

MDF and DSF - *The New Ultra High Strength Concretes*

A new generation of ultra high strength concretes has been developed to rival the properties of metal! David Bennett reports

A break through in ultra high strength cement technology occurred in the 70's following two decades of experimental research which started during the time of the Queen's Coronation. Chemists at ICI Special Projects team lead by Derek Birchall in Runcorn were looking for a 'wonder' inorganic material that could replace organic polymers (plastics) and certain metals like aluminium. The growing emphasis on non-combustibility of raw materials, the rise in cost of hydrocarbons and high energy cost of production of organic plastics led the researchers to look at the possibility of making a macro defect free cement (MDF) as a replacement material. The major attraction of cement was simply the energy cost savings in manufacture. To produce one cubic metre of cement, organic polymer or aluminium requires 10, 100 and 1000 GJoules respectively of energy. Clearly cement has an advantage in energy saving over aluminium and organic polymers because it hydrates with the addition of water under normal air temperatures. There is no need to heat the process to high temperature. The big problem was how to overcome cement's low tensile and bending strength, and low fracture toughness compared to plastics and metals. The main reason for this is the large amount of voids in the material caused by air entrapped during mixing, and in the pores and capillaries formed within the material, when water is desiccated during cement hydration.

Removal of these large flaws from the 'cement paste' was possible by better particle packing in the wet and dry state. The ICI researchers found that by introducing a small proportion of water soluble polymers into the cement and water mix. inter-particle friction and surface tension was greatly reduced. This allowed particles to pack more closely and significantly increase the tensile strength. Using such techniques an MDF cement polymer paste was created by mixing it virtually earth dry under high shear and turning it into a dough like putty. The deformable dough was then rolled to eliminate entrapped air bubbles and moulded into desired shapes by extrusion, pressing or other conventional plastic pressing operations. The small residual voids that remain are filled by the chemical processes of hydration which contract or collapse by desiccation. In this way it proved possible to reduce the voids in MDF cement to less than 0.1%.



Early results of MDF cement paste compared favourably with aluminium and exceed the properties of ordinary concrete by significant margins. (See table 1). If MDF cement is reinforced by fibres such as glass, carbon or Kevlar, a composite material can be formed having a fracture toughness exceeding that of aluminium. The processes used in fabricating products from MDF cement are quite unlike those used in conventional concrete technology. They are allied to organic polymer technology. Where MDF products have to be extruded or injection moulded. Utility and luxury articles in MDF cement have been made that would usually be formed in metal or reinforced plastic e.g. Door handles, loudspeaker cabinets, a guitar and even a suspension spring for a car. ICI sold the MDF licence to a Japanese Conglomerate who after some years of further development work, were unsuccessful in their attempts to market a new loudspeaker cabinet made with MDF and abandoned the technology.

Dense Silica Particle cement (DSP) which was conceived by Bache in 1981, no doubt inspired by the pioneering researches of Birchall and his team; is quite different, since the cement paste is workable and can be cast like ordinary concrete. The high strength is achieved by controlling

the particle- size distribution of the cement to minimise the void spaces between cement grains. Bache added a very finely divided silica (particle size 0.1µm) - a by product of silicon and silicon alloy - to Portland cement to fill the voids left by the cement particles and eliminated the coarse aggregates. The silica has the added advantage of reacting chemically with the cement paste to become an integral part of the matrix. A dispersion surfactant (superplasticiser) is also necessary to achieve workability so that DSP composite cement when mixed with the minimum amount of water can be poured into forms and moulds. The properties of DSP are comparable with MDF in compression, but can be more brittle without steel fibre being added, and therefore can have a lower tensile strength.

Compact Reinforced Composite or CRC

A DSP concrete with fibre reinforcement was developed by Aalborg, Portland in Denmark in 1986. It was called Compact Reinforced Composite concrete - CRC for short - and has been the subject of a number of research projects. One of its special properties is its very high bond strength due to the large content of micro silica and steel fibres. CRC can be used to glue together narrow joints between two reinforced concrete sections, similar to welding steel sections and has been called a concrete weld cement. Reinforcing bars only have to have a bond length of three times the bar diameter for a tension lap. For practical reasons the gaps between joints are usually 80mm or 100mm wide to be able to pour and compact the CRC.

CRC was first developed for precast construction, but has been modified for in situ applications. It is supplied as a dry mortar – with binder, sand and steel fibres. Water is the only ingredient added on site. The high strength of CRC with its mortar like consistency - it does not contain coarse aggregates - allows for very close rebar spacing; making it possible to precast thin, lightweight structural elements e.g. balcony slabs and slender staircases.



DUCTAL

Ductal was developed jointly by Bouygues and Lafarge in the 1990's and is another DSP product formulated to achieve high ultimate load carrying capacity and enhanced durability. It has a compressive strength ranging from 200MPa to 800 MPa.

By eliminating the coarse aggregate fraction, incorporating steel fibres, applying pressure to the high strength mix before and after setting, and then heating the hardened cement for up 3 days at 90degC; very high compressive strengths are obtained. However the cost and practicality of applying pressure to the mix and supplying heat treatment in the field, must be assessed for each application.

A typical 200Mpa mix is shown in Table 2. The steel fibres used were 0.2mm in diameter and 12mm long, and were incorporated at a dosage of 2% by volume of the mix. For site applications Ductal is mixed in a conventional batching plant and placed in formwork without the application of pressure. When the Ductal has set, it is heat treated at 90degC for two days. The concrete exhibits very little sensitivity to creep and shrinkage. Moderate shrinkage is observed during the heat treatment, but thereafter there is absolutely no further shrinkage movement. It is evident that Ductal when prestressed, closely matches steel for economy of section depth and mass, and reduces the self weight of conventional prestressed concrete beams by a considerable margin.

The first major structure to use 200MPa Ductal was a 60m span truss footbridge in Sherbrooke, Canada in 1995. The 30mm thick by 3.30m wide walkway slab acts as the stiffening top chord of the 3m deep truss. The struts and tension ties that connect the top and bottom chord members, are thin walled stainless steel tubes filled with Ductal Confining the concrete in external tubing enhances the compressive strength to 350 MPa. The bottom chord comprises twin Ductal beams that are 320mm wide by 380mm deep. External post tensioning tendons placed longitudinally; pass through the bottom chord beams while the 30mm top slab is transversely prestressed. No rebar was used for any part of the structure, not even for distribution steel.

The 'Footbridge of Peace' built over the river Han in Seoul for the 2002 World Cup, is a 120m long double T arch that has been precast entirely with Ductal. The depth of the section is 1.3m and has a top slab and walkway 4.3m wide and only 30mm deep. One day we are going to build concrete reinforced structures with MDF reinforcing bar and slender I beams the size of steel sections cast on site with DSP concrete. This is no fantasy.