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Development of new concrete mixtures based on Aplite and Perlite.

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ABSTRACT

Cement extenders are commonly used as an addition to concrete mixtures to increase material properties.
A mineral called aplite is a cement extender. This mineral contains many possible favourable properties.
An experimental research on aplite has been carried out at the University of Stavanger. This study presents the effect of aplite in light-weighted concrete. Specimens with different amount of aplite in different cement were tested in various environment and time points. Compressive strength and density were measured. Thermal conductivity of perlite, a volcanic rock, was determined by using LabVIEW.
Time played an important role on aplite's pozzolan effect. The test results indicated that the long term compressive strength increases immensely with small amounts of aplite.
Application of aplite can permit a decrease in use of Portland cement and still obtain a higher compressive strength in the concrete.

INTRODUCTION

In 2006 “Heli-utvikling” had a vision “to develop and improve the concrete technology by sustainable use of mineral resources”. After testing hundreds of minerals they ended up with a mineral called aplite. Aplite is an exciting product that is believed to have many favourable properties. Potential properties are high strength, reduced permeability, reduced heat of hydration, reduced shrinkage and resistance against sour environments and high temperature. Many companies such as Heli-utvikling, StatoilHydro, Vegdirektoratet and Skanska are involved in the research of aplite. Despite this, documentation is still lacking [1].
Perlite is used to make a lightweight concrete but it offers many advantages beyond its lightweight. Perlite concrete provides thermal insulating and has sound deadening properties as well, depending on mix design [2].
This study has examined one of the potential properties of aplite, high strength. Increase of compressive strength by using a cement extender such as aplite can allow a decrease in use of cement. This is more environmentally friendly and cost efficiently [3].
Compressive strength was tested by making a light weighted concrete using aplite and perlite. Aplite`s reaction to different time interval, heat generation, cement types and the effect of different amount of aplite was examined. Thermal conductivity of light weighted concrete has been inquired as well.

MATERIALS

Aplite

Aplite is an intrusive igneous rock of a simple composition. The mineral is fine – grained light-colored (white, gray or pink) granite consisting almost entirely of quartz and feldspar [4].
Aplite is a natural pozzolan. A material that reacts pozzolanic is a finely-divided material that reacts with calcium hydroxide and alkalis to form compounds possessing cementitious properties [5].
Fig.1 shows the particle size distribution for aplite used in the experiments that have been carried out.

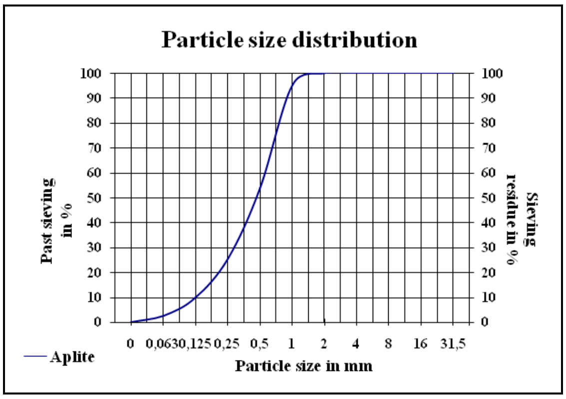

Figure 1: Particle size distribution for aplite. The distribution was done according to NS-EN 993-1 and 2 [6, 7].

Perlite

Perlite is a generic term for naturally occurring siliceous volcanic rock. Perlite separates itself from other volcanic glasses by the ability to expand four to twenty times its original volume, when it's quickly heated to above 871 ºC. This expansion is due to the presence of two to six percent combined water in the crude perlite rock. When the combined water vaporizes, it creates countless tiny bubbles in soften, glassy particles. It is this "popcorn" occurrence that gives perlite its exceptional physical properties [8]. Fig.2 shows how much the perlite volume expands, during rapid heating.

Figure 2: Three stages of perlite [9].

Aalborg white

Aalborg white, CEM I 52.5 NA L is a rapid hardening cement with a high early (2 days) and standard (28 days) compressive strengths as shown in fig.3. Its unique properties are white colour, high consistency, extraordinarily low content of alkali and high sulfate resistance [10].

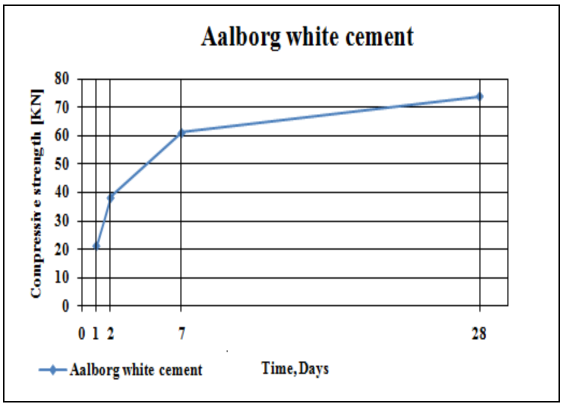

Figure 3: Compressive strength generation for Aalborg white cement. Values are retrieved from Norcem datasheet [10]

Norcem industry

Industry cement, CEM-I – 42,5RR is a rapid hardening cement with a high early (2 days) and moderate (28 days) compressive strengths as shown in fig.4. When a high and early hardening is preferred, industry cement is used. It is especially suitable for casting in cold weather. Due to a very high heat generation, the cement is not suitable for massive constructions. Its high alkali content makes a combination with reactive aggregate unacceptable [5, 11].

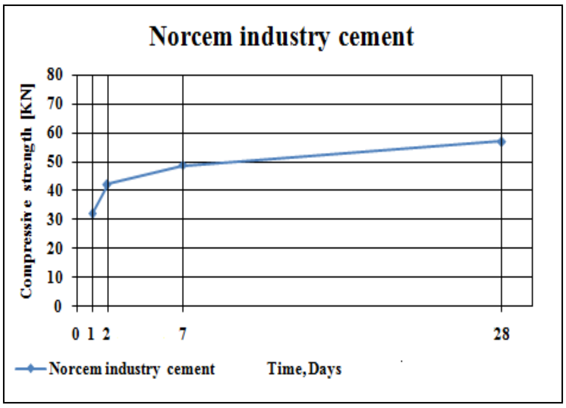

Figure 4: Compressive strength generation for Norcem industry cement. Values are retrieved from Norcem datasheet [11]

Norcem standard cement FA

Norcem standard cement FA, CEM II/A-V 42,5 R is a moderate hardening cement with a moderate early (2 days) and (28 days) strengths. It has high alkali content, but because of favourable influence from flying ash it can be used in combination with reactive aggregate [5, 12].

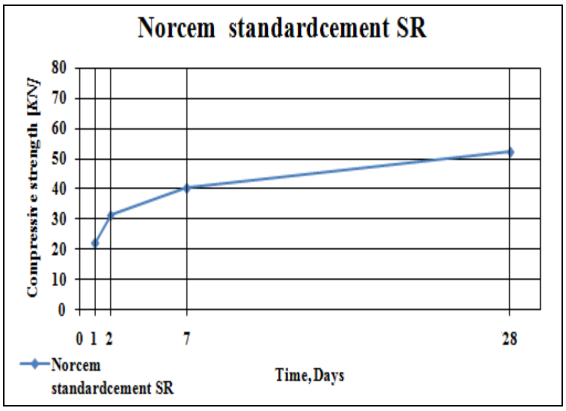

Figure 5: Compressive strength generation for Norcem standard cement SR. Values are retrieved from Norcem datasheet [12]

EXPERIMENTS

Following tests for aplite have been carried out:

- Replacing cement with different amount of aplite.
- Replacing perlite with different amount of aplite.
- Examining the effect of aplite combined with different types of cement.
- Examining the effect of increased heat generation.
- Examine when the pozzolanic reaction initiates.

Subsequent experiments were done as well:

- Thermal conductivity for light weighted perlite concrete.
- Density for perlite, aplite and Forsand sand.

Compressive strength testing

Compressing strength testing was divided into three parts:

- Making the cubes
- Density testing
- Compressive strength testing

Making the cubes

The cubes were made according to NS-EN 12390-2 [13].

Method:

Water and cement was blended to a homogeneous mixture by the means of an iron rod. Aplite and perlite was added to the mixture and stirred to an apparently identical structure. With the mixture completed, the shuttering was lubricated and the mixture was filled in two layers. The first layer was thrusted 25 times by an iron rod to the bottom of the shuttering. The second layer was then filled and thrusted 25 times, but only to underlying layer. The concrete surface was afterward even out with the iron rod.
The cubes was covered with plastic to prevent dehydration and hardened for three days in a room at 20±4 ºC.
After three days, the cubes were placed in a water bath for further hardening.
Table 1 shows the composition in the various mixtures. To maintain a constant volume, particles density has to be considered when replacing different particles. Table 2 shows density of different particles. Determination of replacement mass was found according to:

Volume of known mass (m1)

$$V1 = \frac{m1}{\rho 1} \qquad (1.1)$$

Replacement mass (m2)

$$m2 = \rho 2 * V2 \qquad (1.2)$$

Table 1: Compositions for various mixtures. Cement types are denoted with $^{(1)}$ Aalborg white $^{(2)}$ Norcem industry cement and $^{(3)}$ Norcem standard cement FA

Mixture	Water [g]	Cement [g]	Aplite [g]	Perlite [g]
Reference	600	$500^{(1)}$	0	200
1	600	$450^{(1)}$	41.4	200
2	600	$400^{(1)}$	82.8	200
3	600	$300^{(1)}$	165.6	200
4	600	$200^{(1)}$	248.4	200
5	600	$400^{(2)}$	82.8	200
6	600	$400^{(3)}$	82.8	200
7	600	$500^{(1)}$	172.3	150
8	600	$500^{(1)}$	344.6	100
9	600	$450^{(1)}$	41.4	200
10	600	$400^{(1)}$	82.8	200

Density testing

Determination of volume and density for the cubes was done according to NS-EN 12930-7 [8]. Fig. 6 illustrates the methods for estimation of volume and density.

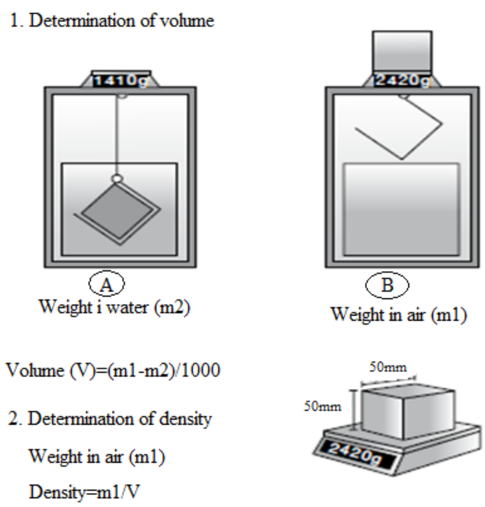

Figure 6: Determination of volume and density.

Compressive strength test

The cubes dimension was first measured in according to NS-EN 12930-2 [14]. Then the compressive strength test was carried out by a material testing machine Z020/TH2S, Zwick 2001. The machine is shown in fig.7 and was limit to press cubes with compressive strength less than 19.5 KN. Another machine called Toni Tech, was used to press cubes with larger compressive strength. The test specimens were measured for compressive according to NS-EN 12930-3 [15].
Cubes were placed centric in the material testing machine with the load direction perpendicular to the cast direction. The loading was applied continuously with a loading speed giving a pressure increase of 0.5 N/mm^{2}s.

Figure 7: Material testing machine Z020/TH2S, Zwick 2001

Density testing of aplite, perlite and Forsand sand

Densities shown in table 2 for aplite, perlite and Forsand Sand was found according to NS-EN 1097-6 and NS-EN 1097-7 [16, 17]. Density of cement usually given as 3.15 g/cm^3 [18].

Table 2: Density of different particles

Particle	Density [g/cm^3]
Aplite	2.65
Perlite	0.77
Forsand sand	2.77
Cement	3.15

Thermal conductivity for perlite

Equipment:
- Cylinder form
- PT-100 sensor
- Polystyrene top cap and bottom cap
- Hairdryer

- Steel wire
- poly chem. air shrink RG59/6
- Hobart blender
- Iron rod

Method:

The experiment can be divided into two parts:

- Making the cylinder
- Testing the cylinder

Making the cylinder

Top and bottom cap of a concrete cylinder form was removed and replaced with polystyrene caps. Center of the caps were marked to indicate where the iron rod was going to be placed. The form was lubricated with lubrication oil and polystyrene caps were greased with Vaseline to prevent water from leaking through the caps.
Poly chem. air shrink was placed around the iron rod and then shrunk using a hair dryer. Then the iron rod was placed with its surrounding poly chem. air shrink through the top cap and fastened to the bottom cap.
The mixtures were made consistent with table 3. Further it was poured into the cylinder form and placed in a room at 20±4 ºC. It hardened for three days and was then extracted for testing.

Table 3: Compounds of the cylinders

Test	Cement [g]	Water [g]	Sand [g]	Perlite [g]
1	3500	2500	9000	0
2	3500	4000	0	2000

Testing the cylinder:

Unlike many other properties, thermal conductivity cannot be directly measured. Intermediate quantities must be determined from which the conductivity may be ultimately calculated.

Thermal conductivity was tested for two different cylinders. It is necessary to examine the heat flow through these materials. To do so an assumption has to be made. The concrete cylinder has a known thermal conductivity and by determining heat flow through the reference cylinder, one may assume that both of the cylinders contain the same heat flow rate. By this approximation, thermal conductivity can be calculated for the perlite cylinder. Time and temperature are thus the only variables for thermal conductivity. The experiment was performed for 40 minutes before temperature was measured inside the cylinder. LabVIEW was used to record time and temperature. Temperatures inside the cylinder were measured every 5 seconds.
LabVIEW is a graphical programming environment used to develop advanced measurement, test, and control systems using intuitive graphical icons and wires that resemble a flowchart [12].
The measurement that was obtained from LabVIEW was used in following formulas:
Heat transfer

$$Q = \frac{2\pi l\kappa(T1-T2)}{\ln(r2-r1)} \qquad (1.3)$$

Thermal conductivity

$$\kappa = \frac{Q\ln(r2/r1)}{2\pi l(T1-T2)} \qquad (1.4)$$

Where Q is the heat transferred per unit time, per unit length of cylinder [W/m^2] and κ is the thermal conductivity of the material [W/mK or W/m°C]. T1 is the temperature outside pipe or cylinder [K or°C], T2 is the temperature inside pipe or cylinder [K or°C], r1 is the cylinder outside diameter [m] and r2 is the cylinder inside diameter [m][19].

Results

Replacing Aalborg white cement with different amounts of aplite:

Four mixtures have been made with different amount of aplite shown in table 1. Fig. 9 illustrates mean values of compressive strengths for mixture 1 (blue line), mixture 2 (red line) and reference cube (green dotted line).

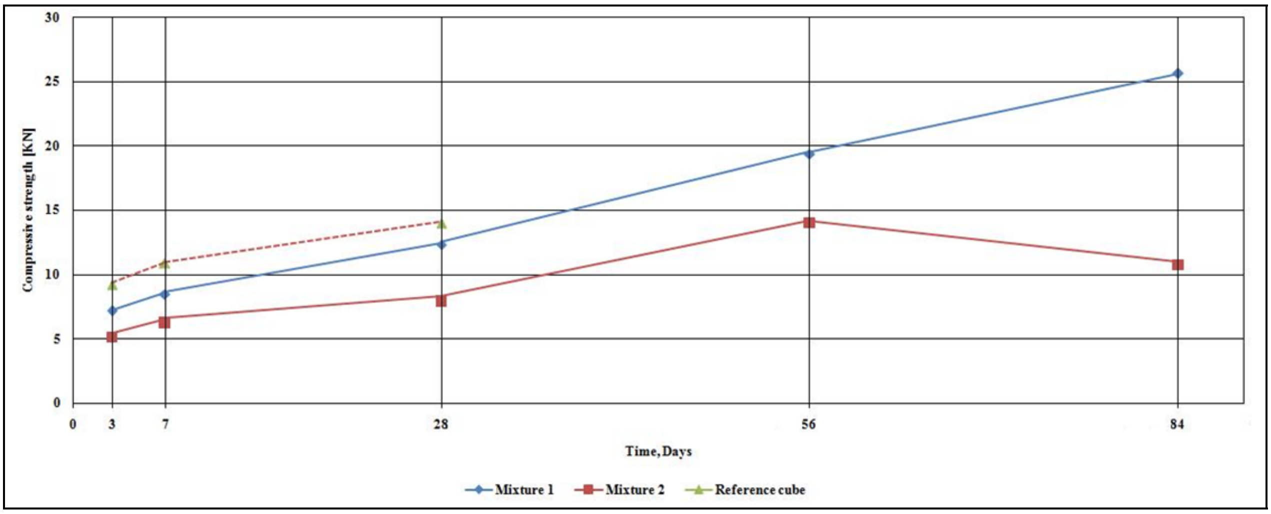

Figure 8: Compressive strength of mixture 1 and 2 compared to reference cube

Fig. 10 illustrates mean values of compressive strength for mixture 3 and 4.

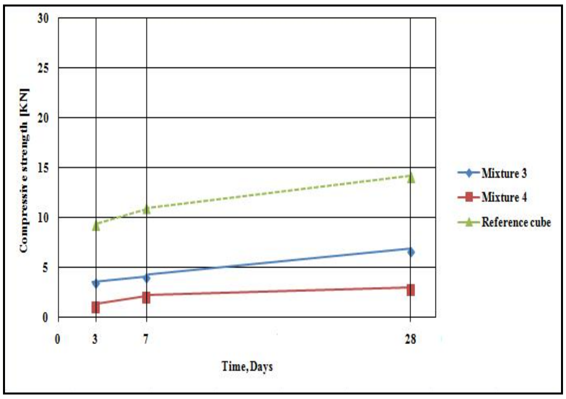

Figure 9: Compressive strength for mixture 3 and 4 compared to reference cube

Examining the effect of aplite on different cement:

Three mixtures have been made containing Aalborg white cement, Industry cement and Standard cement FA. The mean value of their compressive strength is illustrated in fig.10.

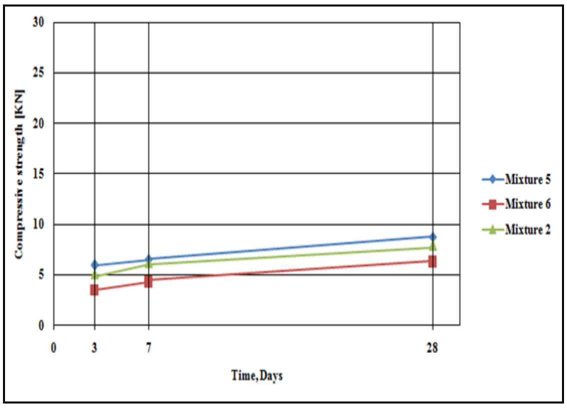

Figure 10: Compressive strength for mixture 2 (Aalborg white cement), 5 (Norcem industry cement) and 6 (Norcem standard cement FA)

Replacing perlite with different amount of aplite:

Two mixtures have been made by replacing aplite with perlite according to table 1. The mean value of their compressive strength is illustrated in fig.11.

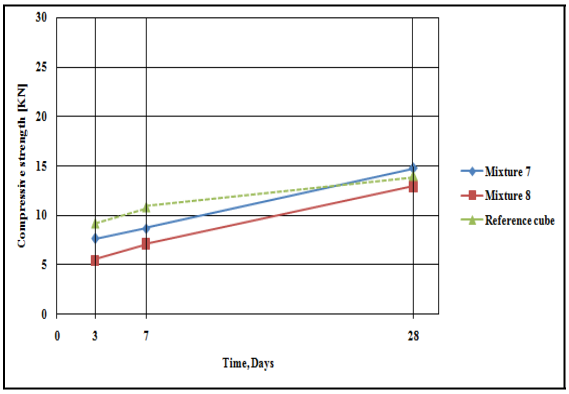

Figure 11: Compressive strength for mixture 7 and 8 compared to reference cube

Increased heat generation of water bath

Mixture 9 and 10 was made according to table 1. The mean value of their compressive strength is illustrated in fig.12.

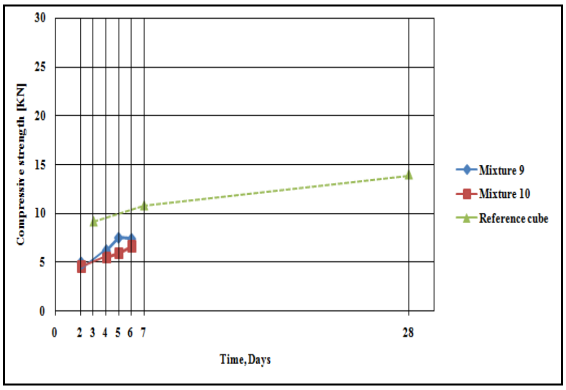

Figure 12: Compressive strength for mixture 9 and 10 compared to reference cube.

Thermal conductivity

Two cylinders containing different mixtures were measured using LabVIEW. Temperature development from these cylinders is illustrated in fig.13. Temperature after 40 minutes is shown in table 4.

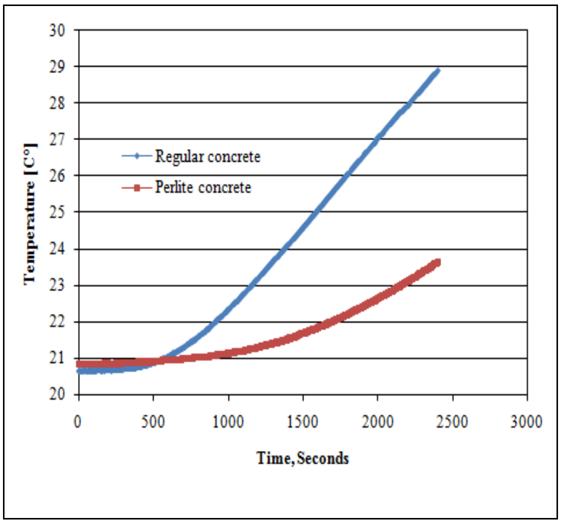

Figure 13: Internal temperature readings done by LabVIEW

Table 4: Temperature after 40 minutes

Cylinder	Internal temperature, T1 [℃]	External Temperature, T2 [℃]
Regular	28.745	54
Lightweight (perlite)	23.495	56

Table 5: Cylinder dimensions

Inner radius, r3 [m]	0.0275
Outer radius, r2 [m]	0.15
Length, l [m]	0.28

Results from table 4 and 5 are used in calculations according to 1.3 and 1.4. Calculated values are displayed in table 5.

Table 6: Calculated values for heat transfer and thermal conductivity

Cylinder	Heat transfer, Q [W/m^2]	Thermal conductivity, κ [W/m℃]
Regular	42.5	1.7
Lightweight (Perlite)	42.5	1.32

Discussion

Replacing Aalborg white cement with different amounts of aplite:

It was a tendency that when aplite was added the short-term strength of the concrete decreased. The reduction of short-term strength was dependent of the amount of aplite. This was probably due to the water/cement-reaction. The reaction had to be carried out for a while to make calcium hydroxide available for the aplite [5]. Another reason for reduction could be the loss of hydration from the cement.
Comparison between mean values for the mixtures with aplite and the reference cube, revealed a substantial difference in the compressive strength development. Mixtures without cement extenders such as aplite are said to have their compressing strength development ended at 28 days [18]. For mixture with aplite as shown in fig.8 the development continued beyond 28 days.
Mixture 1 in fig.8 demonstrated an increased compressing strength of 5.22 KN after 56 days, compared to for the reference cube (28 days). The total increase was 38.9 %. After 84 days the increase was 11.62 KN, yielding a total increase of 82.9 %. The aplite had clearly a strong pozzolan effect on the long term-strength.
Mixture 2 in fig.8 had a higher rate of strength increase compared to mixture 1 between 28 days and 56 days. Despite an increase of 0 % compared to the reference cube (28 days). This may be due to a higher reduction in short-term strength when more amount of aplite is added. After 84 days an increase in the total strength was expected. A reduction was observed in fig.8. This may be due to the use of a testing machine that had a higher pressure increase then the one used for the cubes below 19,5 KN. This may give a more inaccurate measurement.
Mixture 3 and 4 fig.9 showed substantial reduction for short-term strength when replacing large amount of cement with aplite. These two mixtures were only tested for 28 days. The effect of time beyond 28 days for these mixtures is unknown. One may assume that the mixtures would need prolonged hardening to achieve a larger compressing strength compared to the reference cube.

Examining the effect of aplite on different cement:

The objective of this experiment was to observe the behavior of aplite mixed with different types of cement.
According to fig.10 mixture 5 (industry cement) has the highest compressive strength after 3, 7, and 28 days. This is likely due to a higher production rate of calcium hydroxide during the water/cement reaction of industry cement. The following behavior activates aplit`s pozzelan reaction earlier then the other mixture. This yields a high compressing strength for mixture 5.
Mixture 2 (Aalborg white cement) also has a high compressing strength, but it is slightly less than mixture 5. This may be due to higher early hardening for industry cement than Aalborg white.
Fig.10 shows that mixture 6 has low compressive strength. Standard cement FA yields a moderate early hardening. This may lead to a low production rate of calcium hydroxide and therefore a late pozzolan initiation.
Aplite reacts differently with different types of cement, this yields that use of aplite is more favorable with designated cement types.

Replacing perlite with different amount of aplite:

The purpose of this experiment was to obtain a high compressive strength by using aplite as aggregate.
When perlite is replaced with aplite the short-term strength (3 days) goes down as shown in fig.11. Perlite has high water

consumption, due to its shape. Aplite does not consume the same amount of water, which causes free water in the mixture. During cementing, the water vaporizes leaving the cement with numerous pores [9]. This yields low early strength.
As indicated in fig.11 strength development rate decreases after 7 days for reference cube. For mixture 7 and 8 the development increases, probably due to pozzolan initiation.
Replacement of perlite with aplite will probably give a high long term hardening (56 and 84 days), but it will also lead to a higher density for the cubes. This makes it hard to compare these specimens with the other light weight specimens.

Increased heat generation of water bath

The aim of the experiment was to obtain a high compressive strength by increasing the heat in the water bath.
By raising the temperature in a reaction mixture the atoms, ions and molecules are set in a more powerful movement. Due to this, more vigorous collisions occur. More chemical reactions are the result. This is why reactions speed usually increases with temperature [20].
It is known that the hardening is doubled for every increase of 10 °C. The water bath temperature was increased from 20 °C to 60 °C. In theory the temperature change should provide a 16 times increase in the hardening process. As shown in fig. 12 results did not comply with theory.
Because of a malfunction, there was a replacement on day two with a smaller water bath than the one initially used. Higher vaporizing rate was the consequence and frequent water refilling was crucial. Mixture 9 and 10 in fig.12 was tested for 6 days, and only 4 days with 60 °C. Due to the water bath problems the experiments provided limited results.

Possible error sources when measuring compressive strength

There are several uncertainties when measuring compressive strength, both systematic and random. Systematic uncertainties could be due to calibration errors by the testing machine. Random errors could due to blending the mixture in an unequal structure, placing the cubes inaccurate in the machine or having different room temperature when the cubes are hardening.

Thermal conductivity

The objective of this lab was to determine thermal conductivity of perlite concrete. To do so, it was necessary to examine flow of heat through the sample of perlite cylinder as well as regular concrete whose thermal conductivity was known. Perlite concrete provides thermal insulation
It is shown in fig.13 that the temperature inside the cylinder increased more for regular concrete than the perlite. This leads to a lower thermal conductivity for perlite concrete than regular concrete as shown in table 6. Whether if this measured thermal conductivity is correct, is uncertain. Compared to other perlite mixture the calculated thermal conductivity is slightly too high [2]. Thus the experiment provides inaccurate results.

Possible error sources when determining thermal conductivity

Key assumption concerning the rate of heat flow was made for this lab that in reality may contribute to error. It was assumed that the rate of heat flow through a regular concrete was identical to the rate through the perlite concrete. In reality, this is not necessarily an accurate assumption.

CONCLUSION

Following conclusions may be drawn from the present study:

- When Aplite replaces Aalborg white in small amounts the long-term strength increases immensely
- Time plays a major role when aplite's pozzolan reaction initiates and how large the effect is. Pozzolan reaction seems to initiate somewhere between 7 and 28 days and the effect increases beyond 28 days
- Three different types of cement were used in this experiment. Industry cement was the most favorable cement for aplite.
- Increase of water bath temperature had a poor effect on the hardening process.
- The experiment of perlite showed insulating properties, but the calculated value for thermal conductivity was too high. The experiment that was conducted provided inaccurate results.

It is recommended that for future experiments on aplite, long-term strength analysis is executed.

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