Flexible Polymer-Cement Based Repair Materials and Their Applications

By Ivan Razl

Portland cement-based concrete and mortar are two of the most widely used construction materials. The low cost, high stiffness, high compressive strength, nonflammability, and ease of fabrication are the most obvious advantages of concrete. The low tensile strength; brittle nature; and, to some extent, long-term durability of concrete represent its most serious limitations. Reinforcing concrete with steel provides the necessary tensile strength, and the incorporation of fibers increases the toughness (resistance to crack propagation) of concrete. The polymer modification of cement paste greatly increases the tensile and flexural strengths and reduces the brittle nature (increases toughness) of mortars and concrete.

History

The ancient history of using natural polymers, including asphalt, to modify lime and clay mortars goes back to Babylonia, Egypt, and ancient India. The Europeans in the Middle Ages knew how to use oxen blood and egg whites to increase the strength and durability of lime mortars. The modern history of man-made modifiers starts in the late 1950s with the development of butadiene styrene, polychloroprene, and acrylic latex and their use in modifying mortars and concrete. The main application of polymer-modified cements at that time was in concrete repair. The use of polymers in the fabrication of bridge and parking garage overlays was developed in the U.S. and Canada in the early 1970s. The main function of the polymer was to reduce concrete permeability and increase resistance to chloride penetration, toughness, and adhesion.

Classification

The polymer-modified portland cement paste is a composite material consisting of an inorganic cement paste and polymer. Both materials are totally different. Accepted definitions for portland cement, polymer, and composite material are as follows (Encyclopedia Britannica):

*"**Portland cement** is binding material in the form of a finely ground powder, usually gray, that is manufactured by burning and grinding a mixture of limestone and clay or limestone and shale. When mixed with water, the anhydrous calcium silicates and other constituents in the Portland cement react chemically with the water, combining with it (hydration) and decomposing in it (hydrolysis) and hardening and developing strength."*

*"**Polymer** is any class of natural or synthetic substances composed of very large molecules, called macro-molecules, that are multiples of chemical units called monomers."*

*"**Composite material** is a solid material that results when two or more different substances, each with its own characteristics, are combined to create a new substance whose properties are superior to those of the original ..."*

The performance characteristics of polymer-modified cement are controlled by characteristics of its individual components. The main characteristics of a polymer and hydrated portland cement paste are listed in Fig. 1. The type of cement paste, type of polymer, and their respective quantities largely control the properties of polymer cement composites. However, there are other influences controlling the final properties of the composite such as the type of surface-active agents used, mixing, and curing. There are a large number of polymer (monomer) types that are used in modification of portland cement paste. Figure 2 shows the main classes of materials available. In this article, discussion will be limited to polymer latexes and redispersible polymer powders. These types of polymers can be further classified by their chemical natures.

The glass transition temperature T_g of a polymer is important, as it affects the flexibility of polymer cement. Below the T_g temperature, polymers exhibit "glassy" behavior and are relatively brittle with limited flexibility. When at temperatures above T_g, the polymer is more flexible, tough, and exhibits a larger elongation in tension. At T_g, other properties change, such as density, specific heat, dielectric coefficient, rates of gas/liquid diffusion through the polymer, and conductivity. The mechanism of polymer modification of portland cement is complex, but can be schematically described in three separate steps:

1. Immediately after mixing with water, the cement paste particles start to hydrate and cement gel begins to form on the surface of the particles;
2. Mixture of cement gel-covered unhydrated cement particles is enveloped with a close-packed layer of polymer particles; and
3. The closely packed polymer particles start forming polymer films (membranes) after the removal of water by hydration and evaporation.

The polymer modification results in an improvement in mechanical properties, a decrease in permeability, and an increase in chemical resistance. The typical relationship between the polymer content, expressed as polymer/cement ratio (meaning the weight of polymer solids divided by the weight cement solids), is shown in Fig. 3. The T_g of the acrylic polymer used in the study presented in Fig. 4 was 55 °F (13 °C). The polymer modification affects many other properties, which are summarized in Fig. 5. The typical application of polymer-modified cements (mortars) are in concrete repair mortars, polymer-modified cement coatings, and polymer-modified concrete.

Flexible Polymer Cement Composites and Applications

Highly flexible polymer-modified cements (mortars) can be formulated using various types of polymers with a low T_g temperature. The typical tensile load deflection curves of non-reinforced or reinforced polymer-modified cements (mortars) at two different levels of polymer modification are shown in Fig. 6 and 7, respectively. The key reason for using these materials is their flexibility, allowing waterproofing of concrete structures with "moving cracks." The crack bridging capacity of polymer-modified cement is shown in Fig. 8. In addition, these materials, due to their high polymer content, exhibit a considerably higher chemical resistance (even in acidic environments) when compared with conventional portland cement mortars or concrete.

Case History—The Repair of Concrete Digester Tank, Bedford, Nova Scotia, Canada

In 1993 the concrete roof of a digester tank in Bedford, Nova Scotia, collapsed. The most probable reason for the failure was deterioration of the prestressed gunite concrete combined with a temporary excessive pressure in the tank. The concrete roof was replaced with a "gas holding" steel roof. Time and excessive pressure eventually caused the reinforced concrete tank, which measured 35 ft (10.7 m) in diameter and 22 ft (6.7 m) high, to develop vertical and horizontal cracks. The repair required long-term sealing of the

POLYMER	PORTLAND CEMENT
• Organic	• Inorganic
• Low modulus of elasticity	• High modulus of elasticity
• Tough	• Brittle
• High tensile strength	• Low tensile strength
• Relatively high elongation	• Very low elongation
• Sensitive to temperature	• Insensitive to temperature
• Expensive	• Inexpensive

Fig. 1: Main characteristics of a polymer and hydrated portland cement paste

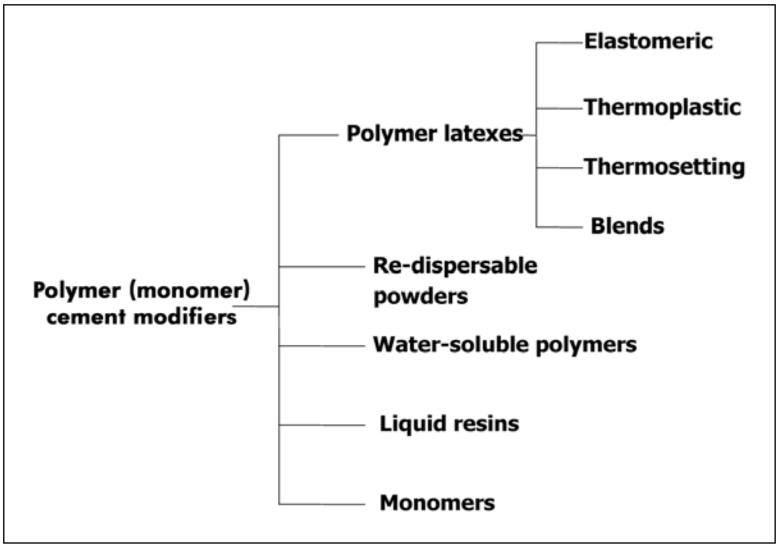

Fig. 2: Classification of polymers (monomers) used in modification of portland cement paste

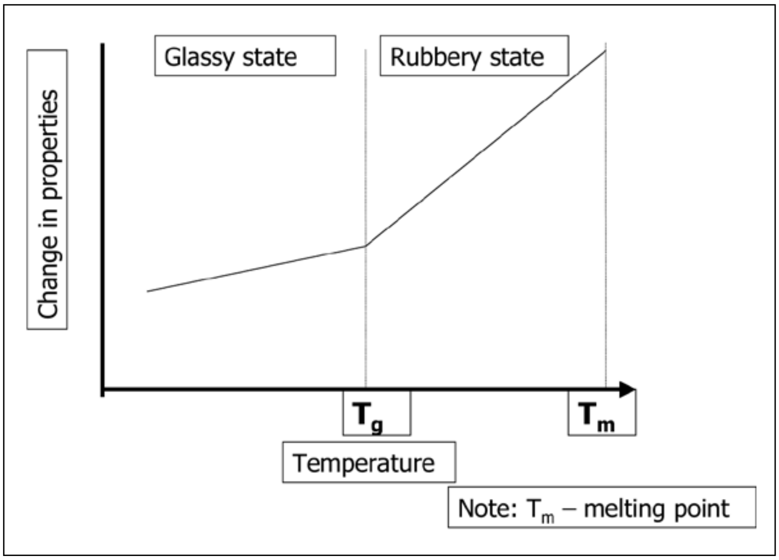

Fig. 3: Glass transition temperature T_g *of an amorphous (non-crystalline) polymer*

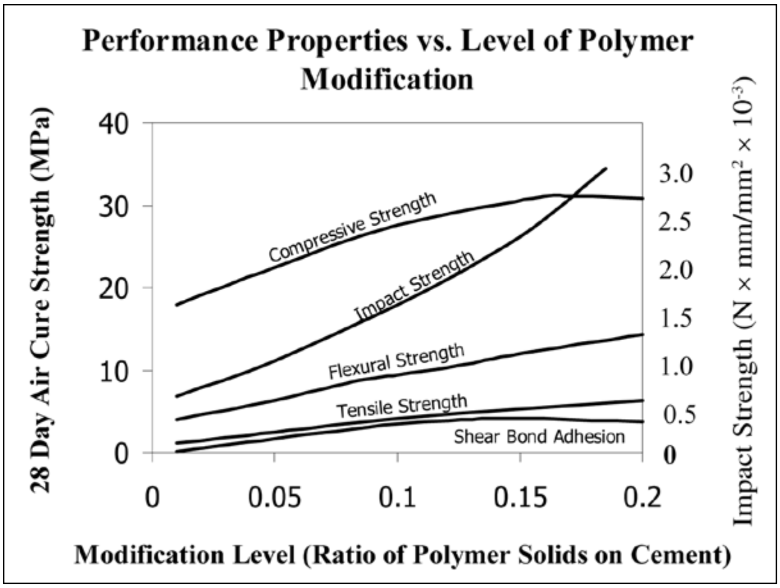

Fig. 4: Typical relationship between polymer/cement ratio (p/c) and strength properties of a mortar (T_g of the polymer = 13 °C)

• Adhesion	increased
• Modulus of elasticity	increased or decreased
• Water vapor permeability	decreased
• Hydraulic permeability	decreased
• Drying shrinkage (at 28 days)	decreased or increased
• Creep	decreased or increased
• Chemical resistance	improved in some chemicals
• CO_2 permeability	decreased
• Chloride penetration resistance	increased

Fig. 5: Typical effects of polymer modification on performance of polymer-modified, portland cement mortars

cracks in the reinforced concrete wall as well as concrete protection.

The designer selected two materials for the repair: alkaline-resistant glass and polymer, fiber-reinforced, micro-silica enhanced mortar as a primary waterproofing layer and a highly flexible, polymer-modified cement as the secondary waterproofing and protective layer.

The crack spanning tests carried out on the fiber-reinforced mortar showed that the maximum crack width of this material, reinforced with the welded wire fabric placed over the cracks, was approximately 0.03 to 0.04 in. (0.75 to 1 mm). The tests and the practical experience with this material system have also shown that if the crack did telescope through the layer, it would be only hairline. Since it was difficult to accurately determine the movement of the cracks in the reinforced concrete wall of the tank under the fully loaded condition, it was possible that the primary waterproofing layer would develop fine through-cracks due to movement of the substrate cracks. Therefore, an additional protective coat of a flexible portland cement-based material was applied as a secondary waterproofing and protective layer. The high level of polymer modification provides a very low modulus of elasticity material, with 10% direct tensile elongation. The high flexibility allows crack spanning of fine cracks and the high polymer content provides improved chemical resistance when compared with conventional concrete.

After cleaning the tank by sandblasting, the vertical and horizontal cracks were covered using a 16 gage galvanized welded fabric 12 in. (0.3 m) wide with an opening of 2 x 1 in. (5.1 x 2.5 cm), mechanically fastened to the concrete. After the placement of the welded wire fabric, a 1/2 in. (1.3 cm) thick layer of fiber-reinforced mortar was applied to the concrete surface of the tank. The material was mechanically applied using the “wet process” shotcrete method. The following day the surface of the primary layer was thoroughly cleaned with high-pressure water. Then a layer of flexible cement, approximately 1/8 in. (0.3 cm) thick, was rolled on in two coats. The waterproofing protective system was air cured for approximately one week before the tank was put back into use. No additional fabric reinforcement was used in the flexible cement layer.

The performance of the repair has been excellent. The interior of the tank was inspected in 1997, 4 years after the installation, and no leaks or deterioration of the waterproofing system was found. Further exterior inspections in 1999, 2000, and 2001 also revealed no leaking.

The key innovative feature of this project was the crack spanning mechanism employed. The crack spanning mechanism of the primary layer was as follows: the movement of the crack creates a very high shear force at the interface of the primary layer and the substrate concrete at the edges of the crack. The presence of the welded wire fabric increases the tensile strength of the layer, thus forcing a small, 1/4 in. (0.6 cm) de-bonding on each side of the crack due to the presence of the high shear forces. The presence of high volume, high modulus fiber in the mortar layer is also very important for arresting the crack trying to propagate through the layer. This mechanism has been thoroughly tested and the site evaluated. There is a limit to what crack movement this mechanism can span. Since there was a possibility of cracks exceeding this movement under the full load of the liquids in the tank, a secondary flexible cement layer was applied.

The crack spanning of the secondary layer is controlled by the flexibility and thickness of the cement layer. The experience and the testing showed that fine cracks are spanned using the flexible cement material.

An additional important feature of this repair is the long-term successful performance of the polymer cement layer under continuous immersion in heavily polluted liquids. Also, the flexible cement, with its high level of polymer modification, provides a better chemical resistance in acidic environments when compared with conventional concrete or mortar. The chemical resistance of the material in various chemical environments has been thoroughly investigated.

Case History—The Repair, Waterproofing, and Chemical Protection of a Wastewater Treatment Facility, Windsor, Ontario, Canada

In 1996 the city of Windsor, Ontario, undertook major repairs of reinforced concrete structures at a wastewater treatment facility. The main problems were cracking and leaks in concrete tanks immediately behind the primary filtration station. There was also some chemical deterioration at the effluents level, approximately 15.7 in. (40 cm) high and 0.16 to 0.2 in. (4 to 5 mm) deep. In addition, reinforced concrete troughs (where the flocculants are being introduced into the stream of liquid) suffered from chemical deterioration, approximately 0.24 to 0.31 in. (6 to 8 mm) deep, due to the lower pH in that area. The reinforced concrete structure was approximately 30 years old. There were no signs of freeze/thaw damage or spalling of concrete due to the corrosion of the reinforcing steel.

The design engineers specified highly flexible polymer-modified mortar coating to provide waterproofing and chemical protection of the concrete tanks.

High-pressure water was used to clean the surface of the concrete tanks. The vertical to horizontal junctions (slab to wall) were coved and surface deterioration was repaired where required, using a thin set patching mortar (these areas were relatively small in comparison with the total area treated). The entire area was coated with 0.08 in. (2 mm) thick flexible polymer-modified mortar applied in two coats. The cracks and the coves were reinforced with a polypropylene mesh.

Case History—Municipal and Industrial Land-fill Sites, Chemical Protection of Dry Pre-Cast Manholes, Brantford, Sarnia, Ontario, Canada

An extensive investigation of concrete manholes and concrete drainage pipes of municipal

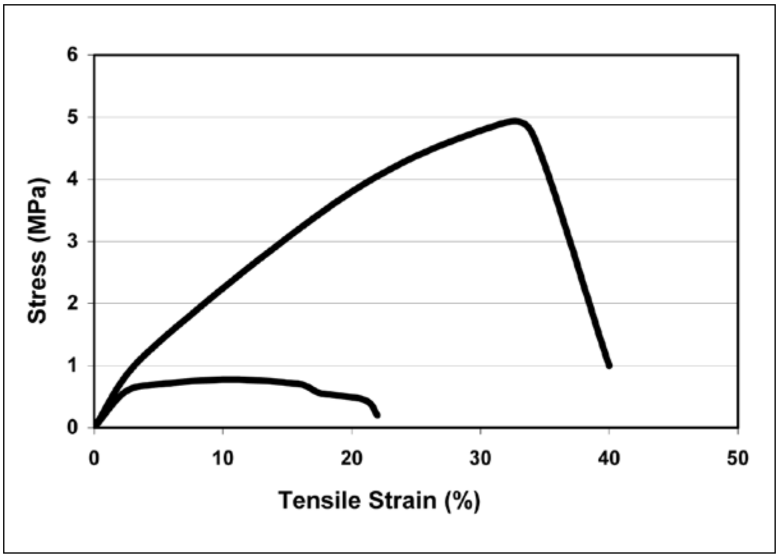

Fig. 6: Tensile stress strain curves of FCC, polymer level, nonreinforced, and reinforced

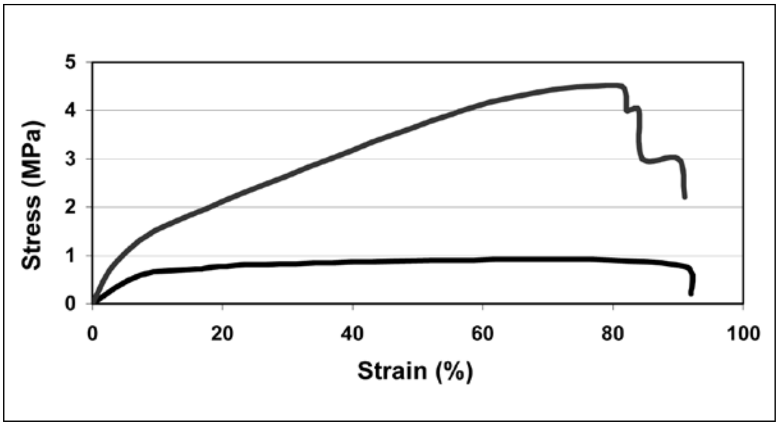

Fig. 7: Tensile stress strain curves of FCC, polymer level, nonreinforced, and reinforced

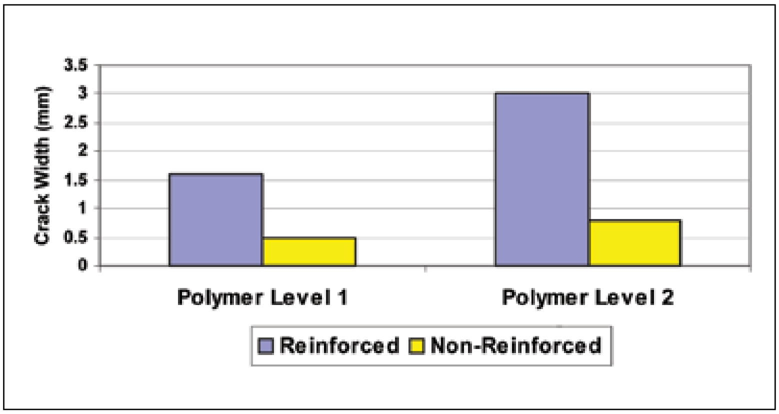

Fig. 8: Crack spanning widths of FCC, polymer level 1 and 2, nonreinforced, and reinforced

land-fill sites in Ontario, using a robotic TV camera investigation, showed that after 25 to 30 years of service, there was approximately 0.47 to 0.59 in. (12 to 15 mm) deep concrete deterioration in many areas, due to chemical attack. Since the specified design life of such structures is presently changing from 30 to 100 years, the design engineers have been looking for various methods to increase the chemical resistance of wet or dry cast concrete pipes and manholes. The typically used epoxy coatings exhibit a high chemical resistance, but in a negative side application, the epoxy coating debonds, because the water is getting behind the coating. The polymer-modified mortars with a high content of a low T_g polymer provide a considerable improvement in chemical resistance when compared with portland cement mortar. This improvement is sufficient to increase the service life of the pre-cast concrete components to presently specified levels and beyond. In addition, they do not exhibit the problem of de-bonding as the epoxy coatings do. Also, they are less expensive and easier to apply when compared with the epoxies.

The dry-cast concrete pipes were cleaned using high-pressure water. The flexible polymer-modified mortar was applied by spraying and brushing. The brush was used to provide a "pin-hole" free coating approximately 0.04 in. (1 mm) thick. The second coat was applied in the same manner and thickness. The material was air-dry cured.

Case History—Underground Reinforced Concrete Tanks, Port of St. John's, Newfoundland, Canada

Large volume, underground reinforced concrete tanks were built during the World War II and used for storing bunker oil. In 1997 it was decided to refurbish the tanks and use them as storage tanks for drilling mud used in oil drilling off the shore of Newfoundland. The tanks exhibited severe cracking. The most serious problem was the concrete contamination with oily residues and the original bituminous protective coating.

The concrete surface was cleaned using high-pressure water and sand in combination with industrial degreasers. The degreasing of the surface was repeated several times.

The cracks were treated with a highly flexible polymer-modified mortar layer, reinforced with an approximately 5.9 in. (15 cm) wide polypropylene reinforcing fabric. The rest of the areas were coated with a different type of a flexible polymer-modified mortar, designed to provide long-term chemical resistance to drilling mud.

Case History—Negative Side Waterproofing of Underground Parking Garage Slabs, Hotel Carlton, Bratislava, Slovakia

The open pit method was used in construction of an underground parking garage structure in the front of Hotel Carlton, Bratislava, Slovakia. The structure is situated near the Danube River with a very high ground water level. A preformed waterproofing membrane was used on the positive site. The water leaks that occurred during and shortly after the construction were completely treated with injections of a chemical grout (polyurethane). The ground slab, which exhibited severe water leaks, was waterproofed by using the following procedure: the active water penetration through cracks was stopped using a hydraulic cement based water plug material. The slab was treated with two coats 0.08 in. (2 mm) thick of a highly flexible polymer-modified mortar, reinforced with a polypropylene fabric. In addition, the surface was coated with an acrylic, waterborne floor coating and two coats of waterborne clear sealer to provide color to the surface. The treatment provided total waterproofing of the slab. The treatment has been now functioning for more than 1 year without any sign of water penetration.

Case History—Repair, Waterproofing, and Chemical Protection of an Elevated, Reinforced Concrete Tank, Chemical Works, Novaky, Slovakia

The reinforced concrete tanks used for the storage of calcium hydroxide solution have deteriorated considerably over the last 40 years. The excessive spalling of concrete due to corrosion of the reinforcing steel and severe cracking were the main problems. The interior surface of the concrete tank was originally protected and waterproofed by a layer of a bituminous material. This created an additional problem, since the bitumen was partly impregnated into the concrete surface.

Deteriorated concrete was removed using chipping hammers and high pressure water. Polymer-modified cement rust-proofing material containing corrosion inhibitors was applied over all the exposed steel. In the areas of high level of bitumen contamination of the concrete surface, a bonding layer, approximately 0.59 in. (15 mm) thick, of fiber reinforced wet shotcrete mortar enhanced by a high level of micro-silica, was used. Two layers of a highly flexible polymer-modified mortar applied in the total thickness of approximately 0.12 in. (3 mm), provided the final waterproofing and protection of the interior of the reinforced concrete tank. The exterior of the tank was repaired using the same procedure and materials.

Case History—Repair and Waterproofing (Oil-Proofing) of an Industrial Wastewater Treatment Facility, Slovnaft Bratislava, Slovakia

This industrial wastewater treatment facility treats water containing a high content of hydrocarbon oil residues and dispersed solid materials coming from the oil refining and petrochemical manufacturing processes of the company. The liquid industrial wastes are subject to a complex treatment process that takes place in various types of reinforced concrete tanks. Over the course of many years the cracking of the concrete structures resulted in the penetration of the hydrocarbon residues to the exterior of the structures. In 2000 and 2001 a number of tanks were repaired and waterproofed using the following procedures and materials.

The interior surface of the concrete tanks was coated with a 2 in. (5 cm) thick layer of oil and grease, which was mechanically removed first. This was followed by the removal of delaminated concrete by chipping out the cracked areas to form approximately 1.6 x 1.6 in. (4 x 4 cm) grooves. The concrete surface was cleaned with repeated treatments of industrial detergents and high-pressure water. The chipped-out grooves and delaminated areas were patched with a fiber-reinforced, microsilica enhanced repair mortar and the exposed reinforcing steel was treated with two coats of polymer-modified mortar coating containing migrating corrosion inhibitors.

The crack areas were brush coated with two coats of a highly flexible polymer-modified mortar, for a total thickness of 0.08 in. (2 mm). The entire surface was brush coated with two coats of flexible polymer-modified mortar for a total thickness of 0.06 in. (1.5 mm). The smooth surface of the final coat was achieved by using a steel trowel.

The same procedure was used to repair the exterior of the tank, but the relatively thick layer of flexible polymer-modified mortar was replaced with two coats of polymer-modified cement coating with a consistency of a thick latex paint. Conventional paint rollers were used to apply this material.

Extensive evaluation and testing were carried out prior to application in larger areas. The chemical resistance and waterproofing characteristics under the high water pressure of the flexible mortar coating were thoroughly evaluated. A large number of bond tests were also carried out to develop the surface preparation procedures necessary to achieve a bond to the surface that, even after extensive cleaning, still contained a significant content of oil residues impregnated into the surface of the concrete tanks. The repairs have been very successful in obtaining a high bond to the waterproofing surface and providing a complete water-tightness to the tanks.

Versatile Materials

The polymer-modification of mortars or concrete mainly increases the toughness, and to some extent the tensile and bending strengths, of these materials. By using a higher level of polymer modification with a polymer exhibiting a low T_g, a high flexibility of such composites can be achieved. The main use of these materials is in thin section applications, in waterproofing, and in chemical protection of concrete structures. The high flexibility allows spanning of substrate cracks and provides waterproofing and protection that cannot be achieved using conventional mortars or high T_g polymer-modified mortars.

__Ivan Razl__, PhD, P.Eng, is Technical Director of Gemite Products. Razl has extensive experience in research and development of polymer and cement composite systems, concrete protection and restoration materials, and novel building systems, including floor and roof systems. He is a project leader and is responsible for all theoretical considerations, material design criteria, design of experiments, analysis and interpretation of data, and all the decisions that will be made during a development program. Razl has undergraduate degrees from the Chemical Technology College, Zlin, Czech Republic, and the Chemical University, Pardubice, Czech Republic. He also has an MSc in Chemical Engineering and a PhD in Chemical and Civil Engineering from the University of Toronto. Razl is registered with The Association of Professional Engineers of Ontario, and is a member of many associations, including the Construction Specifications Institute, Canada; ICRI; ACI; the Building & Concrete Restoration Association of Ontario; the EIFS Council of Canada; and the Toronto Society for Coatings Technology.