

Structural lightweight aggregates concrete

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Structural lightweight aggregates concrete

Abstract

This paper addresses the development of a structural lightweight aggregates concrete (SLWAC), aiming at a good balance between a low specific density and thermal conductivity, and high mechanical properties. The mix design is performed by applying the modified Andreasen and Andersen model to secure a densely packed matrix, composed of a binder and lightweight aggregates. The water absorption of the applied lightweight aggregates, expanded clay, is studied and an effective water dosage is determined from the obtained results. The fresh behaviour test of the designed concrete shows an acceptable workability, under a water-cement dosage of 0.35. The developed SLWAC shows excellent thermal properties, with a low thermal conductivity of about 0.20 W/(m·K); and moderate mechanical properties, with a 28-day compressive strength of about 34 MPa (class of LC30-33 according to EN 206-1), with an apparent density of about 1250 kg/m³. The significantly low thermal conductivity of the developed concrete under this strength class can find a wide application potential, both for structural and thermal insulating purposes.

1. Introduction

Concrete is the most used man-made building material. This is mainly because of its properties such as: versatility, common availability, durability and economic efficiency. On the other hand, there are some aspects that still limit the concrete application. For example, its high density and high thermal conductivity. That motives this research to develop a lightweight concrete with a good balance between thermal and mechanical properties but with the focus on good mechanical properties.

The previous study resulted, inter alia, in a ultra-lightweight concrete with a density of 650 kg/m³, a thermal conductivity of 0.12 W/(m·K) and a compressive strength of 12 MPa [1]. In this lightweight concrete, expanded glass as lightweight aggregates (LWA) are used. The LWA appears to be the weakest component of the lightweight aggregate concrete. The crushing strength of expanded glass is relatively low so for any further improvement of the mechanical properties, another LWA type is needed. In this case the research goal is to develop a LWAC composite by using a mechanically stronger and economically more attractive LWA, aiming at the properties mentioned in Table 1.1.

Table 1.1

Properties comparison between normal weight concrete (NWC) and the goal SLWAC of this research

Properties	Normal weight concrete	Target LWAC
Dry density (kg/m ³)	2400 [2]	< 1200
Thermal conductivity (W/m·K)	1.7 [3]	< 0.4
Compressive strength (MPa)	20 – 60 [2]	> 30

This article shows a short summary of the research project and will consist of the methods, results, discussion and conclusion of the design process and the hardened state properties of a structural lightweight aggregate concrete (SLWAC).

2. Method

2.1. SLWA concrete design

Two widely used LWAs are expanded glass and expanded clay. The major differences between these two are that expanded clay is mechanically stronger but at the same time has a higher thermal conductivity. Besides the density and the crushing resistance, the particle size distribution (PSD) is an important factor. The knowledge of the PSD of each material allows a more accurate and optimal design of concrete. Table 2.1 shows the properties of the used aggregates.

Table 2.1
Properties of LWA

Type	Material	Particle size (mm)	Loose bulk density (kg/m ³)	Particle density (kg/m ³)	Crushing resistance (MPa)
Fraction 0.25-1	Expanded glass	0.25-1	530 ± 53	1000 ± 100	5.8 (+ 10%)
Fraction 1/4	Expanded clay	1-4	450 ± 65	850 ± 125	> 3.0
Fraction 4.5	Expanded clay	2-10	450 ± 25	840 ± 50	> 3.0
Fraction 6.5	Expanded clay	2-10	650 ± 25	1190 ± 50	> 8.0

The modified Andreasen and Andersen model is used for an optimized packing of the solid particles. The performance of concrete is strongly linked to the porosity, i.e the void fraction. A minimum porosity gives a maximum strength and can be achieved by an optimal particle size distribution (PSD).

The modified Andreasen and Andersen model for the mixture PSD reads as follows:

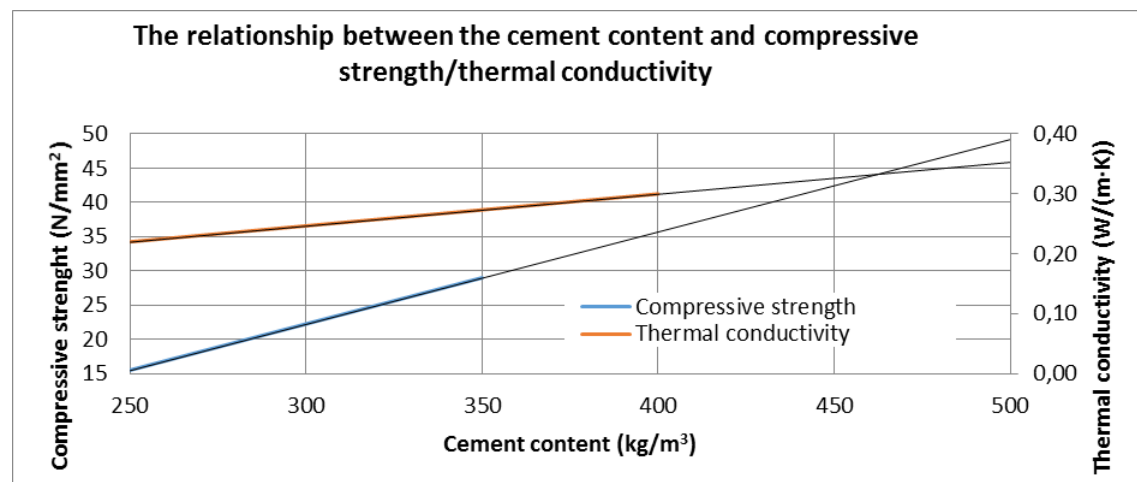
$$P(D) = \frac{D^q - D_{min}^q}{D_{max}^q - D_{min}^q} \quad (1)$$

In this modified Andreasen and Andersen model the P(D) is the fraction of the total solids being smaller than size D, D is the particle size (µm) and q is the distribution modulus.

To reach an optimal packing the modified Andreasen and Andersen model acts as a target function. The mix grading close to this target curve is achieved with an algorithm based on the Least Squares Method (LSM). This algorithm minimizes of the deviation between the target curve and the composed mix curve [4].

Alduaij used expanded clay as LWA and reported a compressive strength of 15.5 to 29.0 MPa when increasing the cement content 250 to 350 kg/m³ [5]. On the other hand, Unal et al., discovered a linear relationship between the cement content and thermal conductivity of the LWAC. The thermal conductivity increased from 0.22 to 0.3 W/(m·K) as the cement content increased from 250 to 400 kg/m³ [6].

Because the cement content is affected by the distribution modulus q , it is important to choose this value carefully.



Graph 2.1: The linear relationship between the cement content and the compressive strength/thermal conductivity

Graph 2.1 gives an indication of the influence of the cement content on the compressive strength and thermal conductivity. The aim of this study is a SLWAC with a thermal conductivity lower than 0.4 W/(m·K), and a compressive strength better than 30 MPa. This means a cement content between 375 and 500 kg/m³ to obtain this mechanical and thermal objective.

An important feature of LWA is the high water absorption rate. The estimation of water absorption by aggregates is still one of the major challenges related to the production of lightweight aggregate concrete. However, the water absorption by LWA also encourages internal curing and the improvement of the paste aggregate interface transition zone, which is beneficial to the mechanical properties of the LWAC [7]. One of the ways to prevent the composite from losing the workability because of the high water absorption rate of the LWA is to pre-soak the aggregates before the concrete mixing process.

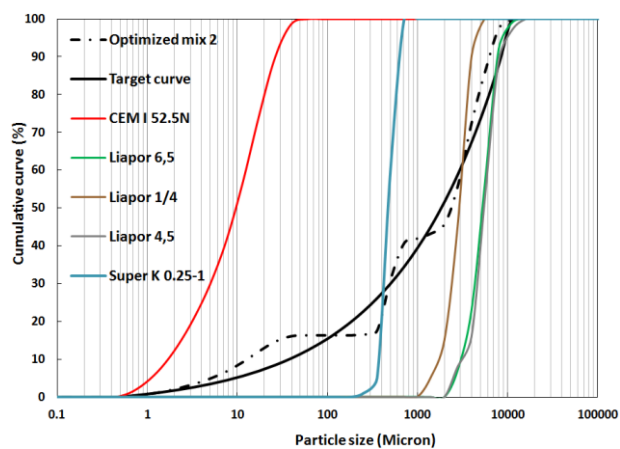
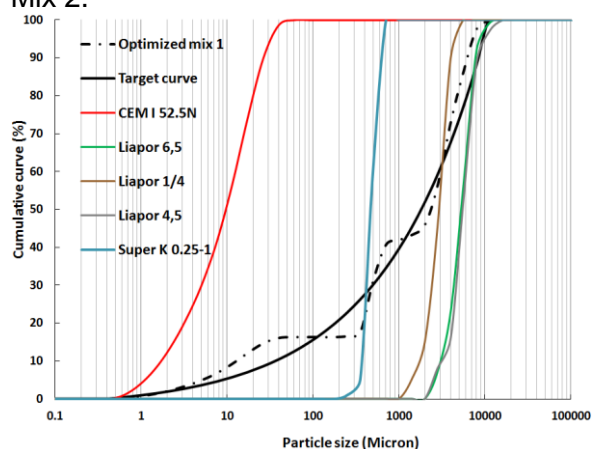
To measure and compare the workability of different mixtures two methods are used in this study: the flow table test and the slump test, according to the NEN-EN 13279-5 [14] and NEN-EN 12350-2 [15].

3. Results and discussion

After testing 8 different mixes (pre-test stage) for workability tests, two mixtures were selected for larger batches analyses. In general the main problem of failing the workability tests was the segregation, bleeding or very dry mixtures. The amount of powders or coarse material, water and superplasticizer (SP) played a big role in this segregation and bleeding process. The mix proportioning of LWAC is generally less

accurate than that of NWC. The amount of water or/and paste penetration into the LWA can influence the accuracy of the mix design.

Graph 3.1 and Graph 3.2 show the particle size distributions of the optimized Mix 1 and Mix 2.



Graph 3.1: Particle size distribution of the optimized Mix 1 with a q-modulus = 0.37

Graph 3.2: Particle size distribution of the optimized Mix 2 with a q-modulus = 0.36

Table 3.1

Mix proportions of all the tested mixtures

	Mix 1 (kg/m ³)	Mix 2 (kg/m ³)
Q-modules (Modified A&A)	0.37	0.36
CEM I 52.5N	425.00	425.00
LWA Fraction 0.25-1	204.22	200.12
LWA Fraction 6.5	0.00	313.77
LWA Fraction 1/4	174.53	181.73
LWA Fraction 4.5	205.12	0.00
Intended W/C	0.40	0.35
Superplasticizer (% of cement mass)	0.00	0.77
Water content	170.00	148.75
Total mass	1178.87	1269.37

Table 3.2

Hardened state properties

	Mix 1	Mix 2
Dry mass (kg/m ³)	1074.50	1256.77
Thermal conductivity (W/m·K)	0.291	0.201
Compressive strength (MPa)	23.29	34.24

The compressive strength of the mixtures develops quickly. The 24 hour strength of Mix 1 reached already 88% of its strength at 28 days: 23.3 MPa. Mix 2 had also a fast strength development. After 24 hours it already reached 90% of its strength at 28 days, 34.3 MPa. The main reason for the fact that Mix 2 is stronger than Mix 1 is the different aggregate type. The coarse aggregate are mostly the weakest parts of a mixture. The crushing strength of Fraction 6.5 is almost three times as high as Fraction 4.5.

The rapid strength development for certain applications could be advantageous, in comparison with other concrete types. Demolding and loading the concrete can take place within 24 hours. This could have a big positive influence on the construction technology and the construction speed. A reason for this could be the crushing strength of the expanded clay aggregates. These will stay the weakest part of the mixture, even when the cement hydration continues. Nevertheless, further attention and study is needed to determine the heat development and monitor the concrete's temperature at the early age, to avoid thermal cracking.

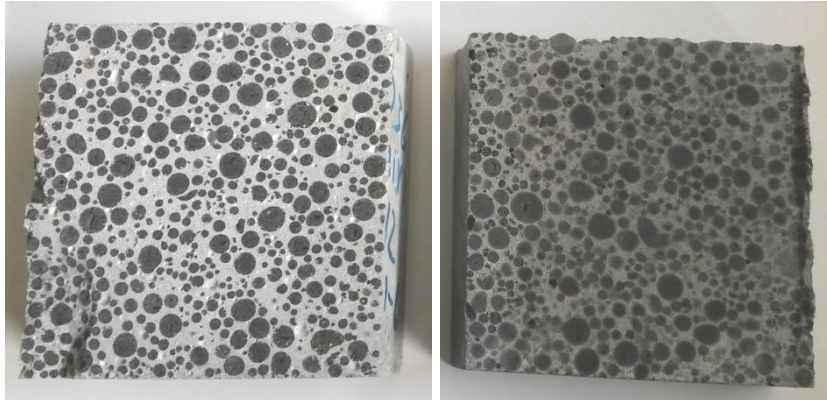
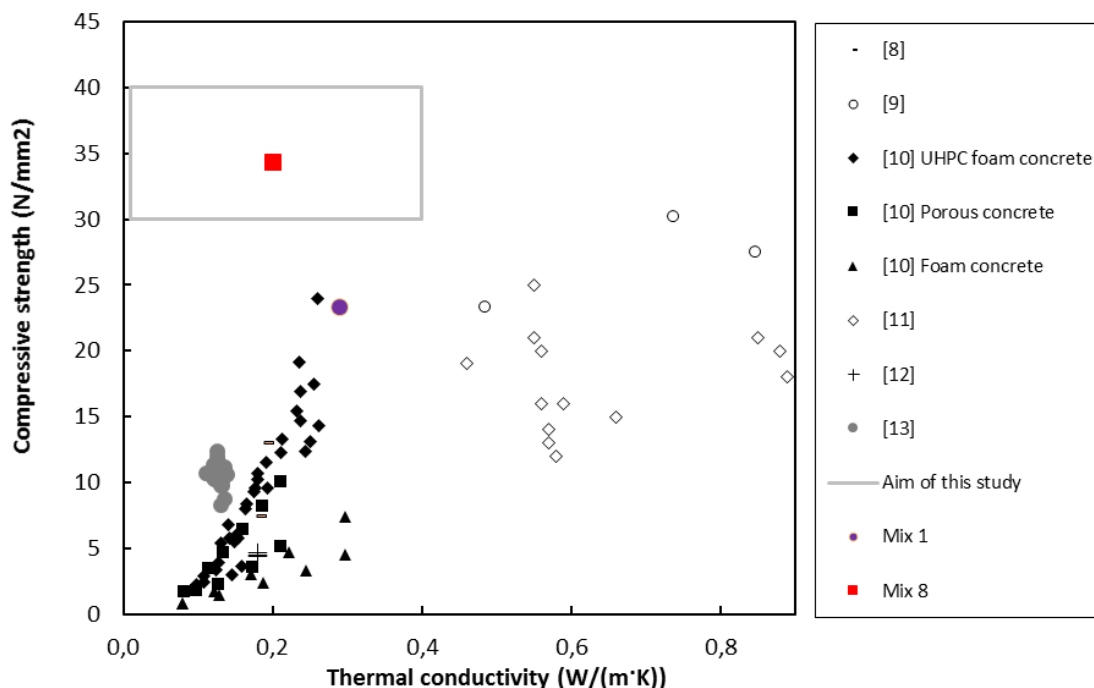


Image 3.1: Picture of sections of 100 x 100 x 100 mm³ samples of (from left to right): Mix 1 and Mix 2.

Image 3.1 shows the sections of the two different concrete mixtures. The cement paste ratio of Mix 1 is higher compared to Mix 2. The aggregates in all the samples are well distributed. It is clear that Mix 1 consists of another aggregate type compared to Mix 2. The shape of Fraction 4.5 is more spherical than the Fraction 6.5.

The volumetric content of the cement paste in Mix 1 is higher compared to that of Mix 2. This observation can be explained by the water amount in the mixtures. Mix 1 has significantly more water in the mixture in the fresh state compared with Mix 2. This cement paste content explains also the higher thermal conductivity. Because cement paste has a higher thermal conductivity than aggregates and there is more cement paste in Mix 1 than in Mix 2, the thermal conductivity of Mix 1 is higher



Graph 3.3: Literature comparison, relationship between compressive strength and thermal conductivity

4. Conclusion and recommendations

This research addresses the development of a SLWAC, aiming at a good balance between a low thermal conductivity and high mechanical properties. The designed lightweight concrete could be applied in structures such as long span bridges, high rise buildings, and buildings where foundation conditions are poor. Based on the investigation presented in this article, the following conclusions are drawn:

- Applying the described design methodology, two SLWACs are developed using two different types of expanded clay aggregates. Mix 2 showed the best results, with a very low thermal conductivity of about 0.20 W/(m·K); and moderate mechanical properties, with a 28-day compressive strength of about 34 MPa, and a density of about 1250 kg/m³.
- The final properties of a LWAC are strongly linked to the applied LWA type. This study presents big differences between two expanded clay aggregate types, not only for the hardened state properties but also for the fresh state properties.
- The final compressive strength of LWAC is strongly limited by the applied LWA. While there is still hydration ongoing after 24 hours, the compressive strength will only increase about 10% after 24 hours, due to the weakness of the used LWA.
- The rapid strength development of the designed SLWAC could be advantageous for certain applications. Demolding and loading can take place within 24 hours. This could have a big positive influence on the construction technology and the construction speed.
- The w/c ratio has not only a big influence on the mechanical properties, but also the thermal conductivity. Because a higher w/c ratio provides in ratio for more cement paste, which results in a higher thermal conductivity (even with a similar cement content).

There are several ways to further improve the SLWAC developed in this study. The first is a longer pre-soaking time of the aggregates. This gives a better workability, which can

later result in less mixing water input. The advantage of less mixing water can be a lower thermal conductivity and higher strength.

Another improvement could be the PSD of the mixtures. This current mixtures are missing a lightweight sand type that can cover the particle fractions 100-300 micron and 800-1250 micron. This causes gaps in the PSD which results in a deviation with the target line, found by the modified Andreasen and Andersen model. When this will be improved, the workability and the mechanical properties will improve as well.

The chosen q-modulus influences the ratios between the coarse and finer materials in the mixture. For the development of the mixtures in this research a q-modulus of 0.37 is used. To decrease the density and the thermal conductivity a higher q-modulus is recommended, so that more coarse LWA particles would be present in the mixture.

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