering firm familiar with CP and conductive overlays designed a simple system incorporating both elements. BNL technicians installed the CP system as designed. On the top of the cleaned bridge deck, a platinum-niobium covered copper wire was installed as the primary anode. The conductive overlay functions as the secondary anode to uniformly distribute the CP current across the bridge deck surface.

A Virginia construction company, who had experience in placing both polyester and epoxy resin overlays, was contracted to place the conductive overlay. Screed rails were set for the placement of a 1/2-inch thick overlay on the westbound lane. An air operated vibratory screed was set on the screed rails and adjusted to provide a uniform overlay thickness across the entire width of the lane.

The conductive composite was mixed in mortar mixers (Figure 6) for 3-5 minutes, transported in wheelbarrows and spread in front of the screed. The screed was pulled along the screed rails by hand (Figure 7). The overlay surface was tyned to provide a skid-resistant surface. There were some inconsistencies in

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the mix, due to the batch mixing; however, for a first time installation, it was deemed satisfactory.

A Bidwell paver was used to place the overlay on the eastbound lane (Figure 8). The screed height was adjusted for a ½-inch thick overlay across the bridge deck surface. The paver was self-propelled so it was easier to control for continuous placement. During this placement, a small Bobcat loader was used to transport the mixed composite to load the paving machine hopper. Once the overlay was compacted and screeded to the proper elevation, the surface was tyned across the lane to provide a skid-resistant surface.

The CP system was first activated in December 1987 at 1 mA True Root Mean Square (TRMS) per square foot of anode. The total current was calculated at 4.42 amps TRMS. Test results over the next few years indicated that the rectifier remained very stable and delivered a constant preset current to the CP system. The average anode current density for the first few years of operation was only 1.05 mA-TRMS/ft² of anode. During this period, the temperature of the overlay varied from 24-89 °F. The relatively low average voltage, 3.04 TRMS, providing an average current of 4.24 amp TRMS, indicates the high efficiency of the system. The entire system was periodically examined for approximately 10 years and appeared to be operationally sound.

STEEL-FIBER REINFORCED POLYMER CONCRETE

Precast, underground vaults, for natural gas regulator stations used by the Brooklyn Union Gas Company (BUG), Brooklyn, NY and the Consolidated Edison Company of New York (ConEd), New York, NY, have traditionally been fabricated with steel-reinforced PCC. Exterior surfaces, of the vaults, were epoxy coated to prevent the ingress of moisture into the vault. When these vaults are used to replace existing vaults in service, it was often necessary to offset the buried gas lines to align with the precast penetrations or field-cut new penetrations. Cutting through the reinforcing-steel subsequently weakens the structure and/or allows water ingress. The additional time involved, in moving the gas pipelines or altering the vault is costly.

A steel-fiber reinforced PC was developed to precast vaults for natural gas regulating stations (13). A benefit that was gained included longer maintenance-free service life due to increased physical and durability properties as compared to PCC. The higher strengths also allow designers to reduce wall thickness, thereby, decreasing vault weights that allowed for easier transportation and installation. Penetrations can be cut to match existing street lines, at time of installation, thus eliminating the need to have right and left handed vaults. Since the reinforcing steel-fibers are randomly dispersed throughout the PC, there will not be any loss of strength.

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It is well known that silane-coupling agents increase the bond between the aggregate and resin. These will also increase the compressive, flexural and tension strength of the composite by 15-25 %. Durability also increases because the increased bond, between aggregate and resin, is less susceptible to moisture intrusion.

A structural design study, of vaults, used by BUG and ConEd was made using the physical properties of PC. The study indicated that the higher strength properties of PC could allow for 50 % thinner wall sections. Thus, the overall weight, of the cast PC vaults, will be about half the weight of a PCC vault. The two principal properties that were of concern to the structural design engineers, were flexure strength and the ductility of the PC. The flexure strength measured for the PC formulation, given in Table 4, was 4700 psi with a standard deviation of 500. A typical load-deflection curve is shown in Figure 9. The area under the load-deflection curve, beyond the yield point, is at least ten times the area under the yield point. This indicates that the material is ductile and will not be subject to a catastrophic failure. The ductility, of the PC, was entirely related to the use of ribbed fibers having a 20 to 1 aspect ratio (length to width). In the polyester PC, the load is transferred to the steel fibers and at the yield point they begin to carry most of the load. The steel-fibers slowly pull out of the polymer matrix, as they are being loaded, until the ultimate load is reached. At this point, the structure can no longer carry any load. An epoxy resin PC has a higher yield point, but its bond, to the steel fibers, is so good that the fibers themselves fail in tension, and thus allow a catastrophic failure (Figure 9).

Quarter-scale models, of PC vaults, were cast. The center-to-center dimensions were 2-feet by 1.5-feet by 1.5-feet with a wall thickness of 1-inch. A model vault was evacuated, thereby subjecting it to a uniform pressure. A peak pressure of 1650 psf was obtained. The box was subjected to several complete loading-unloading cycles without suffering any damage. The test actually subjected the model vault to pressures 60 % higher than the design load of 1000psf. Tests were also run on model boxes with pipe penetrations installed through the walls and cemented in place with an epoxy mortar (Figure 10). Test results on these boxes were similar to the initial tests.

Full-scale drawings, using the PC design criteria that was developed by BNL, were made for vaults required by both ConEd and BUG. The BUG vault was approximately 7-feet by 7-feet by 6-feet and the ConEd vault was approximately 6-feet by 4-feet by 3-feet. Hardinge Bros., Elmira, NY, was contracted to build the forms and cast two PC vaults, of each type, using the formulation developed by BNL. These were put in service by both utilities and monitored for several years. Within the first year, the ConEd maintenance group was so impressed with the ease of installation and the performance of these vaults that they decided to place them on their standard parts list.

SUMMARY

This document has reviewed three different polymer composites that were developed for specific applications. Each one is unique unto itself. By carefully selecting the aggregate and resin formulations, entirely different properties were obtained. Knowledgeable contractors have shown that they can safely work with these materials in field or factory precast applications. These composites may not be inexpensive, but they do have sophisticated uses; therefore, cost may not be an insurmountable objection.

Consumers must understand that each and every PC formulation available was developed for a specific product end use. Thus, every different product developed may require its own unique formulation. Careful developmental studies must first be undertaken to ascertain that physical, chemical, thermal, and/or electrical properties, of the composite, can be obtained. Then, full-scale field or in-house applications must be performed. When these studies have been completed, and the results are satisfactory, a full-scale production operation may commence. Polymer composites are not the panacea for every application, but they certainly can satisfactorily solve many problems.

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TABLE 1
IPC Formulation Developed For The
Long Island Lighting Company

<u>Materials</u>	<u>Manufacturer</u>	<u>Pounds/cubic foot of IPC</u>
Macrolite 3.5-7	3M Company	5.0
Macrolite 7-14	3M Company	6.0
Macrolite 14-30	3M Company	12.5
Macrolite 30-50	3M Company	2.5
P-2000	Fillite, USA	2.5
DE-83R	Great Lakes Company	5.0
Flexoglass resin	Dural International	16.5

Notes:

1. Macrolite: multicellular glass beads with ceramic shell
2. P-2000: alumina silicate microsphere
3. DE-83R: decabromodiphenyl oxide flame retardant agent
4. Flexoglass: moisture insensitive epoxy resin

TABLE 2
Physical and Thermal Properties of IPC

Property	Typical Values	Test Method
Thermal conductivity	0.1-0.15 BTU/hr-ft-°F @ 80 °F 0.03-0.05 BTU/hr-ft-°F @ -240 °F	Dynatech comparator
Density	40-55 lb/ft ³	
Compressive strength	1300-2500 psi	ASTM C 495
Flexure strength	500-900 psi	ASTM C 78
Tensile bond strength	200-350 psi	ACI-503R Appendix A
Water absorption	0.1-0.5 wt %	
Flammability	Self-extinguishing in 5-10 seconds	ASTM D 635
Linear curing shrinkage	0.06-0.15 %	BNL test method
Freezing and thawing	Up to 300 cycles with a 10-20 % loss of strength	ASTM C 666

TABLE 3
Properties of Sprayable Electrically Conductive Coatings

Property	Typical Values	Test Method
Electrical resistivity: @ 10-15 mils thick @ 20-40 mils thick	3.5 ohm-cm 1.6 ohm-cm	4 pin method with Nilsson Model 400 AC impedance meter
Tensile bond strength: number of freeze-thaw cycles 0 100 200	450 psi 440 psi 430 psi	Elcometer Adhesion Tester
Permeability: @ 10-20 mils thick	5,990 coulombs	

TABLE 4
Steel-Fiber Reinforced PC Mix Design

Materials	Quantity, wt %
Coarse stone	
¼ inch max. traprock	13.5
½ inch max. traprock	13.5
Graded silica sand (US Sieve 16-100)	40.5
Silica flour (US Sieve 250-350)	13.5
Steel fibers, ribbed, 1.5 inch long, aspect ratio=20	9.0
Resin, orthophthalic polyester	10.0

Notes:

1. Polyester resin must contain 1-wt % silane coupling agent.
2. Polyester resin may be cured at room temperature using cobalt naphthenate and methyl ethyl ketone peroxide.
3. All aggregates and sand must contain less than 0.5-wt % moisture.



Figure 1. Installing IPC overlay on sloped walls of containment dike.



Figure 2. Vibrating screed used to finish IPC overlay.



Figure 3. Taisei Shot-Ret machine.

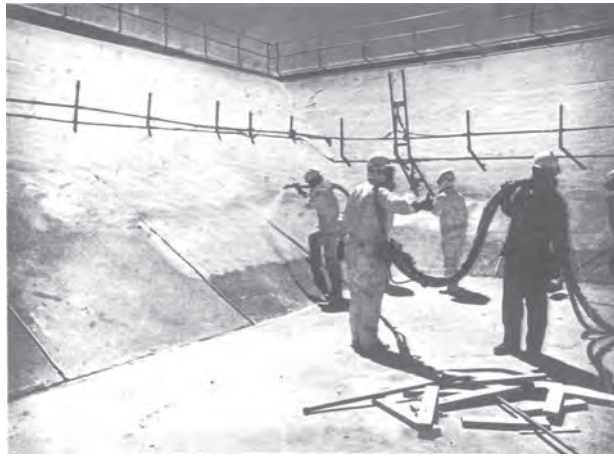


Figure 4. Spray application of IPC overlay on dike walls.



Figure 5. Spray application of electrically conductive coating.



Figure 6. Mixing the electrically conductive PC overlay composite.



Figure 7. Screeding the electrically conductive PC overlay.

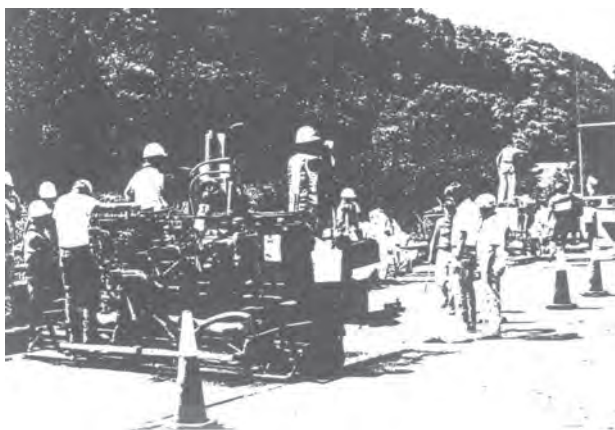


Figure 8. Modified Bidwell paver placing the electrically conductive PC overlay.

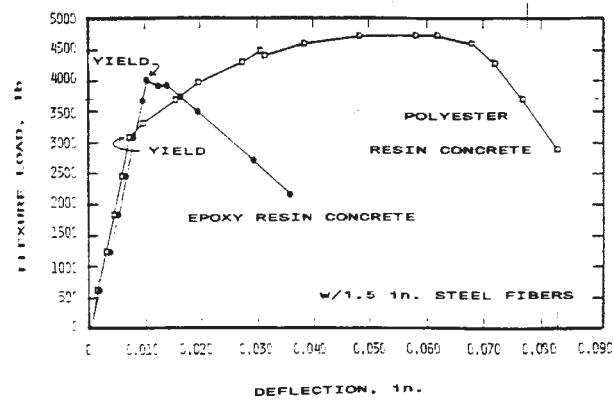


Figure 9. Load-deflection curves of steel-fiber reinforced PC.

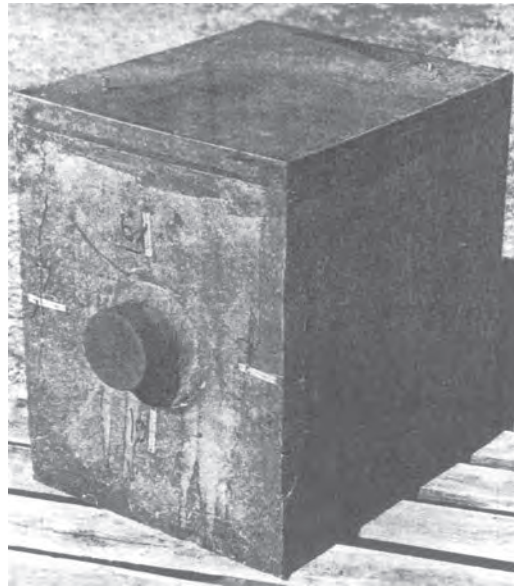


Figure 10. Quarter-scale model vault after being tested to failure.

How Polyester Polymer Concrete Highway and Bridge Deck Overlays Became “State of the Art”

by J. Maass

Synopsis: This paper reviews the history of polyester polymer concrete highway and bridge deck overlay with a focus on the work done in California and adjacent states. The paper discusses the early work done at Brookhaven Labs, the watershed I-80 job done at Donner Pass (including updates relating to the job), and then reviews the large number of successes over the last thirty years.

Keywords: bridge and deck overlay; CalTrans; Donner Pass; highway overlay; I-80; polyester resin; polymer concrete; premix method; unsaturated polyester

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INTRODUCTION

My goal with this paper is to share with you the history of polyester polymer concrete highway and bridge deck overlay with a focus on the work done primarily in California. I will review the early work done at Brookhaven Labs, the watershed I-80 job done at Donner Pass (including updates relating to the job), and then review the large number of successes over the last thirty years.

According to the best information I have been able to gather, it was definitely over breakfast, and most probably near Barstow, California in 1991. It was at that meeting that Cal-Trans Resident Engineer on the I-15 Project, Fran Flesner, mentioned to the on-site consultant, Steve Frank, that the term “experimental” was being dropped from the polyester polymer process. Steve asked Fran what that meant. Fran answered, “Lots more future work.” He was right.

The first scientific research on the use of polymers on highway and bridge deck overlays began at the Bureau of Reclamation and Brookhaven National Laboratory under sponsorship of the Federal Highway Administration in the late 1960's. That experimental work first began using unsaturated polyester resins, as well as epoxy and methyl methacrylate and other polymers as potential binders from aggregate to be used for Highway and Bridge Deck Overlays. The Bureau of Reclamation and Brookhaven National Laboratory jointly developed the drop-in or broom and seed method in which first resin and then aggregate are broadcast over the deck until the desired thickness is achieved.

In the early 1980's, Cal-Trans was using the premix or Oregon method. This method, by contrast, calls for batched concrete mixers to combine the polyester – styrene aggregate mixture and to distribute the resultant mix with screeds and control wires so as to control thickness and finish with regular concrete finishing methods. The resin-to-aggregate ratio is similar in the two methods and so are the costs.

Cal-Trans elected in 1985 to go forward with its first major application of polyester polymer concrete highway overlay. The site chosen was the Donner Pass section of I-80, just west of the Nevada border. The Pass had gotten its name from weather. The Pass is named for the tragic Donner Party that froze in 1846 enroute to gold country and the warm climate of California. Extreme weather changes are characteristic of the Pass. The Pass is now the route of Interstate 80 as it crosses the Sierra Nevadas between Reno, Nevada and Lake Tahoe, California.

A report on a 1982 field test done under federally funded research entitled, "Experimental Overlays Utilizing Magnesium Phosphate, Methyl Methacrylate and Polyester-Styrene Concrete" describes the I-80 site as follows: "The site was located on eastbound Interstate 80 at approximately 6,500 feet in elevation on a +5% grade with varying super-elevation up to 8%. The existing pavement surface, which was constructed in 1962, consisted of non-reinforced PCC with skewed joints at 15-foot spacing. The pavement was extremely deteriorated due to rain and chain abrasion. The pavement is subjected to large daily temperature fluctuations and severe freeze-thaw conditions."

The average 1983 daily traffic (ADT) for this four-lane freeway was 9,750 with a truck ADT of 950. The average rainfall is 61 inches, including an average snowfall of 410 inches. (2)

Reichhold's 32300 flexible isophthalic polyester resin was utilized on this research project. This resin is currently marketed with silane coupling agents premixed into the resin under the specification. The Reichhold product code is 32043.

The 1985 Donner Pass job was, in fact, the culmination of seven years of both lab tests. The California Department of Transportation (Cal-Trans) conducted Field tests and a literature search. Cal-Trans experiments included: (1) high density, low slump PCC, (2) Butadiene styrene latex modified PCC, (3) epoxy bonded PCC, (4) epoxy concrete, (5) methyl methacrylate (MMA) polymer concrete and (6) polyester – styrene polymer concrete.

Of all these systems, Cal-Trans selected the polyester-styrene based system.

Suppliers of the polyester-styrene based systems suggest that the systems have the following benefits:

- Permits rapid application and allows for fast return to use with little or no disruption of traffic

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- Protects steel reinforcements from infiltration of water and chloride ions from de-icing salts, which accelerate corrosion
- Adds minimal additional dead load to the structure
- Creates a long-lasting, skid resistant surface
- Provides high resistance to wear
- Reduces costs by minimizing traffic disruption and control.

Early testing had also concluded that sandblasting of the pavement surface was not adequate to ensure good bonding. A more complete cleaning of all contaminants from the old pavement surface is a must. Humble Equipment provided a shotblaster developed specifically for pavement overlay work. (*Figure 1*)

The shotblaster “throws” 3000 pounds of small steel shot per minute against the roadway. Most of the 0.046-inch diameter shot is caught in a vacuum hood filtered and reused many times.

THE JOB

The job was awarded to Brutoco Engineering on May 21, 1985. The project included nearly ten (10) lane miles of polyester-styrene concrete overlay on a three-lane-wide pavement that included a five-percent grade. The PCC pavement was severely abraded due to truck tire chain abrasion. Daily temperature variation of 50 F and more occurred on the site. The contract included repair of several PCC slabs full depth due to severe cracking. Many less severely cracked slabs were overlaid with polyester-styrene concrete.

Following surface preparation with a shotblaster, the contract specified a high molecular weight with methyl methacrylate primer coat or an unsaturated diaromatic oxide glycol fumerate. It was suggested the project be used to evaluate two alternative polyester resins identified as Type II and Type IV respectively. Type II was a wax-free unsaturated isophthalic polyester cut in 40-45% styrene to a viscosity of 75 to 200 cps. This is the unique polyester type, supplied earlier by Reichhold, with which Cal-Trans had had so much success. Its unusual feature is the resin’s high flexibility with tensile strength of 2500 psi and a minimum elongation of 35%. Type II was actually supplied by the Koppers Company (later acquired by Reichhold).

The other system tested was designated as Type IV. It was also an unsaturated isophthalic polyester but more rigid. The resin was supplied by Chagrin Valley Industries (later known as FTI). The following table lists typical polyester-styrene resin’s physical properties: (see Appendix 1).

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The aggregate specified was ½ -in maximum with less than 25% crushed particles, maximum oil absorption of one percent and a moisture content of less than ½ percent at the time of mixing. Dry Mix Products of Roseville, California delivered aggregate in reusable nylon bags, which held 3,500 pounds of dry aggregate.

A mobile, screw-auger type continuous mixer with self-contained separate aggregate, resin and peroxide initiator compartments was used. The peroxide, methyl ethyl ketone peroxide (Reichhold's 46-709) was introduced into the resin prior to mixing with the aggregate. Flow sensing valves and alarms were also required.

Each mixer was loaded with five bags of rock and four bags of sand, or about 31,000 pounds in all, which was blended at 55-45 percent ratio. This was then mixed with an additional 12 to 14 percent polymer resin (about 50 to 60 gallons resin and one gallon catalyst per cubic yard). (*Figure 2*) Each mixer carried about 400 gallons of resin and 15 gallons of catalyst in its divided resin tanks. Each mixer was reloaded every 45 minutes. As it was loaded, one crewmember cleaned the screw by running dry aggregate through it, followed by hand scraping if needed. Each evening the system was washed down with acetone. (*Figure 3*)

The finishing machine was Gomaco C-450. Dry screenings were specified to be broadcast over the overlay after finishing to ensure initial skid resistance. The 3.6 miles was applied to a minimum thickness of ¾-in over six weeks in the fall and an additional four weeks in the spring. (*Figure 4*) The schedule allowed for downtime so as to avoid rain and snow so common to the Donner Pass.

THE UPDATE

In his 1988 paper, Paul Kraus, then Senior Materials and Research Engineer at Cal-Trans concluded, "Due to the nature and cost of repairing bridge decks, polyester-styrene concrete overlays on bridge decks have proven to be a viable and satisfactory rehabilitation technique. Over twenty-five bridge decks have been overlaid with polyester-styrene concrete overlays and all the overlays are performing well. There have been no delaminations on any polyester concrete overlay placed by contract and only one experimental overlay has shown minor delaminations. None of the bridge deck overlays placed since 1983 have shown signs of wear or cracking. Advantages include: rapid return of the structure to traffic, protection of the reinforcing steel from water and deicing salts, minimal additional dead load, no modifications to the barrier rails required, grade or slope corrections can be made, and installation involves using familiar construction techniques."

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In 1996, I contacted Henry Jerzak, Cal-Trans Material and Research Associate, now retired, who supplied the wear data shown as Appendix 2.

According to Jerzak, wear data for Type II, the flexible or elastomeric polyester-styrene, was very similar to the Type IV. Based on the ready availability of Type II and its flexibility, a required prerequisite for movement on bridge decks, Cal-Trans continues to specify the Type II flexible polyester (with the addition of 1% silane to improve bonding to the aggregate.) Jerzak says that this is finally the ideal system that sticks to concrete. "If properly primed, it sticks tenaciously" indicated Jerzak. "The few problems encountered were always found to be applications related, i.e. poor surface preparation, severe weather conditions (applied below 40 F) or inadequate catalyst. It is a simple system, but must be done right the first time," he concludes.

In 1991, Al Klail completed the Benicia-Martinez bridge deck over San Francisco Bay for General Contractor, Kiewit Pacific Co. This single bridge consumed approximately 850 cubic meters of polyester polymer concrete. (*Figures 5-8*) Shortly thereafter, Al was also the key man on site of the approach to the Golden Gate Bridge, the project known as Doyle Drive. Videos of this project installed at night in the fog with bridge traffic moving in adjoining lanes have been shown at TRB.

For the past several years, Cal-Trans has specified approximately two-dozen projects per year. Other states have shown interest in the excellent results obtained by Cal-Trans. The state of Nevada virtually copied the specifications written by Cal-Trans, and has been overlaying bridge decks with the same resin system for 14 years. In 1999, the state of Utah did its first polyester polymer concrete project overlaying two bridge decks on Bengenter Highway, south of Salt Lake City. In 2000, the state of New York led a project in upstate New York, about one hour north of Albany. The project consisted of overlaying Martin Marietta composite bridge panels with polyester polymer concrete. Again in 2000, Cal-Trans also led a project for the polyester polymer concrete overlay of a Martin Marietta composite bridge deck near the town of Mecca, California.

There were several other large projects in 2000: Interstate 405 in Costa Mesa, California; Interstate 5 in Gorman, California; and Highway 395 near Reno, Nevada.

CONCLUSION

Dozens of jobs have now been completed using Polyester Polymer Concrete Highway and Bridge Deck overlays without a single failure. In each case, Reichhold 32043 was the resin of choice. The storage quality is excellent.

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That's the story of how polyester polymer concrete highway and bridge deck overlay has gone from "experimental" to "state of the art."

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"A Guide to Polyester Polymer Concrete Bridge and Highway Overlays," Reichhold Chemicals, Inc., Research Triangle Park, NC 27709, Copyright 1990.

The author also utilized information supplied by the following:

- a. Frank Fekete, President, FTI, Monroeville, PA,
- b. Steve Frank, Product Manager, Atlas Construction Supply, Inc., San Diego, CA,
- c. Henry Jerzak, retired. California Department of Transportation, Sacramento, CA.

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APPENDIX 1

	Type II	Type IV
	Polyester Concrete	Polyester Concrete
Resin Viscosity (77 °F) (CA 434)	75-200 cps	400-500 cps
Resin Tensile Strength (CA 434) minimum	2,500 psi	8,000 psi
Resin Elongation (CA 434) minimum	35%	5%
Flexural Strength (24 hours)	1,800 psi	2,100 psi
Compressive Strength (24 hours)	5,800 psi	9,000 psi
Bond to Dry PCC (24 hours)	900 psi	720 psi
Bond to SSD PCC (24 hours)	750 psi	280 psi
Modulus of Elasticity (24 hours)	1.2×10^6 psi	2.6×10^6 psi
Thermal Coef of Expansion	14.6×10^{-6} psi in/in/°F	-

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APPENDIX 2

Polyester Styrene Concrete

Type IV

03-Placer-80-E.B. Lane #3. Right Wheel Track

Each site is an average of 3 readings

Mile Post (Approximately)

Date	52.00	53.33	52.48	52.68	Avg
10/22/1986 225D	15	14	13	11	13
06/04/1987 751D	55	53	36	24	42
06/26/1989 804D	60	66	51	32	54
09/18/1991 735D	69	106	59	55	72
09/23/1993 364D	54	57	32	19	41
09/22/1994					
Total Wear	253	296	197	141	222

Readings are thousandths of an inch. Average wear .028" per year

Donner Pass Job I-80
October 1985



Figure 1: Seven foot shotblaster.

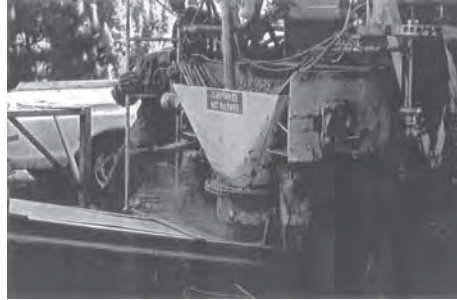


Figure 2: Back of Haws mixer.



Figure 3: Spreading of the premixed polymer concrete.

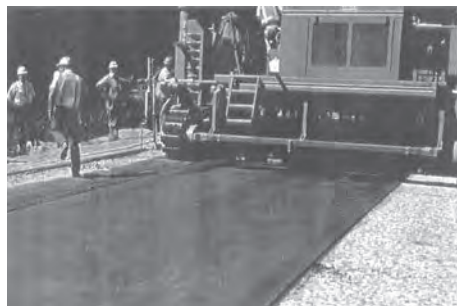


Figure 4: Placing of the 3/4 inch overlay.

Benicia-Martinez Bridge Deck
(San Francisco Bay)
Fall 1991



Figure 5: View of the Benicia-Martinez Bridge (San Francisco Bay).



Figure 6: Application of the primer.



Figure 7: Automated deposition of the premixed polymer concrete.



Figure 8: Inspection of placed 3/4 inch overlay.

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