3.6 Polymer Impregnated Concrete

Another common area where polymers have been used in conjunction with cured Portland cement concrete structures has been in the formation of polymer impregnated concrete. Chosen monomer/monomers are impregnated into the prepared concrete surface and subsequently polymerized, typically by the application of heat and the activation of chemical initiators within the monomer constituent. An improvement in the physical properties such as the mechanical strength (compressive, flexural and tensile) and modulus of elasticity have generally been observed when this impregnation process had been completed. Theoretically any voids within the cementitious matrix could be sealed by this impregnation process, thus preventing the penetration of water and carbon dioxide from entering the structure. Analysis also suggested that the corrosion of reinforcing bars within the concrete was subsequently prevented by using this process if all the voids are sealed. An increase in the durability and resistance to the damage that can result in concrete as a consequence of water freezing within the pores and expanding, (i.e., freeze-thawing cycle), has also been identified. A variety of monomers can be used to produce polymers with either a glassy or a rubbery consistency. Typically monomers impregnated into concrete structures included MMA, styrene, acrylonitrile and vinyl chloride.

3.6.1 Concrete Preparation and Impregnation Process

Most polymer impregnation applications (such as concrete bridges, floors and walls) involved the partial impregnation of the monomer(s) species into the cementitious substrate to depths of up to 0.04 m. Full impregnation of the monomer species involved initially removing the air contained within the cementitious microstructure by applying a vacuum. The monomer was then introduced into the microstructure under pressure to aid the impregnation process. The techniques involved in this process cannot be applied practically to large surface areas such as concrete floors or bridges and are generally used to fully impregnate precast concrete structures such as beams. The process of impregnation principally involves three stages, removal of moisture from the concrete, introduction of the monomer, polymerization followed by curing. Before impregnation of the monomer could begin the cementitious material had to be prepared. Initially the concrete surface was carefully cleaned to remove any contaminants and loose materials, which hinder the absorption of the monomer into the substrate.

It is generally accepted that the concrete will contain a certain degree of moisture and its removal is generally achieved by heating the surface. The disadvantage of this process is that the heat was normally applied to one surface only of the concrete structure, (i.e., the surface undergoing the impregnation process). Hence the distribution of moisture could vary throughout the concrete matrix. Heat was generated from fuel burners or infrared heaters and directed towards the surface of the concrete. This process is carried out for several hours until the substrate surface has achieved a suitable temperature and the vast majority of moisture held within the microstructure is removed. Moisture content of less than 2% is desired within the cementitious matrix before the impregnation of the resin component proceeds. One of the key disadvantages of utilizing polymer impregnated systems in relation to polymer concrete is a heat source is required to initiate curing and produce a hardened composite. A layer of dry sand is normally distributed over the surface onto which the monomer is poured. The temperature of the concrete is generally not allowed to exceed 100 °C in order to avoid damage such as cracking. The purpose of the sand is to act as a barrier in order to prevent the monomer dissipating to undesirable areas. Indeed the quantity and period over which saturation occurred would be governed by the type of monomer and degree of impregnation desired which in the vast majority of cases was partial rather than complete. Once the impregnation of the monomer had been completed the substrate is generally covered with polyethylene to prevent a loss in the monomer concentration due to evaporation. Typically the monomer is allowed to penetrate into the concrete matrix for a period of four to twelve hours in order to ensure penetration occurred to a suitable depth, i.e., 0.04 m. Once this period had expired, polymerization of the monomer species was initiated. This was normally achieved by exposing the monomer to a suitable temperature in order to activate the initiator (typically benzoyl peroxide) contained within monomer. Free radicals are subsequently generated which initiate polymerization of the monomer. The heat source used to initiate polymerization was normally steam in order to avoid any potential hazards associated with the monomer, (i.e., flammability).

This polymerization process normally occurred over three to six hours. Other chemicals, (i.e., TMPTA), were incorporated into the monomer system in order to promote crosslinking and hence the formation of a crosslinked polymer matrix within the concrete microstructure.

3.6.2 Physical Properties

Most significant improvement in the physical characteristics of the concrete was observed by adopting this process. Negligible creep was also observed unlike with traditional concrete systems. Whilst significant improvements in compressive strength of polymer impregnated concrete were also recorded. Research tended to suggest that the depth of penetration did inherently govern the stability of a concrete slab to freeze thawing and hence the overall durability. A slight improvement in the abrasion resistance of the impregnated concrete surface in relation to that observed without any polymer modification was also noted (Table 3.2).

An assessment of the benefits of impregnating the cementitious microstructure with a resin determined a general improvement in the region of 30% to the coefficient of thermal expansion. Whilst a dramatic reduction in the ability of water and other contaminants to penetrate the surface was observed, in some cases a reduction of up to 99% was recorded. The inclusion of the resin effectively reinforced the internal structure of the concrete substrate which was capable of withstanding structural changes to a greater extent during loading. Certain investigations did indicate that long-term prevention of contaminants penetration into the microstructure was linked to the type of monomer which had been utilized. The ability of the monomer to penetrate into the concrete substrate will be governed by its viscosity and surface tension. Penetration of the monomer obviously increased the porosity of the concrete structure. Of course this parameter will be influenced by a number of factors, water to cement ratio, chemical composition of the cement and temperature of curing. All these factors along with the degree of polymerization will govern the overall depth of polymer impregnation. The potential of a reaction between the cementitious matrix, (i.e., calcium silicate hydrates), and the monomer was also a possibility which could affect the physical performance of the polymer impregnated concrete.

Table 3.4 Typical physical properties recorded for Portland cement concrete impregnated with MMA polymerised by cobalt radiation (adapted from [30])

Physical properties	Value registered
Compressive strength (MPa)	139.7
Tensile strength (MPa)	11.2
Modulus of elasticity (MPa)	43436
Water absorption (°C)	0.29

3.6.3 Common Uses of Polymer Impregnated Concrete

This type of process was initially favored on concrete bridge decks due to the enhanced physical performance, durability and chemical resistance of the impregnated cementitious material. Impregnation with a resin also had the advantage of potentially sealing the pores present within the concrete matrix and hence making the surface more impervious to water.

Resin monomer(s) have been impregnated into concrete floors within industrial situations in order to rectify cracking to the surface and enhance the long-term performance. The absence of solvent within these resin constituents means the process is kinder on the environment and less hazardous to human health. This process allows the repair of the concrete surface rather than resorting to alternative methods such as repairing the concrete completely as recasting it is an expensive process. Such a process has the advantage of hardening the surface and improving the durability and resistance to chemical attack. The impregnation of monomer, pre-polymers into stonework to seal and protect the exposed surface has also been undertaken.

Alternative uses for this type of technique involved the complete impregnation of post tension beams with the desired monomer. These beams were ideally suited in areas where adverse environmental conditions would be experienced such as a high degree of corrosion which are normally observed with exposure to seawater (coastal areas). These beams exhibit excellent strength characteristics and durability along with a minimal creep which enable them to withstand higher loads than those capable of being supported by ordinary precast beams.

3.6.4 Disadvantages Associated with Polymer Impregnated Concrete

Although an impressive increase in the strength and durability of partially impregnated concrete was observed in some cases, this material did tend to be more brittle than traditional Portland cement structures. The use of this process to enhance the physical performance of concrete and prevent deterioration of the matrix was used throughout the 1970s. However, a link was established with this process and elevated chloride content within the impregnated concrete structure. This would seem unusual as this procedure essentially was supposed to seal the voids within the microstructure and prevent the absorption of damaging elements. Analysis however, attributed this phenomenon to the drying, polymerization process inducing cracking within the structure thus allowing compounds to enter the matrix once more.

One of the principle areas which also caused concern was where areas of impregnated and ordinary concrete overlapped or were in close proximity to each other. The sometimes significant differing in physical characteristics, i.e., strength, coefficient of thermal expansion could potentially produce a point of weakness with the structure resulting in failure of the concrete within these regions