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THE INFLUENCE OF GRANITE ON THE PERFORMANCE OF AUTOCLAVED AERATED CONCRETE

Chris Straub, Sven Segers, Miruna Florea, Jos Brouwers

Abstract

Autoclaved Aerated Concrete (AAC) has been well known in Central Europe for decades. In traditional cement and concrete research a huge increase of knowledge has improved the material behaviour and efficiency. The understanding of the mineral reactions and properties in AAC has also improved, but several relations are still unknown. While the influence of ordinary raw materials (quartz, fly ash, free lime, cement, gypsum, Al-powder, water) is mostly known, the behaviour of non-traditional substitutes for environmental purposes can so far only be determined by trial and error. In this research a closer look is taken on the influence of granite on AAC, before and after autoclaving. The aim is to understand the reactions with the aim of improving the characteristics of AAC.

The parameters for the fresh material properties are for example the slump flow, rising height over time, temperature development and green-body strength, while in the final AAC the compressive strength, the raw- and true density, the thermal conductivity, the phase content and the microstructure are determined.

Keywords: Autoclaved aerated concrete, granite, material substitution

1 Introduction

Granite is a hard, light-coloured, coarse-grained, crystalline, intrusive igneous rock essentially composed of quartz, alkali feldspar, plagioclase feldspar and mica. Granite is a well-known rock material; the ancient Egyptians and the Romans already used granite in their time. In modern times, since the development of industrialised cutting and polishing methods, granite is mainly used for ashlar works such as funerary monuments in cemeteries.

The granite processing industry (cutting and polishing) produces vast amounts of granite rock waste (coarse grains) and granite dust (fine powder), which in many cases are disposed in landfills [1].

Especially the fines can be interesting for the autoclaved aerated concrete (AAC) industry. The material is already fine, so the energy intensive grinding can be reduced or skipped, whereas the high quartz content and total SiO_2 content make the material interesting as a quartz replacement. The minimum quartz content of granite is 20%, but most granites have more, and approximately 70% total SiO_2 is not uncommon.

2 Material and methods

2.1 Materials

All materials used for preparing the samples are technical grade and, if not indicated otherwise, fulfil the recommended requirements for AAC production [2–5] or originated from AAC material suppliers (Table 1). All experiments follow a sand-based reference recipe (provided by HESS AAC Systems B.V., Table 2). Granite was obtained from Graniet import BeNeLux B.V. The material was freshly milled in a ball mill to the particle size distribution (PSD) as shown in Figure 1.
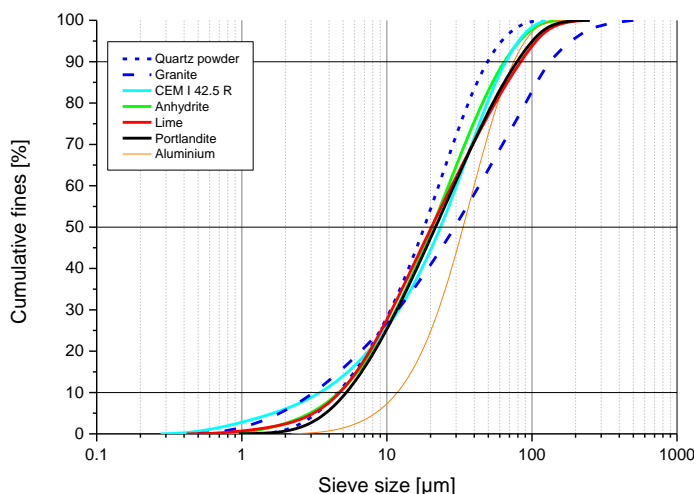

Figure 1: Particle size distribution of the raw materials.

The chemical compositions of the raw materials was measured by X-ray Fluorescence (XRF, PANalytical Epsilon3) with pressed powder tablets and the particle size distributions was obtained by a laser granulometer (Malvern Mastersizer 2000), as shown in Table 1 and Figure 1. The true density of the powders was determined by using a helium pycnometer (Micromeritics AccuPyc II 1340).

Table 1: Chemical composition of the raw materials.

Chemical compositions	Quartz	Anhydrite	Cement	Portlandite[1]	Lime[2]	Granite
$Na_2O + K_2O$	0.05	0.37	1.08	0.11	0.27	9.07
MgO	-	1.20	0.96	0.33	0.58	0.91
Al_2O_3	0.85	0.65	4.88	0.13	0.40	16.20
SiO_2	98.6	1.55	15.7	0.30	0.67	65.72
SO_3	-	53.7	3.98	0.05	0.03	0.07
CaO	0.01	38.9	66.5	70.1	95.9	2.92
Fe_2O_3	0.03	0.19	2.48	0.17	0.26	2.87
L.O.I.	0.26	3.08[3]	2.38	27.4	1.81	1.38
True density [kg/m³]	2570	2950	3120	2300	3240	2677

[1] Calcite content ≈ 15% (det. by LOI and density). [2] Portlandite content ≈ 10% (det. by LOI and density), Slaking lime test (EN 459-2): $t_{60°C}$ = 10 min / T_{max} = 75.8 °C.
[3] The L.O.I of anhydrite was measured at 650 °C.

Table 2: Mix design of the samples.

Mix proportions	Ref.	10%	20%	40%	60%	80%	100%
Quartz	8.0	7.2	6.4	4.8	3.2	1.6	-
Granite	-	0.8	1.6	3.2	4.8	6.4	8.0
CEM I 42.5 R				2.4			
CaO				1.0			
$Ca(OH)_2$				0.3			
$CaSO_4$				0.3			
H_2O				7.5			
Al Powder				0.01			
W/P	0.625	0.625	0.625	0.575	0.550	0.525	0.516

2.2 Methodology

For the preparation of the samples, the experiments were performed as follows: after preheating the specific water amount (dependent on the water-to-powder-ratio, W/P ratio) to 45 °C, it was put in the mixer (A Swinko EZR 22 R,R/L with a 4-bladed propeller mixing rod) and stirred at a slow speed. Separately, the aluminium powder (Benda-Lutz® 5-6380 from Benda-Lutz Skawina Sp. z o. o. / SunChemical) was manually pre-dispersed in water: A small part of the mixing water (≈ 100 ml) was separated. The Al powder and half of the water were mixed in a closed container by strongly shaking (with a tiny droplet of surfactant). Quartz and portlandite were successively added and mixed for minimum 60 seconds, in order to ensure homogeneity. The addition of lime (time = 0), cement and anhydrite (after 30 s) was performed and then the mixing was continued for 90 s. Finally the aluminium powder suspension was added (and the container rinsed out with the remaining separated water to ensure that all Al powder is utilized and the W/S ratio is correct). The mixture was poured immediately into insulated moulds.

The samples were demoulded on the following day (after about 12 h) and placed directly in the autoclave (autoclave: Maschinenbau Scholz GmbH & Co. KG / steam generator: WIMA ED36). The autoclave was programed as follows: 20 min vacuum (-0.8 bar), heating up to 187 °C / 11 bar within 1.5 hours, holding a plateau of 187 °C / 11 bar for 5 hours, cooling down to 0 bar within 1.5 hours. After this procedure, at least 5 cm of each side of the sample were removed by band saw to obtain an undisturbed pore structure (eliminating the "wall-effect").

3 Results

3.1 Green body

The spread flow was kept in a range of 25 ± 3 cm, determined with a cylindrical cone of the dimensions of 7 cm diameter and 6 cm height [6]. The water-to powder ratio (W/P) was adapted accordingly (Table 2). Due to the coarser PSD the water demand of the mixture decreased with increasing granite content.

The temperature (Figure 2) and stiffening (Figure 3) of the mixture were monitored by a thermocouple and a self-made indenter (similar to Vicat).
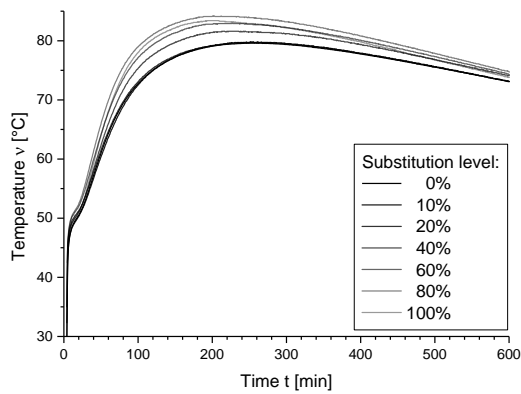
Figure 2: Temperature evolution of the AAC green body during time.
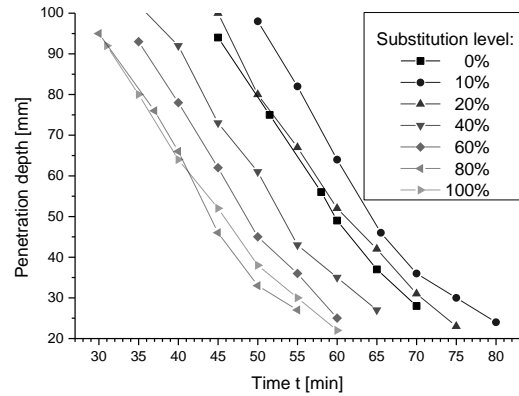
Figure 3: Stiffening of the green body expressed as penetration depth during time.

The effect of the granite powder on temperature- and rising development are negligible, whereas the reduced water amount (starting from 40% replacement onwards) is the driving force for the increased temperature and as an effect of this the earlier stiffening of the green body takes place.

3.2 Hardened State

Due to the fact that the compressive strength of AAC is highly dependent on the raw density and the moisture content, all samples were dried at 60 °C until constant mass and the raw density was determined. The measured compressive strength was normalized and expressed as A-Value [3]:

$$A\text{-}Value = \frac{\sigma}{0.016*\rho} \tag{1}$$

The raw density and the A-value are displayed in Figure 4. With increasing granite content the A-value is raising up to 80% quartz replacement, and even at full replacement the strength exceeds the reference material. The increase of the raw density is mostly related to the reduction of the W/S ratio of initial mixture.
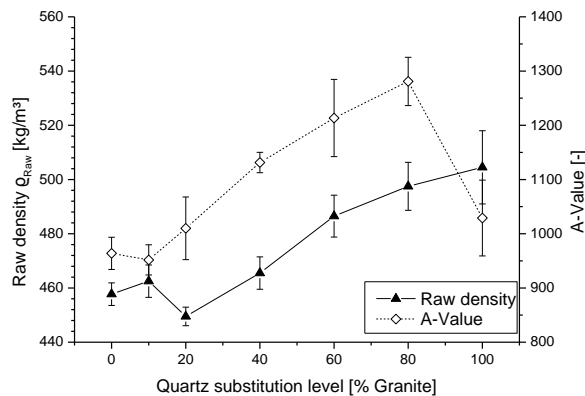

Figure 4: Raw density and A-value of AAC prepared with various substitution levels of granite powder replacing quartz powder.

Taking into account the true density of quartz and granite powder (Table 1), the change in the true density of the produced AAC (Figure 5) cannot be explained simply by the substitution. Under the assumption that the density decrease with increasing substitution level was caused by a higher amount of hydration products, the values corresponds very well with the strength results, which have their maximum at 80% substitution as well.
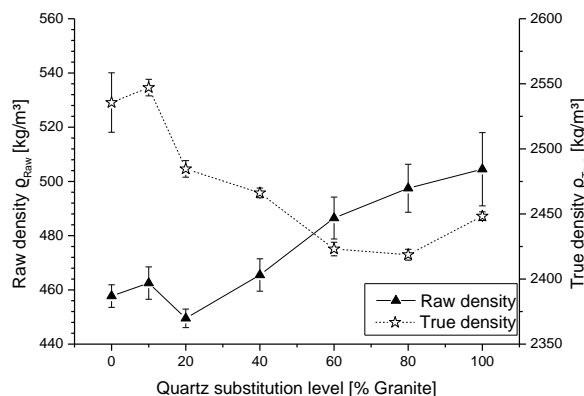

Figure 5: Raw density and true density of the AAC samples prepared with various substitution levels of quartz by granite powder.

The thermal conductivity (Figure 6) is highly linked with the raw density (Figure **5**), which is as well more related to the initial W/S ratio than to be any influence of the granite substitution. The drying shrinkage (Figure 6) however could be successfully decreased by granite substitution. The recommended limit of the drying shrinkage (0.4 mm/m) was exceeded by the reference AAC due to the unusual purity and fineness of the applied quartz powder, whereas the granite addition showed a quite rapid decrease of the shrinkage with increasing substitution level.
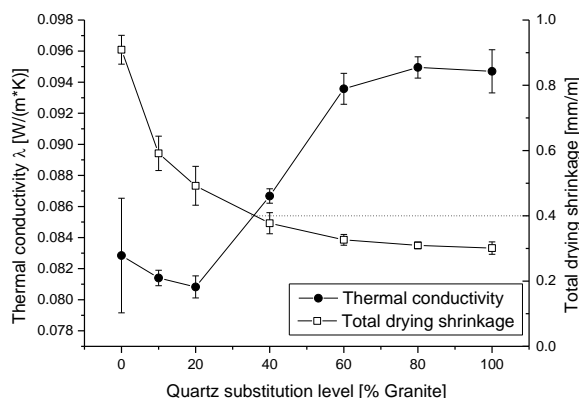

Figure 6: Thermal conductivity and total drying shrinkage of the AAC samples prepared with various substitution levels of quartz by granite powder. The dotted line is the recommended maximum of the drying shrinkage.

The phase analysis by XRD is presented in Figure 7. A higher granite content correlates to a higher content of observed granite minerals (e.g. mica, feldspar). The tobermorite content increases significantly with the granite addition, the highest contents being obtained at 60 and 80 percent. This corresponds with the strength results. Additionally a slight shift of the 00l

peak (≈ 11.3 Å) towards higher d-values is noticeable, which is due to enhanced aluminium incorporation. Katoite could be detected in increasing amounts with increasing substitution levels. This and the peak shift of the tobermorite might be related with the higher aluminium intake of granite into the system compared to pure quartz. Other identified phases are anhydrite, ellestadite and calcite; which is unavoidable due to random carbonation during the green curing. The aragonite content decreases with increasing substitution level.
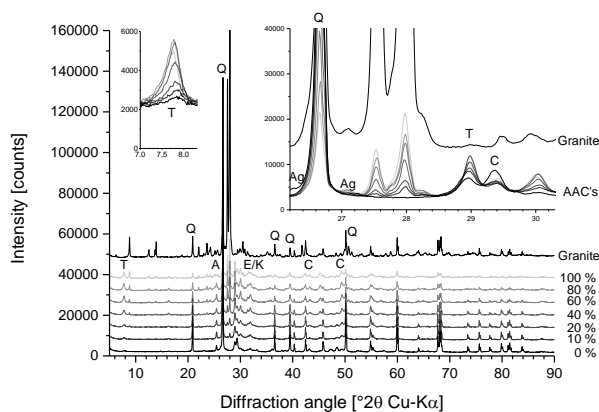

Figure 7: XRD diagraph of AAC samples prepared with varying proportions of granite powder. The granite powder (not labeled) is composed of Quartz, Feldspar (Albite and Orthoclase), Mica (Biotite), and a member of the Chlorite family / T: Tobermorite; Q: Quartz; C: Calcite; A: Anhydrite; K: Katoite; E: Ellestadite; Ag: Aragonite.

Microstructural changes were investigated by SEM (Figure 8 - Figure 11). Already at small percentages of replacement the matrix appears denser, and the tobermorite is more crystalline.
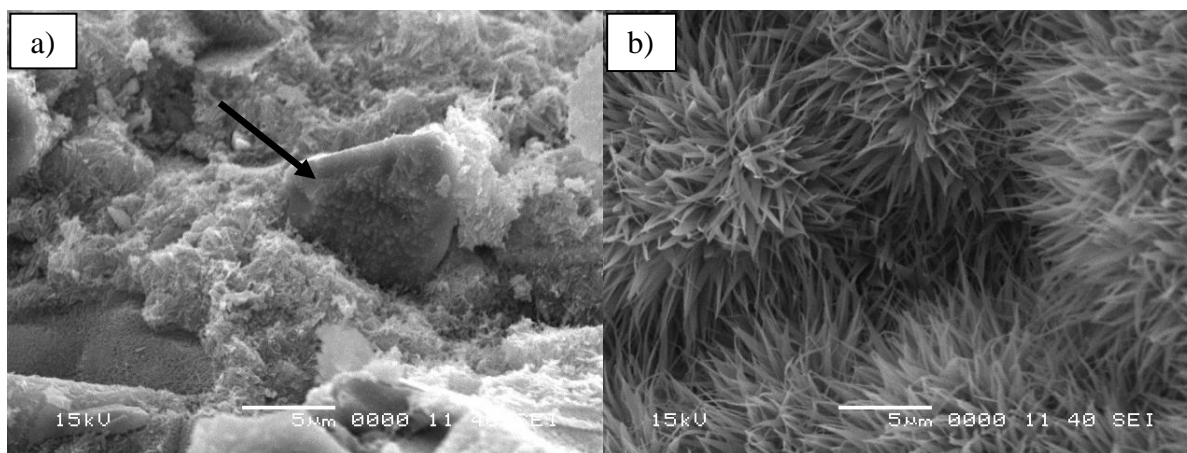

Figure 8: SEM-SE image of the reference AAC (= 0% granite), fractured surface a) matrix with partly dissolved quartz grain (arrow) b) Tobermorite appearance in the pores.
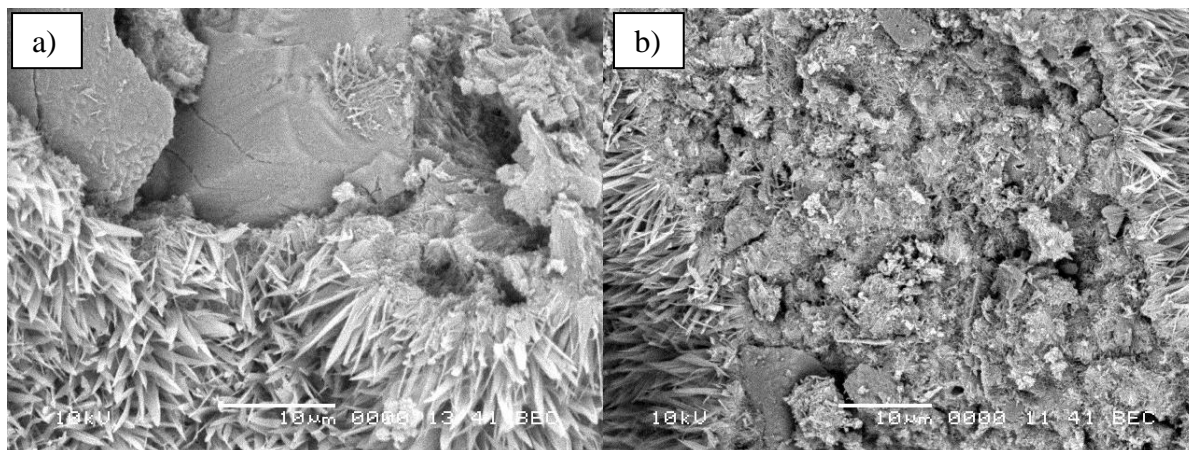
Figure 9: SEM-BSE image of AAC prepared with 40% granite replacing quartz.
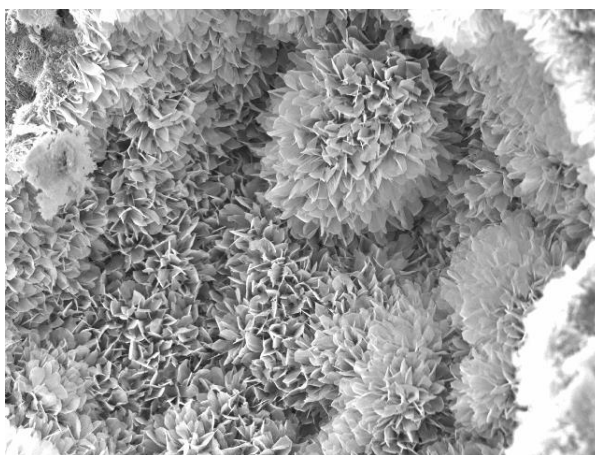

Figure 10: SEM-SE image of AAC prepared with 80% granite replacing quartz. View into a pore with tobermorite mineralization. Scale is equal to Figure 9.
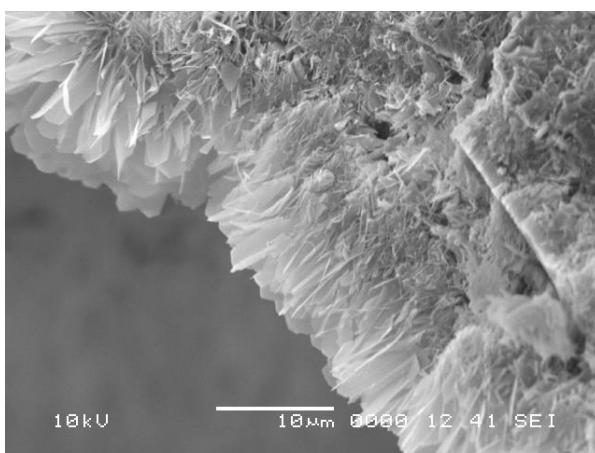

Figure 11: SEM-SE image of AAC prepared with full replacement of quartz by granite powder. The broken surface is approximately orthogonal to the viewing direction, which leads to Tobermorite crystal length of approximately 8-10 µm.

4 Summary & Conclusions

It is possible to substitute quartz powder as raw material by granite powder in AAC up to 100%. In the current study the best result in terms of strength was the sample with 80%

granite powder and 20% quartz. The workability in the fresh state was optimized for each mixture by adopting the water amount accordingly. This lead to a faster green curing time and therefore possibly, a faster production. The granite substitution is beneficial for the strength and the shrinkage of the AAC samples. This is most likely due to the slightly coarser particle size of the granite powder, which decreases the solvability of SiO_2 and therefore leads to more crystalline tobermorite. This could be confirmed by XRD and SEM.

In conclusion it can be stated that granite powder can serve as quartz replacement in AAC, but there might be limits of applications depending on the local properties of the material.

Acknowledgements

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