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Air entrainment in fly ash concrete: effect of sequence of AEA-SP addition

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Abstract

Frost resistance of concrete is directly dependent on its air content and parameters of air void system. Nowadays concrete is rarely produced without water-reducing agents, used also in air-entrained mixes. Sequence of adding admixtures during mixing seem to affect final properties of concrete, concerning its performance throughout service life.

This work is a result of studying the effect of different adding sequences of air-entraining agents (AEA) and superplasticizer (SP) on air content in mortar. The basis for work is a study of foam index change for different materials and adding sequences, carried out by a group of BSc students in spring 2015 [1].

Consequently, a set of experiments for materials of interest (2 different AEAs, 1 co-polymer SP, 1 OPC, 1 Norwegian fly ash and 1 limestone filler), used in the above mentioned study, were performed.

The following parameters of the mix were selected: OPC/FA – 70/30, mass of limestone – 5% of binder, w/c ratio – 0,45. Matrix volume was changed during the experiment from 330 to 400 litres. Whole range of received data is included in the report for a broader overview of the effect of AEA and SP mixing sequence.

The results shows that, notwithstanding matrix volume and type of AEA used, sequence of adding admixtures has a significant influence on the air content in concrete both in fresh and hardened state.

It is noted that when SP is added after AEA, the effect of AEA is reduced while in mixes where AEA is added after SP, the air content is higher, presumably due to adsorption of SP. The highest air content gives adding AEA together with SP. The appreciable difference in the air content is also noted for different AEAs, coming from different producers. An attempt for characterizing of air-void parameters for most interesting cases was abandoned due to insufficient strength for polishing of young fly ash mortar, unveiled at last stage of the procedure.

1 Introduction

Freezing and thawing occurred in cold and harsh environment can cause scaling and cracking in badly prepared concrete and with inadequate amount of air. To prevent deterioration, it is important to stabilize the right volume of air and create a system of air pores in the concrete, mainly, by use of Air Entraining Agents (AEAs).

In the Scandinavian countries, as in the rest of Europe, there is a clear tendency towards reduction of cement consumption, mainly for ecological reasons. Therefore, concrete with fly ash has become a very popular product. However, it appeared to be hard to determine the right dosage of AEA for this type of concrete. The reason is a fly ash which can contain too much carbon because of incomplete combustion in the power plant (high Loss on Ignition – LOI), so the quality of fly ash can vary significantly.

Even if we obtained the correct dosage of AEA and SP, thanks to the FI test [1], one should comprehend that the air-entraining problem is more complicated. Dosages of admixtures can vary in practice and they do not necessarily correspond with material data sheets, giving recommendations on dosing of admixtures depending on composition and volume of the mix. The water reducing admixtures, usually Superplasticizers, are used in mixes to improve the workability when w/b ratio is low, which is often a case. Therefore, dealing with air entraining of concrete cannot be considered without looking at procedure of adding AEAs and SP, as one of the most crucial factors to consider when obtaining frost resistant concrete for particular exposure conditions. Investigation on adding sequence of AEAs and SP in the mortar mixes can show which mixing procedure can give us the most predictable air content and which can give the least.

The scope of this thesis is to investigate the sequence of adding Superplasticizer (SP) and Air Entraining Agents (AEA) to obtain stable air content in the fresh and hardened concrete. Sequences are taken from the FI report [1] written as a Bachelor Thesis in 2015, and all the results from it are compared with the obtained on mortar specimens. Foam Index test is used to measure the amount of AEA for obtaining stable foam, and it is very useful in the initial phase of calculation of dosage of admixtures like AEAs and SP. However, during work, selection of correct dosage of AEA was found complicated, therefore some changes in output dosage of AEA were made. In the experiments, selected materials were the same as ones that had been used in the Foam Index test. Throughout the work, different sequences of adding abovementioned admixtures and variable dosages have been studied for 2 types of AEA. Consequently, air content in the hardened concrete was measured.

2 Background

2.1 FI test. Final results

Foam Index test was made and described in the Bachelor Thesis [1] by the students from Gjøvik University College. Main target of their research was to find the sequence and dosage of AEAs and SP to obtain stable foam. In the investigation, different fly ashes, cements, fillers and admixtures were used.

The results show (see Appendix A), that the air entrainment stability depends strongly on type of AEA, combination with Superplasticizer (SP) and binder powder. It was found, that SP added to the mixes before AEA reduces the negative effect of carbon in the fly ash in several cases, whereas SP added after AEA in most cases has a negative effect on air entrainment. Results obtained in the experiments have shown that AEA is less effective at higher carbon content in the fly ash as depicted in theory. The Foam Index test shown, that there is a difference in using ordinary Portland cement (OPC) and OPC in combination with fly ash.

The FI report [1] includes also results from experiments made on the cement and fly ash from USA. The US fly ash had lower carbon content than the Norwegian fly ash.

By virtue of insufficient quantity of the materials from USA, it was impossible to incorporate mixes with them in present report.

2.2 Literature study

2.2.1 Freezing and thawing in the concrete structures

Depends on the air content in the hardened concrete, the freeze-thaw resistance can vary. Freezing and thawing in combination with de-icing salts or seawater in the cold and harsh environments, like in the Scandinavian countries, can cause frost damage called scaling in the concrete structures when it does not have the right volume of air pores. Possibility of frost damage depends on the air void size distribution expressed as specific surface and specific factor. The size of the fine porosity is also important when dealing with frost resistance. Water in pores with lower diameter will freeze at lower temperature while water in pores with bigger diameter will freeze in temperatures close to 0˚C. Both forms of deterioration: internal and external can occur in concrete independently. Resistance to both damage forms is dependent on air voids.

In the Scandinavian countries, as it is in other countries, cement in combination with fly ash is used for reduction of cement consumption. Because of the variety of the fly ash, dosage of AEA can vary. It is caused by the carbon content, measured as a Loss on Ignition. The influence of carbon content in the fly ash was described in the papers, written by Gebler and Klieger [2], [3] and [4].

2.2.2 Air pore system in concrete

Pores in concrete can be divided into micro and macro. In the micro pores there are capillary- and gel porosity which are formed during hydration process. Capillary pore size is 0,1-10 microns and the gel pore size is nanoscopic. Macro pores cannot be filled with water without extra force applied. Serving as sites for pressure release and ice formation during freezing, macro air voids improve concrete frost resistance. Reducing anisotropy of concrete body AEA is used to organize and refine air void structure, and by that improve range of concrete properties (see 2.2.3).

The air void system is established during the mixing process and, if it is stable, it can be the same in the fresh and the hardened concrete. However, there are some factors influencing the air pore system. G. Fagerlund [6] describes three different mechanisms for the air-pore instability of the fresh concrete. First mechanism is a loss of coarse air-bubbles due to handling, transport and compaction and it does not affect on the freeze-thaw resistance so much. The second mechanism is dissolution of small bubbles in the water and due to this mechanism reduction in the freeze thaw resistance can obtain. The last mechanism is transfer of air from small to coarser bubbles and it influences on the air content and leads to a reduction in the freeze thaw resistance. The air pore system in the fresh concrete may differ from the hardened concrete because of the factors affecting it in the period between production and setting.

As we can read in the Du & Folliard's paper [7], "Air bubbles in fresh concrete are inherently unstable. The interfaces between the dispersed air and the surrounding matrix contain free surface energy and the thermodynamic tendency is to reduce the interfacial surface areas. Thus, all air bubbles have persistence.”

Persistence of air bubbles in mortar (our case) is controlled by many parameters and conditions, most important of them to mention are: paste volume, fineness of cement, binder constituents, content of filler and its size, sieve curve of sand, and application of air-entraining agent (AEA).

2.2.3 AEA and its influence on the concrete properties

According to the Norwegian Standard NS 2001, concrete used in the concrete structures should be produced with right volume of air pores to obtain frost resistance. It can be done by adding the air entraining admixtures, like AEA, during the concrete production. AEA are used to entrain small and evenly distributed air bubbles throughout the concrete. In the Norwegian Standard NS EN 934-2 [8], the Air Entraining Agents are described as: “Admixtures which allow a controlled amount of small evenly distributed air bubbles to be incorporated within the composition remain after curing.”

The main reason to use the AEAs is to obtain the freeze-thaw resistance in the concrete structures. However, there are other effects, which can be observed when using AEAs. For instance, small bubbles can improve workability. We will see later that the workability has correlation with the air content, as it was also noted by Eickschen E. [5]. The negative effect of using AEAs can be lower strength of concrete. This is why it is so important to obtain the right dosage of AEA to increase frost-resistance and not lose the strength. As the dosage of air-entraining admixture increased, concretes containing fly ash tended to show instability of air content in the fresh state.

As it is written in the paper [9], AEAs belong to the group of chemical admixtures also known as ‘’surfactants” which is an abbreviation of “surface active admixtures”. Surfactants generally have a molecular structure of a long non-polar hydrocarbon chain at one end and a polar group at another. Since surfactant molecules have a strong bipolar nature, they tend to be absorbed and usually concentrate at the air-paste interface (around the air voids). As a result, of this property, the surface layer around the entrained air voids may have a different composition with respect to the bulk fluid in the mixture.

2.2.4 Superplasticizers (SP)

Superplasticizing/water reducing admixtures are organic poly-electrolytes, which belong to the category of polymeric dispersing agents. Some of them are synthetic, while others are from natural products. They are used in the concrete to reduce the amount of water or to increase the workability in the mixes with low w/c -ratio. They are not working as a retarder and it can be dosed drop wise without giving a poor effect. They are mainly used with the AEAs, but it is important to know when the SP should be added to the mix. As we can read in the Foam Index test [1], the SP can suppress the foam, which means that we can obtain lower air content by incorrectly using AEAs and SP.

2.2.5 Sequence of adding Superplasticizers and Air Entraining Agents

Mixing procedure is very important during concrete production. It can influence the properties of both fresh and hardened concrete. Depending on the sequence of adding admixtures into the mixture, quantity of added admixtures can vary. While adding more air entraining agents can influence on the air content in the concrete, increasing time of mixing over 2 minutes, according to Eickschen's paper [5], does not influence the air content significantly. Combination of superplasticizer (SP) and air entraining agent (AEA) in a mix is a major issue due to lack of knowledge on how admixtures affect each other. Even if one fined the right dosage of these admixtures in some experiment, there would be a problem to reproduce the same concrete with the exact amount of air content because of other factors, which can influence, like volume of the mix or different fly ash.

AEAs are active surface substances, surfactants, which "settle down" on the cement particles between water and air bubbles. The admixtures orient themselves so that one end faces towards the water (hydrophilic end), while the other end is hydrophobic (afraid of water) and creates stability in the air void system.

Some particles of SP attach themselves to the surface of the cement grains while the rest scatters in the liquid. This causes the cement grains to physically separate from each other simultaneously achieving a longer opening time and increased water reduction.

3 Methods and Experiments

3.1 Materials

In the experiments, selected materials left after the measurements in the FI test [1] were used. All materials were stored in buckets at room temperature of 20˚C. To the reference mixes, aggregate was taken from big container and the moisture of it was measured every time before mixing. The proper mixes were made on material constant moisture by isolating a required volume of aggregate in a sealed bucket with plastic liner.

3.1.1 Cement, fly ash and filler

Binder	Density [g/cm^3]	Carbon content [%]	L.O.I [%]	Blaine [m^2/kg]	Data sheet
Norcem Standard OPC	3,15	0	2,35	396	Appendix B
Norcem Fly Ash FA	2,30	1,74	2,27	334	Appendix B
Limestone	2,73	0	37,66	362	Appendix B

Table 1 Cement, fly ash and filler data

3.1.2 Air Entraining Agent (AEA)

Norwegian AEA, based on the producer statement, is diluted 1:9, i.e 1 part of AEA: 9 parts of water. Table 2 below shows recommended dosages based on the datasheets to obtain 4-6% air in concrete. After all reference mixes, mass of AEAs was chosen as 0,7 mass % of binder. As we can see in the table included in the Appendix A, in the FI report [1], 7 different AEAs were investigated. In this report, only 2 AEAs were taken under consideration. AEA4 and AEA5 were chosen because they gave the most representative results.

AEA	Description	Minimum recommended dosage (μl/g)	Maximum recommended dosage (μl/g)	Data sheet
AEA4 – Sika Multi Air	Olefin sulfonate	0,1	1,95	Appendix B
AEA5 – Mapeair 25 1:9	Based on the synthetic tensides and tall oil derivatives	0,1316	1,316	Appendix B

Table 2 Description and recommended dosage of AEA

3.1.3 Superplasticizer (SP)

In all experiments, mass of Superplasticizer was chosen as 0,45% of mass of binders, that corresponds to about 4,5 µl/g.

SP	Description	Minimum recommended dosage (µl/g)	Maximum recommended dosage (µl/g)	Data sheet
SP – Dynamon SX - 130	Akrylpolymer	3	12	Appendix B

Table 3 Description and recommended dosage of SP

3.2 Proportioning and correction

3.2.1 Proportioning and weighed in materials

Calculation of all materials needed for concrete is the most important part of the concrete production. Mistake during calculation can have significant influence on the properties of fresh and hardened concrete. Therefore, there had been a great focus on the calculations before first reference mixes were done. First reference mixes were done based on the Skanska Excel sheet which did not work for mortars with fillers. In our case, where mortar with filler was investigated, it was very helpful to create a new Excel sheet (Appendix C) which included all data and, without any problem and in a very fast way, it was possible to calculate proportions of the concrete for different dosages of Superplasticizer or Air Entraining Agents. Results obtained based on the new calculation sheet were included in the report.

First of all, moisture of the aggregate was checked from formula as followed:

$$f = \frac{m_{wet} - m_{dry}}{m_{dry}}$$

Matrix volume and theoretical air content were assumed on the beginning of the work, so it was possible to calculate volume of the aggregate:

$$V_{agg} = 1m^3 - V_{matrix} - V_{air}$$

Knowing the moisture and the mass of the aggregate, it is easy to calculate to mass of water absorbed by the aggregate:

$$M_{w,abs} = f * M_{agg}$$

w/b – ratio of 0,45 was selected for all the mixes. If it is known, the formula below can be used:

$$\frac{M_{w,total}}{M_C + M_{FA} + k * M_{LS}} = 0{,}45$$

where:

$$M_{w,total} = M_{w,added} + M_{w,abs} + M_{w,AEA} + M_{w,SP}$$

C – cement, FA – fly ash, LS – limestone, W - water

Mass of the cement was assumed as 70% mass of cement and fly ash, mass of fly ash – 30% mass of cement and fly ash, and mass of limestone – 5% mass of cement, fly ash and limestone:

$$M_C = 0{,}7 * (M_C + M_{FA})$$

$$M_{FA} = 0{,}3 * (M_C + M_{FA})$$

$$M_{LS} = 0{,}05 * (M_C + M_{FA} + M_{LS})$$

If all those relationships are known, formula below can be used to calculate mass of cement:

$$V_{matrix} = \frac{M_C}{\rho_C} + \frac{M_{FA}}{\rho_{FA}} + \frac{M_{LS}}{\rho_{LS}} + \frac{M_{w,added}}{\rho_W}$$

Mass of admixtures is calculated as followed:

$$M_{AEA} = 0{,}007 * (M_C + M_{FA})$$

$$M_{SP} = 0{,}0045 * (M_C + M_{FA})$$

After all calculation, proportioning values were multiplied by the volume of the mix to get masses of the materials weighed in to the mix. Table 4 below present values of the weighed in materials for matrix volume 400 litres depending on the sequence (see 3.3):

Mass of:	No Sp and AEA	3.5.1	3.5.2 3.5.3 3.5.4
Cement [g]	690,1	696	698,7
Fly Ash [g]	295,7	298,3	299,4
Limestone [g]	51,9	52,3	52,5
Aggregate [g]	3206,5	3206,5	3206,5
Water [g]	403,3	400,2	397,8
AEA [g]	-	7	7
SP [g]	-	-	4,5

Table 4 Normalized proportions [kg/m^3]

When the results from experiments are obtained, to calculate air content due to density method and correct proportions, formulas presented below can be used:

- Mass of free water can be calculated:

$$M_{w,free} = 0{,}001 * (M_{w,added} + \frac{M_{agg} * (f - abs)}{1 + f - abs} + M_{AEA} + 0{,}7 * M_{SP})$$

where:

$M_{w,added}$ – mass of added water
M_{agg} – mass of dry aggregate
f – moisture of the aggregate
abs – absorption of the aggregate
M_{AEA} – mass of AEA
M_{SP} – mass of SP

- Theoretical air void free volume [m^3]:

$$T_{a,v,f,v} = 0{,}001 * (\frac{M_C}{\rho_C} + \frac{M_{FA}}{\rho_{FA}} + \frac{M_{LS}}{\rho_{LS}} + \frac{M_{agg} * (1 - f)}{\rho_{agg}} + M_{w,free})$$

- Theoretical air void free density [kg/m^3]:

$$T_{a,v,f,d} = \frac{M_{w,free} + 0{,}001 * (M_C + M_{FA} + M_{LS} + \frac{M_{agg}}{1 + f} + 0{,}3 * M_{SP})}{T_{a,v,f,v}}$$

- To calculate air content due to density method, fresh density from experiments is needed. Then, formula can be used as followed:

$$A = 1 - \frac{\rho_{fresh}}{T_{a,v,f,d}}$$

3.2.2 Correction of concrete part materials

Correction of concrete volume for measured air content:

$$V_{concrete,measured} = 1 - \varepsilon_{air,theor} + \varepsilon_{air,measured}$$

Mass of concrete part materials in 1m^3 corrected for measured air content:

$$\left.\begin{matrix} m_{agg}^{'} \\ m_{w}^{'} \\ m_{c}^{'} \\ m_{admix}^{'} \end{matrix}\right\} = \left.\begin{matrix} m_{agg} \\ m_{w} \\ m_{c} \\ m_{admix} \end{matrix}\right\} * V_{concrete,measured}$$

$$\sum = \rho_{concrete}^{'}$$

Mass of concrete part materials in 1m^3 corrected for measured density:

$$\left.\begin{matrix} m'^{'}_{agg} \\ m'^{'}_{w} \\ m'^{'}_{c} \\ m'^{'}_{admix} \end{matrix}\right\} = \left.\begin{matrix} m'_{agg} \\ m'_{w} \\ m'_{c} \\ m'_{admix} \end{matrix}\right\} * \frac{\rho_{concrete,measured}}{\rho_{concrete}^{'}}$$

$$\sum = \rho_{concrete,measured}$$

3.3 Mix procedures

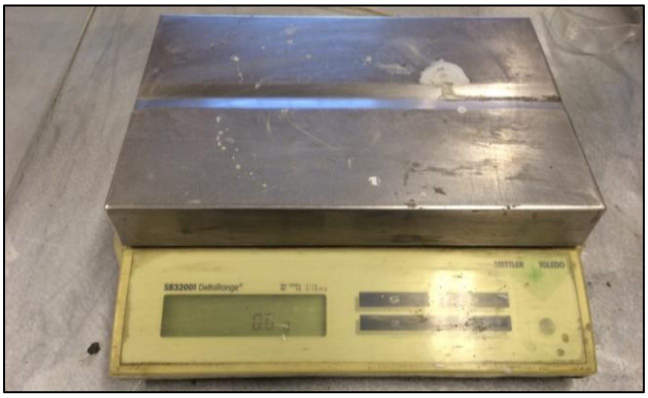
Before the proper mixes, reference mixes were done. Thanks to that, we could obtain the required workability and repeatability of the experiments. At the very beginning, it was assumed that target workability is slump of 80-90mm. Lower slump means that the consistence of the concrete is stiff. With low w/b ratio, it was necessary to increase SP to obtain required workability.

Numeration of the sequences was taken from the FI report [1] and it was as followed:

3.5.1 – only AEA, without SP
3.5.2 – SP after AEA
3.5.3 – SP before AEA
3.5.4 – SP with AEA

First of all, dry and wet materials were weighed. In the sequence 3.5.1 and 3.5.2, AEA was added to the mix with water and SP was added separately. In the sequence 3.5.3 AEA and SP were added with half of the water respectively but in the sequence 3.5.4 SP was added together with AEA to the water and then to the mix.

All materials were weighed on the scale with accuracy 0,1g presented on the Picture 1 below:



Picture 1 Scales

After all reference mixes, procedure for mixing was clarified. The diagrams in Eickschen's paper [5] show that the mixing time of the air entraining admixtures, longer than 2 min, does not have significant influence on the air content. Therefore, variation of mixing time and its impact on Air content was not studied. Independently from the sequence of adding SP and AEAs, time of mixing for all sequences was the same. The mixes were done in the Hobart mixer presented on the Picture 2:

Picture 2 The Hobart mixer and stopwatch

The mixing procedures for the particular sequences are presented below:

a) No AEA and SP
   1) Dry materials 1min
   2) Water 3min

b) 3.5.1 Only AEA
   1) Dry materials 1min
   2) Water + AEA 3min

c) 3.5.2 SP after AEA
   1) Dry materials 1min
   2) Water + AEA 2min
   3) SP 1min

d) 3.5.3 SP before AEA
   1) Dry materials 1min
   2) $\frac{1}{2}$ water + SP 1min
   3) $\frac{1}{2}$ water + AEA 2min

e) 3.5.4 SP with AEA
   1) Dry materials   1min
   2) Water + AEA + SP   3min

3.4 Measurements method

Procedure for all the experiments was always the same, and it was followed as (numbers in the brackets show time after mixing):

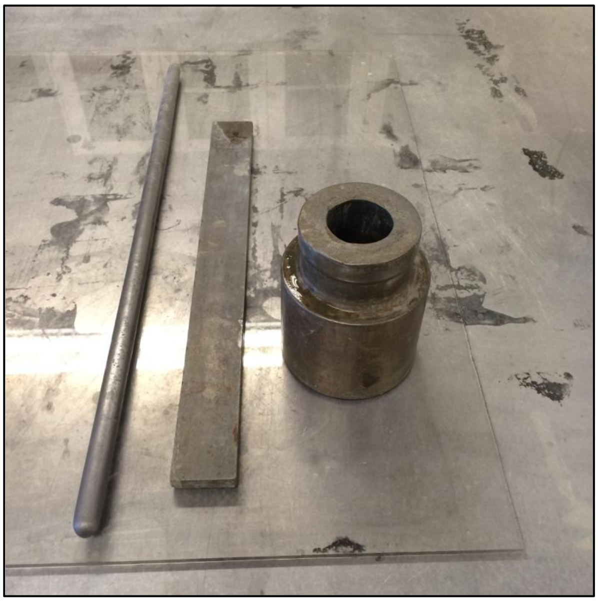
- Slump test (5min)
- Density method (8min)
- Pressure method (9min)
- Specimens (12 min)

3.4.1 Slump test

The slump test was done on the flat surface. Before every measurement, the steel cone, steel rod, steel flat and the surface should be moisture to avoid sticking of the concrete. The steel cone was filled with two layers and each layer was compacted with 25 rod-digging to bottom of each layer. When the concrete was compacted and the surface was levelled, the steel cone was lifted.

Equipment is shown in the Picture 3:

- Steel cone (high: 120mm, top diameter: 40mm, lower diameter: 80mm)
- Steel rod
- Steel flat to levelling surface



Picture 3 The steel cone, steel rod and steel flat

3.4.2 Density and pressure method

Based on the Norwegian Standard NS-EN 12350-6:2009 [10] procedure for **density method** is as follows:

1) Calculation of the volume of the container (V)
2) Weighing the container (m_1)
3) Filling the container with concrete in two layers and compact it with rod and some additional hammering on the sides to get side of coarse air bubbles
4) Levelling the surface
5) Weighing the container with concrete (m_2)
6) Density is calculated from the formula:

$$D = \frac{m_2 - m_1}{V}$$

To calculate the air content in the fresh concrete, the formula is used as follow:

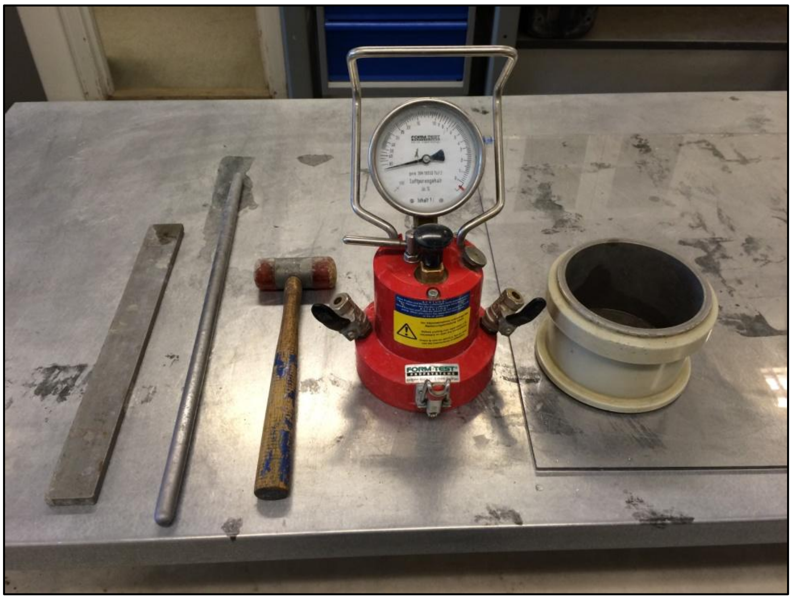
$$A = 1 - \frac{\rho_{fresh}}{\rho_{TAvf}}$$

Where:

ρ_{fresh} depends on the value of the mass and the volume of the container. The volume of the container is unchangeable but the error of the mass can occur.

Equipment is shown in the Picture 4:

- Container (volume 1l)
- Chamber
- Hammer
- Steel rod
- Steel flat to levelling surface



Picture 4 Equipment for pressure and density test

One of the most important things to control in these experiments are compacting and levelling the surface. If some errors occur during experiments, the results can be affected. Below, calculations of error are presented:

For example:

Mass of empty container: 1113g

Mass of container with concrete: 3372g

Fresh density: $\rho_{fresh} = \frac{3{,}372kg-1{,}113kg}{1l} = 2259\ kg/m^3$

Theoretical density: 2351 kg/m^3

Air content: $A = 1 - \frac{2259}{2351} = 3{,}913\%$

With 0,1g error during weighting:

Mass of container with concrete: 3372,1g

Fresh density: $\rho_{fresh} = \frac{3{,}3721kg-1{,}113kg}{1l} = 2259{,}1\ kg/m^3$

Theoretical density: 2351 kg/m^3

$$Air\ content:\ A = 1 - \frac{2259{,}1}{2351} = 3{,}908\%$$

$$Error: \frac{3{,}913 - 3{,}908}{3{,}913} * 100\% = 0{,}128\%$$

ρ_{TAvf} depends on the corrected masses of all the part materials. Based on the Excel sheet, it is important to weigh all materials with accuracy to one decimal place. Then, we can test assured that our components are in the right proportions.

The pressure method is based on the Boyle'-Mariotte's law, which states that at constant temperature the volume occupied by an ideal gas (air in this case) is proportional to the applied pressure; pV=constant=p'V'. Based on the Norwegian Standard NS-EN 12350-7:2009 [11], procedure for the pressure method is as follow:

1) Points from 1) to 4) are the same like in the density method
2) Cleaning the flanges of the container and cover it assembly (ensure that there is a good seal between the container and the cover)
3) Open valves
4) Inject water through either valve until water emerges from the other valve
5) Close valves and pump air into the chamber
6) Release the lever and read the indicated value

Accuracy of this method mostly depends on the preparation of the sample, but it is also important to do experiment carefully. It is difficult to quantify of the error in this method, because the equipment used in the experiments can be leaky and some of the pressure can escape.

3.4.3 Specimens

Samples are made in the 4x4x16cm moulds. Procedure for the sampling is as follows:

1) Wetting the moulds with water
2) Filling the moulds with concrete in two layers, compacting each layer with rod and vibrating table with frequency 50 Hz for 5 sec each layer

3) Levelling the surface
4) Cover the samples with plastic for 24±1h
5) Specimens should be removed from the moulds, weighed (m_1), volume of the specimens should be determined (V) and then they should be placed in the water (temperature of the water should be about 20˚C)
6) Density of the hardened concrete can be calculated
7) Air content in the hardened concrete can be calculated using the density of the hardened concrete

3.4.4 Air void analysis/ Image analysis

The last part of the work was to quantify the air void system in the hardened concrete using the ASTM C457 method. Thanks to this method, total air content, specific surface and the air-void spacing factor can be determined. Based on these factors, freeze thaw resistance can be evaluated.

The most important thing in this method is the samples preparation. If the samples are badly prepared, the results will be affected. To this experiment, 6 samples with two different Air Entraining Agents were chosen. Each sample was cut into two parts to provide good base for polishing, increase number of specimens, and observe how bubbles are distributed from top to bottom of specimens.

Each sample was prepared using procedure as follow:

1) Cutting into two parts using diamond saw
2) Gridding
3) Polishing each part of the sample using equipment on the Picture 5 and powders starting from 120 grit, then sand paper with 240 and 320, and again powders 600, 800, 1000 and finally the finest one 1200 grit.
   After every step samples were checked under the microscope whether there is an improvement in polishing. As we can read in ASTM standard [10], use of ultrasonic cleaners may be harmful to the surface, so we decided to place half of the samples in the ultrasonic bath for 5min between every step and the second half of the samples were just cleaned under the water using a soft brush.

Picture 5 The polishing equipment

4) The polished surface is coloured with black marker the air voids are filled with a white powder ($BaSO_4$) with particle size 1 -4 microns
5) Prepared samples are scanned using the scanner and thanks to the Matlab script, factors like total air content, specific surface and air-void spacing factors can be calculated

3.4.5 PF – method

Another method to estimate the air void system in the hardened concrete is PF – method. It is based on measurements of porosity in concrete by drying and weighing a sample in different moisture conditions. Samples used in the PF method do not have to be regular geometrically but in our experiments specimens with approximately the same dimensions (4x2x16cm) were used.

Procedure:

1) Drying the samples at 105˚C for 7 days to constant mass (W_1)
2) Water suction for 7 days (W_2)
3) Determine the volume of the samples (V)
4) Pressure saturation under water at 50 bar water pressure (W_3)

Calculations:

- Total porosities (including all pores):

$$\varepsilon_{tot} = \frac{W_3 - W_1}{V} \text{ [\%]}$$

- Porosities including only gel- and capillary pores:

$$\varepsilon_{suc} = \frac{W_2 - W_1}{V} \text{ [\%]}$$

- Air content:

$$\varepsilon_{air} = \frac{W_3 - W_2}{V} \text{ [\%]}$$

- The Pore Protection Factor can be calculated from the formula as followed:

$$PF = \frac{\varepsilon_{air}}{\varepsilon_{air} + \varepsilon_{suc}} = \frac{P_a}{P_s + P_a} \text{ [\%]}$$

Where:

P_a is the air/macro porosity that does not fill by water suction

P_s is the suction porosity

PF should be >25% for frost resistance in the presence of de-icing salts and >20% for pure water.

4 Results and discussion

Influence on the air content depends on the sequence of adding SP and AEA

Figure 1 shows the main goal of this work – difference in the air content depends on the sequence of adding admixtures. On the graph, two different Air Entraining Agents are presented – Mapeair 25 (AEA5) and Sika Multi Air (AEA4). The dark blue bar represents mix without AEA and SP. The red bar represents sequence 3.5.1 (only AEA). The green bar represents sequence 3.5.2 (SP after AEA). The purple bar represents sequence 3.5.3 (SP before AEA) and the light blue bar represents sequence 3.5.4 (SP with AEA). For the matrix volume 330 litres dosage of the SP was 0,2% of the mass of the binders while in the matrix volume 400 litres dosage of the SP was 0,45% of the mass of the binders.

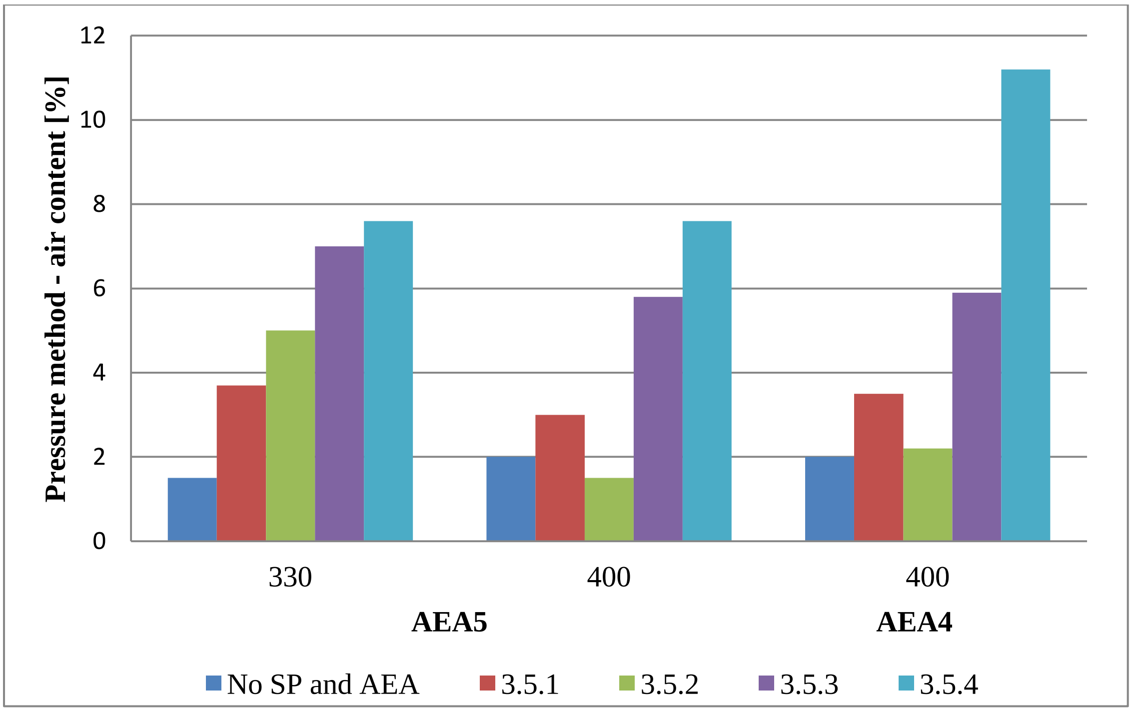


Figure 1 Master plot. Total air content for different adding sequences, AEAs and matrix volumes

In the table 5 and 6, results from experiments made on the matrix volume 330 and 400 litres are presented. For the matrix volume of 330 litres only one type of the AEA was used – Mapeair 25 while in the experiments with matrix volume of 400 litres two different AEAs were used – Mapeair 25 and Sika Multi Air. For all experiments, the same data were used: w/b ratio 0,45; OPC/FA was 70/30 and Limestone was 5% mass of the cement, fly ash and limestone.

AEA5 – Mapeair 25										
Matrix volume = 330 litres										
	No SP and AEA		3.5.1		3.5.2		3.5.3		3.5.4	
	Mix 1	Mix 2	Mix 1	Mix 2	Mix 1	Mix 2	Mix 1	Mix 2	Mix 1	Mix 2
Slump [mm]	30	40	20	20	60	45	60	35	60	60
Density method – air content [%]	[-1,1]	[-1,0]	1,8	1,4	4,2	3,4	7,0	6,0	7,3	7,4
Pressure method – air content [%]	1,5	1,5	3,6	3,7	5,2	5,0	7,4	7,0	7,8	7,6
Matrix volume = 400 litres										
	No SP and AEA		3.5.1		3.5.2		3.5.3		3.5.4	
	Mix 1	Mix 2	Mix 1	Mix 2	Mix 1	Mix 2	Mix 1	Mix 2	Mix 1	Mix 2
Slump [mm]	20	20	25	30	100		90		90	
Density method – air content [%]	0,5	0,6	1,2	1,5	[-0,5]		3,1		6,9	
Pressure method – air content [%]	2,0	2,0	3,0	3,0	1,5		5,8		7,6	
Average density of specimens [kg/m^3]		2294,49		2260,18	2295,07		2211,88		2154,08	
Air content in hardened specimens [%]		0,7		2,1	0,6		4,2		6,7	

Table 5 Air content in mixes with AEA5

AEA4 – Sika Multi Air										
Matrix volume = 400 litres										
	No SP and AEA		3.5.1		3.5.2		3.5.3		3.5.4	
	Mix 1	Mix 2	Mix 1	Mix 2	Mix 1	Mix 2	Mix 1	Mix 2	Mix 1	Mix 2
Slump [mm]	20	20	25		105		90		90	
Density method – air content [%]	0,5	0,6	2,1		0,3		5,0		12,6	
Pressure method – air content [%]	2,0	2,0	3,5		2,2		5,9		11,2	
Average density of specimens [kg/m^3]		2294,49	2263,4		2287,74		2188,36		2044,37	
Air content in hardened specimens [%]		0,7	2,0		0,9		5,2		11,4	

Table 6 Air content in mixes with AEA4

[ ] – negative values. Results obtained in the density method where materials data needed for calculations. The negative values of the air content can be caused by the wrong value of the fly ash density. As we can see in the data sheet (Appendix B), density of fly ash can vary depending on Loss on Ignition.

As we can see on the Figure 1, there is an effect of adding sequence for SP and AEA. We can also observe that dosage of SP has influence on the air content. When we consider mixes with matrix volume 330 litres, SP does not affect the air content because quantity of SP is low. When we look at the bars where results from mixes with 400 litres of matrix volume are presented, there is an effect of adding SP after AEA. When we compare these results and the results from FI test report [1], we can see that in both cases SP 'kills' air when it is added after AEA. The most efficient sequence is 3.5.4 when we add AEA with SP at the same time. We can also observe that there is no significant difference in the air content when we compare AEA4 and AEA5 for the sequences without SP and AEA, 3.5.1, 3.5.2 and 3.5.3 for the matrix volume 400 litres. However when we came to the sequence 3.5.4 there is a significant difference in the air content. It means that the AEA4 – Sika Multi Air is more efficient that AEA5 – Mapeair 25.

Workability vs. air content

Figure 2 shows the relationship between workability and the air content due to pressure method for experiments done with matrix volume 330 litres and AEA5.

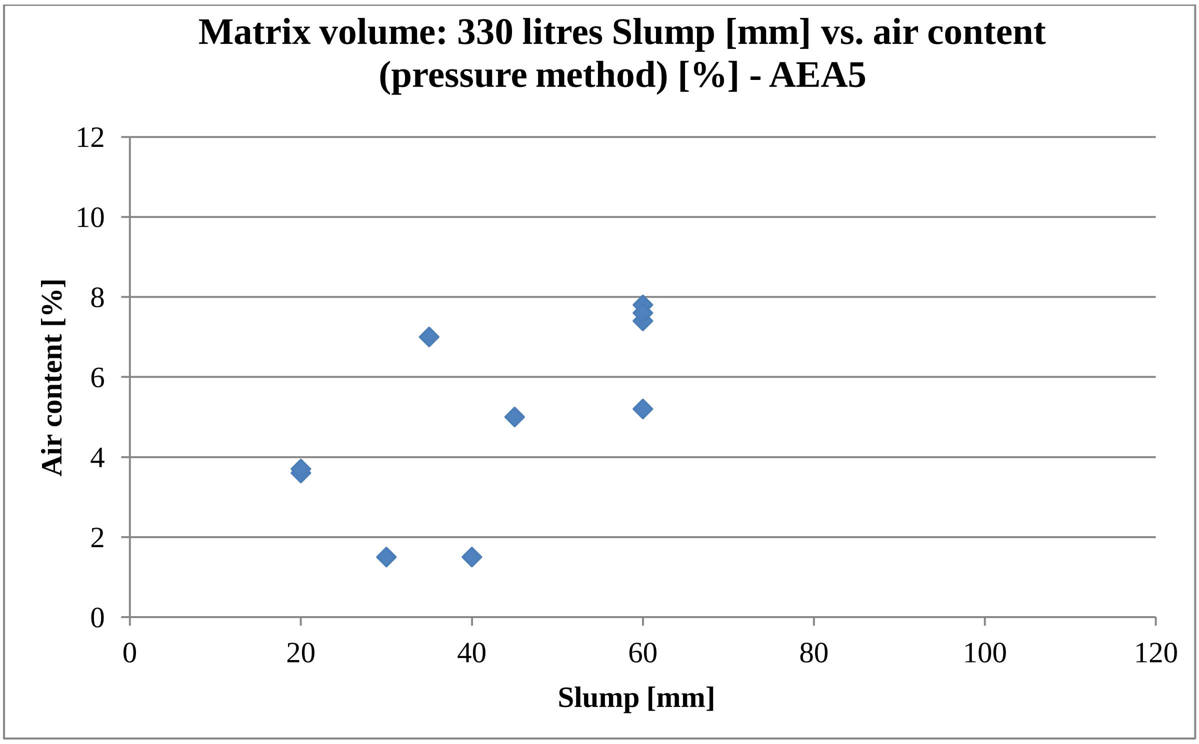


Figure 2 Matrix volume 330 litres: workability vs. air content - AEA5

Figure 3 shows the relationship between workability and air content due to pressure method for experiments done with matrix volume 400 litres and AEA5.

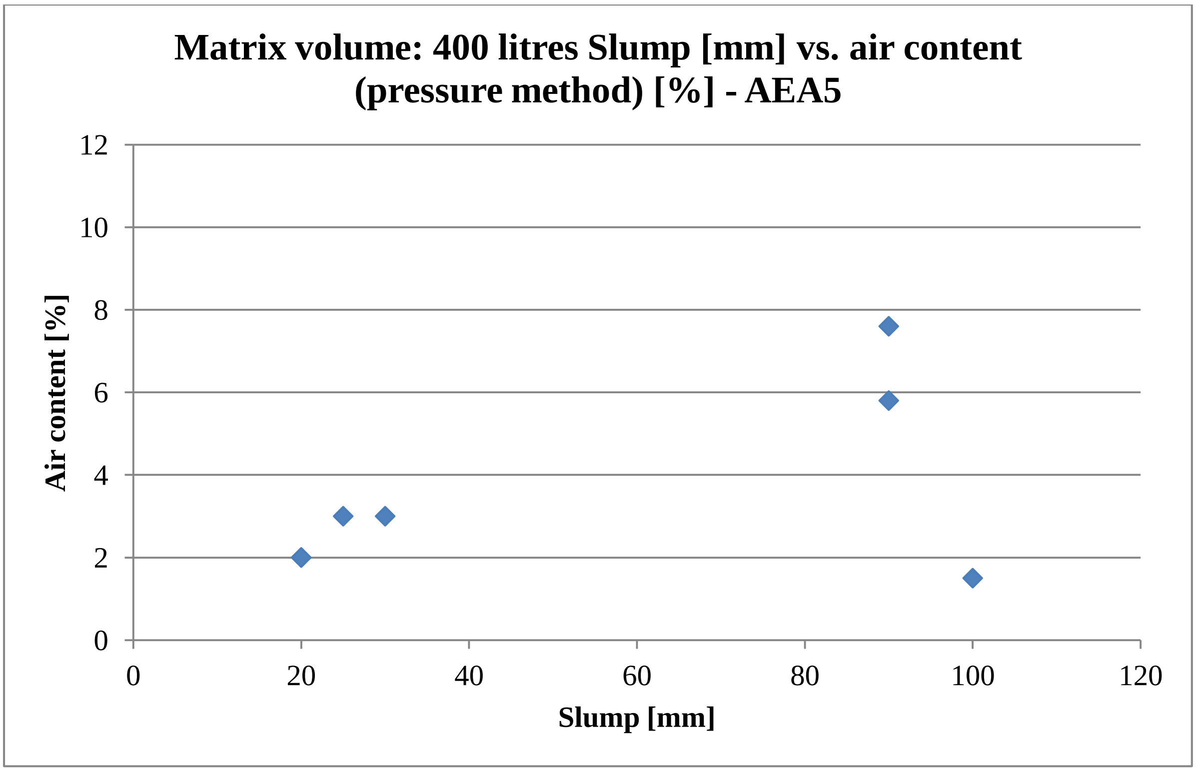


Figure 3 Matrix volume 400 litres: workability vs. air content - AEA5

Figure 4 shows the relationship between workability and air content due to pressure method for experiments done with matrix volume 400 litres and AEA4.

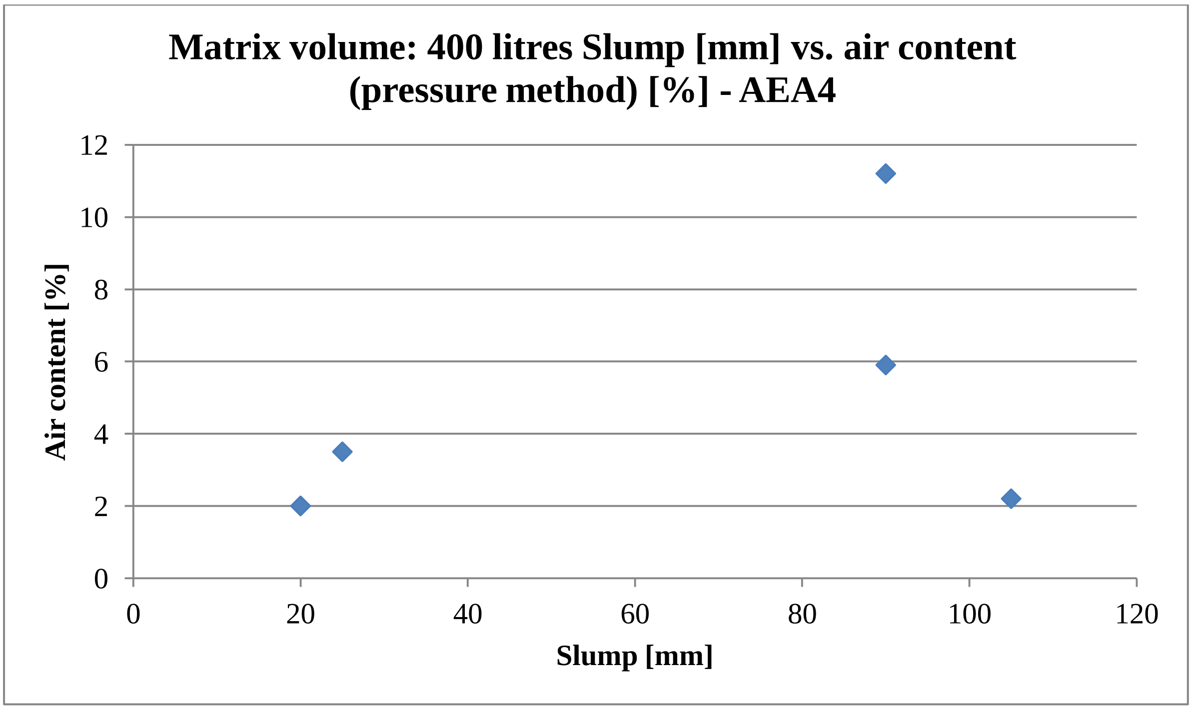


Figure 4 Matrix volume 400 litres: workability vs. air content - AEA4

As it is seen from figure 2, with higher workability air content increases. The results on the figure 2 are with low dosage of SP and the consistence of the mortar is stiff and stiff/plastic. We cannot observe any relationship between parameters as we can see on the figures 3 and 4, where the consistency is more flowable. It seems that for the slump below 90mm, the air content in concrete increases. However, when we exceed 90mm, the air content significantly drops down. Both of the experiments were done on the same matrix volume and with the same dosages of AEA and SP. It verifies that SP has influence on the air content. When we increase the workability, the air content also increases. However, special care should be taken when increasing the SP dosage, because of known negative effects of high dosage of SP on the air content, as it usually contains damper according to manufacturer.

Pressure method vs. density method

Figure 5 shows correlation between the density and pressure method. The comparison was made for all experiments with 330 and 400 litres of matrix volume and for AEA4 and AEA5 as well.

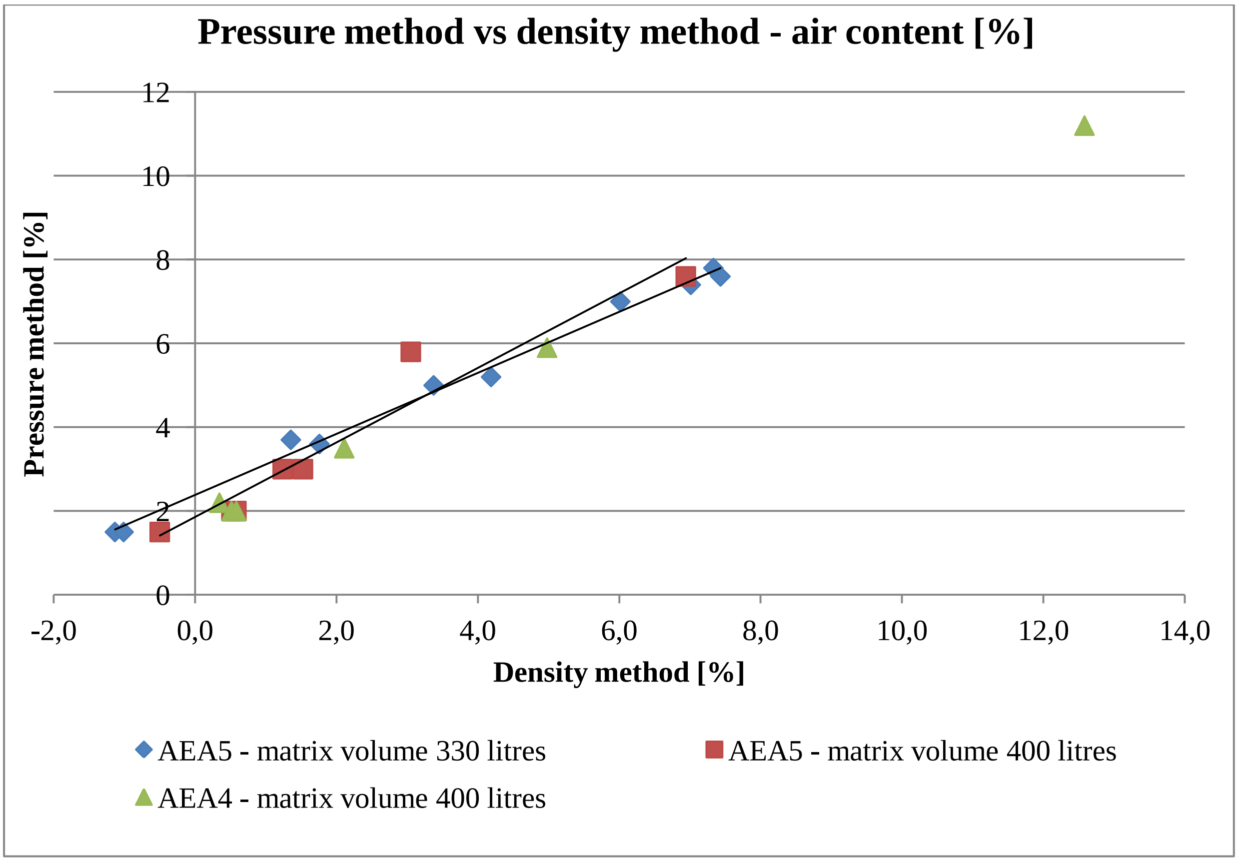
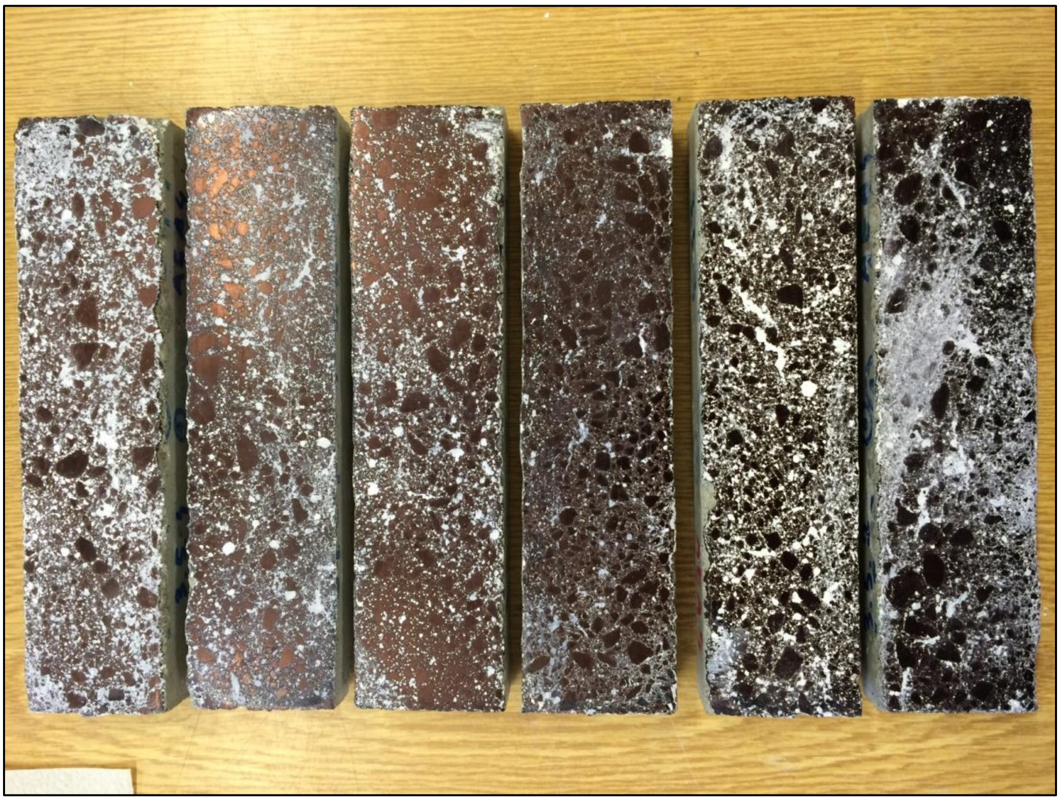


Figure 5 Pressure method vs. density method - air content [%]

As we can see on the figure 5, there is a good correlation between the pressure and the density method for all cases, indicating that measurements were taken in a consistent manner. There are some smaller or bigger outliners which could be caused by the failure in the measurements, but all in all the good correlation was kept for all experiments.

Image analysis

After polishing samples using powder with 1200 grit, the surface of the samples observed under the microscope was rough and it was not ready for further preparations (see photos D30, D31 and D32). Despite this, we decided to coloured half of the specimens and see whether the roughness of the surface has big influence on the further results. On the picture below, coloured and filled samples with the white powder ($BaSO_4$) are presented:



Picture 6 Prepared samples for Image analysis

As we can see, the samples are not representative and in the Image analysis we would obtain erroneous results. There is a noticeable excess of white powder, $BaSO_4$, which filled the roughed surface of the specimens and, as it is known, white points in the Image analysis represent air pores in concrete.

Therefore, we decided to polish the second half of the samples using finer sand paper, 2000 and 4000 grit. Normally, the process of polishing is finished on 1200 grit powder. Sand papers with finer size are rarely in use for concrete / mortar. Unfortunately, surface was still rough and it was not ready to further experiment.

The roughness of the surface is caused by fly ash in mortar, which matures longer than cement and limestone used in the mixes. During the polishing, immature particles of the fly ash were separate and it caused rough surface.

Due to lack of results on hardened mortar, we decided to perform PF test [12] instead of Image analysis. From the PF-method we obtain total air content in hardened state, which can be compared with total air content in a fresh state. Unfortunately, parameters of pore structure cannot be obtained from PF-method.

Air content in the fresh concrete vs. Hardened concrete

In the table 7 comparisons between the air content in the fresh and hardened concrete is presented. The air content in the fresh concrete is taken from Pressure method and in the hardened concrete from PF test. PF factor is also included in the table below.

		AEA5			AEA4	
Method	3.5.2	3.5.3	3.5.4	3.5.2	3.5.3	3.5.4
Pressure method [%]	1,5	5,8	7,6	2,2	5,9	11,2
PF – method [%]	3,4	7,4	8,8	4,1	7,5	12,5
PF factor [%]	16,4	28,7	34,3	20,1	31,1	43,4

Table 7 Results from Pressure method and PF test

As we can see, independently from the sequence, air content in the hardened concrete is higher than in the fresh concrete by 1-2%. It may be caused by the coalescence of smaller air bubbles to bigger, as it is described in the Fagerlund's paper [6], resulting in higher air content in the hardened concrete. In the PF test, at least 3 specimens from every sequence should be tested. In our case only one specimen from every sequence was tested, therefore the results should be treated with care.

In the table PF factors, which determine the frost resistance, are presented. Almost all specimens have PF factor above 20 % what means that they are frost resistant for fresh water).

5 Conclusions

Air entrainment and stability of the pore system in fresh and hardened concrete is an extremely complex problem. It is caused by the lack of knowledge about the effectiveness of the sequences of adding admixtures and others factors affecting the air-void system in the concrete. Every component in concrete mixture, including cement, fly ash, binders and admixtures affect the air void system to varying degree. Use of different mixers, transport, placing and compaction methods and other operations affect the air entrainment. This report is focused on adding sequence of admixtures - Air Entraining Agents (AEAs) in combination with Superplasticizer (SP) and its effect on the air-void system.

Investigation about sequence of adding AEAs and SP included in this report was based on the FI report [1]. Based on the results obtained in this experimental investigation, following conclusions are drawn:

1) When we are talking about combination of adding admixtures, it is clearly seen that the Foam Index test results correlate well with results on mortar mixes in present report. The most effective sequence, when the highest volume of the air pores in concrete is required, is the sequence where Air Entraining Agent is added with Superplasticizer. Both tests show also that SP added after AEA 'kill' the air in the mix, hence this sequence should be avoided during production of air-entrained concrete.
2) As it was mentioned in this report, calculations have significant influence on the final results. Before the right Excel sheet was created, Excel sheet from Skanska had been used. Skanska Excel sheet was created for simple calculations with ordinary Portland cement (OPC) or Fly ash cement (FA cement). In this case, OPC was mixed with fly ash and filler in the laboratory so the Excel sheet from Skanska did not suit our test program.
3) Dosage of the SP has influence on the air content in the concrete if dosage of the AEA is kept constant. Higher dosage of the SP increases the workability

of mixture, so the air content in concrete decreases as we can see on the screen shots from Excel sheet included in the Appendix C.

4) Concerning adding sequences, different AEAs behave in the same way. Only total air content differentiates, depending on the efficiency of surfactant.
5) There were many combinations of different mixture parameters used in the work. Despite clear correlations of some of the parameters, the data requires to be regained from repeated experiments to increase data pool and probability of conclusions.

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Appendix A – Foam Index – Results table

Appendix B – Material data sheets

Appendix C – Calculations

Appendix D – Photo documentation

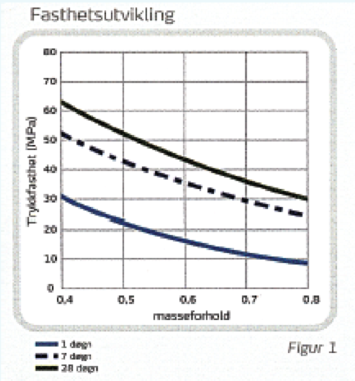
Appendix A – Foam Index – Results table

Procedure		3.5.1	3.5.3	3.5.4	3.5.2
Material/binder	AEA	AEA(without SP) µl/g	SP before AEA (SP/AEA) µl/g	SP with AEA (SP/AEA, time stable) µl/g	SP after AEA (SP) µl/g
OPC(NO)	AEA1	0,6	-	-	-
OPC(NO)	AEA2	0,8	-	-	-
OPC(NO)	AEA3	0,6	-	-	-
OPC(NO)	AEA4	0,4	-	-	-
OPC(NO)	AEA5	0,6	4/0,6	4/0,6(4,5sek)[1]	4
OPC(NO)	AEA6	0,6	4/1	4/1(3,5sek)	2
OPC(NO)	AEA7	0,4	-	-	4
OPC(NO) 70% + FA(NO)30%	AEA1	2,6	4/1,8	4/1,8(6,59sek)	2
OPC(NO) 70% + FA(NO)30%	AEA2	4	-	-	2
OPC(NO) 70% + FA(NO)30%	AEA3	1,8	-	-	2
OPC(NO) 70% + FA(NO)30%	AEA4	1,4	4/1,8	4/1,8(26,5sek)	2
OPC(NO) 70% + FA(NO)30%	AEA5	3,2[3]	4/1,2[4]	4/1,2(4,41sek)	2
OPC(NO) 70% + FA(NO)30%	AEA6	5,4	-	-	4
OPC(NO) 70% + FA(NO)30%	AEA7	2,8	4/1	4/1(5,31sek)	4

Table A1 Foam Index - results table

Table A1 shows results obtained in the FI test described in the report [1] written by the Bachelor students from Gjøvik University. In this table, dosages of AEAs and SP in unit of µl/g are presented. For AEA5 we can see that there are indexes with dosages. They mean that these values are average from 5 tests. Number in the bracket show time where foam was stable. As it is known from this report and from FI report [1] SP "kills" the foam.

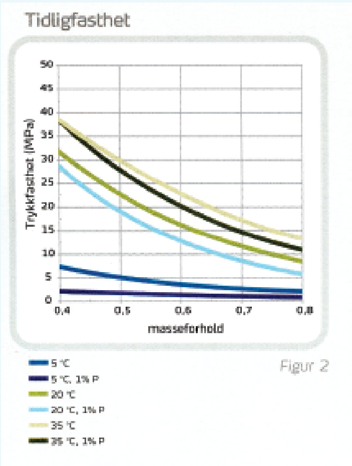
Appendix B – Materials data sheets



Figur 1

Fasthetsutvikling

Fasthetsutvikling er en sentral egenskap for planlegging, styring og utførelse av alle betongarbeider. Fasthetsutvillingen er avhengig av sementtype, tilslag, masseforhold, herdeforhold (temperatur, tid og fuktighet), og eventuell bruk av tilsetningsmaterialer eller -stoffer. I figur 1 er vist et eksempel på trykkfasthetsutviklingen som funksjon av masseforhold og alder ved 20°C vannlagring for betong med Norcem Standardsement.



Figur 2

Tidligfasthet

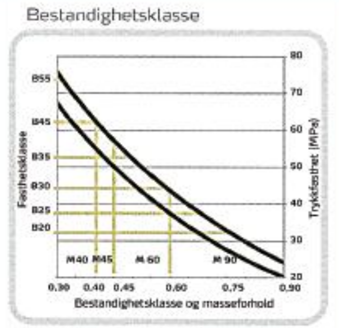
Tidligfasheten i betong er avhengig av temperatur og eventuell dosering av tilsetningsstoff med retarderende effekt. I figur 2 er vist trykkfasthet for betong etter 1 døgn med forskjellig masseforhold med og uten 1% plastiserende tilsetningsstoff (P-stoff) med Standardsement. Prøvene er lagret ved 95% luftfuktighet ved varierende temperatur.

Fasthetsklasse - masseforhold

Med normal, god styring av betongproduksjonen, er det behov for en overhøyde på ca 7 MPa ved de ulike fasthetsklassene for å produsere med tilstrekkelig sikkerhet mot undermålere. Standardsement gir følgende retningsgivende verdier for minste og største masseforhold i ulike fast-hetsklasser for betong uten luftinnføring.

Fasthets-klasse	**B20**	**B25**	**B30**	**B35**	**B45**
Minste - største masse-forhold	0,68 - 0,76	0,57 - 0,68	0,51 - o,57	0,42 - 0,51	0,35 - 0,42

Norcem Standardsement er tilpasset norske forhold og kan benyttes til betong i alle eksponerings-, bestandighets- og fasthetsklasser. Standardsementen har en fasthetsprofil som er tilpasset minimum sementbehov for konstruksjoner i bestandighetsklasse M60. Sementen har relativt høy tidligfasthet, moderat sluttfasthet, moderat varmeutvikling, god støpelighet og veldokumenterte bestandighetsegenskaper.



Figur 3

Bestandighetsklasse

NS-EN 206-1 klassifiserer betongens miljøpåvirkninger i eksponeringsklasser. I nasjonalt tillegg til denne standarden er de ulike eksponeringsklassene gruppert i seks bestandighetsklasser med krav til betongens maksimale masseforhold (se tabell 3). Tabell 2 viser anbefalte kombinasjoner av bestandighets- og fasthetsklasser. Retningsgivende verdier for største masseforhold i de ulike fasthetsklassene er gitt i tabell 1. I figur 3 er vist sammenhengen mellom bestandighetsklasse og fasthetsklasse i et variasjonsbelte forårsaket av ulike produksjonsforutsetninger. Figuren gjelder for betong med Standardsement uten luftinnføring.

Anbefalte kombinasjoner	
Bestandighetsklasse M90	Fasthetsklasse B20 el høyere
Bestandighetsklasse M60	Fasthetsklasse B25 el høyere
Bestandighetsklasse M45	Fasthetsklasse B35 el høyere
Bestandighetsklasse M40	Fasthetsklasse B45 el høyere

Valg av bestandighetsklasse (nasjonale krav)						
Eksponeringsklasse	**M90**	**M60**	**M45**	**MF45***	**M40**	**MF40***
X0	•	•	•	•	•	•
XC1, XC2, XC3, XC4, XF1		•	•	•	•	•
XD1, XS1, XA1, XA2, XA4			•	•	•	•
XF2, XF3, XF4				•		•
XD2, XD3, XS2, XS3, XA3					•	•
XSA	**Betongsammensetning og beskyttelsestiltak fastsettes særskilt. Betongsammensetningen skal minst tilfredsstille kravene til M40.**					
Største masseforhold v/(c + Ekp)	**0,90**	**0,60**	**0,45**	**0,45**	**0,40**	**0,40**

** Minst 4% luft*

Deklarerte data

Norcem Standardsement tilfredsstiller kravene til Portlandsement

EN 197-1-CEM I 42,5R

Kjemiske data		
Egenskap	Deklarerte data	Krav iflg NS-EN 197-1
Finhet (Blaine)	370 m^2/kg i) / 380m^2/kg ii)	
Trikalsiumaluminat C_3A	7 %	
Alkali (ekv Na_2O, NB21)	1,3% i) / 1,3% ii)	Deklarert verdi iht NB21
Mineralske tilsetninger	4%	≤ 5%
Glødetap	2,5%	≤ 5%
Uløselig rest	1%	≤ 5%
Sulfat (SO_3)	3-4%	≤ 4%
Klorid	< 0,085%	≤ 0,1%
Vannløselig Cr^{6+}	< 2 ppm	≤ 2 ppm *)
Spesifikk vekt	3,15 kg/dm^3	

i) Brevik-produsert
ii) Kjøpsvik-produsert

**) I henhold til Forskrift om vannløselige kromater i sement- og betongrelaterte materialer*

Fysikalske data		
Egenskap	Deklarerte data	Krav iflg NS-EN 197-1
Trykkfasthet 1 døgn	21 MPa	
Trykkfasthet 2 døgn	32 MPa	≥ 20 MPa
Trykkfaasthet 7 døgn	42 MPa	
Trykkfasthet 28 døgn	52 MPa	≥ 42,5 MPa ≤ 62,5 MPa
Begynnende bindetid	130 min i) / 125 min ii)	≥ 60 min
Ekspansjon	1 mm	≤ 10 mm

i) Brevik-produsert
ii) Kjøpsvik-produsert

www.norcem.no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TILLEGGSMATERIALE
FLYGEASKE

PRODUKTINFORMASJON - OKTOBER 2015

FLYGEASKE www.norcem.no

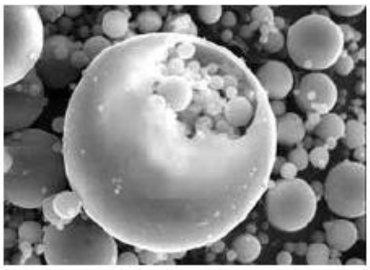
Norcem AS ivaretar salg av flygeaske til sement- og betongproduksjon. Flygeasken er sertifisert i overensstemmelse med kravene i NS-EN 450-1, klasse A.

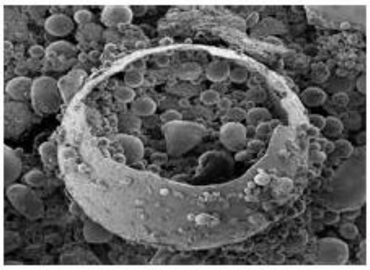
Flygeaske er et bearbeidet restprodukt fra kull brukt i kullkraftverk. Flygeaske er silikatholdig og er et pozzolan som sammen med sement og vann gir en tettere betong. Kombinert med sement har flygeaske vært brukt i Norge siden 80-tallet. Norcem FA-sementer inneholder flygeaske.

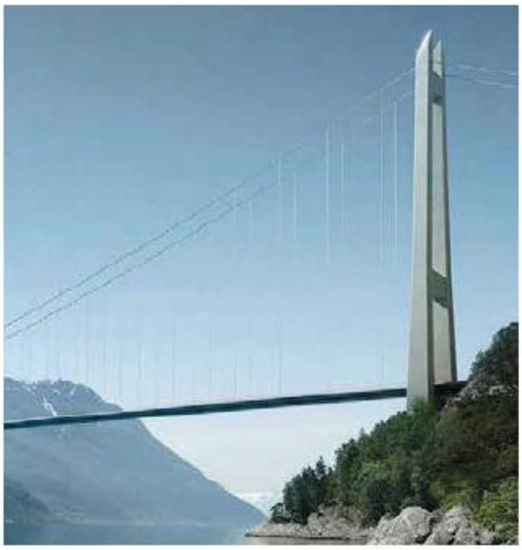
DEKLARERTE VERDIER

Flygeasken er sertifisert i overensstemmelse med kravene i NS-EN 450-1:2012, klasse A.

Egenskap	Deklarerte verdier	Krav i henhold til NS-EN 450-1
Glødetap (%)	≤ 5,0	Tilfredsstiller kravene gitt NS-EN 450-1
Klorid (% Cl^-)	≤ 0,10	Tilfredsstiller kravene gitt NS-EN 450-1
Sulfat (% SO_3)	≤ 3,0	Tilfredsstiller kravene gitt NS-EN 450-1
Fritt kalsiumoksid (% fri CaO)	≤ 1,5	Tilfredsstiller kravene gitt NS-EN 450-1
Reaktivt kalsiumoksid (% reaktiv CaO)	≤ 10	Tilfredsstiller kravene gitt NS-EN 450-1
Partikkeldensitet (kg/m^3	2300	Dekl.verdi +/- 200 kg/m^3
Øvrige kjemiske og fysiske parametere		Tilfredsstiller kravene gitt NS-EN 450-1







Construction

Product Data Sheet
Edition 5.3.2011
Sika Multi Air 25

Sika® Multi Air 25

Multi Component Synthetic Air Entrainer

Description	Sika Multi Air 25 is a multi component synthetic air entrainer. Sika Multi Air 25 meets the requirements of ASTM C-260 for air entraining admixtures.
Applications	Sika Multi Air 25 is recommended for use whenever air entrained concrete is desired. Sika Multi Air 25 is very effective in specialized applications such as low slump, harsh, lean mixes or in mixes utilizing fly-ash.
Benefits	Air entrainment is recognized as the most effective prevention against concrete damage caused by repetitive freeze-thaw cycles. Air entraining agents help to prevent scaling by creating microscopic air voids that water trapped in the concrete can expand into when the concrete freezes. This prevents cracking caused by the natural expansion of ice. Entrained air voids in the concrete will also increase durability in harsh environments where concrete is exposed to deicing salts, marine salts and sulfates. Besides that Air entraining agents also improve workability and placeability of a concrete mixture and reduce bleeding.

How to Use

Dosage	The amount of Sika Multi Air 25 will vary depending on the mix design and air content required for a particular project. Dosage rates needed to entrain between 4 and 6 percent will typically fall between 0.5 and 1.5 fl. oz. per 100 lbs. (10 - 195 ml/100 kg) of cementitious materials. In special applications such as paving, dry cast applications or mixes utilizing flyash, the dosage may increase above the recommended dosage range. In cases such as this, actual testing is recommended to determine proper dosage range. If required, higher air content may be obtained by increasing the dosage rate. Combination with other admixtures, particularly water reducers, accelerators and retarders, may decrease or increase the effectiveness of Sika Multi Air 25, therefore random air content tests with an air-meter after batching should be performed to provide desired consistency. In mixes requiring a lower or higher amount dosage rate, it is always recommended to contact your local regional office or technical service department at 1-800-933-7452.
Mixing	Measure the required quantity per batch manually or with automatic dispenser equipment. Add Sika Multi Air 25 to mixing water or sand. Do not mix with dry cement. When used in combination with other admixtures, care must be taken to dispense each admixture separately into the mix. **Combination with other Admixtures:** Combination with other admixtures, may affect the amount of entrained air in the mix. If multiple admixtures are used, actual air content should be verified as per applicable ASTM standards to ensure desired level of air entrainment is achieved.

Sika®

Construction

Packaging	Sika Multi Air 25 is available in 55 gallon drum (208 liter), 275 gallon totes (1040 liters) drums and bulk delivery.
Storage and Shelf Life	Sika Multi Air 25 should be stored at above 40°F (5°C). If frozen, thaw and agitate thoroughly to return to normal state. Shelf life when stored in original packaging in dry warehouse conditions between 50°F and 80°F (10°C - 27°C) is 1 year.
Typical Data	
Appearance	Yellow, clear liquid
Specific Gravity	1.010
Caution	**IRRITANT.** Contains Sodium C14-16 Olefin Sulfonate for Bioterge 40 (CAS:68439-57-6) and Amides, coco, N,N-bis (hydroxyethyl) (CAS: 68603-42-9). May cause eye/skin/respiratory irritation. May be harmful if swallowed.
Handling and Storage	Avoid direct contact. Wear personal protective equipment (chemical resistant goggles/gloves/clothing) to prevent direct contact with skin and eyes. Use only in well ventilated areas. Open doors and windows during use. Use a properly fitted NIOSH respirator if ventilation is poor. Wash thoroughly with soap and water after use. Remove contaminated clothing and launder before reuse.
First Aid	**Eyes** – Hold eyelids apart and flush thoroughly with water for 15 minutes. **Skin** – Remove contaminated clothing. Wash skin thoroughly for 15 minutes with soap and water. **Inhalation** – Remove to fresh air. **Ingestion** – Do not induce vomiting. Dilute with water. Contact physician. **In all cases contact a physician immediately if symptoms persist.**
Clean Up	Use personal protective equipment (chemical resistant gloves/ goggles/clothing). Without direct contact, sweep up spilled or excess product and place in suitable sealed container. Dispose of excess product and container in accordance with applicable local, state, and federal regulations.

KEEP CONTAINER TIGHTLY CLOSED • KEEP OUT OF REACH OF CHILDREN • NOT FOR INTERNAL CONSUMPTION • FOR INDUSTRIAL USE ONLY

All information provided by Sika Corporation ("Sika") concerning Sika products, including but not limited to, any recommendations and advice relating to the application and use of Sika products, is given in good faith based on Sika's current experience and knowledge of its products when properly stored, handled and applied under normal conditions in accordance with Sika's instructions. In practice, the differences in materials, substrates, storage and handling conditions, actual site conditions and other factors outside of Sika's control are such that Sika assumes no liability for the provision of such information, advice, recommendations or instructions related to its products, nor shall any legal relationship be created by or arise from the provision of such information, advice, recommendations or instructions related to its products. The user of the Sika product(s) must test the product(s) for suitability for the intended application and purpose before proceeding with the full application of the product(s).

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Prior to each use of any Sika product, the user must always read and follow the warnings and instructions on the product's most current Technical Data Sheet, product label and Material Safety Data Sheet which are available at www.sikausa.com or 800-933-7452. Nothing contained in any Sika materials relieves the user of the obligation to read and follow the warnings and instruction for each Sika product as set forth in the current Technical Data Sheet, product label and Material Safety Data Sheet prior to product use.

SIKA warrants this product for one year from date of installation to be free from manufacturing defects and to meet the technical properties on the current Technical Data Sheet if used as directed within shelf life. User determines suitability of product for intended use and assumes all risks. Buyer's sole remedy shall be limited to the purchase price or replacement of product exclusive of labor or cost of labor. NO OTHER WARRANTIES EXPRESS OR IMPLIED SHALL APPLY INCLUDING ANY WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE. SIKA SHALL NOT BE LIABLE UNDER ANY LEGAL THEORY FOR SPECIAL OR CONSEQUENTIAL DAMAGES. SIKA SHALL NOT BE RESPONSIBLE FOR THE USE OF THIS PRODUCT IN A MANNER TO INFRINGE ON ANY PATENT OR ANY OTHER INTELLECTUAL PROPERTY RIGHTS HELD BY OTHERS.

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1-800-933-SIKA

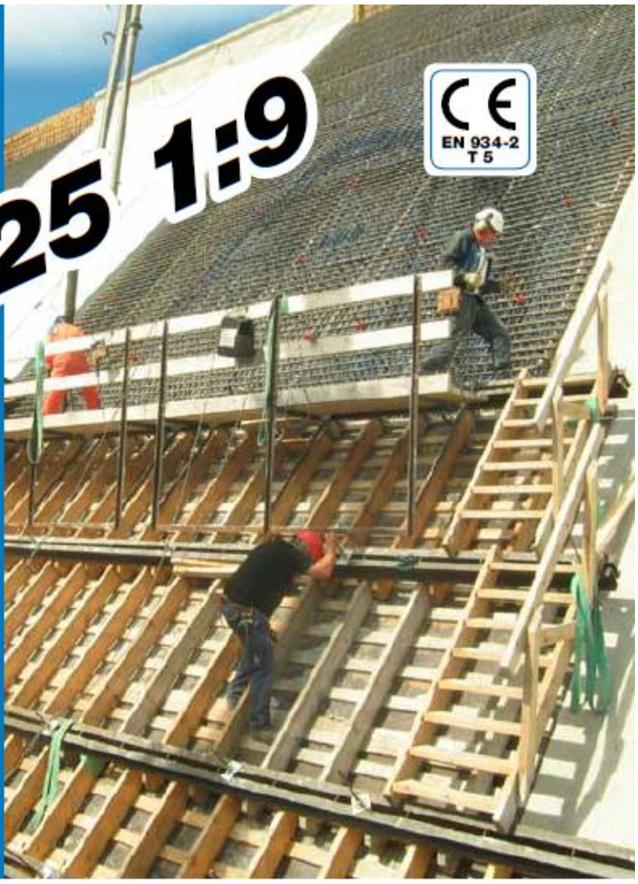
Regional Information and Sales Centers. For the location of your nearest Sika representative, contact your regional center.

U.S.: **North East Region:** Fairless Hills, PA, Phone: (215) 295-5600 **North Central Region:** Marion, OH, Phone: (800) 851-1545
South East Region: Conyers, GA, Phone: (770) 760-1300 **South Central Region:** Mesquite, TX, Phone: (972) 289-6460
Western Region: Santa Fe Springs, CA, Phone: (562) 903-3650

Canada: **Ontario:** Mississauga, ON, Phone: (905) 795-3177, **Alberta:** Edmonton, AB, Phone: (780) 486-6111

MAPEI

Mapeair 25 1:9



Air entraining admixture

AREA OF USE
Mapeair® 25 1:9 is a surface active agent which promotes the formation of small air bubbles and is used to improve the frost resistance of concrete and mortar.
Mapeair® 25 1:9 also gives improved workability and reduces the risk of segregation. The product is usually used in combination with Mapei's plasticising or superplasticising admixtures.
Mapeair® 25 1:9 is based on synthetic tensides and tall oil derivatives.

TECHNICAL CHARACTERISTICS
Concrete always contains a certain amount of air (1 - 3 %). In order to meet the usual requirements of 4 - 6 % air in fresh concrete, **Mapeair® 25 1:9** is added, which produces smaller and more evenly distributed air bubbles, which leads to improved freeze-thaw resistance.

Air introduced during mixing is transformed into small evenly distributed pores in the presence of **Mapeair® 25 1:9**. These entrained air bubbles also improve the workability and reduce the amount of water required. Increased air content generally leads to a decrease in compressive strength. A general guide is that 1 % of air reduces the compressive strength by 5 %. This is partly compensated for by the reduced need for water and by adding plasticising and/or superplasticizing admixtures.

Mapeair® 25 1:9 will also improve stability during transportation by reducing the risk of segregation for concrete containing a low volume of fine particles and actively preventing bleeding (transportation of water to the surface of fresh concrete).

WORKING INSTRUCTIONS
Mapeair® 25 1:9 is delivered ready for use and can be added directly into the mixer. To obtain an even distribution of air from batch to batch, it is important that **Mapeair® 25 1:9** is added at the same stage of the mixing procedure each time.

The dosage required to give the desired air content varies with aggregates, cement type and quantity present. Other additives may also have an influence. It is important that the addition of **Mapeair® 25 1:9** is determined by test mixing and that the air content in the fresh concrete is regularly checked.

DOSAGE
0.5 - 5.0 litres of **Mapeair® 25 1:9** pr. m³ of concrete.

ATTENTION
Variations in other components in the concrete can greatly influence the formation of air bubbles in concrete. In some cases duration of transport and the type of transportation equipment used can produce variations in air content.
If the mixing time has been too short the total measured air content may increase from production to delivery, whereas in most cases a reduction of air content is observed. Normally this reduction is the result of the release of larger, undesirable air bubbles.

Mapeair 25 1:9

Hence, the producer must base his calculations on experience with the particular constituents used.

PACKAGING
Mapeair® 25 1:9 is available in 1000 liter IBC tanks and in tank.

STORAGE
The product must be stored at temperatures between +8 and +35°C, and will retain its properties for at least one year when stored unopened in original packaging. If the product is exposed to direct sunlight, colour variation may occur, but this will not affect the technical properties of the product.

SAFETY INSTRUCTIONS FOR PREPARATION AND USE
Mapeair® 25 1:9 is not considered dangerous according to European regulations regarding classification of chemicals. It is recommended to wear gloves and goggles and to take usual precautions for handling of chemicals.

For further and complete information about safe use of the product, please refer to the latest version of the safety data sheet.

PRODUCT FOR PROFESSIONAL USE

WARNING
Although the technical details and recommendations contained in this product data sheet correspond to the best of our knowledge and experience, all the above - information must, in every case, be taken as merely indicative and subject to confirmation after long-term practical application: for this reason, anyone who intends to use the product must ensure beforehand that it is suitable for the envisaged application: in every case, the user alone is fully responsible for any consequences deriving from the use of the product.

Please refer to the current version of the technical data sheet, available from our web site www.mapei.com

All relevant references for the product are available upon request and from www.mapei.com

TECHNICAL DATA (typical values)

PRODUCT IDENTITY	
Type:	liquid
Colour:	transparent
Viscosity:	low viscosity < 20 mPa*S
Solid content, (%):	0.42 + 0.04
Density, (g/cm³):	1.00 ± 0.02
pH:	8.5 ± 1
Chloride content, (%):	≤ 0.05
Alkali content (Na_2O-equivalent), (%):	≤ 0.2
CHARACTERISTICS OF CONCRETE CONTAINING MAPEAIR 25 1:9:	
Volume of air in concrete mixture EN 12350-7:	6 % at dosage 0.05 % weight of cement (reference 2.2 %)
Spacing factor in hardened concrete, EN 480-11 (mm):	0.190 (requirement < 0.200)
Specific surface, EN 480-11, (mm²/mm³):	25.2 (requirement > 25)
Frost resistance (scaling) – EN 12390-9 (kg/m²):	0.05 (best classification < 0.1 : excellent)

04.12.2013 GB

BUILDING THE FUTURE

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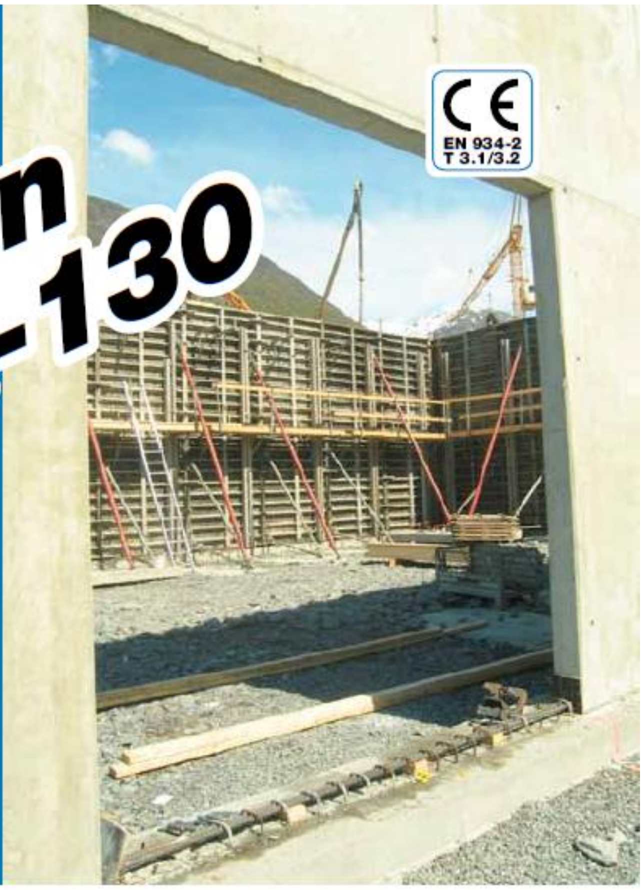
Dynamon SX-130

Superplasticizing admixture



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PRODUCT DESCRIPTION

Dynamon SX-130 is a very efficient liquid superplasticising admixture, based on modified acrylic polymers.
The product belongs to the **Dynamon System** based on the DPP (Design Performance Polymers) technology, a new chemical process that can model the admixture's properties in relation to specific performances required for concrete. The process is developed by means of a complete design and production of monomers (an exclusive Mapei know-how).

AREAS OF APPLICATION

Dynamon SX-130 is a superplasticizing admixture used to improve workability and/or reduce the amount of mixing water.

Dynamon SX-130 is a **Dynamon** version with a higher share of active polymers. At a normal dosage of 0.3 - 1.2 % by weight of cement you will achieve considerable higher water reduction compared to other **Dynamon** products. The product is recommendable if you have a relatively big mixer and/or an accurate dosing system.

All **Dynamon** products are significantly different from conventional sulphonated melamine based and sulphonated naphthalene based superplasticizers, and also from first generation acrylic based polymers in terms of their superior water-reduction.

Over-dosing can cause concrete separation. We always recommend test productions production,using the actual parameters.

Dynamon SX-130 can give higher early strength than other superplasticizers, even at low temperatures.
The dosage required to achieve a particular workability will be considerably lower for **Dynamon SX-130** than for previous superplasticizers. In contrast to conventional melamine or naphthalene based admixtures, **Dynamon SX-130** produces the maximum effect regardless of when it is added, but the time of addition can influence the mixing time.
If at least 80 % of the mixing water is added before **Dynamon SX-130** the required mixing time will generally be shortest. It is nevertheless important to perform tests using the actual mixing equipment.

TECHNICAL PROPERTIES

Dynamon SX-130 is an aqueous solution of active acrylic copolymers which effectively disperse the cement grains.

This effect can be used in three ways:

1. To reduce the amount of mixing water, and simultaneonely maintain the concrete workability. Lower w/c ratio gives increased strength, reduced permeability and improved durability.
2. To increase workability compared to concrete with the same w/c ratio. The strength remains the same but ease of placement is improved.

Dynamon SX-130

3. To reduce both water and cement without altering the mechanical strength. Through this method it is possible to reduce costs (less cement), shrinkage (less water) and also the risk of temperature gradients due to the lower heat of hydration.
This last effect is particularly important for concrete containing a high percentage of cement.

COMPATIBILITY WITH OTHER PRODUCTS
Dynamon SX-130 can be combined with other Mapei admixtures, e.g. **Mapefast** accelerating additives and **Mapetard** retarding admixtures.
The product is also compatible with **Mapeair** air entraining admixtures for production of frost resistant concrete (the selection of air entraining admixtures depends upon the other components e.g. cement type and aggregate).

DOSAGE
To achieve the desired results (strength, durability, workability, cement reduction) add **Dynamon SX-130** in dosages between 0.3 and 1.2 % of the cement weight.
Increased dosages will increase the open time (the time the concrete is workable).

PACKAGING
Dynamon SX-130 is available in 25 liter cans, 200 liter drums, 1000 liter IBC tanks and in tank.

STORAGE
The product must be stored at a temperature of between +8 and +35°C, and will retain its properties for at least one year if stored unopened in its original packaging. If the product is exposed to direct sunlight, colour variation may occur, but this will not affect the technical properties of the product.

SAFETY INSTRUCTIONS FOR PREPARATION AND USE
Dynamon SX-130 is not considered dangerous according to the European regulation regarding the classification of admixtures. It is recommended to wear gloves and goggles and to take the usual precautions taken for the handling of chemicals.

For further and complete information about the safe use of our product please refer to our latest version of the Material Safety Data Sheet.

PRODUCT FOR PROFESSIONAL USE

WARNING
Although the technical details and recommendations contained in this product data sheet correspond to the best of our knowledge and experience, all the above - information must, in every case, be taken as merely indicative and subject to confirmation after long-term practical application: for this reason, anyone who intends to use the product must ensure beforehand that it is suitable for the envisaged application: in every case, the user alone is fully responsible for any consequences deriving from the use of the product.

Please refer to the current version of the technical data sheet, available from our web site www.mapei.com

All relevant references for the product are available upon request and from www.mapei.com

Dynamon SX-130

TECHNICAL DATA (typical values)

PRODUCT IDENTITY	
Appearance:	liquid
Colour:	yellowish brown
Viscosity (Brookfield Viscometer DV-1, LV1, 100rpm at 20±2°C)	easy flowing; < 30 mPa*S
Solids content, %:	30.0 ± 1.5
Density, g/cm³:	1.09 ± 0.02
pH-value:	6.5 ± 1
Chlorides, %:	< 0.05
Alkali content (equiv. Na_2O) %:	< 2.5

CONCRETE PROPERTIES

As a water-reducing admixture (same workability)	Reference	Dynamon SX-130
Cement kg/m³ (type CEM I):	350	350
Admixture dosage (% by weight of cement):	0	0.6
Water to cement ratio:	0.59	0.43
Water reduction (%):	-	27
Workability, mm:		
- slump, 5 min	220	230
- slump, 30 min	200	200
Compressive strength (N/mm² cubes):		
- 1 day	18	25
- 7 day	38	58
- 28 days	50	73

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Appendix C – Calculations

Table C1 shows calculations for mixes with matrix volume 400l and AEA5

matriks volume [l]	400	No AEA and SP		3.5.1		3.5.2			3.5.3				3.5.4		
		30.03	30.03	30.03	30.03	30.03	30.03	06.04	31.03	31.03	06.04	06.04	31.03	31.03	06.04
Proportioning:		mix 1	mix 2	mix 1	mix 2	mix 1	mix 2	mix 3	mix 1	mix 2	mix 3	mix 4	mix 1	mix 2	mix 3
OPC [kg/m^3]		313,67	313,67	316,37	316,37	316,91	316,91	317,59	316,91	316,91	317,18	317,59	316,91	316,91	317,59
FA [kg/m^3]		134,43	134,43	135,59	135,59	135,82	135,82	136,11	135,82	135,82	135,94	136,11	135,82	135,82	136,11
Limestone [kg/m^3]		23,58	23,58	23,79	23,79	23,83	23,83	23,88	23,83	23,83	23,85	23,88	23,83	23,83	23,88
Aggregate [kg/m^3]		1457,50	1457,50	1457,50	1457,50	1457,50	1457,50	1457,50	1457,50	1457,50	1457,50	1457,50	1457,50	1457,50	1457,50
total moisture		0,0188	0,0188	0,0188	0,0188	0,0188	0,0188	0,0188	0,0188	0,0188	0,0188	0,0188	0,0188	0,0188	0,0188
sand absorption		0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003
Water added [kg/m^3]		183,33	183,33	181,90	181,90	181,61	181,61	180,82	181,61	181,61	181,30	180,82	181,61	181,61	180,82
AEA [kg/m^3]		0	0	3,16	3,16	3,17	3,17	3,17	3,17	3,17	3,17	3,17	3,17	3,17	3,17
SP [kg/m^3]		0	0	0	0	0,91	0,91	2,04	0,91	0,91	1,36	2,04	0,91	0,91	2,04
mass of AEA [% of binders]		0	0	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7
mass of SP [% of binders]		0	0	0	0	0,2	0,2	0,45	0,2	0,2	0,3	0,45	0,2	0,2	0,45
free water [kg]		0,4532	0,4532	0,4570	0,4570	0,4578	0,4578	0,4578	0,4578	0,4578	0,4578	0,4578	0,4578	0,4578	0,4578
theoretical air void free volume [m^3]		0,002007	0,002007	0,002014	0,002014	0,002016	0,002016	0,002018	0,002016	0,002016	0,002017	0,002018	0,002016	0,002016	0,002018
theoretical air void free density [kg/m^3]		2310,89	2310,89	2309,22	2309,22	2308,56	2308,56	2308,35	2308,56	2308,56	2308,47	2308,35	2308,56	2308,56	2308,35
SLUMP TEST (5min)															
slump [mm]		20	20	25	30	60	60	100	40	45	60	90	50	50	90
DENSITY METHOD (8min)															
mass of empty container [g]		1112,7	1113	1112,9	1112,7	1113,3	1113,1	1113,1	1112,3	1112,9	1112,2	1113,5	1113,1	1113,9	1112,8
mass of container with concrete [g]		3411,7	3410,4	3393,5	3386,7	3391,9	3394,2	3433	3269,5	3264,8	3273,3	3351,4	3228,2	3226,7	3260,9
fresh density [kg/m^3]		2299	2297,4	2280,6	2274	2278,6	2281,1	2319,9	2157,2	2151,9	2161,1	2237,9	2115,1	2112,8	2148,1
theoretical air void free density [kg/m^3]		2310,89	2310,89	2309,22	2309,22	2308,56	2308,56	2308,35	2308,56	2308,56	2308,47	2308,35	2308,56	2308,56	2308,35
air content [%]		0,5	0,6	1,2	1,5	1,3	1,2	-0,5	6,6	6,8	6,4	3,1	8,4	8,5	6,9
PRESSURE METHOD (9min)															
air content [%]		2	2	3	3	3	2,9	1,5	7	7,4	7	5,8	8,6	8,6	7,6

matriks volume [l]	400	No AEA and SP		3.5.1		3.5.2			3.5.3				3.5.4		
		30.03	30.03	30.03	30.03	30.03	30.03	06.04	31.03	31.03	06.04	06.04	31.03	31.03	06.04
		mix 1	mix 2	mix 1	mix 2	mix 1	mix 2	mix 3	mix 1	mix 2	mix 3	mix 4	mix 1	mix 2	mix 3
SPECIMENS (12min)															
mass of specimen 1 [g]			588,5		581,2		578	588,5		555,1		571,2		551,8	548,9
mass of specimen 2 [g]			590		583		583,6	592,8		553,4		568,3		547,4	555,1
mass of specimen 3 [g]			588,7		587,2		582,8	590,7		556,5		575,6		547,3	555,3
volume of specimen 1 [l]			0,2576		0,2569		0,2575	0,2571		0,258		0,2583		0,2574	0,2554
volume of specimen 2 [l]			0,2559		0,2593		0,2608	0,2565		0,2569		0,258		0,257	0,2572
volume of specimen 3 [l]			0,2567		0,2587		0,2589	0,2585		0,2579		0,2591		0,2552	0,2577
density of concrete - spec 1 [kg/m^3]			2284,55		2262,36		2244,66	2288,99		2151,55		2211,38		2143,75	2149,18
density of concrete - spec 2 [kg/m^3]			2305,59		2248,36		2237,73	2311,11		2154,15		2202,71		2129,96	2158,24
density of concrete - spec 3 [kg/m^3]			2293,34		2269,81		2251,06	2285,11		2157,81		2221,54		2144,59	2154,83
average density of spec [kg/m^3]			2294,49		2260,18		2244,48	2295,07		2154,50		2211,88		2139,43	2154,08
Air content in hardened spec [%]			0,7		2,1		2,8	0,6		6,7		4,2		7,3	6,7
measured volume of concrete [m^3]		0,97	0,97	0,98	0,98	0,98	0,98	0,97	1,02	1,02	1,02	1,01	1,04	1,04	1,03
Correction of mass of part materials for air content [kg/m^3]:															
OPC		323,37	323,37	322,82	322,82	323,38	323,71	329,11	310,70	309,48	310,96	315,07	305,90	305,90	309,54
FA		138,59	138,59	138,35	138,35	138,59	138,73	141,05	133,16	132,64	133,27	135,03	131,10	131,10	132,66
Limestone		24,31	24,31	24,27	24,27	24,31	24,34	24,75	23,36	23,27	23,38	23,69	23,00	23,00	23,27
Aggregate		1502,58	1502,58	1487,24	1487,24	1487,24	1488,76	1510,36	1428,92	1423,34	1428,92	1445,93	1406,85	1406,85	1420,57
Water		189,01	189,01	185,62	185,62	185,32	185,51	187,38	178,05	177,36	177,74	179,39	175,30	175,30	176,24
AEA		0,00	0,00	3,23	3,23	3,23	3,24	3,28	3,11	3,09	3,11	3,14	3,06	3,06	3,09
SP		0,00	0,00	0,00	0,00	0,92	0,92	2,11	0,89	0,88	1,33	2,02	0,87	0,87	1,99
Density [kg/m^3] (ρconcrete')		2177,857	2177,857	2161,535	2161,535	2163,005	2165,214	2198,043	2078,181	2070,063	2078,717	2104,277	2046,086	2046,086	2067,36
Correction of mass of part materials for density [kg/m^3]:															
ρconcrete,measure/ρconcrete'		1,055625	1,05489	1,055083	1,05203	1,053442	1,053522	1,055439	1,038023	1,039533	1,039632	1,0635	1,03373	1,032606	1,039054
OPC		341,36	341,1224	340,6041	339,6184	340,6594	341,0331	347,3576	322,5096	321,7172	323,2876	335,0798	316,2155	315,8716	321,634
FA		146,2971	146,1953	145,9732	145,5507	145,9969	146,1571	148,8675	138,2184	137,8788	138,5518	143,6056	135,5209	135,3736	137,8432
Limestone		25,66616	25,6483	25,60933	25,53522	25,61349	25,64159	26,11711	24,24884	24,18927	24,30734	25,19397	23,7756	23,74975	24,18301
Aggregate		1586,158	1585,054	1569,167	1564,626	1566,726	1568,445	1594,095	1483,254	1479,609	1485,552	1537,75	1454,306	1452,725	1476,045
Water		199,5184	199,3796	195,8399	195,2732	195,2243	195,4385	197,7681	184,8231	184,369	184,7865	190,7778	181,216	181,019	183,1224
AEA		0	0	3,406041	3,396184	3,406594	3,410331	3,466104	3,225096	3,217172	3,230094	3,34359	3,162155	3,158716	3,209422
SP		0	0	0	0	0,973312	0,97438	2,22821	0,921456	0,919192	1,384326	2,14945	0,903473	0,90249	2,0632
Density [kg/m^3]		2299	2297,4	2280,6	2274	2278,6	2281,1	2319,9	2157,2	2151,9	2161,1	2237,9	2115,1	2112,8	2148,1

Table C1 Calculations for mixes with matrix volume 400l and AEA5

Table C2 shows calculations for mixes with matrix volume 400l and AEA4

matriks volume [l]	400	No AEA and SP		3.5.1	3.5.2	3.5.3	3.5.4
		30.03	30.03	07.04	07.04	07.04	07.04
Proportioning:		mix 1	mix 2	mix 1	mix 1	mix 1	mix 1
OPC [kg/m^3]		313,67	313,67	316,37	317,59	317,59	317,59
FA [kg/m^3]		134,43	134,43	135,59	136,11	136,11	136,11
Limestone [kg/m^3]		23,58	23,58	23,79	23,88	23,88	23,88
Aggregate [kg/m^3]		1457,50	1457,50	1457,50	1457,50	1457,50	1457,50
total moisture		0,0188	0,0188	0,0188	0,0188	0,0188	0,0188
sand absorption		0,003	0,003	0,003	0,003	0,003	0,003
Water added [kg/m^3]		183,33	183,33	181,90	180,82	180,82	180,82
AEA [kg/m^3]		0	0	3,16	3,17	3,17	3,17
SP [kg/m^3]		0	0	0	2,04	2,04	2,04
mass of AEA [% of binders]		0	0	0,7	0,7	0,7	0,7
mass of SP [% of binders]		0	0	0	0,45	0,45	0,45
free water [kg]		0,4532	0,4532	0,4570	0,4578	0,4578	0,4578
theoretical air void free volume [m^3]		0,002007	0,002007	0,002014	0,002018	0,002018	0,002018
theoretical air void free density [kg/m^3]		2310,89	2310,89	2309,22	2308,35	2308,35	2308,35
SLUMP TEST (5min)							
slump [mm]		20	20	25	105	90	90
DENSITY METHOD (8min)							
mass of empty container [g]		1112,7	1113	1112,9	1113,1	1112,8	1113
mass of container with concrete [g]		3411,7	3410,4	3373,4	3413,5	3306,2	3130,9
fresh density [kg/m^3]		2299	2297,4	2260,5	2300,4	2193,4	2017,9
theoretical density [kg/m^3]		2310,89	2310,89	2309,22	2308,35	2308,35	2308,35
air content [%]		0,5	0,6	2,1	0,3	5,0	12,6
PRESSURE METHOD (9min)							
air content [%]		2	2	3,5	2,2	5,9	11,2
SPECIMENS (12min)							
mass of specimen 1 [g]			588,5	584,7	592,3	563,2	519,3
mass of specimen 2 [g]			590	580,9	591,7	572,1	518,6
mass of specimen 3 [g]			588,7	583,1	586,1	563,1	524
volume of specimen 1 [l]			0,2576	0,2584	0,2588	0,2573	0,2539
volume of specimen 2 [l]			0,2559	0,2572	0,2585	0,261	0,2549
volume of specimen 3 [l]			0,2567	0,257	0,2566	0,2578	0,2552
density of concrete - spec 1 [kg/m^3]			2284,55	2262,77	2288,64	2188,88	2045,29
density of concrete - spec 2 [kg/m^3]			2305,59	2258,55	2288,97	2191,95	2034,52
density of concrete - spec 3 [kg/m^3]			2293,34	2268,87	2284,1	2184,25	2053,29
average density of spec [kg/m^3]			2294,49	2263,40	2287,24	2188,36	2044,37
air content in hardened spec [%]			0,7	2,0	0,9	5,2	11,4

measured volume of concrete [m^3]		0,97	0,97	0,985	0,972	1,009	1,062
Correction of mass of part materials for air content [kg/m^3]:							
OPC		323,37	323,37	321,18	326,74	314,76	299,05
FA		138,59	138,59	137,65	140,03	134,90	128,17
Limestone		24,31	24,31	24,15	24,57	23,67	22,49
Aggregate		1502,58	1502,58	1479,70	1499,49	1444,50	1372,41
Water		189,01	189,01	184,67	186,03	179,21	170,27
AEA		0,00	0,00	3,21	3,26	3,14	2,98
SP		0,00	0,00	0,00	2,10	2,02	1,92
Density [kg/m^3] (ρconcrete')		2177,857	2177,857	2150,563	2182,214	2102,192	1997,28
Correction of mass of part materials for density [kg/m^3]:							
ρconcrete,measure/ρconcrete'		1,055625	1,05489	1,05112	1,054159	1,043387	1,010324
OPC		341,36	341,1224	337,6022	344,4379	328,4168	302,1393
FA		146,2971	146,1953	144,6866	147,6162	140,7501	129,4883
Limestone		25,66616	25,6483	25,38362	25,89758	24,69299	22,71724
Aggregate		1586,158	1585,054	1555,338	1580,696	1507,172	1386,579
Water		199,5184	199,3796	194,1139	196,1058	186,9842	172,0231
AEA		0	0	3,376022	3,436969	3,277103	3,014893
SP		0	0	0	2,20948	2,106709	1,938146
Density [kg/m^3]		2299	2297,4	2260,5	2300,4	2193,4	2017,9

Table C2 Calculation for mixes with matrix volume 400l and AEA4

Table C3 shows calculations for mixes with matrix volume 330l and AEA5

matriks volume [l]	330	No AEA and SP		3.5.1		3.5.2		3.5.3		3.5.4	
		14.03	14.03	18.03	18.03	10.03	18.03	10.03	16.03	10.03	16.03
Weighed in:		mix 1	mix 2	mix 4	mix 5	mix 3	mix 4	mix 1	mix 2	mix 1	mix 2
OPC [g]		663,7	663,7	575,4	575,4	567	574,4	567	572,9	567	572,9
FA [g]		284,4	284,4	246,6	246,6	243	246,2	243	245,5	243	245,5
Limestone [g]		47,4	47,4	41,1	41,1	40,5	41	40,5	40,9	40,5	40,9
Aggregate [g]		3614,6	3614,6	3614,6	3614,6	3614,6	3614,6	3614,6	3614,6	3614,6	3614,6
total moisture		0,0178	0,0178	0,0188	0,0188	0,022	0,0188	0,022	0,02	0,022	0,02
sand absorption		0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003
Water added [g]		489,9	489,9	426,1	426,1	431,9	425,5	431,9	428,7	431,9	428,7
AEA [g]		0	0	5,8	5,8	5,7	5,7	5,7	5,7	5,7	5,7
SP [g]		0	0	0	0	1,6	1,6	1,6	1,6	1,6	1,6
mass of AEA [% of binders]		0	0	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7
mass of SP [% of binders]		0	0	0	0	0,2	0,2	0,2	0,2	0,2	0,2
free water [kg]		0,5426	0,5426	0,4881	0,4881	0,5061	0,4885	0,5061	0,4959	0,5061	0,4959
theoretical air void free volume [m^3]		0,002234	0,002234	0,002131	0,002131	0,002141	0,002131	0,002141	0,002136	0,002141	0,002136
theoretical air void free density [kg/m^3]		2278,15	2278,15	2298,527	2298,527	2286,226	2298,362	2286,226	2293,475	2286,226	2293,475
	SLUMP TEST (5min)										
slump [mm]		30	40	20	20	60	45	60	35	60	60
	DENSITY METHOD (8min)										
mass of empty container [g]		1112,5	1112,8	1112,1	1113,6	1112,4	1113,3	1112,8	1112,5	1112,4	1113,7
mass of container with concrete [g]		3416,5	3414	3370,2	3381	3302,9	3334,1	3238,7	3268	3231	3236,7
fresh density [kg/m^3]		2304	2301,2	2258,1	2267,4	2190,5	2220,8	2125,9	2155,5	2118,6	2123
theoretical density [kg/m^3]		2278,15	2278,15	2298,527	2298,527	2286,226	2298,362	2286,226	2293,475	2286,226	2293,475
air content [%]		-1,1	-1,0	1,8	1,4	4,2	3,4	7,0	6,0	7,3	7,4
	PRESSURE METHOD (9min)										
air content [%]		1,5	1,5	3,6	3,7	5,2	5	7,4	7	7,8	7,6

matriks volume [l]	330	No AEA and SP		3.5.1		3.5.2		3.5.3		3.5.4	
		14.03	14.03	18.03	18.03	10.03	18.03	10.03	16.03	10.03	16.03
		mix 1	mix 2	mix 4	mix 5	mix 3	mix 4	mix 1	mix 2	mix 1	mix 2
	SPECIMENS (12min)										
mass of specimen 1 [g]		591,1				559,5		545		543,7	
mass of specimen 2 [g]						554,1		553		543,2	
mass of specimen 3 [g]						562,4		553,8		546,9	
mass of spec 1 in the water [g]		333,8				304,9		290,3		291,4	
mass of spec 2 in the water [g]						302		294,9		290,5	
mass of spec 3 in the water [g]						306,4		295,5		293,1	
volume of specimen 1 [l]		0,257				0,255		0,255		0,252	
volume of specimen 2 [l]						0,252		0,258		0,253	
volume of specimen 3 [l]						0,256		0,258		0,254	
density of concrete - spec 1 [kg/m^3]		2297,32				2197,56		2139,77		2154,97	
density of concrete - spec 2 [kg/m^3]						2197,94		2142,58		2149,58	
density of concrete - spec 3 [kg/m^3]						2196,88		2144,02		2154,85	
measured volume of concrete [m^3]		0,97	0,97	0,99	0,99	1,00	1,00	1,02	1,02	1,03	1,03
	Correction of mass of part materials for air content [kg/m^3]:										
OPC		312,62	312,62	265,26	264,99	257,21	261,09	251,69	255,30	250,71	253,81
FA		133,96	133,96	113,68	113,57	110,23	111,91	107,87	109,40	107,45	108,76
Limestone		22,33	22,33	18,95	18,93	18,37	18,64	17,98	18,23	17,91	18,12
Aggregate		1702,59	1702,59	1666,33	1664,64	1639,72	1643,00	1604,49	1610,78	1598,25	1601,36
Water		230,76	230,76	196,43	196,23	195,93	193,41	191,72	191,04	190,97	189,93
AEA		0,00	0,00	2,67	2,67	2,59	2,59	2,53	2,54	2,52	2,53
SP		0,00	0,00	0,00	0,00	0,73	0,73	0,71	0,71	0,71	0,71
Density [kg/m^3] (ρconcrete')		2402,26	2402,26	2263,32	2261,03	2224,78	2231,36	2176,98	2188,01	2168,51	2175,22
	Correction of mass of part materials for density [kg/m^3]:										
ρconcrete,measure/ρconcrete'		0,959096	0,957931	0,997692	1,002817	0,984593	0,995266	0,976536	0,985141	0,976985	0,975995
OPC		289,34	288,99	260,94	262,28	253,76	259,85	251,68	256,54	251,80	254,16
FA		123,99	123,83	111,83	112,41	108,75	111,38	107,86	109,93	107,91	108,91
Limestone		20,66	20,64	18,64	18,73	18,13	18,55	17,98	18,31	17,99	18,14
Aggregate		1575,80	1573,88	1639,21	1647,63	1617,69	1635,22	1604,45	1618,59	1605,19	1603,56
Water		213,57	213,31	193,23	194,23	193,29	192,49	191,71	191,97	191,80	190,19
AEA		0,00	0,00	2,63	2,64	2,55	2,58	2,53	2,55	2,53	2,53
SP		0,00	0,00	0,00	0,00	0,72	0,72	0,71	0,72	0,71	0,71
Density [kg/m^3]		2223,36	2220,66	2226,49	2237,92	2194,88	2220,80	2176,92	2198,61	2177,92	2178,20

Table C3 Calculation for mixes with matrix volume 330l and AEA5

Table C4 shows calculations for PF test for mixes with matrix volume 400l both for AEA4 and AEA5

	Simplified procedure, PF:					Start date and time		Finish date and time			Specimens: halfs, ultrasonic bath treated, one side									
Step 1	7 days drying to constant mass					2016-05-03	14:45	2016-05-09	10:40											
Step 2	7 days water saturation (WS)					2016-05-09	13:00	2016-05-18	09:20											
Step	1 day in pressure tank (PT) under 50 bar					2016-05-18	10:05	2016-05-20	10:15											
	Specimen	AEA	Sequence code	Dimensions, mm			Tolerance on depth, mm	Volume measured V, m3	Weights, kg					Volume of specimen V, m^3	Dry density,	Solid density ρ_{fs}, kg/m^3	Suction porosity ρ_s	Macro porosity ρ_m	Total porosity ρ_t	PF, %
				Length	Width	Average depth			Weight before drying	Dry weight g_1	Weight in the air after WS, g_2	Weight in water after WS, g_3	Weight in the air after PT, g_4	$(g_2-g_3)/1000$	g_1/V	$g_1/(V-(g_4-g_1)/1000)$	$(g_2-g_1)/(V*1000)$	$(g_4-g_2)/(V*1000)$	$\rho_s+\rho_m$	$\rho_m/\rho_t*100\%$
	1	AEA 4	3.5.2	160	40	20,5	0,2	0,0001312	0,2911	0,2810	0,3024	0,1709	0,3078	0,0001315	2 136,9	2 683,9	0,163	**0,041**	0,204	0,201
	2	AEA 4	3.5.3	160	40	16,5	0,2	0,0001056	0,2218	0,2139	0,2314	0,1262	0,2393	0,0001052	2 033,3	2 680,5	0,166	**0,075**	0,241	0,311
	3	AEA 4	3.5.4	160	40	16,7	0,3	0,00010688	0,2059	0,1990	0,2161	0,1117	0,2292	0,0001044	1 906,1	2 681,9	0,164	**0,125**	0,289	0,434
	4	AEA 5	3.5.2	160	40	16,6	0,2	0,00010624	0,2339	0,2256	0,244	0,1379	0,2476	0,0001061	2 126,3	2 682,5	0,173	**0,034**	0,207	0,164
	5	AEA 5	3.5.3	160	40	16,6	0,2	0,00010624	0,2214	0,2115	0,2309	0,1251	0,2387	0,0001058	1 999,1	2 690,8	0,183	**0,074**	0,257	0,287
	6	AEA 5	3.5.4	160	40	16,4	0,3	0,00010496	0,2144	0,2062	0,2236	0,1205	0,2327	0,0001031	2 000,0	2 691,9	0,169	**0,088**	0,257	0,343
							Mass measured	Date Time	03.05.16 14:00	09.05.16 10:45	18.05.16 09:20	18.05.16 09:20	20.05.16 10:20							

Table C 4 PF test - calculation for specimens with matrix volume 400l

Appendix D – Photo documentation

Mixes with matrix volume of 330l and with Mapeair 25

Photo D 1 Sequence 3.5.1 - mix 5 – mixture

Photo D 2 Sequence 3.5.1 - mix 5 – slump

Photo D 3 Sequence 3.5.2 - mix 4 – mixture

Photo D 4 Sequence 3.5.2 - mix 4 – slump

Photo D 5 Sequence 3.5.3 - mix 2 – mixture

Photo D 6 Sequence 3.5.3 - mix 2 – slump

Photo D 7 Sequnece 3.5.4 - mix 2 – mixture

Photo D 8 Sequence 3.5.4 - mix 2 – slump

Mixes with matrix volume of 400l and with Mapeair 25

Photo D 9Sequence 3.5.1 - mix 2 – mixture

Photo D 10 Sequence 3.5.1 - mix 2 – slump

Photo D 11 Sequence 3.5.2 - mix 3 – mixture

Photo D 12 Sequence 3.5.2 - mix 3 – slump

Photo D 13 Sequence 3.5.2 - mix 3 - edge of the slump

Photo D 14 Sequence 3.5.3 - mix 4 – mixture

Photo D 15 Sequence 3.5.3 - mix 4 – slump

Photo D 16 Sequence 3.5.4 - mix 3 – mixture

Photo D 17 Sequence 3.5.4 - mix 3 – slump

Photo D 18 Sequence 3.5.4 - mix 3 - edge of the slump

Mixes with matrix volume of 400l and with Sika Multiair

Photo D 19 Sequence 3.5.1 - mix 1 – mixture

Photo D 20 Sequence 3.5.1 - mix 1 – slump

Photo D 21 Sequence 3.5.2 - mix 1 – mixture

Photo D 22 Sequence 3.5.2 - mix 1 - slump

Photo D 23 Sequence 3.5.2 - mix 1 - edge of the slump

Photo D 24 Sequence 3.5.3 - mix 1 – mixture

Photo D 25 Sequence 3.5.3 - mix 1 – slump

Photo D 26 Sequence 3.5.3 - mix 1 - edge of the slump

Photo D 27 Sequence 3.5.4 - mix 1 – mixture

Photo D 28 Sequence 3.5.4 - mix 1 – slump

Photo D 29 Sequence 3.5.4 - mix 1 - edge of the slump

Photos of the surface seen under the microscope

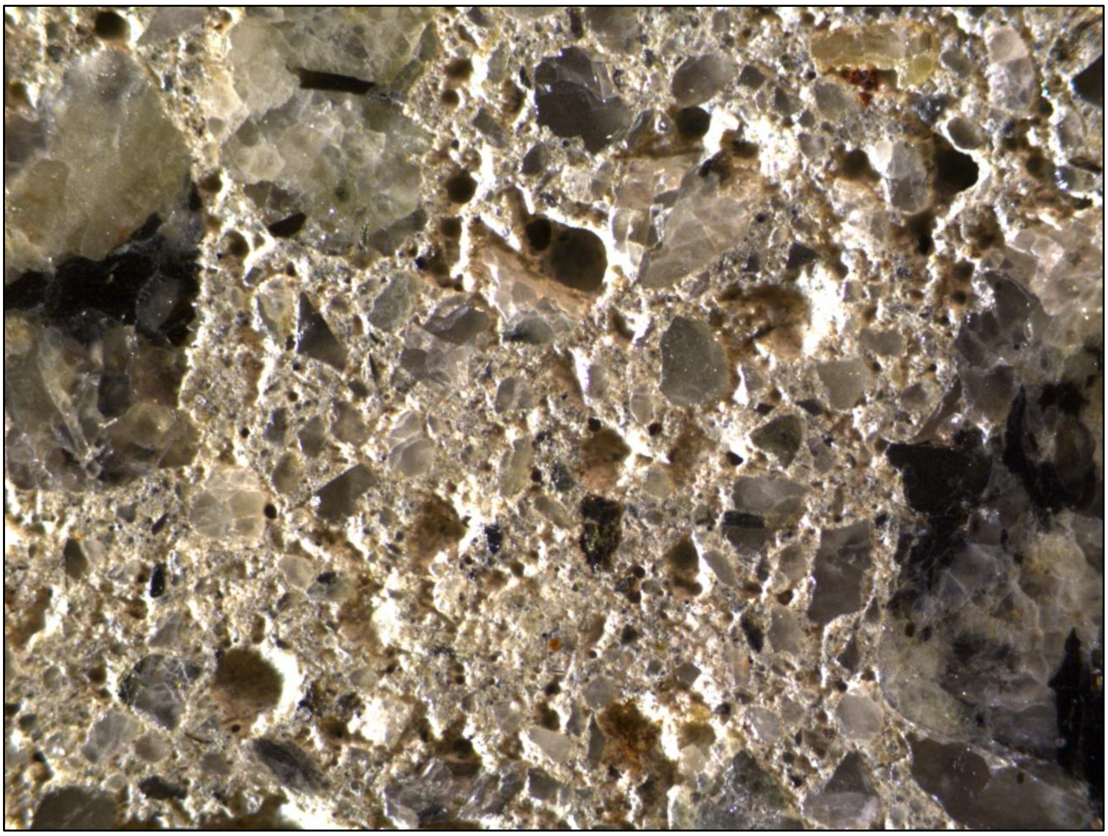

Photo D 30 Sequence 3.5.2 - AEA4 (surface after polishing with 4000µm Sand paper)

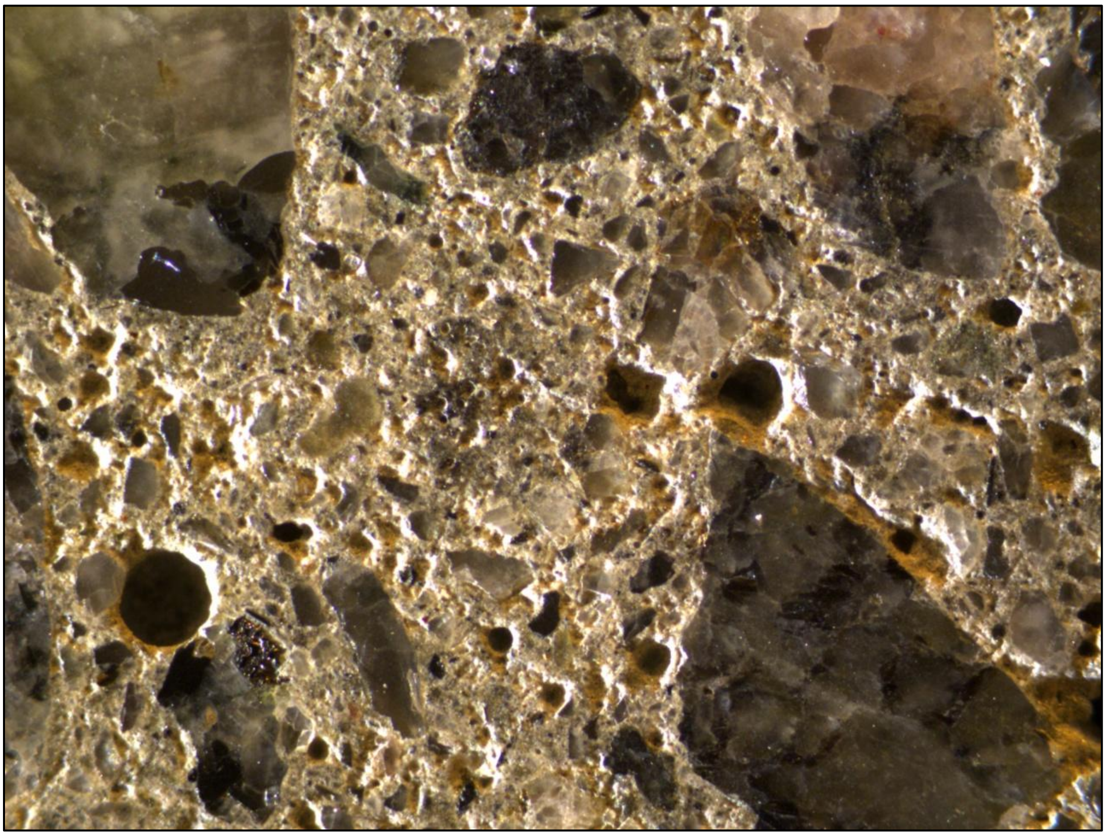

Photo D 31 Sequence 3.5.2 - AEA5 (surface after polishing with 4000µm Sand paper)

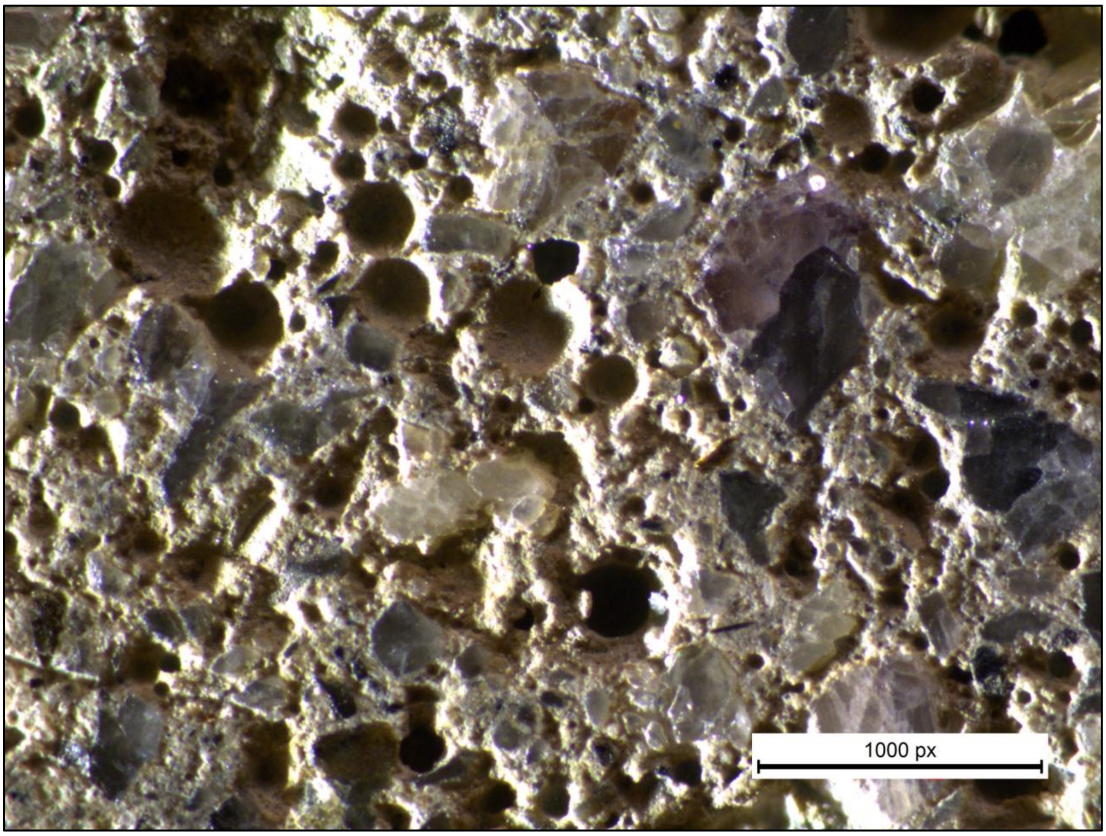

Photo D 32 Sequence 3.5.3 - AEA5 (surface after polishing with 4000µm Sand paper)