Precast Elements in UHPC: Improving on Their Carbon Footprint

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Abstract

Hi-Con has produced precast UHPC since 2001 for the Northern European market. In this market there has been a growing need for information concerning the Environmental Product Declaration (EPD) of building products, and we made our first EPD in 2017. As could be expected the carbon footprint of our products was relatively large as the cement content of UHPC is quite high – but through optimized design the impact on the building was reduced, so that UHPC compares favorably with concrete and steel. Starting January 2023 a strict limit on CO_2-emissions has been introduced for all new buildings – and the number will be reduced every 2 years. Other countries have similar requirements and often builders specify stricter requirements – which means that we have started to change our UHPC formulation to improve sustainability. This could, however, have an impact on some of the properties of UHPC, such as durability.

Keywords: Precast, Sustainability, Durability, Standards.

1. Introduction

Hi-Con is a precast producer in Denmark, that has produced only UHPC – no conventional concrete - since 2001. Over the years more than 100,000 tons of precast elements have been produced and supplied mostly to Northern Europe (Denmark, Norway, Sweden, Finland, Holland and the UK). Typical products are balconies, staircases and façade elements, but also a few bridges have been produced and examples are shown in figure 1.

The type of UHPC used by Hi-Con is called CRC (Compact Reinforced Composite) and it was developed in 1986. Typical mean compressive strength is 165 MPa (24 ksi) and CRC is characterized by combining steel fibres (to provide ductility and crack-control) and conventional rebars. As elements are typically quite slender, cover to the rebars is 10-15 mm (0.4-0.6 in.) and this means that a mortar with maximum aggregate size of 4 mm (0.16 in.) is used in most applications. The low rebar cover also means that durability is very important and typically the effective chloride transport coefficient is below $5 \cdot 10^{-14}$ m^2/s ($6 \cdot 10^{-14}$ sq.yr./s). In 1986 CRC was very different from the type of concrete normally available in the market, so an extensive testing was carried out in the years from 1986 to about 1995, when the first applications were carried out. These tests covered a number of areas and included a few variations on the mix, but typically these variations were with regard to steel fibre type and content, while the binder formulation was kept pretty much constant. This has limited the possibility of varying the mix at later stages if we still want to be able to refer back to the testing carried out in these research projects.

Figure 1 Typical applications for Hi-Con products.

2. Market requirements

When CRC products were first introduced to the market, the main market requirement with regard to documentation concerned structural performance, fire resistance and durability. This was no problem, based on the extensive tests mentioned earlier. As CRC included conventional rebars, design of the CRC elements was similar in principle to Eurocode design – just with some different values. Another focus in Scandinavia, was that balconies had to be well insulated and cold bridges avoided. This is something that was prioritized and that has further improved over the years.

When the first CRC elements were installed, there were few guidelines for UHPC available, and while this has certainly changed over the last few years, there are still no harmonized standards for UHPC. A CEN Task Group has just started work on putting together a proposal for a Eurocode for UHPC, but it will take several years before a document is ready and approved.

In Europe all building products should have a CE-marking (a declaration that your product meets certain standards), but UHPC-products have been exempt from this requirement, as there is no harmonized standard that you can certify against. There is, however, another way to achieve the CE-marking – by using an ETA (European Technical Assessment). You can do this if there is no harmonized standard that covers your product and the ETA has to be approved by the European Commission as well as institutes from all the member countries. Hi-Con produced a special ETA for balconies in UHPC. This was approved in 2017 and now works as a European standard that can also be used by other UHPC producers – and we can CE-mark against this standard. This has really reduced the need for additional documentation when we supply balconies in other countries.

3. Increased emphasis on sustainability in the market

We first saw requests for LCA's (Life Cycle Analysis) and EPD's (Environmental Product Declaration) about 10-12 years ago – especially from countries like Norway, Sweden and Holland – and now it has become a requirement. In Denmark the DGNB system (Deutsche Gesellschaft für Nachhaltiges Bauen) was implemented in 2012 for a number of buildings. The buildings are evaluated on a number of parameters – social, economic, architectural and environmental – and receive a certification based on how high they score. Having a specific EPD for your product helps get a high score, as well as having good insulation, low use of raw materials, no maintenance etc. Our EPD was issued in 2017 and has to be renewed this year and it shows a high carbon footprint (as would most UHPC's based on a high cement content) if compared per m^3, but if we look at a functional unit – such as 1 m^2 of balcony – we compare favorably to conventional concrete and steel, because thicknesses of UHPC balconies are only 80-100 mm (3-4 inches). From January 2023 an additional requirement is mandatory for new buildings in Denmark – less than 12 kg CO2 emission per m2 of building per year (calculated for a 50-year lifetime of the building) (22 lbs/sq.yd.). This number – which includes building, energy consumption etc. - will be reduced every 2 years and is expected to be 9 kg (16 lbs) in 2027. While this limit is not a problem for our current mix composition, there is still emphasis on improving from your current level of emissions.

4. Improving carbon footprint

One way of improving has been to use larger aggregates – essentially adding 5-8 mm (0.2-0.3 in.) aggregates to our existing mix and thus reducing the mortar part – and cement – by 30%. This mix was used for the bridge shown in figure 1 and reduced CO2-emissions by 30%. 8 mm aggregates would be too large for a rebar cover of 10-15 mm (0.4-0.6 in.). With this new mix (especially when a little bit of bauxite sand is added) we had slightly reduced workability, but similar durability and improved strength and stiffness – 200 MPa (29 ksi) and 55 GPa (8,000 ksi).

Other attempts at reducing the carbon footprint, aim at using traditional cement replacement materials, such as GGBS (Ground Granulated Blast-furnace Slag), fly-ash or calcium carbonate fillers. Tests have shown that with GGBS we can replace 25 or 50% of the cement without reducing strength or workability (but we have not yet tested durability), but while we can use this solution for production in Holland (where we have a franchise production), where the GGBS is available, it is not really a sustainable solution in Denmark, where we would have to import GGBS. Fly-ash has some issues as a large part of our products are white. Currently we are making tests with calcium carbonate fillers and the results will be presented at the symposium. One very important thing for us to keep in mind, however, is that in our attempts to reduce CO2-emissions we have to make sure that the mix is not changed so much, that we can not use our ETA and the documentation we already have – and any solutions have to be well tested so we maintain the very good reputation UHPC has of superior strength, ductility and durability.