Design of ultra-lightweight concrete: towards monolithic concrete structures

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Introduction

Lightweight aggregates concrete (LWAC) has been widely applied because of its many advantages such as low density, good thermal insulation and fire resistance. However, literature shows a great variation regarding both mechanical and thermal properties. Furthermore, most of the research focused on either to obtain a structural LWAC with only good strength or as nonstructural material with only low thermal conductivity. Hence, extra insulation materials or load-bearing elements are needed.

The present research aims at the development of a sustainable and durable ultra-lightweight concrete with a good balance between the mechanical and thermal properties. This design concept indicates that a monolithic concrete structure will be in reach. This monolithic concrete structure concept leads to: 1) cost saving, due to the exemption of extra insulation installations; 2) provides architects and structural engineers with more flexibility for the building design; 3) sustainability, as the monolithic structure will ensure a relatively easy maintenance requirement and it is much easier to recycle.

Mix design and experiments

The LWAC is designed applying an innovative mix design method /1/ /2/. This mix design tool is based on the insight that superior properties of a granular mix are achieved when a so-called geometric grading line is designed and obtained, applying a model known as the modified Andreasen and Andersen equation. This particle packing principle insight has been transformed into a numerical mix design, in which all mix ingredients, having their own specific densities and particle size distributions (PSDs), are volumetrically combined via a mathematical optimization routine, i.e. the “target curve” is approached best. This results in improved hardened state properties as well as an improved workability, since more water is available to act as lubricant /3/. The low thermal conductivity (λ) target is achieved by applying a lightweight material as aggregate (LWA). The used LWA, made from recycled glass, have a very low particle density ranging from 300 to 540 kg/m^3.

Therefore, by using cement as binder, lightweight material as aggregates and applying the mix design concept, the obtained LWAC will have a compact matrix with a large amount of non interconnected pores. Theoretically this will lead to obtaining sufficient mechanical properties as well as good thermal insulation. Multiple experiments are performed, including: the flowability, slump and density in fresh state; the density, compressive strength, thermal conductivity and durability in terms of water penetration under pressure in hardened state.

Results analysis

The designed mixes show good workability (e.g. Mix A with a flow of 460 mm and slump of 195 mm). It should be realized that to achieve this flowability, no superplasticizer was dosed, which is an additional feature of the used design method. It can also be seen that the air introduced by the air entraining agent are different, despite the fact that the same amount of air entraining agent was used in these two mixes. This indicates the cement type has an effect on the efficiency of the air entraining agent. As shown in Fig. 1, the cut sample surface from some mixes after performing the compressive strength test, the LWAs are very homogeneously and evenly distributed. This confirms that there was no segregation in the mixtures.

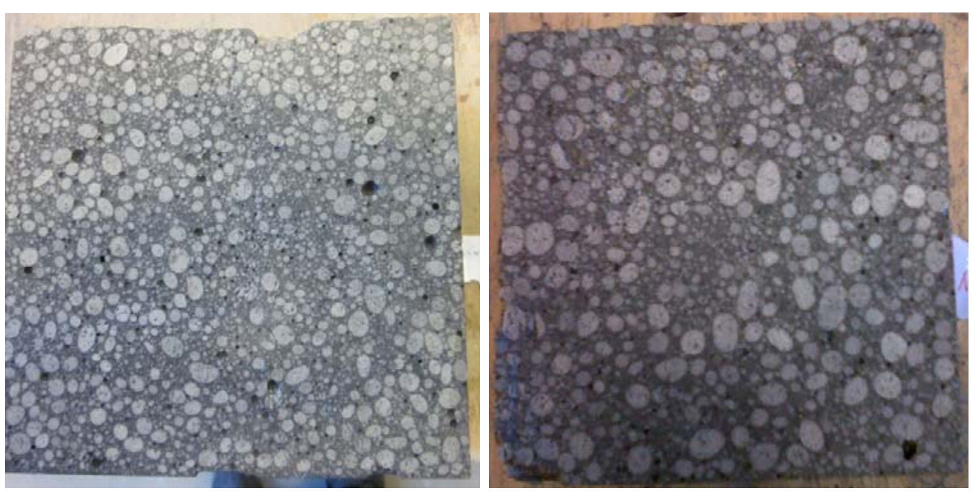

Fig. 1: The pictures of a cut surface of LWAC from two mixes.

Fig. 2 shows the results of the LWAC produced with CEM II/B-V 42.5 N as binder but with different amounts. The 28-day compressive strength decreases from 12 to 10 N/mm^2 when the cement content is reduced from 450 kg/m^3 to 350 kg/m^3. The thermal conductivities of the samples are very similar, between 0.12 and 0.13 W/(m·K). This indicates that the thermal conductivity is not directly related to the cement content (assuming a rather constant density of LWAC).

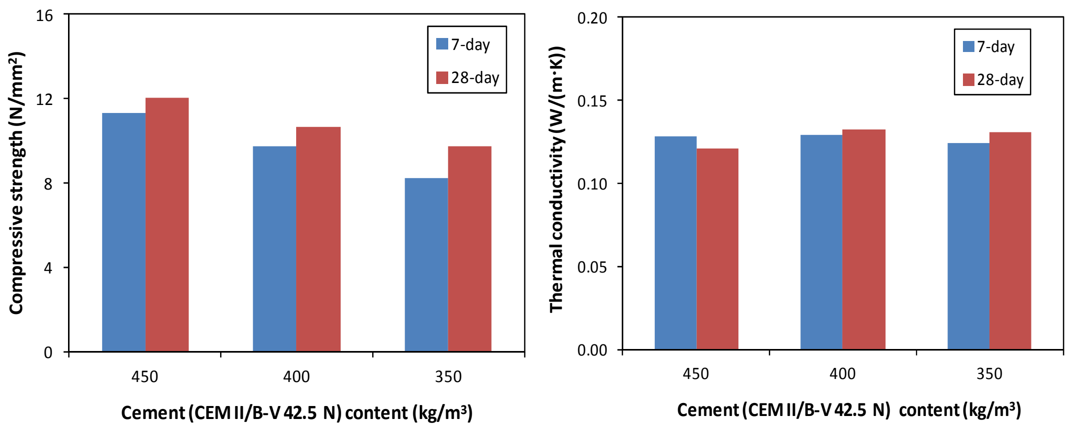

Fig. 2: The properties of the LWAC with different cement content (Left: compressive strength; Right: thermal conductivity).

Chandra and Berntsson /4/ reported a λ of 0.20 W/(m·K) at a dry density of 630 kg/m^3 (i.e. the same density value obtained here). Zareef /5/ reported a LWAC with a λ of 0.18 W/(m·K) at a dry density of 760 kg/m^3 using expanded clay as LWA. Thus, it can be seen that the present LWAC possesses a much lower λ with a similar density range.

Fig. 3: The split surfaces of the LWAC after the water pressure permeability test; water ingress from the side of the bottom surface.

The split samples after performing the water penetration tests are shown in Fig. 3, together with the marked water penetration depths. The results show that although the designed ultra-lightweight concrete has a very high porosity, the permeability to water under the pressure of 5 bars during 72 h is very low, especially in the case of the samples from Mix B (marked with 2-a/b/c in Fig. 3). Hence, the developed ultra-lightweight concrete has an excellent durability, in terms of water penetration under pressure. The low water penetration under pressure further confirms that the applied mix design methodology is a useful tool to design a LWAC: low thermal conductivity, sufficient mechanical properties and good durability are achieved.

Summary

The present study aims at the development of an ultra-lightweight aggregates concrete, with good mechanical properties and a very low thermal conductivity, in order to apply this material for monolithic façade concrete structures, performing as both load bearing element and thermal insulator. Based on the performed study, the following findings can be summarized:

- An ultra-lightweight aggregates concrete with a dry density of about 650-700 kg/m^3 was developed;
- The developed LWAC shows a good workability; and after hardening all the lightweight aggregates are homogeneously distributed in the concrete matrix;
- The effects of the design parameters such as the used cement (type and content) on the concrete properties are investigated;
- The LWAC shows a 28-day compressive strength higher than 10 N/mm^2, and a thermal conductivity of about 0.12 W/(m·K);
- The developed LWAC shows an excellent durability in terms of water permeability under pressure.

Bibliographical references

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