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## AIR ENTRAINED CONCRETE

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**Abstract:** The durability of concrete structures was a major topic since concrete was used for structural purposes. Air entrained concrete was discovered by chance in the mid 1930's during the construction jobs on American highways. Since then the knowledge in this field evolved so that guidelines are available for the design and production of air entrained concrete. The present article is an overview of the effect of air entraining agents, and the way they are used for the production of durable structural concrete.

**Key words:** Air Entrained Concrete, Air Entraining Agents

### 1. SUMMARY

Air entrained concrete is the most complex standard concrete. All internal components as well as all external factors have a major impact on the final results, while great care should be taken during design, handling and placing.

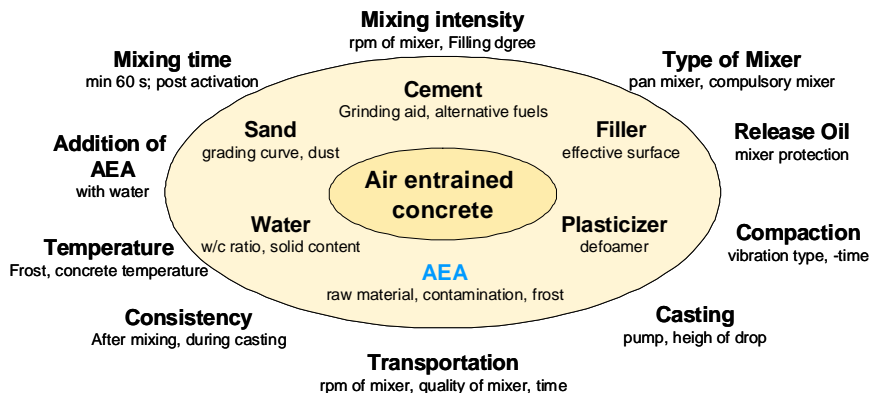


Fig. 1 Elements with an impact on the air entrained concrete

## 2. THE FREEZING MECHANISM INSIDE THE CONCRETE

Water will freeze inside concrete structures, exposed to subzero temperatures. While freezing the water increases his volume with 9 %, which will create an internal pressure in the concrete, which could damage the concrete surface and weaken the concrete matrix.

In winter deicing substances are used on traffic areas, to remove the snow and ice. The soluble salts (natrium chloride, calcium chloride) resulted during the deicing process will penetrate the concrete surface and will cause a sinking of the freezing point of the interstitial water.

The water inside the concrete with no chlorides will freeze at first, when temperatures will sink. Even lower temperatures will cause a freezing of the water that contains soluble salts, starting from the surface to the bottom. The volume increase of the two frozen layers can be absorbed by the nearby areas.

If temperatures will sink even further, the last layer of water located between the already frozen ones, will freeze. The pressures created by the volume increase of this layer can not be absorbed anymore from the surrounding areas, while cracks and exfoliation are imminent.

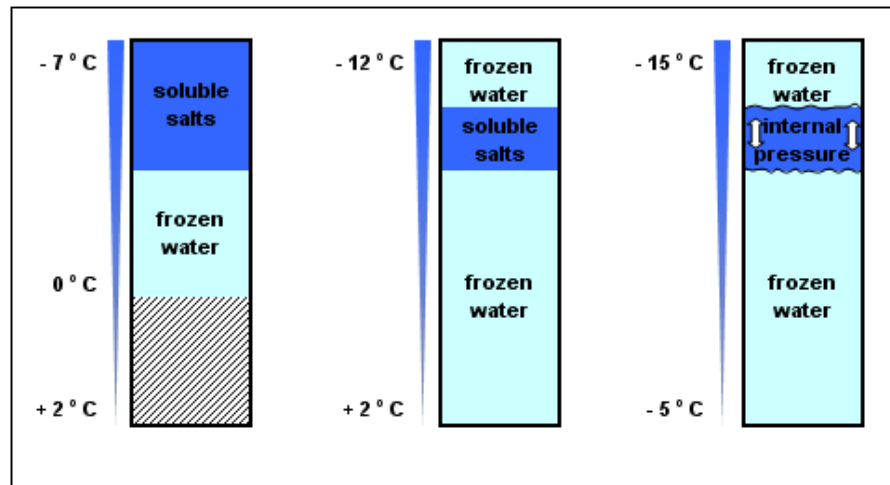


Fig. 2 Freezing of water and soluble salts inside the concrete

## 3. DESIGN AND CHARACTERISTICS OF AIR ENTRAINED CONCRETE

Air entrained concrete is designed according to SR EN 206-1, like any other concrete type, the only difference would be that a foaming agent is used to stabilize air bubbles introduced during the mixing process. Small volumes of foaming agent are required to reach the desired air volume, while small changes in the mix design could affect the final result.

The total amount of air mixed into the concrete should be taken in account during the design, by lowering the aggregates volume accordingly. A total volume of 3-6 % of air is typically entrained during the mixing into the concrete. Furthermore when designing air entrained concrete the strength loose due to the entrained air should be taken into consideration. For every percent of entrained air a strength loss of 1-2 MPa is expected.

To obtain high frost resistance, the cement matrix must contain about 15 % suitable air voids. It can be sad that there are enough effective air voids in a concrete if the results on the pressure meter test show the following air content:

- 3-5 % in a concrete with 32 mm maximum particle size
- 4-6 % in a concrete with 16 mm maximum particle size

The concrete should be produced in efficient mixing units, powerful enough to activate the foaming agent properly. This means that the concrete should be mixed until the air inside has the desired volume and also the needed quality. A mixing time of at least 90 seconds is required when producing air entrained concrete.

Air bubbles with a diameter lower than 300  $\mu\text{m}$ , placed at a distance lower than 200  $\mu\text{m}$  apart are needed to provide the desired freeze-thaw resistance.

Beside a proper air structure inside the concrete matrix durable aggregates and the proper cement (according to CP 012-2007) are the key factors to produce frost resistant concrete. Air entraining agents cannot help if the system is not proper. Weak, cracked or porous aggregates are not suited for frost resistant concrete.

According to CP 012-2007 following requirements need to be fulfilled if producing a frost resistant concrete:

Table 1 Requirements according to CP 012-2007

Exposure Class	Description of the environment	w/c; w/c <sub>equiv</sub>	Min. strength class	Min. cement dosage
XF	Freeze/thaw attack with or without de-icing slats	* air entraining agents will be used		
XF 1	Moderate water saturation, without de-icing agents	0,50	C25/30	300 kg/m <sup>3</sup>
XF 2	Moderate water saturation, with de-icing agents	* 0,55	C25/30	300 kg/m <sup>3</sup>
		0,50	C35/45	320 kg/m <sup>3</sup>
XF 3	High water saturation, without de-icing agents	* 0,55	C25/30	300 kg/m <sup>3</sup>
		0,50	C35/45	320 kg/m <sup>3</sup>
XF 4	High water saturation, with de-icing agents	* 0,50	C30/37	340 kg/m <sup>3</sup>

As already mentioned several factors will influence the air entrainment. The most important ones are:

- granulometry
- aggregates
- temperature
- delivery
- compaction

The air voids are mainly formed around the 0,25-0,5 mm sand fraction. Larger particles have no effect on the air entrainment. Ultrafines from the sand constituents or the cement and some admixtures can inhibit air entrainment.

The temperature of the fresh concrete will affect the air entrainment capability. If the temperature will raise the air entrainment capability will decrease and if the temperature will go down more air will be entrained with the same amount of foaming agent.

During delivery a change of the air content could be expected. Dependent on the method of delivery and vibration during the journey, mixing or demixing processes take place in the concrete. Air entrained concrete must be mixed again before installation and the critical air content is only then determined.

Correct vibration mainly removes the air entrapped during placing, including the coarse voids in the concrete. Pronounced over vibration can also reduce the entrained air by 10 to 30%. Concrete susceptible to segregation can then lose almost all of the air voids or exhibit foaming on the surface.

#### 4. WHY AIR IS NEEDED

Air is added into concrete for different reasons. It can be used for water reduction, segregation resistance, bleeding reducing and for freeze-thaw resistance.

Introduced into the concrete mix, air entraining agents develops during the mixing period a structure of artificial air in the concrete matrix. The small air bubbles act as gliding surfaces. Therefore the water volume can be reduced, while the air bubbles act also as stabilizer for the mix. Concrete mixes with lack of fines could be stabilized using air entraining agents. The most important application of micro air is to produce freeze-thaw resistant concrete. However concrete produced with improper aggregates will not develop freeze-thaw resistance, even if increasing the amount of entrained air. A change of aggregates will be the most suitable solution.

The air structure inside the concrete reduces the capillary water absorption, while providing a space where the interstitial water could expand when freezing.

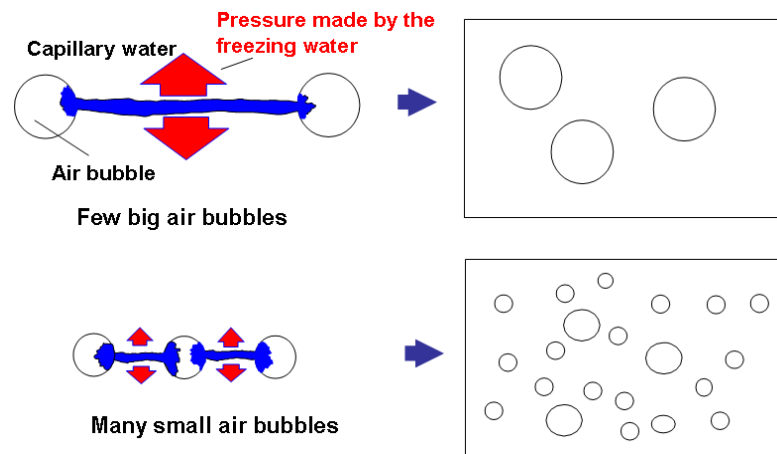


Fig. 3 The freezing phenomenon in concrete structure

Few big bubbles will provide less expansion possibilities, while many small bubbles will provide naturally more expansion alternatives. Also the probability that the air bubbles are full of water, when having a structure with many small bubbles, is low and the expansion pressures of freezing water is lower in small bubbles and not big enough to destroy the concrete matrix. Therefore many countries adopted requirements with regard to the amount and quality of the air entrained into the concrete matrix.

#### 5. HOW TO MEASURE THE ENTRAINED AIR

The air quality and volume can be measured on fresh and on hardened concrete, while the most used methods are the pressure meter and the air void analyzer.

On fresh concrete the air is measured using a pressure meter. The pot will be filled with concrete and compacted completely, to assure that only the artificial entrained air remains into the concrete mass. Pressure is applied to the sample to compress the entrained air in the pores. By balancing the pressure between the pressure chamber and the pot, the entrained air volume is measured. The entrained air is the only compressible element from the mix.

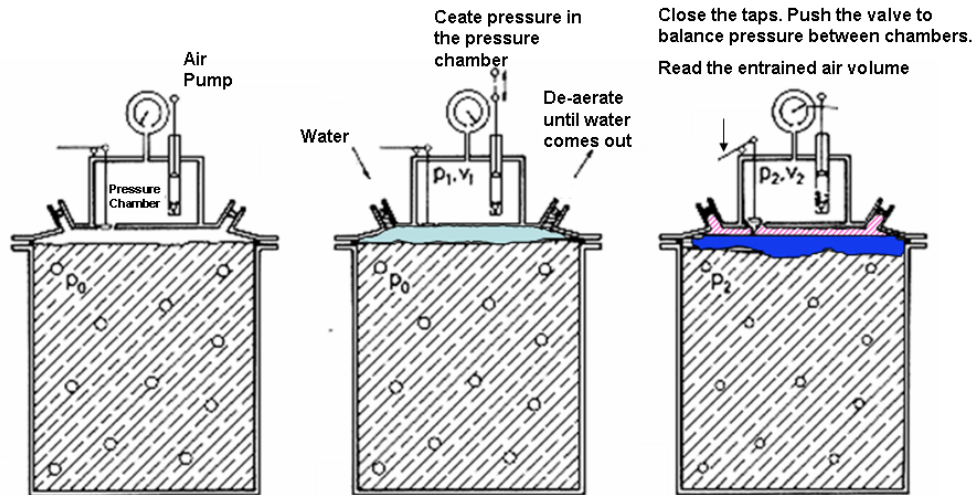


Fig. 4 Steps done to measure the entrained air volume

This type of measurement will provide just a quantitative and not a qualitative result. Only the total amount of air is measured, while no evaluation could be made with regard to the structure of the entrained air.

A proper qualitative analysis of the entrained air could be made on the hardened concrete using the air void analyzer. The structure of the air bubbles will be analyzed on a concrete sample cut from a 15 x 15 x 15 cm cube. Evaluation lines will be drawn on the polished concrete sample. The air bubbles and the spaces between them (spacing factor) will be measured along the drawn lines. The measurement will be done according to EN 480-11.

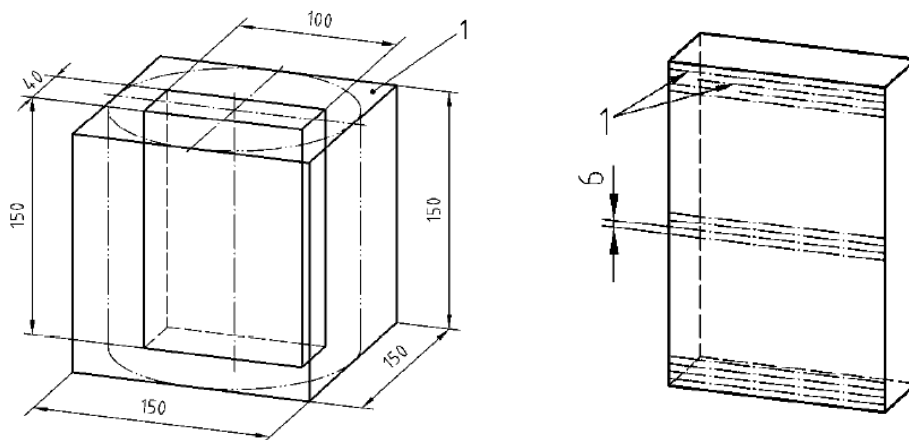


Fig. 5 Sample preparation for the air analysis

## 6. CONCLUSIONS

Air entrained concrete is one of the most demanding concrete types, due to all the factors that have an influence on the final result and the also for the tests that should be done, to assure the proper concrete quality.

Even so entrained micro air is an important factor to overcome shortcomings of the mix design while the most valuable application is to produce freeze-thaw resistant concrete. Micro air is an important component when durable exposed concrete structures are requested.

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