ADDITIONS FOR CONCRETE ACCORDING TO EUROPEAN STANDARD EN-206

Cz. Wolska-Kotańska
Building Research Institute, Poland

1. Introduction

   European Standard EN-206 “Concrete- Part 1: Specification, performance, production and conformity” was established in 2000, after many years of discussion and amendments. EN-206 will be applied in Europe under different climatic and geographical conditions, different levels of protection and under different regional traditions and experience. For this reason, classes for concrete properties are introduced to cover this situation. Where such general solutions are not sufficient, the relevant clauses contain permission for application of national standards or provisions valid in place of use of concrete.

   EN 206 –1 specifies constituent materials to be used for concrete (i.e. cement, aggregates, additions, admixtures and mixing water) and is operable with product standards for these materials and related test methods for concrete. This product standards and test methods standards are under preparation by CEN, and they not all will be available as Europeans standards at the date of publication of EN 206. For this reason, the latest data of withdrawal of national standards conflicting with this standard will be the date when all standards for constituent materials, together with related standards for test methods are available and implemented as European standards or ISO standards, where appropriate, or have the status required by this standard.

   Constituent materials shall not contain harmful ingredients in such quantities as may be detrimental to the durability of concrete or cause corrosion of reinforcement and shall be suitable for intended use in concrete. Only constituents with established suitability for the specified application shall be used in concrete conforming to EN 206-1.

2. Additions for concrete

   EN-206-1 defines additions as finely divided materials used in concrete in order to improve certain properties or to achieved special properties. This standard deals with two types of inorganic additions:

   - type I - nearly inert additions,
   - type II – pozzolanic or latent hydraulic additions.

   General suitability as type I addition is established for:

   - filler aggregate conforming to prEN 12620:1996,
   - pigments conforming to EN 12878.

   General suitability as type II addition is established for:

   - fly ash conforming of EN 450,
   - silica fume conforming to prEN 13263: 1998.

   This paper describes the additions of type II with special consideration to their physical and chemical properties, determined in relevant European standards.

   Fly ash is obtained by electrostatic or mechanic precipitation of dust – like particles from the fuel gasses of furnaces fired with pulverized anthracite or bituminous coal. Fly ash is a fine powder of mainly spherical, glassy particles, which has pozzolanic properties and consists essentially of SiO2 and Al2O3 with the content of reactive SiO2 at least 25 % by mass. It should be noted, when using fly ash, that apart from beneficial pozzolanic action, also other properties of fresh and hardened concrete may be affected. In particular the water requirement (lower or higher), setting time (normally increased) and the early strength (relative reduction).

   Silica fume (SF) is relatively new material consisted of spherical particles of amorphous silicon dioxide smaller than 10^{-6} m, with an average diameter of about 0.1 µm, collected as a by-product of metallurgical process.
used to produce silicon metal and ferro-silicon alloys. Silica fume can be supplied as collected from the filters, and after treatment to increase its bulk density, or as a slurry, typically with a dry content of 50% by mass.

Its specific surface is on the order 20000 m$^2$/kg. Due to such extreme fineness and high content of amorphous silicon dioxide silica fume is more effective pozzolanic material than fly ash. Incorporation of silica fume to Portland cement contributes to the hydration process by providing nucleation sites for Ca(OH)$_2$ and by reacting with calcium hydroxide to form calcium silicate hydrates (CSH).

Its influence on the concrete properties caused by physical and pozzolanic actions results in modification of concrete microstructure, particular within transition zone between cement paste and aggregate particles. It leads to strengthening of this weak region, reducing capillary pores, and thus improves of concrete properties [1,2,3,4].

Many years of research and practical experience have demonstrated that silica fume can be used to produce concrete with improved properties in both fresh and hardened states. This addition is used for the production of new generation of concrete: high and very high-strength concrete, as well as high performance concrete. It is also very effective in case when concrete is subjected to aggressive environment and in case of negative alkali-aggregate problems.

Silica fume is normally used in combination with plasticizer and/or superplasticizer. Other names used for silica fume are: condensed silica fume and microsilica.

3. Requirements concerning the properties of type II additions in European Standards

Chemical and physical requirements for fly ash and silica fume to be used in concrete are specified in EN 450 and prEN 13263 respectively. They are established as characteristic values (upper or lower values). Compliance with a characteristic value is assessed by means of statistical control procedure. The test methods given in these two standards are reference methods. Other methods may be used if a relationship between the results obtained by means of reference method and those of alternative method has been established.

The chemical composition shall be expressed as proportions by mass of sample dried in a well-ventilated oven at $(105 \pm 5)$° C to constant mass and then cooled in dry atmosphere. Table 1 presents chemical properties to be tested and the requirements established in relevant standards for fly ash and silica fume. Because of the nature of these two additions, the requirements for chemical properties for fly ash and silica fume are different. The most difference may be observed in the amount of silicon dioxide. The content of silicon dioxide in silica fume shall not be less than 85%, while in fly ash the reactive SiO$_2$ shall not be less than 25%. In addition to chemical requirements specified in Table 1, the total content of alkalies determined by method described in EN 196-21 and calculated as Na$_2$O equivalent shall be supplied to the purchaser upon request.

Requirements concerning physical and strength properties for fly ash and silica fume as the type II additions for concrete together with the test methods are presented in Table 2. Physical properties and the methods used for their determination are also different in case of those two additions. Silica fume as a very fine powder needs determination of specific surface by nitrogen absorption method (BET), while in case of fly ash, the sieve method is sufficient. Soundness and density are tested only in fly ash, and dry mass is tested only in case of silica fume slurry.

Differences between chemical and physical properties of these two additions are demonstrated in the requirement concerning their activity index, which is the ratio of compressive strength of standard mortars bars prepared with reference cement plus 25% of fly ash or 10% of silica fume (by replacement) to the compressive strength of standard mortar bars prepared with 100% reference cement, when tested at the same age. Mortars with 10% cement replacement by silica fume shall have the same 28 days strength as the mortars made with reference cement.

In case of fly ash, mortars with 25% cement replacement shall have only 75% of reference mortars strength at the age of 28 days and 85% - at the age of 90 days.
Table 1. Chemical properties of type II additions for concrete

<table>
<thead>
<tr>
<th>Property</th>
<th>Requirements</th>
<th>Test method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fly ash according EN 450</td>
<td>Silica fume according pr EN 13263 - 1</td>
<td>EN 196-2</td>
</tr>
<tr>
<td>Loss on ignition, % not greater than</td>
<td>5,0</td>
<td></td>
</tr>
<tr>
<td>Silicon dioxide, % not less than</td>
<td>25,0 (reactive)</td>
<td>EN 197-1, EN 196-2</td>
</tr>
<tr>
<td>Chloride content, % not greater than</td>
<td>0,1</td>
<td>EN 196-21</td>
</tr>
<tr>
<td>Sulphuric anhydride, % not greater than</td>
<td>3,0</td>
<td>EN 196-2</td>
</tr>
<tr>
<td>Free silicon, % not greater than</td>
<td>-</td>
<td>ISO 9286</td>
</tr>
<tr>
<td>Free calcium oxide, % not greater than</td>
<td>1,0</td>
<td>EN 451-1</td>
</tr>
</tbody>
</table>

Table 2. Physical and strength properties of type II additions for concrete

<table>
<thead>
<tr>
<th>Property</th>
<th>Requirements</th>
<th>Test method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fly ash according EN 450</td>
<td>Silica fume according pr EN 13263 - 1</td>
<td>EN 450</td>
</tr>
<tr>
<td>Specific surface, m²/kg, not less than</td>
<td>-</td>
<td>ISO 9277</td>
</tr>
<tr>
<td>Residue on a 0,045 mm sieve, % not greater than</td>
<td>40</td>
<td>EN 451-2</td>
</tr>
<tr>
<td>Soundness, mm, not greater than</td>
<td>10 mm</td>
<td>EN 196-3</td>
</tr>
<tr>
<td>Activity index *, %</td>
<td>(25 % of cement replacement by fly ash)</td>
<td>EN 450</td>
</tr>
<tr>
<td>28 days compressive strength</td>
<td>not less than 75</td>
<td>prEN 13263-1</td>
</tr>
<tr>
<td>90 days compressive strength</td>
<td>not less than 85</td>
<td></td>
</tr>
<tr>
<td>Dry mass content in, % slurry</td>
<td>-</td>
<td>prEN 13263-1</td>
</tr>
<tr>
<td>Density, kg/m³, not greater than</td>
<td>± 150 from the declared value</td>
<td>EN 196-6</td>
</tr>
</tbody>
</table>

* Reference cement – type CEM I, strength class 42,5, conforming to EN 197-1
4. Rules for use of type II additions in concrete

European standards EN 450 - concerning the requirement for fly ash, and pr EN 13263 – concerning silica fume do not give the rules for the use of these additions in concrete. Such general rules are given in EN 206-1, or in national standards for concrete.

The quantities of type II additions to be used in concrete shall be covered by the initial tests, which establish concrete that satisfies all specified requirements for fresh and hardened concrete. Where the producer or specifier can demonstrate an adequate design, based on data from previous tests or long-term experience, this may be considered as alternative to initial tests. Initial tests shall be the responsibility of the producer for the designed concrete, the specifier for prescribed concrete and standardisation body for standardised prescribed concrete. The initial tests shall be repeated if there has been a significant change either in constituent materials or in the specified requirements on which the previous tests were based.

For assessing the properties of concrete, in particular those of fresh concrete, the differences between the type of mixer and mixing procedure applied during the initial tests and those applied during actual production shall be taken into account.

Type II additions conforming to EN 450 and prEN 13263 may be taken into account in concrete composition with respect to the cement content and the water/ cement ratio. For fly ash and silica fume the suitability of k-value concept was established. The k-value permits type II additions to be taken into account:

- by replacing the term “water/cement ratio” with “water/ (cement + k x addition) ratio”,
- in the minimum cement content requirement.

The actual value k depends on specific addition.

4.1 K-value concept for fly ash

EN 206-1 describes the application of k-value concept for fly ash conforming to EN 450 together with cement type CEM I conforming to EN 197-1. K-value concept may be applied to fly ash with other types of cement if their suitability is established.

The maximum amount of fly ash to be taken into account for the k-value concept shall meet the requirement:

fly ash/ cement ≤ 0.33 by mass.

If a greater amount of fly ash is used, the excess shall not be taken into account for the calculation of the water/ (cement + k x addition) ratio, and minimum cement content.

The following k-values are permitted for concrete containing cement CEM I:

<table>
<thead>
<tr>
<th>Cement Type</th>
<th>k</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEM I 32,5</td>
<td>0.2</td>
</tr>
<tr>
<td>CEM I 42,5 and higher</td>
<td>0.4</td>
</tr>
</tbody>
</table>

The minimum cement content required for relevant exposure class (EN 206 specifies 18 exposure classes) may be reduced by a maximum amount of $k \times (\text{minimum cement content} - 200) \text{ kg/m}^3$ and the amount of (cement + fly ash) shall not be less than the minimum cement content required.

The k-value concept is not recommended for concrete containing a combination of fly ash and sulphate resisting cement in case of exposure classes, when the aggressive substance is sulphate.

4.2 K-value concept for silica fume

The maximum amount of silica fume to be taken into account for water/ cement ratio and cement content shall meet the requirement:

silica fume/ cement ≤ 0.11 by mass.

If greater amount of silica is used, the excess shall not be taken into account for k-value concept.

The following k-values are permitted to be applied for concrete containing cement CEM I conforming to EN 197-1:

- for specified water/ cement ratio ≤ 0,45  $k = 2,0$
- for specified water/ cement ratio > 0,45  $k = 2,0$

expect for exposure classes when concrete is subjected to carbonation and frost attack where $k = 1,0$.

The amount of (cement + k x silica fume) shall be not less than the minimum cement content required for the relevant exposure class. The minimum cement content shall not be reduced by more than 30 kg/m$^3$ in concrete for use in exposure classes for which the minimum cement content is ≤ 300 kg/m$^3$. 
5. Application of silica fume in concrete

Application of fly ash in concrete is commonly known and has a long tradition. It is always incorporated into concrete for economical reason, and for reduction of heat of hydration in massive concrete structures, as well as for improving of concrete resistance.

In recent years, many countries have become increasingly involved in research and application aimed at the use of silica fume as a possible partial replacement of Portland cement. The common availability of high-range water reducing admixture has opened a new possibilities for application of silica fume to produce high-strength and high performance, durable concrete. Silica fume, due to its properties, is the necessary addition for the production of these new generation of concrete.

In Building Research Institute in Warsaw the investigations on applicability of silica fume in concrete have been developed in eighties. They gave us an opportunity to know the advantages coming from incorporation of silica fume into concrete mixture. Some of these results were presented on the 5th Conference “Modern Building Materials, Structures and Techniques” in Vilnius – 1997 [5,6]. It was demonstrated that partial cement replacement by silica fume results in increasing of concrete strength, and decreasing of its water and chloride permeability.

In our further research a special attention was involved in the influence of silica fume on the resistance of concrete in aggressive environments, and its resistance to frost [7]. Fig 1. presents the results received during the tests performed in leaching environment.

The samples of mortars containing 0, 5, 10 and 15 % SF were subjected to the action of demineralised water during the period of one year. Then the amount of calcium hydroxide was determined in 0.5 cm outer layer of sample and in 0.5 cm inner layer (inside the sample), by means of thermal analysis. In mortars without silica fume, decreasing of the amount of calcium hydroxide in outer layer in relation to inner layer was 4.11 %. It means that leaching corrosion in this case was intensive.

In mortars containing 5 % SF, the difference between the amount of Ca(OH)$_2$ in inner and outer layer was only 0.63 %. Incorporation of 5 % SF caused significant (more than 6 times) decreasing of lime leaching from the surface of mortar samples. Increasing the amount of silica fume in mortars to 10 and 15 % did not cause further essential changes. It shall be concluded that silica fume is effective addition to concrete subjected to such environment, and 5 % SF, increasing the tightness of concrete, successfully protects its surface against leaching of Ca(OH)$_2$.

The other tests carried out in the environment of 5 % MgSO$_4$ indicated 5.55 % decreasing of the amount of calcium hydroxide in outer layer in relation to inner layer, in mortars without silica fume. In mortars with 5, 10 and 15 % SF the difference decreased and was 2.46; 1.23; and 0.62 % - respectively. In magnesium sulphate medium effectiveness of silica fume protection against corrosion increases with the increase of addition amount in mortar.

The influence of silica fume on concrete resistance to cycles of freezing and thawing was carried out by accelerating method, where only one surface of sample is subjected to the frost action.

Fig 1. Influence of SF on the amount of Ca(OH)$_2$ in mortars subjected to leaching environment.

![Fig 1](image1.png)

Fig 2. Changes of volume in concrete containing 0, 10 and 15 % SF, subjected to freezing and thawing cycles.

![Fig 2](image2.png)
The main criterion of durability in this method is the rate of external destruction and loss of sample volume. Fig. 2. presents the volume changes of concrete subjected to 300 freezing and thawing cycles.

The loss of volume of each sample was calculated from the expression:

$$\Delta V = \frac{V_p - V_k}{A}$$

where $V_p$ and $V_k$ are the initial and final volume respectively, cm$^3$; $A$ is the sample cross-section area before test, cm$^2$.

It was found that loss of volume in case of concrete without silica fume was nearly 8 times bigger than in concrete incorporating 10 % SF. Increasing the amount of SF to 15 % did not cause the further essential improvement of concrete frost resistance.

By analogy to the earlier related test results it may be assumed that even 5 % of SF would be able markedly improve of concrete resistance to freezing and thawing cycles.

All investigations performed in ITB indicated the beneficial influence of SF on concrete mechanical properties and on its durability. For this reason silica fume is desirable addition for concrete, and is particularly used in the production of special concrete with high strength properties, in alkali-aggregate problems in concrete, as well as in case of concrete subjected to the action of aggressive environments [5,6,7,8].

Conclusions
- EN-206 specifies two types of additions for concrete: type I – inert materials, and type II – pozzolanic or latent hydraulic materials.
- As a type II addition EN-206 specifies fly ash and silica fume.
- Requirements for physical and chemical properties of fly ash and silica fume are established in EN 450 and prEN 13263 respectively.
- EN 206 gives the general rules for use of type II additions in concrete ($k$ – value concept).
- Investigations carried out in ITB have proved the beneficial influence of silica fume on concrete strength and durability.

Reference

ILTeka 2001 02 15

Czesława Wolska-Kotańska. D.Sc. Building Research Institute (ITB) in Poland, Department of Concrete, Head of Division for Testing Materials. Author and co-author of a number of research and scientific projects and 80 research publications. Main present research interest: application of silica fume in concrete, high performance concrete, alkali- silica reactions in concrete.