Polymer concrete — a review

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INTRODUCTION

CONCRETE is a building material possessing high compressive strength, durability, fire resistance and other properties when combined with conventional reinforcement or pre-stressing. However, inspite of these qualities, it is relatively much weaker in tension, possesses poor flexural strength, limited ductivity and limited ability to absorb energy. The most important drawback of concrete is its poor impermeability due to presence of voids making it highly sensitive to chemical attack, corrosion, freezing and thawing and also under certain conditions of use such as in marine structures, bridge decks, road pavements, industrial flooring etc.

[illegible] of conventional concrete is its slow rate of attainment of ultimate strength. This weakness is particularly felt in situations where quick repairing of damaged parts is required such as in concrete pavements in air fields and heavily trafficked roads. Newly laid concrete does not have good bonding with old concrete resulting into repeated breakdown of repaired parts.

These above-mentioned difficulties led to the search for new materials that could bring forth solutions to some of these age-old problems of concrete in service. Polymer concretes are one such group of substances which have been developed and tried in several applications. The present paper is a review describing different types of polymer concrete and their applications.

Types of Polymer Concretes,

Polymer concretes can be broadly classified into three main types: (i) Polymer Cement Concrete (PCC) which is made by adding a polymer during mixing of ordinary fresh concrete with polymerization or curing initiated after placement of the materials, (ii) Polymer impregnated concrete (PIC) which prepared by monomer impregnation of normal hardened concrete followed by in-situ polymerisation and (iii) Polymerization and (iii) Polymer Concrete (PC) which is prepared by mixing a monomer or resin with an aggregate and polymerising or curing the material after its placement.

Polymer Cement Concrete (PCC)

The first attempts to improve properties of concrete were made in the direction of using polymers as additives to concrete. Polyvinyl acetate (PVA) dispersions were largely used resulting in improvement of water proofing, resilience, adhesion and resistance to chemical attack. It was, however, soon established that PVA homopolymers were no longer adequate to fulfil the requirements specified particularly in respect of resistance to water.

The PVA is prone to hydrolysis and when added to cement paste, bring about serious losses in strength in water storage. This resulted into the use of number of copolymers. These included vinyl propionate, vinyl chloride (PVP) copolymer, butadiene styrene (BS) Copolymer, Polyvinylidene dichloride (PVDC) and acrylic based polymers. Polymer dispersions for addition to hydraulic binders should not affect the setting properties of cement, should not hydrolyze under high alkylinity of cement and should not have any corrosion promoting effect. Although pure polymers may not have any of these effects to any appreciable extent, the auxiliary chemicals such as protective colloid, emulsifiers, accelerators, regulators etc. invariably associated with polymer dispersions may cause undesireable effects. For best all round perfomance polymers based on acrylics or on copolymerized PVDC have been widely recommended.

The main benefits derived from polymer added cement concrete, good bonding properties with another ordinary concrete, good durability and a high degree of abrasion resistance. Applications for PCC include interior and exterior floor coverings, resurfacing of bridge decks and other patching and repair work.

Polymers in the form of powders have also been added to fresh cement concrete mixes. After casting and initial hardening of concrete, heat is applied to the concrete to melt the polymer thereby permitting it to disperse through the pores of the concrete. A water dispersible epoxy system has recently become commercially available for use in PCC. The epoxy PCC is reported to achieve over 90 percent of its ultimate strength within 3 days.

The ease of adopting existing concrete production equipment to the manufacture of PCC and the relatively low cost in simply adding one more ingredient to conventional concrete enhance the potential applications of PCC. However, properties of PCC are generally only moderately improved over that of conventional concrete.

Polymer Impregnated Concrete (PIC)

PIC composite is prepared by impregnating pre-cast concrete with a liquid monomer and polymerizing the resin in-situ. The major steps in the production of PIC are drying, evacuation, impregnation and polymerization. Drying of the concrete before impregnation at temperatures 100-200°C is the most important step in the whole production even small amount of water remaining in the concrete results in a market strength reduction of PIC even though the total monomer loading may be as high as that of fully dried specimens.

Earlier, polymerization by radiation was the method used widely by researchers in PIC concrete. Recently polymerization by thermo-catalytic method has been widely accepted to be relatively cheaper and simpler than radiation polymerization. In thermo-catalytic method, polymerisation is carried out under warm water which has been found to be more efficient than different wrapper and coating methods.

Degree of impregnation in concrete depends not only on the diameter of cement paste capillaries, impregnation time, applied pressure, viscosity and surface tension of monomer but also on its molecular dimension and the interaction between cement capillaries, walls and the organic molecules.

The thermo-catalytically treated concretes often showed lower mechanical strengths especially when benzoyl peroxide was used as catalyst which hardly penetrated the cement paste owing to its molecular size and prevented complete and homogeneous polymerization of the monomer in the inner layers of the sample.

An automatic plant for mass production of polystyrene-impregnated concrete products by thermal polymerisation has been designed and developed. The productivity of the plant has been reported to be 4 cu meter per hour and cost of PIC manufactured by the plant is $ 500 per cu meter compared to the cost of conventional concrete $ 170 per cu meter. Several monomers have been tried in the development of PIC, however, methyl methacrylate has been found to be the best monomer providing both best strength and durability.

Although substantial progress has been made in the development of polymer impregnated concrete for practical applications the mechanism through which the polymer acts is uncertain. It is expected that property improvement due to impregnation is brought about mostly due to pore-structure modification. The polymer is distributed throughout the concrete in voids and macrofractures and to some extent in the cement paste and aggregate particles increasing the amount of solid per unit volume and simultaneously reducing the effect of pores and micro-cracks as stress concentrators.

PIC made from conventional concrete usually contain 6 to 8% polymer by weight. High impact and good quality concrete may give desired results as polymer loadings of even 3-5% latest thinking seems to be in favour of using a high quality concrete with low polymer loading than a lower quality concrete with a larger quantity of polymer. The concept of improving performance of a poor concrete by the use of larger quantity of polymer is contrary to all economic logic.

Typical improvements in properties by polymer impregnation over conventional concrete are increase in compressing strength to the order of 4 to 5 times, in tensile strength upto 4 times, modulus of elasticity upto 2 times, modulus of rupture upto 4 times, increase in impact of the order of 1.7 times, and reduction in creep deformation by a factor of 10. Water permeability is greatly reduced and resistance to acids, basis, sulphates, hot brine freeze thaw etc, improves significantly.

Polymer impregnated concretes are used in water and sewer pipes, building panels, architectural panels, high strength piling, ocean structures, pre-stressed concrete structural beams, bridge decks; underground support systems, pre-cast tunnel support lining systems, concrete ships, rail road ties, off-shore drilling platform kerbstones etc. Some of the applications described in literature in detail are PIC kerbstones, resurfacing of bridge decks, PIC beds for sulphuric acid factory, PIC slabs for road surfacing and PIC support systems for tunnel lining etc. Performance of PIC for period of 3-5 years has been found satisfactory in these applications.

It has been argued that when judging the merits of polymer modified concretes it is im-

[illegible]portant to relate their properties to the best that can be obtained from conventional concrete and not just to those of the control mixtures used. It is possible to make high strength ordinary concretes using selected aggregates or using high pressure compaction of dry cement sand mixtures followed by subsequent hydration. Compressive strengths of the order of 1000 kg/cm² or more have been achieved. However, it has been seen that though the polymer concrete may not be superior to these high strength concretes in respect of compressive strength, their flexural strength and tensile strengths and chemical resistance are appreciably higher than these high strength concretes.

Most of the applications of polymer impregnated concrete described in the literature are still in their infancy and no commercialisation [illegible] large scale appears to have taken place mainly due to high cost of PIC. On the other hand partial impregnation of concrete has been demonstrated to be the most cost-effective method of using polymer impergnation. Practical difficulties of impregnating and ensuring complete polymerisation of monomer deep inside larger members contribute to this conclusion.

The most promising methods of partial impregnation of horizontal surface requires covering with thin layer (0.6 cm) of dried fine sand, which is then saturated with monomer. For soak times of 10 hours, penetrations of upto 8 cm have been obtained. Polymerization is initiated by the thermo-catalytic method. In case of vertical walls monomer can be applied by brush or roller. It is found to penetrate to a depth of 3-5 cm when concrete is reasonably dry and porous. This effectively seals the panels against rain or chemical penetration.

Polymer Concrete (PC)

Polymer concrete or resin concrete is a composite in which aggregates are bonded by synthetic resin instead of cement. Resin concrete is suitable for both pre-cast or cast-in-place applications. This can be produced utilizing conventional concrete mixing and placing techniques and is therefore readily adoptible to existing concrete production technology.

Applications of polymer concrete include road and bridge overlays, pothole repairs, air field runway repairs, pipes, tunnel support liners, building panels, kerbstones, floor and roofing tiles, window sills, poles for supporting electrical transmission lines.

Epoxy resin mortars have been widely used for surfacing, bonding, gap filling, repairing etc. of cement concrete in the field of architecture and civil engineering. Epoxy polymer concretes are applied where high compressive strength and chemical resistance are required. These concretes are used in Poland mainly for repairs of reinforced concrete structures and for lining floors exposed to chemical aggression or heavy exploitation. Epoxy trowelled floors with a binder content of 15 to 20 per cent are applied by a trowel in 5-10 mm thickness for floors of chemical and food processing factories where high levels of chemical and wear resistance are required. Compressing strengths of the order of 700 kg/cm² and flexural strength of 300 kg/cm² are achieved along with high impact and abrasion resistance.

In India cement concrete pavements are mostly used in case of air fields and heavily trafficked roads. In these situations it is not possible to close the traffic for long period when repair of these pavements are to be carried out. These pavements develop defects like cracking, spalling, cavitation, sinking/heaving and so on. Ordinary repairs with cement concrete requires a minimum curing period of 2-3 weeks and bond between old and new concrete is generally not satisfactory. Bituminous repairs need frequent attention. Repairs with synthetic resin concrete present an attractive alternative. They combine the properties of rapid hardening, good adhesion, toughness, good strength and superior chemical resistance which make them suitable for efficient repair of concrete roads and air fields. Polyester and epoxy sand mortars have found wide range applications.

Polymer concretes are reported to be widely used in Japan in the building and construction field. The binder widely used is polyester resin. The composition of a standard mix is 10% unsaturated polyester resin, 10% calcium carbonate as a filler and 80% aggregate. Products used are pipe, telephone cable ducts, terrazo gutter covers, manholes and a variety of panels. Compressible strengths as high as 1400 kg/cm², tensile strength 110 kg/cm² and modulus of elasticity 3x10⁵ kg/cm² have been reported.

Furan resin concretes and mortars are employed for many applications in Bulgaria requiring chemical resistance. However, furan resins are reported to be moisture—sensitive.

A building may be strengthened at relatively low cost by bonding additional reinforcement to the structure with an epoxy adhesive. An alternative method of strengthening is achieved by bonding steel plates on to the concrete structures in the area of tension and shear stress.

The resins most widely used for PC are epoxy, polyester and furan resins. Recently work has been performed utilizing MMA and styrene monomers. PCs use generally 6 to 8 weight per cent monomer. A concrete using MMA with silane coupling agent has been developed which is known as shotcrete as it achieves full strength of approx. 700 kg/cm² in 10-15 minutes.

The polymer concrete material systems import many of the advantages of the polymer impregnated concretes and in addition the material systems are mixed cast and cured using techniques similar to those for conventional concretes which makes the system more suitable for cast-in-place applications. However, resin concrete is considered to have greater susceptibility to atmospheric temperature than cement concrete since resin is more temperature sensitive than inorganic cement products. The thermo-dependent property of resin concrete is one of the most important properties to be examined when resin concrete is used for structural purposes.

MISCELLANEOUS POLYMER CONCRETES

In addition to the three major types of concrete described above there are a few other concreates in which polymers have been used in one form or the other. Important of these are expanded polystyrene concrete, flexicrete, polypropylene fibre reinforced concrete, and sulphur impregnated concrete. A brief description of these concretes is given below:

EPS concrete

It is a light weight concrete made by mixing expanded polystyrene beads with cement, sand and water in a conventional force mixer. Unlike aerated concrete which requires autoclaving, EPS concrete can be used for both in-situ and pre-cast purposes without requiring autoclaving. Styropor beads act as small regular voidformers in the surrounding mortar. EPS concrete possesses good strength, light weight, low moisture absorption, high thermal insulation and its thermal conductivity does not change when exposed to moisture. It is fire resistant and possesses good sound insulation properties. EPS concrete for general use is of density 600-700 kg/m³ giving a thermal conductivity value of about 0.20 k cal/m hour °C, a compressive strength of 20-25 kg/cm² and flexural strength of 8-10 kg/cm² after 28 days moisturing.

EPS concrete can be used for insulating screeds and renderings, non-load bearing and load bearing components, for roof and wall insulations etc. styropor concrete has been developed and used in several countries including West Germany, Austria, Australia, Canada, Mexico, Brazil, Chile, Venezuela and Peru etc. A firm in Australia used sandwhich components from 50 mm styropor concrete as core faced on both sides with 6 mm asbestos sheet used as wall panels. Size of panel is 2.7 m x 0.9 m. These components have been thoroughly investigated and are licensed under building regulations. In Chile small dwellings as low cost housing have been built from styropor concrete components. The cost is about 40-48 $ per sq. m.

In Venezuela first trial houses were built in styropor concrete in 1968 consisting of styropor concrete core (80-150 mm) between reinforced fair face concrete layers (20 mm). Styropor concrete trough beams for light roofs mainly for bungalows and two storey houses were made and used in Zulia.

Flexicrete

These are low modulus concretes consisting of rubber-crumb, crushed stone aggregate, portland cement and water. The reduced modulus of elasticity of these mortars is mainly attributed to the softer aggregates used in them. These are used as model concretes. Their compressive strength is generally of the order of 10-15 kg/cm² and modulus of elasticity between 500 to 10,000 kg/cm².

Polypropylene fibre reinforced concrete

A viable alternative to asbestos cement product has been developed which is both strong and economical. The new material consists of a cement matrix with reinforcing layers of stretched polypropylene (pp) film which has been fibrillated into a continuous open net work. PP reinforced cement composites are much less brittle than AC products and without the risk of health hazards associated with handling asbestos. PP fibres had been discounted in the past owing to their low elastic modulus and poor bonding with cement. But the use of continuous network of fibrillated film enables cement hydration products to grow through the meshes forming strong mechanical bonds. The composite produced satisfies loading requirements for corrugated AC sheets.

Sulphur impregnated concrete (SIC)

Although this concrete does not use any polymer, the sulphur impregnation is used similar to polymer impregnation in PIC. Compared with monomers sulphur has been found to be inexpensive and readily available in some countries. The sulphur impregnated concretes have been developed from low strength portland cement concrete showing phenomenal improvements in mechanical properties and durability characteristics. The sulphur impregnated concretes could find use in the manufacture of special high strength items such as concrete poles, pipes etc.

CONCLUSION

Concrete polymer materials with their increased strength, stiffness and durability properties [illegible] to provide the answer to age-old problem of cracking and deterioration of concrete under adverse environmental conditions. It must however, be emphasized that the development of many of these new materials is still in its infancy and no large scale commercial applications have [illegible] made. A clear understanding of their short and long term behaviour and thermo-dependent properties is also necessary before safe and economic design methods can be developed. It is well established that the most significant properties of polymer concretes are their excellent resistance [illegible] chemical attack and abrasion and their high impermeability to water and salt solutions.

Polymer concrete composites have not been studied much in India due to high cost of polymer materials. Some preliminary work of exploratory nature has been carried out in a few cases. Some work was carried out at this Institute regarding use of epoxy resins as binders with sand for repairing and patching purposes and for jointless flooring. Some laboratory work was also carried out on preparation of PIC using styrene monomer and thermocatalytic polymerisation. Work on polymer impregnated concrete and resin/sand mortars for repairing of concrete pavements has also been reported from other sources in the country.

It is considered important to develop indegeneous technology of production and use of polymer [illegible] polymer concretes may be useful in some specific applications such as in chemical and industrial flooring, coastal and marine structures, off-shore oil drilling platforms, pipes etc. There is need to develop polymer concrete using low cost indegenous resins. It [illegible] partial impregnation methods of concrete structures to a depth of few millimeters to seal the concrete surface against rain and chemical penetration.

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