UHPC Impact in Colombian Infrastructure Applications, Under a Point of View of Cost and LCA

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Abstract

Ultra-High-Performance Concrete (UHPC) represents a competitive construction material due to its benefits in terms of strength, workability, and durability. For these reasons, this material has gained popularity in the infrastructure sector demonstrating its advantages in reducing project cost and time and improving aesthetics. However, nowadays it is no longer sufficient to decide the best alternative for a project considering only the triple constraint cost, time, and quality. It is also fundamental to evaluate the environmental impacts and lifetime performance of the construction options. In this article, some of the projects built in Colombia with UHPC since 2019 are discussed (including facades and the bridge approach in UHPC vs the bridge approach in steel), where it has been shown that Life Cycle Assessment is considered as a key factor for the formulation of the projects and additional benefits have been delivered to the clients.

Keywords: UHPC, Life Cycle Assessment

1. Introduction

As the days go by, the commitment to the environment is increasing. The construction industry is responsible for 40% of greenhouse gas emissions. In Colombia, the use of special concretes in the market has been implemented in order to obtain better results and mitigate the environmental impact, one of which is UHPC, which has gained great popularity in the infrastructure sector due to its great characteristics and benefits in terms of strength, workability, and durability. It has become one of the best options when choosing the best alternative for a project.

However, it is essential to evaluate the environmental impact and lifetime performance of the material. For this reason, Cementos Argos S.A. through the life cycle assessment team has been calculating the environmental impacts generated by the portfolio of cement products, concretes, and applications for more than three (3) years using the EPD Tool.

In the specific case of UHPC or advanced concrete, various academic studies of projects carried out and specified with the material in Colombia have been conducted, such as the rehabilitation of the Palomas Bridge (carried out in Villavicencio, Colombia), the comparative case of a vehicular bridge in UHPC and conventional concrete to know the behavior of the material as a construction solution. It also includes the analysis of the comparison between a beam in UHPC with strength F'c = 120 MPa and a conventional concrete beam with a strength of F'c = 56 MPa.

2. Bridge Life Cycle Assessment

The investigative advances surrounding UHPC applications in Colombia have two central areas of study: structural and environmental. The former includes properties and performance of mechanical behavior, where the outstanding characteristics of the material and its competitiveness with steel and traditional concrete have already been demonstrated. On the other hand, environmental impact studies have progressed in parallel with the realization of projects or proposals for construction alternatives with UHPC, in their pre-feasibility and feasibility stages, using comparative life cycle analysis (LCA) and costs.

For more than three years, Argos' team specialized in life cycle analysis has been calculating the environmental impacts generated by the portfolio of cement and concrete products and applications, using the EPD Tool software, created by the GCCA and QUANTIS for life cycle analysis. This can provide an environmental impact assessment of UHPC "from cradle to gate" (A1-A3) for clinker and cement, and a "from cradle to grave" (A1-D) for prefabricated elements. The service life of structures is one of the determining factors for the recurrence of maintenance, therefore, costs and waste generation, it is important to use tools that allow monitoring throughout the useful life of the structures.

Vehicle and pedestrian bridges formed by prefabricated modular pieces with post-tensioning systems have been the main UHPC applications in the country. Based on the paper of the Life cycle assessment (LCA) of ultra-high performance concrete (UHPC) structures by T. STENGEL and P. SCHIEBL , Ingenieurbüro Schiebl Gehlen Sodeikat GmbH , Germany; the impacts are calculated for three 3 designs of vehicular bridge (Table 1), article design for UHPC and Conventional Concrete and UHPC Argos design in a service life of 150 years. Conventional concrete, due to its characteristics, has a useful life of 30 years fulfilling its function in the structure (vehicular bridge) and in the case of the UHPC it manages to extend the useful life of the structure up to 150 years. In this analysis we focus on the GWP Global Warning Potential as it is one of the environmental impacts that includes greenhouse gases, its unit of measurement is kgCO2eq/m3 of concrete.

***Table 1**. comparison of solutions for vehicular bridge.*

Vehicular bridge	CEMENT kg/m3	GPW kgCO2 eq/m3 CONCRETE
UHPC concrete (Design Article/Portland cement) reference	750	1,512
UHPC Concrete ARGOS Design	700	1,132
Concrete 40 MPa (Article Design/Portland Cement)	335	340.9

As can be seen in the previous table, we take concrete as a reference with the design of the article and a Portland cement is used. In the case of the ARGOS Design UHPC Concrete, the Max Structural cement that contains calcined clays is used. In the case of conventional concrete, a default concrete of the tool and the design of the article is used. Considering the service life of a structure built in UHPC and that the literature refers to more than 100 years, it is proposed for the exercise to take a range of 150 years as a timeline and analyze the data comparatively. UHPC is a concrete that uses 2.24 times more cement and therefore a higher CO2eq emission from extraction and production. Comparatively with conventional concrete, UHPC by extending the useful life and service life of the structures allows CO2eq emissions to be less over time, while the bridge is built once in UHPC in conventional concrete it would have to be built 5 times in 150 years and it would be issuing 2.42 times more (Figure 1). Thanks to the performance of UHPC, it is possible to optimize the dimensions of the structures, reducing the amount of concrete needed for the construction of the bridge by up to 49% in volume.

Normal concrete bridge UHPC concrete bridge

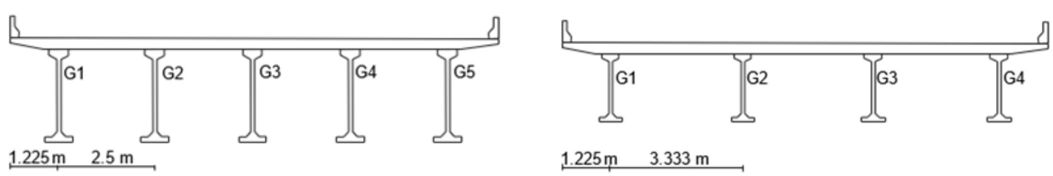

***Figure 1.** Graphic comparison of the number of beams in study bridges. Taken from: https://doi.org/10.1533/9780857097729.3.528*

The Palomas Bridge in Villavicencio allowed the implementation of the rehabilitation of structures as a new application for UHPC in Colombia. One of its three piers was deviated, causing the prefabricated beam to not have enough support and the neoprene pads to be exposed, due to an error in the construction process. The two options evaluated for this case were to demolish the bridge or to reinforce the pier. The first option would have meant disabling the inter-municipal road and generating double the amount of waste, materials, and costs. On the other hand, reinforcing the pier would allow for a smaller section to be created with the help of passive reinforcement for proper UHPC casting. It was decided to construct a pier with a thickness of 0.3 meters, height of 2.7 meters, and length of 10.75 meters, resulting in a UHPC volume of 8.2 cubic meters, which made it possible to extend the life of the bridge without the need for demolition (Figure 2).

Figure 2. *Palomas Bridge reinforcement.*

Using the EPD Tool, a calculation was made estimating the number of emissions generated in the construction of the wall in UHPC, which corresponds to 18270 $KgCO_2$ eq (Table 2). The table shows the emissions generated in each phase of the useful life of the structure, the phase in which more emissions are generated in obtaining the materials; Using non-polluting raw materials is one of the challenges to reduce CO_2 emissions in construction.

Table 2. *Emissions generated by wall in UHPC.*

Category	GWP-tot
Category	kg CO2 eq.
Total	18.27
A1-A3 | Materials	13.21
A1-A3 | Manufacturing	0
A1-A3 | Transport	2232
A1-A3 | Waste management	0
A1-A3 | Storage	0
A4-A5 | Construction process	2573
B1-B7 | Use	-119
C1-C4 | End-of-Life	369,4
D | Benefits	-2909

3. Comparison Between a UHPC Beam and a Conventional Concrete Beam.

Elements intended for the construction of structures with very large spans such as bridge or building beams require designs with materials such as steel or concrete, which to meet the requirements need very large cross-sections, significantly increasing the loads with their own weight. On the other hand, steel, with its high economic costs, becomes unaffordable for some projects.

For the reasons mentioned above, various studies were conducted to analyze the behavior of UHPC applied to these elements and compared with conventional concrete as a prefabricated structure, where a fair comparison is made between two beams subjected to an equal load magnitude. The beam made with conventional concrete has a strength of 56 MPa, and the UHPC beam has a strength of 120 MPa. Both beams have a length of 6 m, and their cross-section is in the shape of a Pi or double T (Figure 3).

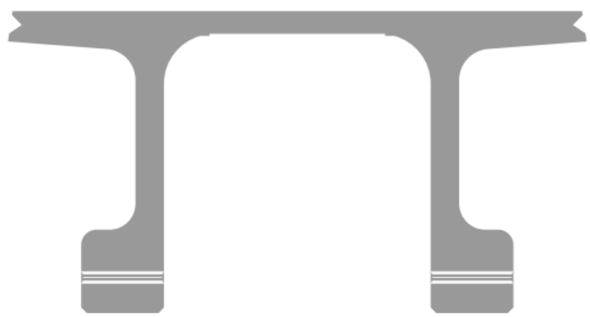

Figure 3. *Cross-section of a Pi or double T beam. Taken from: Advanced Concrete Modular Systems Catalog, Argos.*

The amount of concrete required for a UHPC beam capable of withstanding a compression of 120 MPa is 0.342 m3, while a beam with a strength of 56 MPa has a concrete requirement of 0.62 m3. This represents a reduction in the amount of concrete required when opting for the UHPC beam alternative, which, compared to the quantities required by conventional concrete, becomes an advantage, as it allows to produce more elements.

Other advantages of UHPC compared to conventional concrete are governed by its unique properties (Table 2), one of the most important being the reduction of CO2eq. This is due to the reduction in the amount of material and the prolongation of the useful life and service of the structure. In other words, over the years, structures made with UHPC have a lifespan of up to 150 years, and in addition to their high physical and chemical resistance, they reduce the maintenance and rehabilitation of the elements. Additionally, this concrete undergoes a carbonation process where CO2 equivalent emissions are reduced by more than 4% over time. It is also worth mentioning that when analyzing avoided emissions at an age of 150 years for the beam elements studied in the two different materials, concrete (UHPC) compared to conventional concrete, has a 52% reduction in kg of CO2 equivalent emissions (Table 3).

Table 2. *Physical and Chemical Properties of UHPC Concrete. Taken from: https://cor-tuf.com/ultra-high-performance-concrete-uhpc-fundamentals-applications/.*

Properties	**Traditional concrete**	**UHPC**
Permeability	800 – 1300 coulombs*	44 coulombs
Resistance to freeze/thaw	28 cycles	3,000+ cycles
Useful life	15 – 25 years	100+ years
Compressive strength	17.237 – 34.474 MPa	172.369 – 344.738 MPa
Flexible force	2.758 – 4.826 MPa	13.789+ MPa
Tensile strength	2.068 – 4.826 MPa	11.721 MPa
Impact resistence	1x	2x
Greater weight in the structure		25-33 % thinner walls
Reduce foundation requirements		< weight
Lower carbon footprint		< Amount of material
Less construction time		Faster construction
Flexibility		Ideal in architectural desings complex
Chemical resistence		High resistance to attack by salts, sulfates and corrosion
Union with other materials		> Stickiness
Maintenance		< Maintenance

Table 3. *Summary results of kgCO2 equivalent and emissions avoided according to calculations obtained by the Global Warming Potential (GWP). Taken from: GWP and own elaboration, Argos.*

Constructive solution	**GWP kgCO2eq/m3 concrete**	**GWP kgCO2eq/beam**		**Avoided emissions**	
		75 years	**150 years**	**75 years**	**150 years**
PI joist in concrete UHPC (6 m)	1,255	777	768	-2%	-52%
PI joist in concrete de 56 Mpa (6 m)	787	794	1,588		

4. Conclusions

While UHPC may require a higher initial cost compared to traditional concrete, this new concrete technology offers a much lower life cycle cost. Less material is required for construction projects, and foundation and support requirements are reduced. The possibility of producing prefabricated elements reduces construction time and eliminates the need for plastering, puttying, or rendering, which generates cost savings in several phases of the project.

Noise emissions, dust generation, and other harmful emissions created during on-site construction are also reduced. When the cost of UHPC is distributed over the product's life cycle, it has significant cost benefits over standard concrete.

5. References

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