Air Content in Fresh Air-Entraining Cement Mortars

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Abstract. The durability of a cement composite is the most important criterion for assessing this material. However, due to the durability of the cement composite, its frost resistance is an important property. In order to ensure concrete frost resistance, the European standard PN-EN 206-1: 2013 requires its aeration at the level of 4 - 7%. The Committee 201 of the American Concrete Institute (ACI) also requires the use of an air-entraining admixture in concretes exposed to frost damage. The amount of air-entraining admixture is significantly influenced by the composition of the cement used. In order to minimize the problems with obtaining frost-resistant concrete, an attempt was made to create air-entraining cements. This article presents the effect of the amount and type of dosing of air-entraining admixtures (natural and synthetic) on the air content in fresh air-entraining cement mortars. The test cements used also differed in the production method: joint mixing of components and joint grinding of components. Based on the research, a lot of valuable information was obtained related to the influence of the preparation of air-entraining cements on the air content in the mortar, e.g. mortars with mixed cement with natural air-entraining admixture have a higher air content. The air content is higher in the cement co-ground with natural air-entraining admixture. A synthetic air entraining admixture added separately to mixed cements with silica fly ash and ground granulated blast furnace slag increases air entrainment in mortars. The synthetic air-entraining admixture added separately to co-milled cements causes an increase in air entrainment in the mortars, except for those containing cement with ground granular blast furnace slag.

1. Introduction
The idea of producing cements that aerate concrete is to spread the use of cements with additives (CEM II - CEM V). The use of cements with non-clinker components is important economically and environmentally important, as the production process emissions CO₂ and less Portland clinker is used in the production of these cements and waste from other industries is used. The problem, however, is the design of frost-resistant concrete using cements with additives. Among the more important material factors affecting the frost resistance of concrete include the type of cement. It is generally recommended to increase the dose of air-entraining admixture above the recommended one in cases where the cement has an increased specific surface area or has a low alkali content [1]. However, it is difficult to determine unequivocally the effect of cement type on the aeration stability of the mix and frost resistance of concrete due to the lack of structured research in this area. It may happen that a change of cement type, while maintaining all other technological and material parameters, may reduce the frost resistance of concrete [2], [3]. From the point of view of the final aeration effect, the type and quantity of mineral additives the type and amount of mineral additives contained in cements (CEM II, metallurgical cement CEM III and multi-component cement CEM V). Mineral additives induce favourable changes in the porosity structure of concrete, reducing the proportion of capillary pores and
increasing the amount of gel pores [4]. However, the effect of additives on the frost resistance of concrete is variable [5] and their quality results in a different demand for air-entraining agent dosage [6]. Therefore, the concept of using an air-entraining admixture already in the production of cement in order to achieve greater durability of the manufactured building elements, construction elements and erected buildings. How the aeration in cement slurry changes depending on the cement used, the air-entraining admixture and the dosage method is shown in the following sections using mortar tests as an example.

2. Experimental procedure
The tests were carried out on standard mortars using standard sand (1350 g), distilled water (225 g), air entraining cement (450 g) or base cement (450 g) together with an air-entraining admixture in powder form. Two air-entraining admixtures were used: synthetic (A) and natural (D). Seven cements differing in composition and production methods were used: joint mixing of components (m - mixed) and joint grinding of components (w - co-milled). The chemical compositions and types of cements studied are given in table 1 and table 2. The amount of air-entraining admixture included in the air-entraining cements has been determined experimentally so that the concrete produced will be aerated according to standard 206-1 in an amount between 4 - 7% [7]. Each air-entraining cement had a separately fixed admixture dose.

| Table 1. Chemical compositions of cement. |
|------------------------------------------|
| SiO₂ | Al₂O₃ | Fe₂O₃ | CaO | SO₃ | Na₂O | MgO | K₂O | LOI |
| Clinker in co-milled cements | 21.95 | 4.70 | 3.14 | 66.60 | 0.42 | 0.24 | 1.20 | 0.62 | 0.15 |
| Clinker in mixed cements | 20.80 | 5.18 | 2.94 | 63.90 | 4.61 | 0.12 | 1.38 | 0.73 | 0.64 |
| Clinker in mixed CEM I | 20.30 | 5.27 | 2.52 | 63.50 | 2.67 | 0.13 | 1.46 | 0.76 | 2.72 |
| Granulated slag | 38.24 | 5.99 | 1.01 | 44.99 | 0.88 | 0.51 | 6.52 | 0.56 | 0.40 |
| Silica fly ash | 54.20 | 26.81 | 5.62 | 3.03 | 0.34 | 0.61 | 0.82 | 2.92 | 2.26 |

Standard mortars were made according to the PN-EN 196-1:2006 standard - Methods for testing cement. Part 1: Determination of strength [8]. The mixer and mixer bowl were moistened before mortar production. In mortars with the air-entraining admixture which was separately added, it was dosed to the mixing bowl along with the cement. After mixing the ingredients, the air content of the fresh mortar was checked. Testing the air content was performed using the pressure method according to PN-EN 1015-7:2000 [9]. The test was carried out in an apparatus with a volume of 0.75 l. Fresh mortar was placed in the container in three layers, each layer was compacted with ten shocks.

3. Results and discussions
The results of testing the air content of mortars made from air-entraining cements and from cements with an air entraining admixture added separately are shown in figures 1-7.

Air entraining admixture type A and D in mortars containing mixed cement. Mortars with mixed cements CEM I, CEM II/B-S, CEM V/B(S-V) and air entraining admixture D have a higher air content than mortars containing admixture A. The air content increased by 0.5% and 1.0%. Characteristically, the above values were recorded for mortar with Portland cement and for two mortars with cements containing ground granulated blast furnace slag in the amounts of 33% and 44%. In mortars with cements containing silica fly ash (CEM II/B-V, CEM V/A(S-V)), there is no difference in air content when admixture A and D is used. Also in mortars with metallurgical cement
CEM III/A there is the same air content. Only in mortar with CEM III/A-NA cement with the air entraining admixture D is the air content lower by 1.5%.

Air entraining admixture type A and D in mortars containing co-ground cement. In mortars with co-blended cements (CEM I, CEM II/B-V and CEM III/A-NA), the air content is the same regardless of the air entraining admixture used. However, in mortars with Portland multicomponent cements, the air content is higher when admixture D is used. The increase in air content ranges from 0.5% to 1.5%. In contrast, in mortars with CEM III/A and CEM II/B-S cements with D admixture, the air content is lower by 0.5%.

### Table 2. List of innovative air-entraining cements for concrete and type of air-entraining admixture.

| Air-entraining cement symbol | Method of manufacture: co-mixed (m) / co-milled (w) | Typ of air-entraining admixture: A (synthetic)/ D (natural) | Symbol of cement with separately addend air-entraining admixture |
|------------------------------|-----------------------------------------------------|----------------------------------------------------------|---------------------------------------------------------------|
| CEM I A m                    | m                                                   | A                                                        | CEM I m + A                                                   |
| CEM I D m                    | m                                                   | D                                                        | CEM I m + D                                                   |
| CEM I A w                    | w                                                   | A                                                        | CEM I w + A                                                   |
| CEM I D w                    | w                                                   | D                                                        | CEM I w + D                                                   |
| CEM II/B-V A m               | m                                                   | A                                                        | CEM II/B-V m + A                                              |
| CEM II/B-V D m               | m                                                   | D                                                        | CEM II/B-V m + D                                              |
| CEM II/B-V A w               | w                                                   | A                                                        | CEM II/B-V w + A                                              |
| CEM II/B-V D w               | w                                                   | D                                                        | CEM II/B-V w + D                                              |
| CEM II/B-S A m               | m                                                   | A                                                        | CEM II/B-S m + A                                              |
| CEM II/B-S D m               | m                                                   | D                                                        | CEM II/B-S m + D                                              |
| CEM II/B-S A w               | w                                                   | A                                                        | CEM II/B-S w + A                                              |
| CEM II/B-S D w               | w                                                   | D                                                        | CEM II/B-S w + D                                              |
| CEM III/A A m                | m                                                   | A                                                        | CEM III/A m + A                                               |
| CEM III/A D m                | m                                                   | D                                                        | CEM III/A m + D                                               |
| CEM III/A A w                | w                                                   | A                                                        | CEM III/A w + A                                               |
| CEM III/A D w                | w                                                   | D                                                        | CEM III/A w + D                                               |
| CEM III/A-NA A m             | m                                                   | A                                                        | CEM III/A-NA m + A                                            |
| CEM III/A-NA D m             | m                                                   | D                                                        | CEM III/A-NA m + D                                            |
| CEM III/A-NA A w             | w                                                   | A                                                        | CEM III/A-NA w + A                                            |
| CEM III/A-NA D w             | w                                                   | D                                                        | CEM III/A-NA w + D                                            |
| CEM V/A (S-V) A m            | m                                                   | A                                                        | CEM V/A (S-V) m + A                                           |
| CEM V/A (S-V) D m            | m                                                   | D                                                        | CEM V/A (S-V) m + D                                           |
| CEM V/A (S-V) A w            | w                                                   | A                                                        | CEM V/A (S-V) w + A                                           |
| CEM V/A (S-V) D w            | w                                                   | D                                                        | CEM V/A (S-V) w + D                                           |
| CEM V/B (S-V) A m            | m                                                   | A                                                        | CEM V/B (S-V) m + A                                           |
| CEM V/B (S-V) D m            | m                                                   | D                                                        | CEM V/B (S-V) m + D                                           |
| CEM V/B (S-V) A w            | w                                                   | A                                                        | CEM V/B (S-V) w + A                                           |
| CEM V/B (S-V) D w            | w                                                   | D                                                        | CEM V/B (S-V) w + D                                           |
Figure 1. Air content in mortars with air-entraining cement CEM I.

Figure 2. Air content in mortars with air-entraining cement CEM II/B-V.

Figure 3. Air content in mortars with air-entraining cement CEM II/B-S.
Figure 4. Air content in mortars with air-entraining cement CEM III/A.

Figure 5. Air content in mortars with air-entraining cement CEM III/A-NA.

Figure 6. Air content in mortars with air-entraining cement CEM V/A(S-V).
**Figure 7.** Air content in mortars with air-entraining cement CEM V/B(S-V).

Air entraining admixture A and D together and separately in mortars containing mixed cement. In mortars with blended cements containing silica fly ash, the air content with D and A admixtures added separately increases, except for CEM V/A(S-V) cement with A admixture. The differences in air content for mortars with admixture D are in the range of 0.5% to 2.5%, while for mortars with admixture A the differences are in the range of 0.5% to 1.5%. In the other mortars with A added separately, the air compactness did not change. In mortars with admixture D, on the other hand, the air content decreased by 0.5% and 1.0% with the exception of mortar with CEM III/A cement (increase of 0.5%).

Air entraining admixture A and D together and separately in mortars containing co-ground cement. Mortars with ground cement and admixture D added separately have a higher air content than those in which was the air entraining cement. The differences range from 0.5% to 3.0%. Most mortars with ground cement and admixture A added separately also show a higher air content than mortars from air entraining cements with admixture A. The differences in air content range from 0.5% to 3.0%. The exception here is mortars with metallurgical cements, in which the amount of air is the same regardless of the dosage method.

Air entraining admixture A in mortars containing mixed cement and co-ground cement. Four mortars with cements ground together with admixture A showed an increase in air content in the range of 1.0% to 1.5%, while three mortars showed a decrease in air content in the range of 0.5% to 1.0%. Based on the mortar tests carried out, it is difficult to determine the effect of air content depending on the composition of the cements.

Air entraining admixture D in mortars containing mixed cement and co-ground cement. Mortars with co-ground cements with aerating admixture D generally had a higher air content than mortars with blended cements with aerating admixture D. In mortars with co-ground cements, the air content increased by 1.0% and 1.5%. The exceptions are CEM II (B-V) cements (there was less air in the co-milled cement by 0.5%) and CEM V/B(S-V) (the same amount of air).

**4. Conclusions**

Based on the research conducted, it can be concluded that no single dose of the same air-entraining admixture can be determined for different types of cements to aerate concrete. Each cement, due to differences in composition, required a different amount of air-entraining admixture.
Also, a different dosage of air-entraining admixture had to be used due to the production method: cement mixed with air-entraining admixture and cement co-milled with air-entraining admixture.

In general, it can be stated that mortars with an air-entraining co-ground cement had a higher air content than mortars with an air-entraining mixed cement.

The air content of mortars with the air-entraining admixture added separately also showed a higher air content in most cases compared to mortars made of air-entraining cements.

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