Compact Reinforced Composite

CRC is the designation for a special type of Fibre Reinforced High Performance Concrete with high strength (150-400 MPa) developed by Aalborg Portland A/S and now marketed and sold by CRC Technology. Because of a large content of steel fibres the matrix of CRC is very ductile and that makes it possible to utilise rebars much more effectively without having large cracks under service conditions.

The size of the fibres and the largest grains of the matrix dictate the distance between reinforcing bars and the cover layer to the reinforcement, both of which have to be optimised in the slender structures, which can be produced with CRC. This is the reason for typically using a mortar composition for CRC and for using short fibres. Often a cover layer of 10-15 mm and a similar distance between individual bars are used.

With the high fibre contents, CRC is especially suitable for pre-cast applications, but in-situ cast concrete with 6% by volume of fibres has also been produced - for joints between slabs made in conventional concrete - using a poker vibrator for compaction. For these applications a premix called **CRC JointCast** is usually supplied.

CRC has been the subject of a number of research projects investigating mechanical properties as well as durability and fire resistance. This information is necessary in order to be able to use CRC for structural applications, as this type of material is not covered in existing standards and codes of practice.

Mechanical properties depend on type of aggregate, curing, content and type of fibres, reinforcement etc., but they will typically be in a range of:

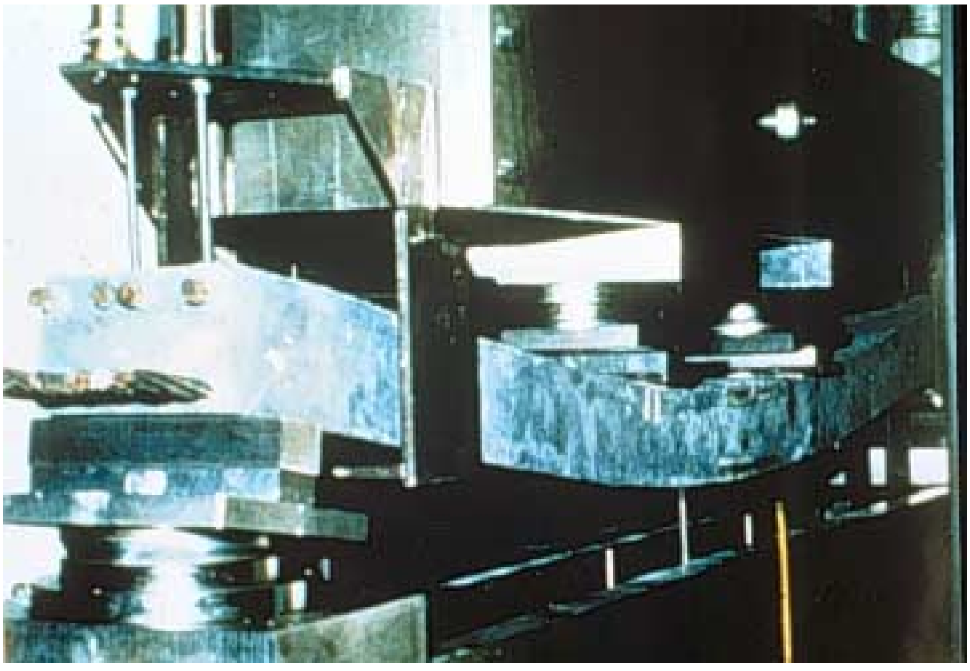
Compressive strength	140-400 MPa
Bending strength	100-300 MPa
Young's modulus	40-100 GPa
Density	2600-3500 kg/m^3

Strength and ductility

It is possible to achieve a compressive strength higher than 400 MPa in CRC, but in order to utilise this kind of strength, it is necessary to provide ductility. Otherwise, the use of reinforcement corresponding to the compressive strength of CRC would result in large cracks even at moderate loads in bending. In CRC this ductility is achieved by the use of small and strong steel fibres. As the strength of CRC is considerably higher than the strength of conventional concrete, the content of fibres is also considerably larger.

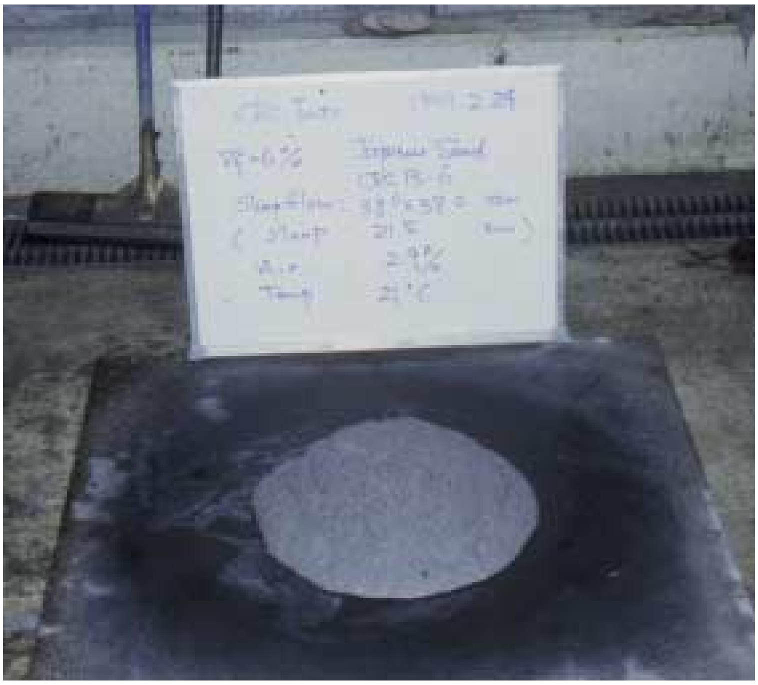
This enables CRC to behave in a very ductile manner. An example is the CRC beam shown below, which achieved a centre deflection of 70 mm in 4-point bending. The beam was cycled to full load – a bending stress of more than 300 MPa - 3 times, yet the amount of cracking was minor. All the cracks appeared at the transverse reinforcement.

This means that a strength and ductility similar to that of steel can be achieved in CRC but, as the density of CRC is less than half that of steel, CRC has the more favourable strength/weight ratio. This can in some cases make CRC better suited for long spans, moving structures or cantilevered structures.



Workability of CRC

CRC is thixothropic, which means it responds well to vibrations. A slump test is not very well suited for measuring the workability of CRC, but as the slump test is universally known and very simple to perform, the effect on slump of varying the content of fibres is shown in the following pictures. Shimizu, Japan carried out tests with fibre contents of 2, 6 and 9% by volume. 6% by volume corresponds to about 450 kg per m^3. Shown in the pictures below are results of a slump test on the 2% and the 6% mix. A 2% mix has been used for most pre-cast applications while a 6% mix is used for CRC JointCast applications.



CRC – pre-cast applications

The high strength of CRC and the very small cover to the reinforcement, which can be used with the very dense matrix, makes it possible to produce light and slender structures in CRC. This has been utilised in a number of applications such as for drain covers, manhole covers, balcony slabs, staircases, beams and columns. For other applications, such as linings for deep mines, the main need has been strength.

Initially CRC was primarily used in high profile buildings, where a special design has been made in each case, but over the last few years a number of projects have been carried out with CRC for especially staircases and balcony slabs. At the moment 3 pre-cast manufacturers in Denmark, one of which only produces CRC, produce CRC for pre-cast applications. The larger number of projects and a more steady production means that CRC has been able to compete with traditional solutions economically as well as technically. A number of examples of pre-cast applications are shown in the following pictures.

Pictures of staircase and walkway designed by Henning Larsens Tegnestue in CRC at Maersk Training Centre.

CRC staircase and walkways in Århus, Denmark designed by 3XNielsen.

Staircase at Aalborg Portland A/S. Beam produced in dark CRC and steps in lighter CRC.

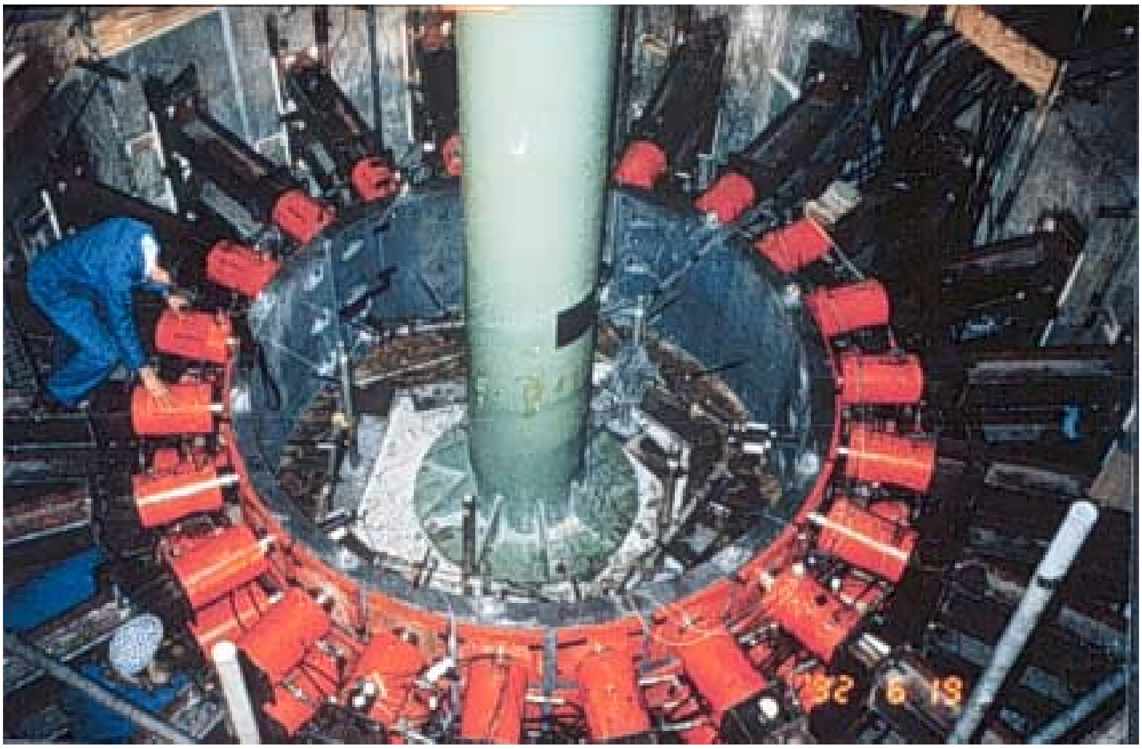
Spiral staircase in CRC produced as elements connected using CRC JointCast. The steps are cantilevered from the inner banister – a CRC beam which carries a lot of torsion. Architects are Arkitektgruppen Århus.

Staircase at the library of Roskilde University, Denmark. The staircase was designed by Henning Larsens Tegnestue.

Staircase at the School of Music in Viborg, Denmark. The staircase is designed by Kjær & Richter.

Staircase for the new offices of architects Arkitektgruppen Århus. There are no supporting beams for the staircase, the load is carried by the steps.

Formwork for balcony slabs being placed on one of the vibration tables at Hi-Con.



CRC linings being installed for testing at Taywood Engineering.

CRC blocks for lining of a mine at Boulby, Scotland. Blocks were produced by Tarmac.

CRC balcony slabs at Løngangsgade, Hillerød, Denmark designed by Arkitekttegnestuen Møllestræde.

Cantilevered balcony slabs in Nansensgade, Copenhagen being put in place. The slabs are supported by the four “flaps”, that are bolted into the deck. The thickness of the “flaps” is 60 mm to allow room for placing insulation on top and below the “flaps”. Domus architects have designed the balcony slabs.

CRC balcony slabs at Vognfjederen, Copenhagen. The slabs are supported at three points and are designed by Arkitektgruppen Århus.

The first of 117 cantilevered balcony slabs for Sandegraven, Vejle in Denmark. The slabs are designed by C.F. Møllers Tegnestue.

The balcony slabs at Sandegraven, Vejle at different stages of installation. The installation process is quite simple, as the “flaps” are bolted to the floor.

CRC balcony slabs for a retirement home. The slabs are simply supported.

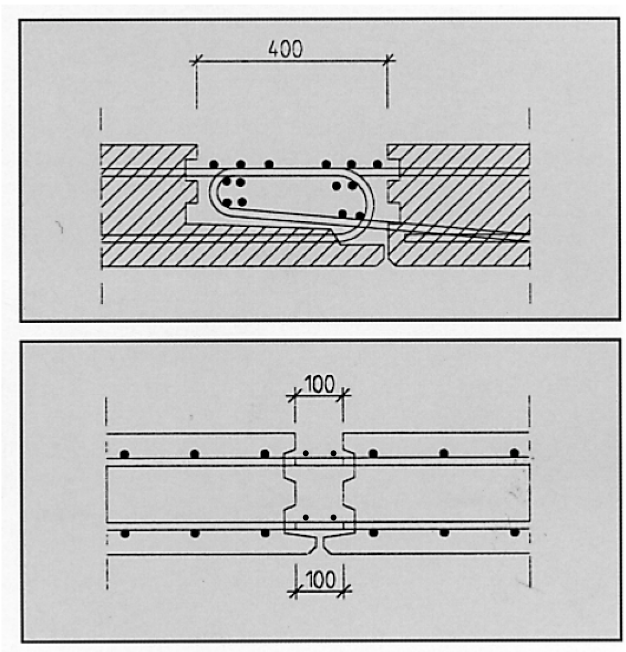
Cantilevered slabs being put in place in Silkeborg, Denmark.

CRC JointCast

The combination of high strength, a large silica fume content and fibre reinforcement provides CRC with exceptional bond properties, which are utilised in a product called CRC JointCast. CRC JointCast is used for in-situ cast joints between pre-cast elements in conventional concrete. As full anchorage of a reinforcing bar can usually be achieved with an embedment length of 5-8 bar diameters after only 3 days, CRC JointCast can provide small and simple joints that have full moment resistance and considerable ductility.

A number of different types of joints have been tested and for bar diameters from 8 mm up to 51 mm. The system was first used to connect slabs for a new building at Aalborg University. In this case a column/flat slab system was used where the columns were placed in a 6x6 m grid. This could have been done with an in-situ cast slab, but in order to take advantage of the flexibility and speed of erection of using elements a system was developed where pre-cast 3x6 m slabs were joined with CRC JointCast in the middle of a span and over the columns.

CRC JointCast is used where it can provide a solution that is better, faster or cheaper and preferably all of those. Examples could be where traditional joints are much too complicated or too expensive, or where the possibility of having a full strength joint in 3 days can be used in the building process. Yet another application is in seismic areas, as the joint is often the weakest part in precast buildings. With CRC JointCast the joint has sufficient strength and ductility to avoid failure in this area.



Traditional joint on top with looped bars and a number of transverse bars. CRC JointCast joint with straight bars is shown below. Both joints are with 16 mm bars. This type of joint – with permanent shutters – is intended for use in bridges or other places where it is difficult to provide shuttering under the joint.

End of bridge slab joint with 20 mm cover to the rebars at the bottom.

Detail of the joint prior to casting. The rebars were mounted with strain gauges for testing purposes.

Pictures showing CRC JointCast used at Aalborg University. The 100 mm wide joints are stronger after 3 days than the slabs, which means that failure will never occur in the joints.

A number of different types of connections using CRC JointCast have been tested in full scale at Building Research Establishment, England. The tests have been part of a project investigating innovative jointing techniques for use by the precast industry.

High Impact Resistant Concrete (HIRC)

With the high strength and ductility of CRC it is well suited for resisting impact loads. The ductile performance of CRC helps distribute local loads to larger parts of the structure. This has been demonstrated in tests with explosives, but it has also been demonstrated for projectiles. In this case the CRC matrix is combined with a special reinforcement. The picture shows CRC slabs after being hit with 50 cm long projectile fired from a cannon at 300 m distance. The weight of the projectile was 47 kg.

The thickness of each slab is 200 mm. 5 slabs were placed together and the projectile was caught in the first 2, causing no damage to the remaining slabs.