ADVANCED CONCRETE TECHNOLOGY

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ABSTRACT

Extensive research on concrete technology has resulted in advances which include precast and prestressed concrete and their applications, improvements in rebars, light weight concrete, super plasticisers and admixtures for various requirements, ferrocement, fibre reinforced concrete, polymer concrete, gunite or shotcrete, high performance concrete, ready mixed concrete, self-compacting concrete, geopolymer concrete, reactive powder concrete, self-curing concrete, self-healing concrete and nanotechnology applications. Ssome of the recent advances in concrete technology are briefly presented.

Introduction

Concrete is by far the most widely used construction material today. The versatility and mouldability of this material, its high compressive strength, and the discovery of reinforcing and prestressing techniques which helped to make up for its low tensile strength have largely contributed to its widespread use. Extensive research on concrete technology has resulted in many advances to achieve greater strength and durability of concrete structures. Reactive powder concretes with compressive strengths of 700 MPa and more were developed by Pierre Richard in France in 1994. Some of the recent advances in concrete technology are briefly presented.

High Performance concrete

High performance concrete (HPC) is defined as concrete meeting special combination of performance and uniformity requirements that cannot always be achieved routinely using conventional constituents and normal mixing, placing and curing practices. The characteristics of HPC are developed for particular applications and environments; some of the properties that may be required are high strength, high early strength, high modulus of elasticity, high abrasion resistance, high durability and long life in severe environments, low permeability and diffusion, resistance to chemical attack, high resistance to frost and deicer scaling damage, toughness and impact resistance, volume stability, ease of placement, compaction without segregation, and inhibition of bacterial and mold growth.

High performance concretes are made with carefully selected high quality ingredients and optimized mix designs; these are batched, mixed, placed, compacted and cured to the highest standards. Typically such concretes have a low water-cement ratio of 0.20 to 0.45. Plasticizers are generally used to make these concretes fluid and workable. Figure 1 shows Parliament Library building constructed in 2002 using fibre reinforced (FR) HPC 50 MPa for bubble type units. The bubble unit was tested at CSIR – Structural Engineering Research Centre (SERC), Chennai.

Polymer Concrete

A new type of concrete known as Polymer concrete has been developed based on research by concrete technologists. Great improvement has been observed in various properties of concrete including compressive strength, permeability, impact resistance and abrasion resistance. There are four types of polymer concrete namely, Polymer impregnated concrete, Polymer cement concrete, Polymer concrete, and Partially impregnated and sulphur coated polymer concrete.

Polymer impregnated concrete is one of the widely used polymer composite. It is a conventional precast concrete which is dried in oven or dielectric heating after curing for removing entrained air. A low viscosity monomer is then diffused through open cell and polymerized by using radiation, application of heat or by chemical initiation. The monomers mainly used are: methylmethacrylate (MMA), Styrene, Acrylonitrile, *t*-butyl styrene and other thermoplastic monomers. Figure 2 shows light beacon tower developed by CSIR – SERC using polymer impregnated panels.

Polymer cement concrete is made by mixing cement, aggregates, water and monomer. The plastic mixture is cast in moulds, cured, dried and polymerized. The polymers used are: polyster-styrene, epoxy styrene, furans and vinylidene chloride. It is reported only epoxy resin produced a concrete that showed superior characteristics over ordinary concrete.

Polymer concrete is an aggregate bound with a polymer binder instead of Portland cement. It is necessary to minimize the void volume in the aggregate mass so as to reduce the quantity of polymer needed for binding the aggregates. This can be done by properly grading and mixing the aggregates. The graded aggregates are prepacked and vibrated in a mould. Monomer is then diffused through the aggregates and polymerization is initiated by radiation or chemical means. A silane coupling agent is added to the monomer to improve the bond strength between the polymer and the aggregate. In case polyester resin is used no polymerization is required.

Partially impregnated and sulphur coated polymer concrete: Partial impregnation may be sufficient in situations where major requirement is surface resistance against chemical and mechanical attack in addition to increase in strength. The partially polymer impregnated concrete can be produced by initially soaking the dried specimens in liquid monomer like methyl methacrylate, then sealing them by keeping them under hot water at 70°C to prevent or minimise loss due to evaporation. The polymerization can be done by using thermal catalytic method in which 3% by weight of benzoyl peroxide is added to the monomer as a catalyst.

Reactive Powder Concrete

Reactive powder concrete (RPC) was developed in France in the early 1990s. The world's first RPC structure, the Sherbrooke bridge (60 m span prestressed concrete pedestrian bridge) was erected in Quebec, Canada, in July 1997 (Fig.3). RPC is an ultra high strength and high ductility cementitious composite with advanced mechanical and physical properties. It consists of a special concrete where the microstructure is optimized by precise gradation of all particles in the mix to yield maximum density. It extensively uses the pozzolanic properties of highly refined silica fume and optimization of Portland cement chemistry to produce the highest strength hydrates.

RPC is composed of very fine powders (cement, sand, quartz powder and silica fume), steel fibres (optional) and super plasticizer. The super plasticizer, used at its optimal dosage, decreases the water-cement ratio while improving the workability of the concrete. A very dense matrix is achieved by optimizing the granular packing of the dry fine powders. This compactness gives RPC ultra high strength and durability. Apart from their exceptional mechanical properties, RPCs have an ultra dense microstructure giving improved water proofing and durability characeteristics.

Self Compacting Concrete

Self consolidating or Self-compacting concrete (SCC) is a flowing concrete mixture that is able to consolidate under its own weight. The highly fluid nature of SCC makes it suitable for placing in difficult conditions and in sections with congested reinforcement. Use of SCC can also help minimize noise on the worksite that is induced by vibration of concrete. Also the time required to place large sections is considerably reduced. It can also reduce defective workmanship due to improper compaction of concrete particularly in situations with heavy and congested reinforcement.

Mix proportions for SCC differ from those of ordinary concrete, in that the former has more powder content and less coarse aggregate. Moreover, SCC incorporates high range water reducers (HRWR, superplasticisers) in larger amounts and frequently a viscosity modifying agent (VMA) in small doses. In the case of SCC, rounded aggregates would provide a better flowability and less blocking potential for a given water-to-powder ratio, compared to angular and semi-rounded aggregates. Self-compacting concrete mixtures should be designed for a combination of filling ability, resistance to segregation, and ability to pass through and around reinforcement without blockage.

Geopolymer Concrete

Geopolymer is an inorganic alumino-silicate polymer synthesized from predominantly silicon (Si) and aluminium (Al) materials of geological origin or by-product materials such as fly ash. Investigations conducted by researchers have shown that Geopolymer concrete can be produced with good compressive strength and is suitable for structural applications. Due to their ceramic-like properties, geopolymers are believed to possess good fire resistance. Heat cured low calcium fly ash based Geopolymer concrete shows excellent resistance to sulphate attack and fire, good acid resistance, undergoes low creep and suffers very little drying shrinkage. They can be used as a substitute for cement in concrete, thereby reducing CO_2 emissions by the cement industry. Detailed studies on Geopolymer concrete have been carried out at CSIR – Structural Engineering Research Centre, Chennai. St. Peter’s University, Chennai, has developed Geopolymer concrete bricks (Fig.4) and hollow blocks for building construction.

Self-curing concrete

Excessive evaporation of water (internal or external) from fresh concrete should be avoided; otherwise, the degree of cement hydration would get lowered and thereby concrete may develop unsatisfactory properties. Curing operations should ensure that adequate amount of water is available for cement hydration to occur.

The ACI-308 Code states that “internal curing refers to the process by which the hydration of cement occurs because of the availability of additional internal water that is not part of the mixing Water.” Conventionally, curing concrete means creating conditions such that water is not lost from the surface i.e., curing is taken to happen ‘from the outside to inside’. In contrast, ‘internal curing’ is allowing for curing ‘from the inside to outside’ through the internal reservoirs (in the form of saturated lightweight fine aggregates, superabsorbent polymers, or saturated wood fibers). ‘Internal curing’ is often also referred as ‘Self–curing.’

The following materials can provide internal water reservoirs namely, lightweight aggregate (natural and synthetic, expanded shale), LWS Sand (Water absorption =17 %), LWA 19mm Coarse (Water absorption = 20%), Super-absorbent Polymers (SAP) (60-300 mm size), SRA (Shrinkage Reducing Admixture) (propylene glycol type i.e. polyethylene-glycol), and Wood powder.

Some specific water-soluble chemicals added during the mixing can reduce water vaporation from and within the set concrete, making it ‘self-curing.’ Self-curing agent can absorb moisture from atmosphere and then release the moisture into concrete. It is added into concrete during mixing, such that concrete can be self-cured after placing without the need of any external curing. Thus, water evaporation after removal of formwork can be reduced, and the degree of cement hydration improved without extra standard curing. Furthermore, compressive strength will be enhanced with the reduced shrinkage arising from water evaporation, making it ideal for concrete placing without any external curing. The chemicals should have abilities to reduce evaporation from solution and to improve water retention in ordinary Portland cement matrix.

Bioconcrete or Self-healing cement

Concrete is the most widely used building material but is prone to cracks due to several reasons like shrinkage, internal stresses, chemical action and temperature. Water and other salts seep through these cracks, initiate corrosion, and thus reduces the life of concrete. Concrete structures usually show some self-healing capacity, i.e. the ability to heal or seal freshly formed micro-cracks. This property is mainly due to the presence of non-hydrated excess cement particles in the materials matrix, which undergo delayed or secondary hydration upon reaction with water. Scientists have developed a new type of self-healing concrete in which bacteria mediate the production of minerals which rapidly seal freshly formed cracks, a process that concomitantly decreases concrete permeability, and thus better protects embedded steel reinforcement from corrosion.

The use of bacteria improves the stiffness and compressive strength of concrete. Initial results show that the addition of specific organic mineral precursor compounds plus spore-forming alkaliphilic bacteria as self-healing agents produces up to 100-µm sized calcite particles which can potentially seal micro- to even larger-sized cracks.Further development of this bio-concrete with significantly increased self-healing capacities could represent a new type of durable cement concrete.

By adding bacteria to concrete the microscopic fissures can be healed. The idea of a bioconcrete has been around for about 15 years although having a viable option has been somewhat difficult. The process seems simple. When putting the concrete together, add in some bacteria and also food for growth. It seems simple enough but in order to meet the requirements for tensile strength, the bugs and the nutrients would have to meld in the mixture without causing any problems.

The bacteria identified are those that literally use salts for food and energy. They are known as the *Bacillus* and *Sporosarcina* genera. These bacteria are naturally found in alkaline environments and survive there using a rather interesting mechanism. They use milky-like substances, such as calcium lactate, a main component of baking powder, for nutrition. Then, when done, they send out the waste in the form of calcium carbonate, also known as limestone.

Unlike most bacteria, these genera had the ability to form spores, meaning they could lie dormant for years, if not centuries and still remain viable. This offered the opportunity to not only maintain concrete in the short-term but also to ensure troubles would not arise for decades or longer meaning less costs for maintenance and a reduced chance of creating those eyesores. Bacteria-based fillers are being developed so they can be added straight to existing structures. Research in Delft Technical University showed healing of crack with a width of 0.5 mm. Some of the main challenges are ensuring that the healing agent survives the mixing process, effectiveness after a period of time and cost for producing large quantities.

LiTraCon

LiTraCon is a trademark for a translucent concrete building material. The name is short for light-transmitting concrete (Fig.5). The material is made of 96% concrete and 4% by weight of optical fibres. It was developed in 2001 at the Technical University of Budapest. The most notable installation of it to date is Europe Gate, a 4 m high sculpture made of LiTraCon blocks, erected in 2004 in observance of the entry of Hungary into the European Union. The product won the German *Red Dot 2005 Design Award* for highest design qualities.

Reinforcement Bars

Up to 1960s, the Indian construction industry has been using 250 MPa, low yield strength mild steel plain bars for concrete reinforcement. Apart from low tensile strength, these bars also have low bond strength. In 1970s, cold twisted deformed (CTD) bars were introduced by restricting carbon content to a low level and the proof strength was increased from 250 to 415 MPa. Thermo-mechanically treated (TMT) bars are a recent technological advancement for the production of high strength deformed bars having better ductility than CTD bars. These bars are made under three grades confirming to minimum yield strengths of 415, 500 and 550 MPa TMT rebars as per IS:1786. Micro alloyed steel bars are also produced now to increase strength, toughness and ductility. Small quantities of alloys such as titanium, vanadium, niobium, and other elements are used either separately or in combination to obtain the improvement. The high ductility is beneficial for earthquake resistant structures in severe seismic zones. Micro alloyed bars are produced in India in the grades of Fe415 and Fe500.

FRP rebars are made of fibres of glass, carbon, aramid and basalt. They provide an alternative to steel bars with advantages like resistance against corrosion, non-conducting and hence can be used near high voltage and magnetic fields. FRP bars also help to reduce dead load.

Application of Nanotechnology

Nanotechnology is one of the most active research areas that include a number of disciplines including civil engineering and construction materials. Nano-engineering or nano-modification of cement is an emerging field. Synthesis and assembly of materials in the nanometer scale range offer the possibility for the development of new cement additives such as novel superplasticizers, nanoparticles, or nanoreinforcements.

Nano-SiO_2 has been found to improve concrete workability and strength, increase resistance to water penetration, and help control the leaching of calcium, which is closely associated with various types of concrete degradation. Nano-SiO_2 was found to be more efficient in enhancing strength than silica fume. Addition of 10% nano-SiO_2 with dispersing agents was observed to increase the compressive strength of cement mortars at 28 days by as much as 26%, compared to only a 10% increase with the addition of 15% silica fume. Even the addition of small amounts (0.25%) of nano-SiO_2 was observed to increase the strength, improving the 28 day compressive strength by 10% and flexural strength by 25%.

Nano-TiO_2 has proven very effective for the self-cleaning of concrete and provides the additional benefit of helping to clean the environment. Nano-TiO_2 containing concrete acts by triggering a photocatalytic degradation of pollutants, such as carbon monoxide, chlorophenols, and aldehydes from vehicle and industrial emissions.

Nano-Fe_2O_3 has been found to provide concrete with self-sensing capabilities as well as to improve its compressive and flexural strengths. Nano-Al_2O_3 has been shown to significantly increase the modulus of elasticity (up to 143% at a dosage of 5%) but to have a limited effect on the compressive strength.

Nanoclay particles have shown promise in enhancing the mechanical performance, resistance to chloride penetration, and self-compacting properties of concrete and in reducing permeability and shrinkage.

Studies were conducted at St. Peter’s University on microwave synthesis of Zirconium dioxide (ZrO_2) nanopowder and its reinforcement in geopolymer gel. Nano ZrO_2 possesses good mechanical, thermal, electrical and optical properties. The nano powder was prepared by the microwave assisted process with citrate sol-gel method. The characteristic properties of nanoparticles were studied by FTIR, UV-Visible, and XRDanalysis. The geopolymer gel was prepared by mixing of fly ash with an alkali activated solution in a solid to liquid ratio of 1:1. The ZrO_2 nanopowder was mixed with geopolymer gel in the ratio of 1: 10. The Zirconia nanoparticles reinforced geopolymer moulds are characterized by the compressive strength, thermal resistivity (at 300°C) and SEM analysis (Fig.6). It is found that small amount of ZrO_2 nanopowder could increase the compressive strength and thermal resistivity of geopolymer.

Carbon nanotubes/nanofibers (CNTs/CNFs) are potential candidates for use as nanoreinforcements in cement-based materials. They exhibit extraordinary strength with moduli of elasticity of the order of TPa and tensile strength in the range of GPa, and they have unique electronic and chemical properties. The resistance to crack propagation is increased while providing such novel properties as electromagnetic field shielding and self-sensing. One of the main challenges is the proper dispersion of CNTs/CNFs into cement paste, partly due to their high hydrophobicity and partly due to their strong self-attraction.

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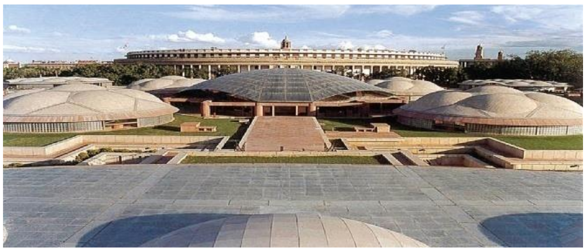

Fig.1 Parliament Library building with FR HPC (50 MPa) bubble type units.

Fig.2 Light beacon tower at CSIR – SERC, Chennai

Fig.3 The Sherbrooke Reactive Powder concrete Footbridge, Quebec, Canada.

Fig.4 Geopolymer brick

Fig.5 LiTraCon panel

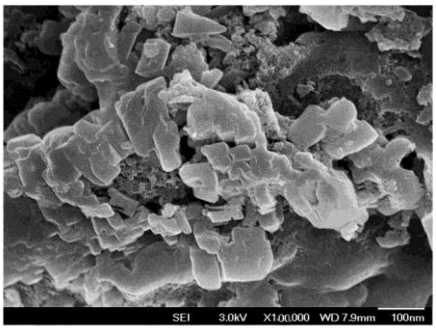

Fig.6 SEM image of ZrO_2 nanoparticles reinforced Geopolymer gel.