PD CEN/TR 16639:2014

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Use of k-value concept, equivalent concrete performance concept and equivalent performance of combinations concept

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National foreword

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The UK participation in its preparation was entrusted by Technical Committee B/517, Concrete, to Subcommittee B/517/1, Concrete production and testing.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Published by BSI Standards Limited 2014

ISBN 978 0 580 83192 8
ICS 91.100.30

Compliance with a British Standard cannot confer immunity from legal obligations.

This Published Document was published under the authority of the Standards Policy and Strategy Committee on 30 April 2014.

Amendments/corrigenda issued since publication

Date	Text affected

TECHNICAL REPORT
RAPPORT TECHNIQUE
TECHNISCHER BERICHT

CEN/TR 16639

March 2014

ICS 91.100.30

English Version

Use of k-value concept, equivalent concrete performance concept and equivalent performance of combinations concept

Utilisation du concept de coefficient k, concept d'équivalence de performance et concept d'équivalence de performance en combinaison

k-Wert-Ansatz, Prinzipien des Konzepts der gleichwertigen Betonleistungsfähigkeit und Konzept der gleichwertigen Leistungsfähigkeit von Kombinationen aus Zement und Zusatzstoff

This Technical Report was approved by CEN on 26 November 2013. It has been drawn up by the Technical Committee CEN/TC 104.

EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

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Ref. No. CEN/TR 16639:2014 E

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Foreword

This document (CEN/TR 16639:2014) has been prepared by Technical Committee CEN/TC 104 “Concrete and related products”, the secretariat of which is held by DIN.

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0 Introduction

0.1 General

This report outlines the current understanding of the use and application of three concepts used within EN 206:2013 for Type II additions to concrete. These are the k-value concept, the Equivalent Concrete Performance Concept (ECPC) and Equivalent Performance of Combinations Concept (EPCC).

Within 5.2.5 of EN 206:2013 k-values are given for fly ash and silica fume and a recommended k-value for GGBS as well as general principles for the ECPC and the EPCC concepts. It is also stated in EN 206:2013 that modifications to the rules of application of the k-value concept are permitted if ‘suitability is established’. As stated within EN 206:2013 the establishment of suitability should result from provisions valid in the place of use of the concrete. In order to further explain the three concepts and to give guidance to the regulation writers and users of these concepts, this report provides background information and an overview of these concepts and rules of application as used within Europe.

0.2 Task Group 5

CEN/TC 104/SC 1 created Task Group 5 (TG 5) “Use of Additions” and assigned them the task to update EN 206-1:2000, 5.2.5 as part of the revision of EN 206-1. Because of the publication of product standard EN 15167-1 for ground granulated blastfurnace slag (GGBS), TG 5 was also asked to include rules for GGBS. CEN/TC 104/SC 1 passed various resolutions instructing TG 5 that it should implement the EPCC and ECPC concepts and the existing k-value concept for use of additions at the concrete mixer.

The rules for the use of type II additions in concrete according to EN 206:2013 are given in 5.2.5 “Use of additions”. For two additions, fly ash and silica fume, specific requirements for their use with k-values are given. In this prescriptive k-value concept for concrete mix design, the defined rules are on the safe side and cover all possible variations for the possible permutations of cement and addition. An alternative option is the use of ECPC and EPCC concepts. Their principles are described in EN 206:2013, 5.2.5.3 and 5.2.5.4 while examples for the assessment using these concepts are given in this CEN/TR. The rules for these performance concepts should also be safe and lead to a more efficient use of additions.

0.3 *k*-value concept

With respect to the k-value concept in EN 206:2013, it was agreed that for fly ash and silica fume prescriptive k-values and cement substitution rates will be given which are proven to be on the safe side. Although the k-value concept for GGBS is included in some national regulations (see /2/) only a recommended value is given in EN 206:2013 due to limited practical experience. In national provisions, however, modifications to the rules of the k-value concept may be applied where their suitability has been established, e.g. higher k-values, increased proportions of additions, other additions (including type I), combinations of additions and other cements than those normally permitted. In this report the derivation of the prescriptive k-value approach is explained. The report also describes how the k-value concept should be applied by users such as the concrete producers.

0.4 ECPC and EPCC

The equivalent performance concepts, ECPC and EPCC, for the use of additions may be applied where suitability has been established. In countries where ECPC and EPCC are applied, nearly always, GGBS as addition to concrete is used under these concepts. This report describes how the ECPC and EPCC are applied in some European countries.

1 Scope

This Technical Report provides more detailed information on the k-value concept principles of the equivalent concrete performance concept (ECPC) and the equivalent performance of combinations concept (EPCC) in accordance to EN 206:2013, 5.2.5.

2 *k*-value concept

2.1 *k*-values in EN 206:2013

The *k*-value concept has been established for a number of years in a number of countries and was therefore implemented in EN 206-1 for fly ash and silica fume. In CEN/TC 104/SC 1 report N 278 (June 1996) the background was given to the application of *k*-value concept with fly ash concrete [1]. Later this concept was also applied for concretes containing silica fume and in some member states *k*-values for concretes with ground granulated blastfurnace slag (GGBS) are given in national application documents.

In EN 206:2013 prescriptive *k*-values are given for fly ash and silica fume and a recommended one for GGBS. These *k*-values allow the use of these additions in concrete throughout Europe with a restricted range of cement types within the requirements of the standard without any further verification procedure, i.e. without further testing except for the normal quality control for the concrete. In a prescriptive concept for concrete mix designs, the defined rules shall be on the safe side and cover all possible combinations of materials and variations for the given addition.

The *k*-value concept is a prescriptive concept. It is based on the comparison of the durability performance (or strength as a proxy-criterion for durability where appropriate) of a reference concrete with cement “A” against a test concrete in which part of cement “A” is replaced by an addition as function of the water/cement ratio and the addition content. With the proof of durability indirectly the proof for the exposure classes is given.

The *k*-value concept permits type II additions to be taken into account:

— by replacing the term “water/cement ratio” with “water/(cement + *k* * addition) ratio” and;

— the amount of (cement + *k* * addition) shall not be less than the minimum cement content required for the relevant exposure class.

When part of Cement “A” is replaced by an addition, the limiting values that have to be applied are those that would apply for Cement “A”.

The rules of application of the *k*-value concept for fly ash conforming to EN 450-1, silica fume conforming to EN 13263-1 and ground granulated blast furnace slag conforming to EN 15167-1 together with cements of type CEM I and CEM II/A conforming to EN 197-1 are given in corresponding clauses in EN 206:2013.

Modifications to the rules of the *k*-value concept may be applied where their suitability has been established (e.g. higher *k*-values, increased proportions of additions, other additions (including type I), combinations of additions and other cements than permitted.

2.2 Use of *k*-values in the member states

The use of *k*-values for type II additions in concrete has developed differently across the European member states over years. Within the revision work of EN 206:2013 member states experience was compiled with a series of differing enquiries. In 2007 a “Survey of National requirements used in conjunction with EN 206-1:2000” was published [2]. For the use of additions this enquiry was focused to the regulations for different classes of LOI for fly ash, environmental compatibility and the use of *k*-values, especially for fly ash and silica fume. Five countries responded on the use of k-values for GGBS.

In March 2007, CEN/TC 104/WG 15 presented the results of a survey on the “Use of GGBS as a type II addition in concrete to EN 206-1”. Eight countries reported on the use of GGBS and it was found that GGBS is used as type II addition under the ECPC, EPCC and the *k*-value principles. However, the amount used based on the *k*-value concept is relatively limited and this experience is confined only to some Nordic countries [3].

Within the revision work of 5.2.5 “Use of additions” in EN 206:2013, TG 5 also prepared an enquiry on the use of *k*-values for additions [4] focusing the experience with the different additions, the *k*-values and the determination of these *k*-values. In total 12 countries answered to the enquiry. Three countries do not use the *k*-value concept as they are using existing performance concepts and one country does not use the *k*-value concept for GGBS resulting in nine countries with regulations for using GGBS with the *k*-value concept. The answers of the enquiry can be compiled as follows:

— The *k*-value was mostly established based on results of research work and experience.

— The compressive strength is mostly evaluated after 28 days on concrete samples (9 countries) or mortar (1 country).

— Where the *k*-value was determined the relationship between the compressive strength and water/cement-ratio of concrete samples was used.

— The type of cement and the maximum proportions of additions permitted vary widely in the National regulations, from the use with CEM I only to the use with all cements where the additions are also used in cement.

— Fly ash is used with more cement types than silica fume and GGBS using the k-value concept.

— *k*-values for fly ash vary from 0,2 to 0,8, those for silica fume from 1,0 to 2,0 and those for GGBS from 0,4 to 1,0.

— Where *k*-values had been determined the durability aspects had also been taken into account.

— Most of the countries have experience with *k*-value concept for fly ash and silica fume, only a few countries use the *k*-value concept for GGBS.

The single answers to the TG 5 enquiry are given at the end of this report.

2.3 Procedure for using the *k*-value concept

2.3.1 Principle of the *k*-value concept

Type II additions contribute to concrete properties by various mechanisms. Their influence on concrete properties depends on the characteristics of the individual material properties, on the age of concrete, on the ambient conditions (temperature, humidity) and various other parameters. To take into account these effects in the concrete mix design, the *k*-value method uses the relationship between the water/cement ratio and the strength of concrete. The concept was introduced by Iain A. Smith for the first time in 1967 for the design of fly ash concretes with fly ash amount up to 25 % [5] and has developed further on.

Based on the established concept of EN 206-1 and related Eurocodes the concrete mix design is based on the 28 days strength of concrete. Consequently the standardised prescriptive *k*-value for a concrete addition is related to this age. Nevertheless, when a *k*-value has to be defined, the durability of concretes shall be considered for the relevant exposure classes.

In concretes containing type II additions, the term “water/cement ratio” is replaced with “water/(cement + $k \cdot$ addition)” ratio. The factor k indicates the contribution of the addition in concrete compositions reaching the same strength like the reference concretes without addition.

When the condition of equal strength is assumed, Formula (1) is fulfilled for a specific *k*-value.

$$\omega_o = w_a / \left(c_a + k \cdot a\right) \qquad (1)$$

When these parameters have been determined for equal strength, k can be calculated;

$$k = \left(w_a / \omega_o - c_a\right) / a \qquad (2)$$

or if normalized to the cement content c_a of the concrete with addition

$$k = (\omega_a / \omega_o - 1) / (a / c_a) \quad (3)$$

where

ω_o	is the water/cement ratio of reference concrete without addition;
w_a	is the water content of the concrete with addition;
c_a	is the cement content of the concrete with addition;
a	is the addition content;
ω_a	is the water/cement ratio of concrete with addition (w_a/c_a).

In prescriptive concrete design methods using the k-value concept, the constant k reflects the maximum value, which could be used to prove that the water/(cement + k · addition) ratio of the concrete does not exceed the maximum water/cement ratio as defined for the respective exposure class. It does not give any information about the effective performance of the used addition in the individual concrete mix.

When evaluating the results of different sets of concrete tests, various k-values could be determined as the efficiency of a concrete addition is dependent on a number of parameters (e.g. quality and properties of addition, amount of addition, cement type and properties, water/cement ratio, age, temperature, etc.). The calculation of k-values indicating the efficiency of a concrete addition is usually performed by the comparison of the water/cement ratio vs. compressive strength relationship for references concretes without addition and concretes with addition. For determining the efficiency of an addition, all concretes of a data set calculating k shall be made of the same cement.

2.3.2 Method of calculation

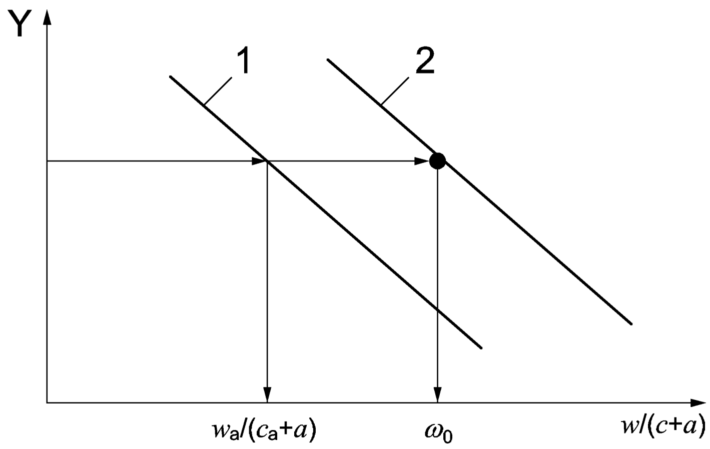
The method of calculating k-values is generally applicable to type II additions according to EN 206:2013. The k-value concept is based on the comparison of the performance of a reference concrete with cement "A" against a test concrete in which part of cement "A" is replaced by an addition as function of the water/cement ratio and the addition content.

The method described in the following, is based on the Smith method developed for fly ash in 1967 [5]. The basis for the calculation of k-value is based on the water/cement ratio vs. strength relationship of concretes with the same content of addition. The determination should preferably not be done on the results of single concretes mixes, but by a set of data. This allows a more precise determination of the water/cement ratio vs. strength relationship. To arithmetically describe that relationship, different empirical formulae could be used. Usually a linear relationship gives a good approximation of strength in restricted ranges of water/cement ratio

Compressive strength = a - b · water/cement ratio

But also other nonlinear approaches (e.g. Abrams law [6, 7], could be used [8, 9]. The values of the factor "k" may also be given by technical feedback. E.g. in France, where the k-value concept is used for Type II and some type I addition (limestone and siliceous filler), the values are derived from the Bolomey method [10] and adjusted by experience.

Comparison of the different approaches shows that there might be slight differences in the calculated k-values, but the level of the results is similar. The variances in the measured compressive strength results have a much higher impact on the calculated values [11].



Key

1 addition with content a

2 reference

Y strength

Figure 1 — Principle of k-value determination (shown for w / (c + a))

Strength vs. water/cement – relationship of reference concrete:

$$f_o = A_o - B_o \cdot \omega_o$$

For a selected c/a ratio, the linear approximation can be assumed also for the correlation f_a versus w / (c + a) as shown by the following formula:

$$f_a = A_a - B_a \cdot (w/(c+a))$$

When a functional relationship between water/cement ratio and compressive strength based on test results has been determined for reference concretes without addition and concretes with a defined addition/cement ratio respectively both formulae are set to be equal;

$$f_{o\,(\text{reference})} = f_{a\,(\text{addition})}$$

$$f_o = f_a \Rightarrow A_o - B_o \cdot \omega_o = A_a - B_a \cdot w_a/(c+a) \quad (4)$$

$$\omega_o = w_a / (c + k \cdot a) \Rightarrow w_a = \omega_o \cdot (c + k \cdot a) \quad (5)$$

$$A_o - B_o \cdot \omega_o = A_a - B_a \cdot \omega_o \cdot (c + k \cdot a)/(c+a) \quad \text{(5) substituted in (4)}$$

or $A_o - B_o \cdot \omega_o = A_a - B_a \cdot \omega_o \cdot (1 + k \cdot a/c)/(1 + a/c)$

This follows the principle that the parameter k has to be determined on the basis of equal strength. Now, using Formula (3) and necessary arithmetic transformations, k can be determined. In this way of calculation, k will not be a single value but will be a parameter in functional dependence of the water/cement ratio of the reference concretes (ω_o).

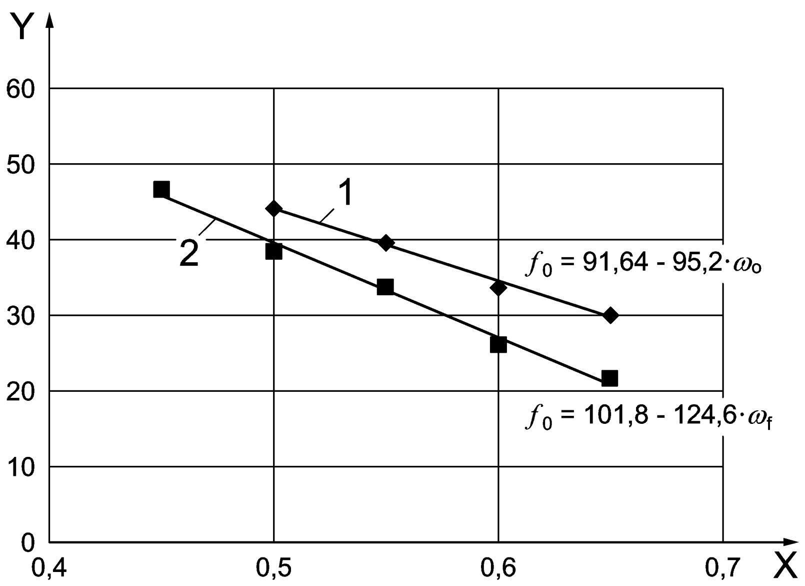
$$k = \frac{(A_a - A_o) \cdot (1 + a/c)}{B_a \cdot a/c} \cdot \frac{1}{\omega_o} + \left[\frac{B_o \cdot (1 + a/c)}{B_a} - 1\right] \cdot \frac{1}{a/c}$$

where

ω_o	water/cement ratio of reference concrete without addition
ω_a	water/cement ratio of concrete with addition (w_a/c_a)
w_a	water content of concrete with addition [kg/m^3]
c_a	cement content of concrete with addition [kg/m^3]
a	content of addition [kg/m^3]
f_0, f_a	compressive strength of concretes [MPa]
A_0, A_a, B_0, B_a	empirical coefficients of the linear relations between water-cement ratio and strength of the reference concrete and the concrete with additions

2.3.3 Example for determination of *k*

For demonstrating the calculation of k, an example is used with concretes containing a fly ash content of 20 % by mass (related to cement plus fly ash). Figure 2 shows the relationship between water/(cement + fly ash) ratio and strength for the concretes with fly ash and the reference concretes without addition which have been used for the calculation.



Key

1 0 % fly ash

2 20 % fly ash

X water / (cement + fly ash) ratio

Y compressive strength at 28 days [MPa]

Figure 2 — Example for strength vs. water / (cement + fly ash) relationship

$$f_o = 91,64 - 95,20 \cdot \omega_o$$

$$f_f = 101,8 - 124,6 \cdot \text{water} / \left(\text{cement} + \text{fly ash}\right)$$ with fly ash/cement = 0,25 (20 % fly ash)

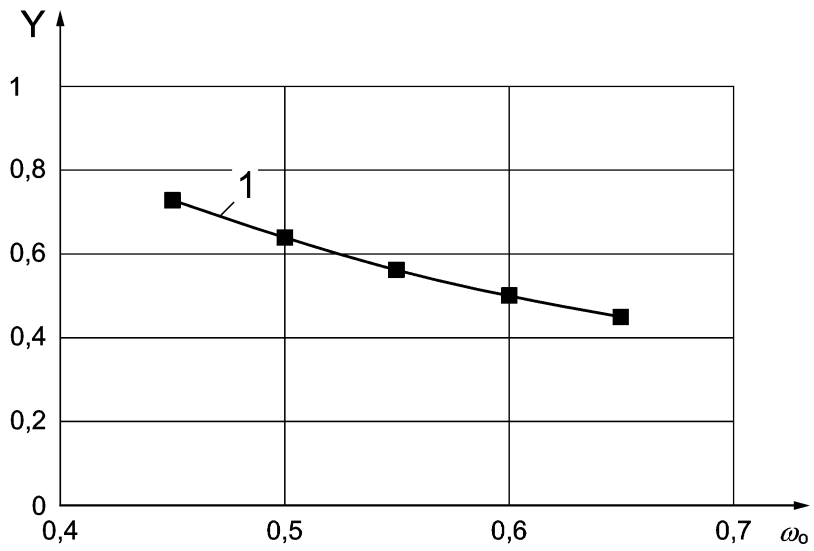
$$k = \frac{(101,8 - 91,64) \cdot (1 + 0,25)}{124,6 \cdot 0,25} \cdot \frac{1}{\omega_o} + \left[\frac{95,20 \cdot (1 + 0,25)}{124,6} - 1 \right] \cdot \frac{1}{0,25}$$

$$\Rightarrow \underline{\underline{k = 0,408 \cdot 1 / \omega_o - 0,180}}$$

With this term, the k-value can be plotted as function of ω_O (see Figure 3).

For a given ω_O, k can be calculated, for example: ω_O = 0,50 k = 0,64

ω_O = 0,60 k = 0,50



Key

1 20 % fly ash

Y k-value at 28 days

Figure 3 — k-value plotted as function of water/cement ratio ω_O of reference concrete

Control

<u>Alternative 1</u>

Select a compressive strength, e.g. 35 MPa

$$f_o = A_o - B_o \cdot \omega_o = 35 = 91,64 - 95,20 \cdot \omega_o$$

$$\Rightarrow \omega_o = (91,64 - 35) / 95,20 = 0,595$$

$$f_f = A_f - B_f \cdot w / (c + f) = 35 = 101,8 - 124,6 \cdot w / (c + f)$$

$$\Rightarrow w / (c + f) = (101,8 - 35) / 124,6 = 0,536$$

$k = (\omega_f / \omega_O - 1)/(f / c)$ with $\omega_f = w / (c + f) \cdot (1 + f / c)$ (see box in Figure 1)

$$\Rightarrow k = \left[\left(0,536\left(1+0,25\right)/0,595\right)-1\right]/0,25 = \underline{0,504}$$

Alternative 2

Select a w/c ratio, e.g. ω_o = 0,50

$$k\left(\omega_o = 0,50\right) = 0,408/0,50 - 0,180 = 0,636$$

$$f_o\left(\omega_o = 0,50\right) = 91,64 - 95,20 \cdot 0,50 = \underline{44,0\ \text{MPa}}$$

$$f_f = A_f - B_f \cdot \omega_o \cdot \left(1 + k \cdot f / c\right) / \left(1 + f / b\right)$$

$$= 101,8 - 124,6 \cdot 0,50 \cdot \left(1 + 0,636 \cdot 0,25\right) / \left(1 + 0,25\right) = \underline{44,0\ \text{MPa}}$$

NOTE The example origins from concretes with fly ash as addition therefore in the formulae the amount of fly ash is represented by the symbol f.

2.3.4 Further recommendations for the application of the *k*-value

For the application of the k-value concept the following recommendations should be considered:

— k-values should be calculated only for water/cement ratios in the range investigated (no extrapolation).

— Beside cement and addition all other concrete components have an effect on the strength of concrete. Therefore keep them constant.

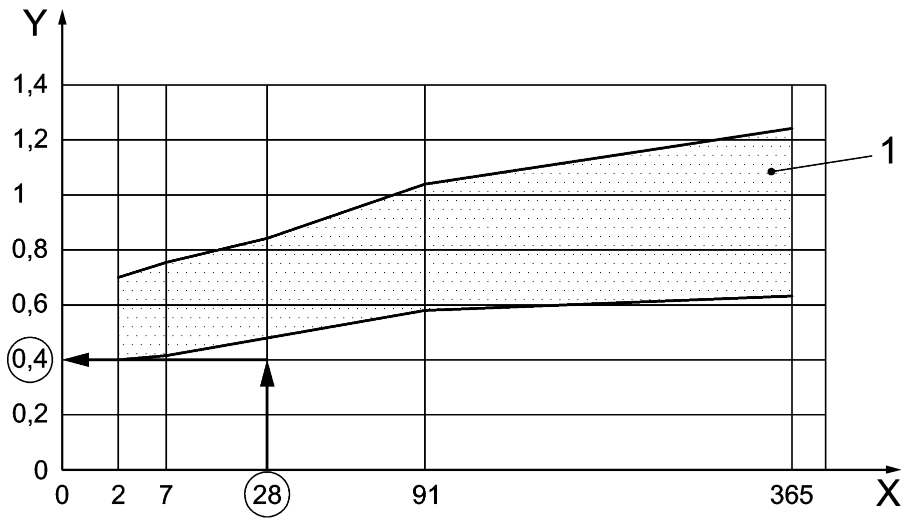
— If a constant workability is preferred, where necessary use a water reducing admixture (plasticiser) to ensure no excessive air is entrained.

— Ensure the variability in the determination of compressive strength is as low as possible because any scattering is magnified in the calculation of the k-value.

2.3.5 Example for establishing a general concept using the *k*-value concept

As an example the principles of the procedure of introducing the k-value for fly ash in the 1990s is demonstrated. The results of this approach were included in EN 206-1:2000.

The determination of the prescriptive k-value is performed in two steps. In the first step, k-values are calculated from concrete tests according to the procedure and recommendation reported above. In the concrete tests all relevant parameters (cement type, strength class, quality of addition, water/cement ratio, etc.) should be considered to allow the definition of a generally applicable prescriptive k-value. Figure 4 demonstrates the range of calculated k-values resulting from concrete strength tests using various combinations of different cements and a fly ash. The fly ash used for durability test as shown in Figures 5 and 6 is representative for a fly ash according to EN 450-1. It had been selected from pre-tests out of a range of more than 30 fly ashes. As shown in Figure 4 a prescriptive k-value of 0,4 was derived taking into account a certain safety margin [12].



Key

1 range of various cement and fly ash combinations

X age of concrete, [days]

Y *k*-value [–]

Fly ash content 20 % of total binder (f / c = 0.025)

Figure 4 — Determination of a prescriptive *k*-value from concrete test results [12]

In a second step, concretes with a composition using k = 0,4 or very similar k-value were produced.

In this case (Figures 5 and 6) the fly ash was taken into account by a k-value of 0,5 on the w / (c + $k \cdot f$) ratio.

Again all relevant parameters (cement type, strength class, quality of addition, water/cement ratio, etc.) were considered in the testing program. With these concretes it was proven that the critical durability requirements for a prescriptive concept (e.g. freeze thaw resistance and carbonation in that case) are fulfilled (Figures 5 and 6).

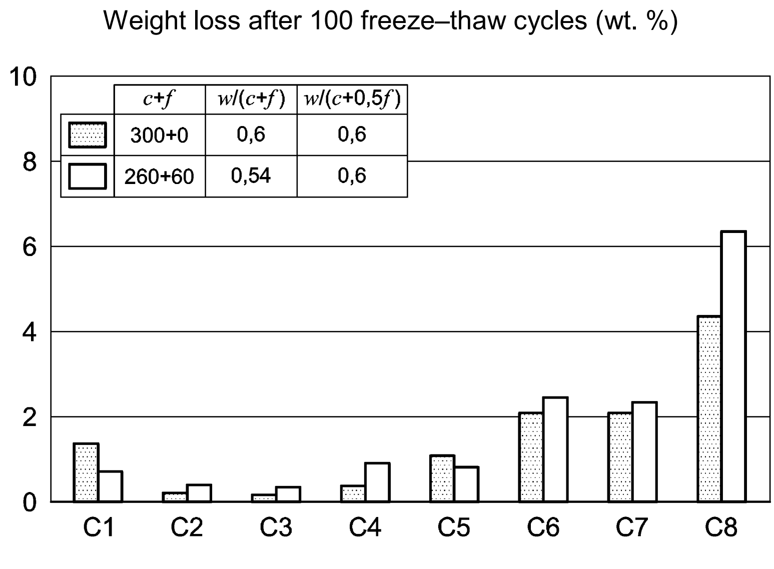


Figure 5 — Results from freeze–thaw testing verifying the suitability of a prescriptive *k*-value [12]

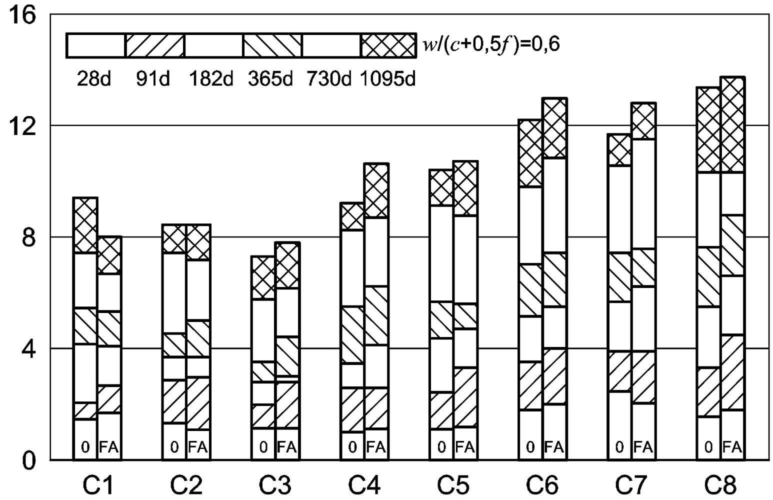


Figure 6 — Results from carbonation tests verifying the suitability of a prescriptive *k*-value [12]

2.4 Application of *k*-value concept by the users

2.4.1 General

Permitted *k*-values and cement substitution ratio (*a*/*c*) have to be taken from EN 206:2013 or derived from national regulations. For the concrete mix, the maximum water/cement ratio (*w*/*c*) and minimum cement content will be specified as a result of the evaluation of the use and conditions.

2.4.2 Example for concrete mix design applying the *k*-value concept

a) Basic assumptions for the example:

1) A concrete using a cement type CEM II/A-S for Exposure Class XC4 shall be designed.

2) According to EN 206:2013, Table F1 (informative annex) a minimum cement content of 300 kg/m^3 is required and a maximum *w*/*c* of 0,50 is allowed for that exposure class.

3) Fly ash should be used as concrete addition ($k = 0,4$) and by that the cement content shall be reduced to 280 kg/m^3.

b) Determination of the fly ash content

EN 206:2013, 5.2.5.2.1 defines that the amount of (cement + k · addition) shall not be less than the minimum cement content required for the relevant exposure class.

$$(c + k \cdot f) \geq 300 \text{ kg/m}^3$$

By transforming that formula, the minimum fly ash content (*f*) can be determined by

$$f \geq (300 - c)/k = (300 - 280)/0,4 = \underline{50 \text{ kg/m}^3}$$

For a cement of type CEM II/A the maximum amount of fly ash to be taken into account shall meet the requirement fly ash/cement ≤ 0,25 by mass.

The maximum amount of fly ash to be taken into account is then

$$f \leq 0,25 \cdot c = 0,25 \cdot 280 = \underline{70 \text{ kg/m}^3}$$

Thus the fly ash content should be in the range between 50 kg/m^3 and 70 kg/m^3 (higher amounts are allowed, but not more than 70 kg/m^3 can be taken into account). For this concrete a fly ash content of 60 kg/m^3 was chosen.

c) Determination of water content

According to EN 206:2013, 5.2.5.2.1, the term “water/cement ratio” (w/c) can be replaced by with the ratio “water/(cement + k x addition)”. This ratio $w/(c + k \cdot f)$ shall be equal or lower than the maximum allowed w/c

$$w / \left(c + k \cdot f\right) \leq 0,50$$

By transforming that formula, the minimum water content can be determined by

$$w \leq 0,50 \cdot \left(c + k \cdot f\right) = 0,50 \cdot \left(280 + 0,4 \cdot 60\right) = \underline{152 \text{ l/m}^3}$$

I.e. the concrete should not contain more than 152 l/m^3 to fulfil the requirements for exposure class XC4.

3 Equivalent concrete performance concept (ECPC)

3.1 General

In 5.2.5.3 of EN 206:2013 the principles of the Equivalent Concrete Performance Concept are introduced. This concept permits amendments to the requirements for minimum cement content and maximum water/cement ratio (wcr) when a combination of a specific addition and a specific cement source is used for which the manufacturing source and characteristics of each are clearly defined. It shall be proven that the concrete has an equivalent performance especially with respect to its interaction with the environment and to its durability when compared with a reference concrete in accordance with the requirements for the relevant exposure class.

In the Netherlands the procedure, criteria and test methods for the assessment of the ECPC are given in the national guideline CUR-Recommendation 48 (in Dutch) [13]. CUR-Recommendation 48 applies to the assessment of the suitability of a combination of one or more specific additions and one or more specific cements for application in concrete. All constituents of cement as mentioned in EN 197-1 with the exception of Portland cement clinker can be used as additions.

Experience

The ECPC has been used in the Netherlands for the past 15 years for combinations of fly ash and cement (CEM I or a combination of CEM I and CEM III) and almost 10 years for combinations of GGBS and cement. The procedures and requirements for combinations of fly ash and cement and also for the combination of cement with GGBS and fly ash are described in the Dutch assessment procedures for certification BRL 1802 [14]. The assessment procedures follow the principles of CUR-Recommendation 48.

Other systems compliant with 5.2.5.3 of EN 206-1:2000 are in existence, e.g. in Germany as a national technical approval [15, 16], and in Belgium as a national standard [17].

3.2 Dutch Method

3.2.1 Definitions

The definitions given in CUR-Recommendation 48 are given below.

Cement types

Cement types refer to those mentioned in column 2 of Table 1 in EN 197-1:2011.

Specific cement

Cement for which the manufacturing source, cement type and strength class are well defined. If two cements identical in type and strength class are manufactured in the same factory, a specific label should be added for identification.

Addition

Finely divided material that complies with the following requirements:

— mentioned as main constituent of cement in EN 197-1 (with the exception of Portland cement clinker),

— physical and chemical properties are well defined and documented,

— proven quality control,

— complies with the requirements in the relevant product standards or guidelines for use in concrete.

NOTE Only additions for which a European or national standard or provisions for the addition valid in place of use, specific for use in concrete complying with EN 206:2013, are within the scope of the recommendation.

Specific addition

Addition, as defined above, for which the manufacturing source and the production method are well documented.

Binder content

Sum of the amounts (kg/m^3) of cement and addition in the test concrete, manufactured with a cement-addition combination.

Reference cement

Cement, that complies with EN 197-1 and is permitted for general use in concrete by NEN 8005. Furthermore, the cement shall have been applied in concrete in the Netherlands during at least 5 years.

Reference concrete

Concrete manufactured with fluvial sand, gravel, water and, if appropriate, an admixture and a reference cement. The composition complies with the requirements of NEN 8005 (National Provisions) for the applicable exposure class (see Table 7).

Test concrete

Concrete manufactured with a combination of cement and addition, for which the equivalent performance with the reference concrete has to be demonstrated. With exception of the binder the nature and dosage of the other constituents are identical to the reference concrete.

Equivalent concrete performance

In the case that the durability aspects, to be tested according to the recommendation, of the test concrete are equal or better than those of the reference concrete, the performance of the test concrete is assessed as equivalent to the reference concrete.

Suitability concrete for application in a specific exposure class

If it is demonstrated following the recommendation that the performance of a test concrete is equivalent to the reference concrete, the composition of which complies with a specific exposure class, the test concrete is assessed suitable for this exposure class.

3.2.2 Procedure and criteria for assessment of durability aspects

Durability aspects

To demonstrate the equivalent performance of the test concrete, depending on the exposure class, one or more of the following durability aspects have to be tested:

— resistance to carbonation,

— resistance to chloride ingress,

— frost-thaw de-icing salt resistance,

— resistance to seawater,

— resistance to sulfates.

ASR is not part of this recommendation. Measures to prevent damage to concrete by ASR are given in CUR-Recommendation 89 [18]. In addition, measurement of the concrete strength at 7 and 28 days is part of the assessment of the test concrete.

Other mechanical properties (tensile strength, bending strength, elastic modulus, shrinkage, creep) do not have to be tested. In structural codes these properties are related to the compressive strength. Since the composition of cement-addition combinations is similar to that of common cements, the relation between compressive strength and other mechanical properties will also be similar.

Assessment procedure

<u>Composition of test and reference concrete</u>

The reference concrete should:

— comply with the requirements of NEN 8005 for the applicable exposure class (see Table 7),

— be manufactured with a reference cement belonging to the applicable exposure class in accordance with Table 1.

— one or more reference cements may be used for testing the different durability aspects.

Table 1 — Reference cement types in relation to the exposure class

Exposure Class	Reference cement types						
	CEM I	CEM II/A-S	CEM II/B-S	CEM II/A-V	CEM II/B-V	CEM III/A	CEM III/B
XC	X	X	X	X	X	X	X
XD					X	X [a]	X
XS					X	X [a]	X
XF2 + XF4	X	X	X	X	X	X [b]	X [c]
XA2 + XA3					X		X

[a] slag content ≥ 50 %

[b] slag content < 50 %

[c] Only for test concrete, manufactured with a combination of slag and cement as binder, with a slag content virtually identical to that of the reference cement.

In Table 1 those cements have been selected for a particular exposure class that are commonly used in the Netherlands in this exposure class.

The composition of the test concrete should comply with the following requirements:

— the minimum clinker content shall be 20 % (m/m) for the combination of Portland cement with slag and 25 % (m/m) for other combinations,

— the maximum limestone content of a cement-addition combination shall be 35 % (m/m),

— the binder content shall be equal or larger than the minimum cement content for the applicable exposure class, as defined by NEN 8005,

— the water/binder ratio (wbr) shall be smaller than or equal to the maximum water/cement ratio (wcr) for the applicable exposure class, as defined by NEN 8005.

The clinker and/or limestone contents shall be calculated by the method used in EN 197-1 for the main constituents of cement.

Durability aspects in relation to the exposure class

Only those durability aspects that are relevant for the exposure class need to be tested (Table 2). For exposure class XA only sulfate resistance is part of the test program. The resistance to other aggressive components is outside the scope of the recommendation.

Only in the case that the sulfate content of the soil or the water leads to a classification in XA2 or XA3, a test of the sulfate resistance is mandatory. In all other cases a cement-addition combination can be applied in XA with only strength testing.

For exposure classes XF1 and XF3 only strength testing is required.

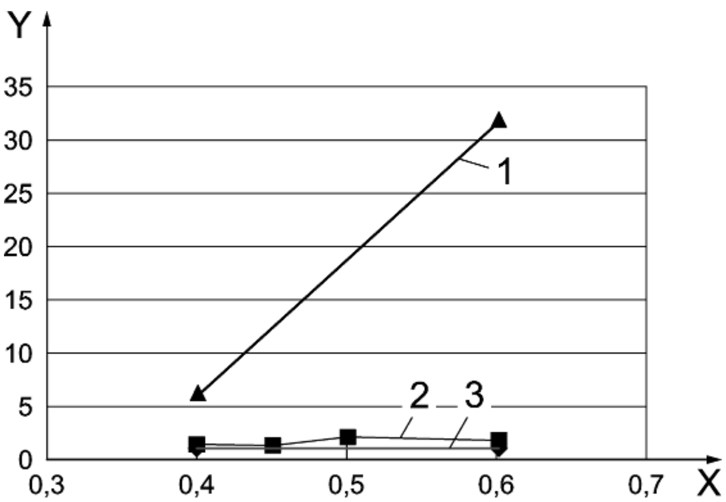
Table 2 — Durability aspects in relation to the exposure class

Exposure Class	Carbonation	Chloride ingress	Freeze–thaw de-icing salt	Seawater resistance	Sulfate resistance
XC	X				
XD		X			
XS		X		X	
XF2 + XF4			X		
XA2 + XA3					X

<u>Suitability related to the exposure class</u>

A test concrete is suitable for application in a certain exposure class if it fulfils the criteria for all durability aspects relevant to the exposure class.

A test program has been performed to investigate if the equivalent performance depends on the binder content and water/binder ratio for combinations with fly ash and slag. The resistance to chloride ingress as tested by the Rapid Chloride Migration (RCM) test was selected to investigate this dependence. For both additions it has been found that there is no relation between the resistance to chloride ingress and *wbr* (tested range: 0,45 – 0,65) at a concrete age of 1 to 3 years (see Figure 7).



Key

1 PC

2 HOC

3 PC + pvla

X *wcf*

Y RCM (10^{-12} m^2/s)

Figure 7 — RCM - value after 1 year versus water/cement ratio for Portland cement (PC), slag cement (HOC) and a combination of Portland cement and fly-ash (PC+pvla)

The concrete composition for each durability test is given in CUR Recommendation 48. In this report only a summary is given. For testing the effects of chlorides on corrosion, a single concrete composition can be applied. This is based on a research project related to the RCM test performed in NL. The background is given in a Dutch CUR report [19].

For the additions fly ash and slag the test for each durability aspect is therefore performed on a single concrete composition with a certain binder content and *wbr*. If the test concrete fulfils the requirements for a certain exposure class, the combination is then allowed for the full range of binder content and *wbr* as defined in NEN 8005 for this exposure class (Table 7).

For additions other than fly ash or slag the assessment of CUR Recommendation 48 has to be performed at both the upper and lower limit of the wbr for the exposure class for which the durability test is relevant (e.g. chloride penetration for XD and XS).

Criteria for assessment

Basic assumptions

The assessment of durability aspects is based on the comparison of *n* samples (of the cement and addition) and the test specimens made from these samples. Approval or rejection is based on the difference in the test results between the test and reference concrete. The limit value is based on the following principle.

For each durability aspect a relative difference *d* [%] is defined (at the level of the population) that is considered unacceptable. In other words, an assessment of the test concrete leading to an average negative difference d should lead to a high probability of rejection for the test concrete.

The basic assumptions for the d-values and the required number of samples were:

— the supplier of the addition is obliged to demonstrate the suitability of his product,

— the procedure should protect the consumer, i.e. limit the consumer risk,

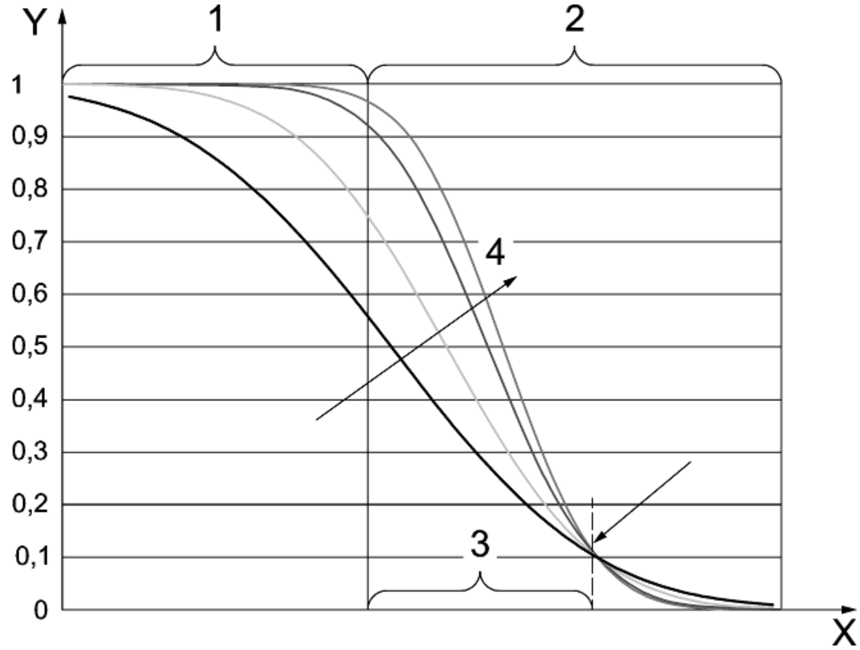
— the procedure should be fair towards the supplier.

These basic assumptions are implemented as follows:

— for each durability aspect a difference *d* [%] is fixed that is considered no longer acceptable anymore. The choice of these d-values is based on expert opinion.

— the consumer risk is fixed at 10 % of that difference.

The supplier is free to choose the number of samples (with a minimum of 3) and can limit the producer risk in this way (see Figure 8).



Key

1 test better than reference

2 test worth than reference

3 no longer acceptable difference (*d*)

4 increasing number of samples

X difference test – reference

Y probability of acceptance

Figure 8 — Difference versus probability of acceptance

<u>The assessment parameter</u>

For each durability aspect j the assessment is based on the parameter T_j:

$$T_j = \frac{\left[m_r - \frac{m_t}{1 + 0.01 d_j} \right]}{s / \sqrt{n}} \quad (6)$$

where

$$s = \sqrt{\left\{ s_r^2 + \frac{s_t^2}{(1 + 0.01 d_j)^2} \right\}} \quad (7)$$

and

m_r is the average test result of the n samples of the reference concrete;

m_t is the average test result of the n samples of the test concrete;

s_r the standard deviation of the averages per sample of the reference concrete;

s_t the standard deviation of the averages per sample of the test concrete;

n the number of samples;

d_j the limit value of the durability aspect j as shown in Table 3.

In Table 8, the procedure for calculating T_j is shown in a flow chart.

Table 3 — Limit values *d* (at the population level)

Durability aspect j	Difference d [%] that leads to rejection with a probability of 90 %
Carbonation	+30
Chloride ingress	+30
Freeze–thaw de-icing salt resistance	+30
Seawater resistance	+40
Sulfate resistance	+40
Compressive strength	- 30

For approval T_j should be larger than the limit values shown in Table 4:

Table 4 — Limit values T_j

Number of samples (n)	Limit value T_j
3	1,533
4	1,440
5	1,397
6	1,372
7	1,356
8	1,345
9	1,337
10	1,330
11	1,325
12	1,321

3.2.3 Test methods

In Table 5 the test methods are listed for the 5 durability aspects. For both carbonation and chloride ingress a natural and accelerated method may be used. The natural method is the reference method. In the case that both methods are used, the natural method is decisive for the assessment.

In the CUR Recommendation some deviations from the test standards listed in Table 5 are prescribed. These differences will not be described further in this document. In the selection of the test methods the order of preference (high to low) was;

— European standards,

— Dutch standards,

— other national standards,

— guidelines.

Table 5 — Test methods for the different durability aspects

Durability aspect	Test standard	Accelerated?	Concrete age at start test (days)	Test duration (days)
Carbonation	Rilem CPC 18	No	3	91/182/364
	prCEN/TS 12390-XX: 2008	Yes	42	56/63/70
Chloride ingress	NT Build 443	No	91	35
	NT Build 492	Yes	28/56/91/182/364	1 – 2
Freeze–thaw	NPR-CEN/TS 12390–9 [a]	No	28	7
Sulfate resistance	(Dutch method) [b]	No	28	182/364
Seawater resistance	(Dutch method) [b]	No	28	182/364

[a] Only freeze thaw with deicing salt is tested; if requirements are met it is also valid without deicing salt.

[b] See CUR Recommendation 48.

During the initial type testing concrete cubes shall be made with water/(C + A) ratio 0,55. The compressive strength of the concrete shall be measured after 7 and 28 days. The strength development can be tested against a reference concrete or against the fixed limit values given in Table 6.

Table 6 — Fixed limit values for cube strength

Age	Limit value
7 days	20 N/mm^2
28 days	33 N/mm^2

If the test concrete meets the strength requirements, the requirements of X0, XF1, XF3, XA1, XA2 and XA3 with exception of the exposure due to sulphates are fulfilled. No extra testing is needed.

Combinations of cement and fly ash that fulfil the requirements of the 7 days limit value meet the requirements of carbonation resistance. The relation between these two material properties has been established many times in Dutch and international literature. The freeze thaw resistance is tested with the CDF test (14 cycles without air entrainment agents; in addition test for the working of air entraining agents).

3.2.4 Quality assurance

Combinations of cement and additions are certified in the Netherlands. Basis for this certification is the assessment procedure BRL 1802 for combination of cement and additions. The procedure for quality assurance is described below.

First, an initial type testing according to CUR Recommendation 48 has to be performed for a cement-addition combination. If the combination passes this test, a certificate is issued that is valid for 1 year. At the end of this period a verification test is performed. If the combination passes the verification test, the certificate is extended for another year until the next verification test.

The verification test serves to assess if the properties of the combination have not changed significantly since the certificate has been issued or extended for the last time. The verification test is performed on concrete or mortar after 7 and 28 days curing.

If the ratio between the concrete and mortar strength is established during the initial testing, then the testing at yearly intervals may be undertaken on mortar prisms and the concrete strength may be calculated using established strength ratios C7/M7 and C28/M28.

The verification can be done against reference or limit values.

3.3 Recommendations for the application of ECPC

The ECPC is extensively used in the Netherlands. Other concrete performance systems according to 5.2.5.3 of EN 206:2013 are existing e.g. in Germany (under the mandate of a national technical approval [15, 16] and Belgium (under the mandate of a national standard [17]).

It is recommended to use the ECPC according to provisions made in EN 206:2013, 5.2.5.3. The procedure shall be used for all cements conforming to EN 197-1 of standard strength class 32.5 or greater and additions referred to in EN 206:2013, 5.2.5.1.

The reference cement shall fulfill the requirements of EN 197-1 and originates from a source that has been used in practice in the place of use within the last five years and used in the selected exposure class.

The reference concrete shall conform to the provisions valid in the place of use for the selected exposure class.

The reference and test concrete for testing shall conform to the following requirements:

— binder content ($C + A$) is equal to the cement content of the reference concrete;

— test concrete $W/(C + A)$ is equal to the W/C of the reference concrete;

— the aggregate type and grading shall be the same.

For the intended exposure classes, Table 1 identifies the required testing.

As indicated in a note to 5.2.5.3 of EN 206:2013, provisions valid in the place of use may place restrictions on the cement types and fly ash loss-on-ignition categories to align the combinations with currently permitted cements.

3.4 Additional information to the use of the Dutch method

Table 7 — Requirements for concrete composition NEN 8005

	Exposure class	Maximum water/cement ratio or water/binder ratio	Minimum cement/binder content kg/m³	Minimum air content [a]	
				Maximum aggregate size D (mm)	Air content % (V/V)
1	No risk of corrosion or attack				
	X0	0,70 [b]	200 [b]	—	—
2	Corrosion induced by carbonation				
	XC1	0,65	260	—	—
	XC2	0,60	280	—	—
	XC3	0,55	280	—	—
	XC4	0,50	300	—	—
3	Corrosion induced by chlorides other than seawater				
	XD1	0,55	300	—	—
	XD2	0,50	300	—	—
	XD3	0,45	300	—	—
4	Corrosion induced by chlorides from seawater				
	XS1	0,50	300	—	—
	XS2	0,45	300	—	—
	XS3	0,45	320 [c]	—	—
5	Freeze/thaw attack with or without de-icing agents				
	XF1	0,55	300	—	—
	XF2	0,55	300	63 31,5 16 8	3.0 3.5 4.0 5.0
	XF2	0,45	300	—	—
	XF3	0,50	300	—	—
	XF4	0,50	300	63 31,5 16 8	3.0 3.5 4.0 5.0
	XF4	0,45	320 [c]	—	—
6	Chemical attack				
	XA1	0,55	300	—	—
	XA2 [d]	0,50	320	—	—
	XA3 [d]	0,45	340	—	—

a Minimum air content refers to measured air content.

b The listed water-cement ratio/water-binder ratio and the listed cement/binder content are only applicable to underwater concrete in non-aggressive water. There are no limit values for unreinforced concrete.

c For members with a thickness > 1 m the cement content may be reduced to 300 kg/m^3, provided that only a low heat cement is used that complies with NEN-EN 197–1.

d Concrete that is exposed to solutions with > 600 mg/l SO_4^{2-} or soil with > 3000 mg/kg sulfates shall be manufactured with sulfate resistant cement according to NEN 3550.

Table 8 — Flow chart calculation assessment paramenter [13]

	Test concrete				Reference concrete			
Test specimen	Sample 1	Sample 2	Sample ….	Sample n	Sample 1	Sample 2	Sample ….	Sample n
1	x_{11}	x_{21}		x_{n1}	y_{11}	y_{21}		y_{n1}
2	x_{12}	x_{22}		x_{n2}	y_{12}	y_{22}		y_{n2}
…	…	…	…	…	…	…	…	…
p	x_{1p}	$x_{2p;}$;		x_{np}	y_{1p}	$y_{2p;}$;		y_{np}
	↓	↓	↓	↓	↓	↓	↓	↓
Sample average	$X_{1.}$	$X_{2.}$		$X_{n.}$	$Y_{1.}$	$Y_{2.}$		$Y_{n.}$
	m_t = average ($X_{1.}$, $X_{2.}$, …., $X_{n.}$) s_t = standard deviation ($X_{1.}$, $X_{2.}$, …., $X_{n.}$)				m_r = average ($Y_{1.}$, $Y_{2.}$, …., $Y_{n.}$) s_r = standard deviation ($Y_{1.}$, $Y_{2.}$, …., $Y_{n.}$)			
	$s = \sqrt{\left\{ s_r^2 + \frac{s_t^2}{\left(1+0,01d_j\right)^2} \right\}}$ Assessment parameter $T_j = \frac{\left[m_r - \frac{m_t}{\left(1+0,01d_j\right)} \right]}{s/\sqrt{n}}$							

4 Equivalent performance of combinations concept

4.1 General

In Europe there are three methods applied to establish the equivalence performance of combinations: the UK method, the Irish method and the Portuguese method. There is considerable long-term experience in using the equivalent performance of combinations concept [20] and British Standards have permitted this concept to be used with GGBS and fly ash since 1982. The National Standards Authority of Ireland (NSAI) has permitted the concept to be used with GGBS and CEM I since 2004, and with GGBS and CEM II/A since 2006. The Portuguese regulations have permitted the concept to be used with GGBS/fly ash/pozzolana/limestone filler with CEM I since 1993 and with other cements since 2005.

The principles of the ”Equivalent Performance of Combinations Concept” permit a defined range of combinations of cement conforming to EN 197-1 and addition (or additions) having established suitability that may count fully towards requirements for maximum water to cement ratio and minimum cement content which are specified for a concrete.

The three methods (UK, IE and PT) have been developed separately and differ considerably in the requirements for the control of the combinations.

4.2 UK method

The UK uses an 'equivalent performance of combinations concept' (EPCC), where:

— An addition added at the concrete mixer may be considered to perform in the same way, as would the same material incorporated into concrete as a constituent of cement.

— This is only permitted when a continuous programme of control testing of the specific addition with the specific cement, is carried out.

The blend of addition and cement is called a 'combination' and BS 8500 (the British Complementary Standard to EN 206-1) contains the following definition:

> **Combination:** "restricted range of Portland cements and additions which, having been combined in the concrete mixer, count fully towards the cement content and water/cement ratio in concrete"
>
> NOTE A procedure for establishing the suitability of combinations is specified in BS 8500–2:2002, Annex A.

Combinations are treated as equivalent to factory-made cements of the same composition and strength class. The factory-made cements permitted by BS 8500 include EN 197-1 and also EN 14216 (Cement – Composition, specifications and conformity criteria for very low heat special cements).

The procedure for establishing the restricted range of combinations that can count fully towards the cement content and water/cement ratio is known as the "Conformity Procedure for Combinations" and only applies for combinations of a CEM I cement of standard strength class 42.5 or greater, conforming to BS EN 197-1 with one of the following additions:

— fly ash conforming to EN 450-1: category A or B;

— GGBS conforming to EN 15167-1;

— limestone fines conforming to BS 7979.

The standards for the three additions contain adequate restrictions on the chemical properties of the additions to ensure that the combinations will meet the chemical and soundness requirements for the equivalent cements in EN 197-1 or EN 14216. However, testing is required to ensure that the combination will achieve the required strength class. Establishment of suitability is based on strength testing with EN 196-1 mortar prisms, using average monthly samples of the CEM I and the addition. The combination shall:

— exceed requirements for early- and 28-day strength by a statistical margin;

— not exceed an upper limit on 28-day strength.

The strength requirements that have to be met are based on those in EN 197-1 but also on those in EN 14216, which has a 22,5 strength class.

Because silica fume can be used within EN 206-1 with a k-value of at least '1', it was not considered necessary to include it in the UK combinations procedure.

In its simplest form, the procedure can be carried out for a fixed proportion of addition to cement and determines (pass/fail) whether that specific proportion meets the strength requirements. If it passes, it is a "permitted proportion". In practice, the procedure is normally carried out by the suppliers of additions who use a more complex approach in order to determine the range of "permitted proportions" (rather than determine whether one specific proportion is permitted).

The requirements are described in Annex A and Annex C of BS 8500-2, which are attached in 4.6 in this report.

Annex A sets out the normative requirements. Annex C provides an informative example that is typical of the approach taken by suppliers of additions in order to certify one source of addition used in combination with several sources of CEM I cement. Here, relationships have to be established between the proportion of addition and strength for each of the CEM I cements and re-established every two years. Monthly testing of samples of the addition combined with samples of the CEM I cements determines limits on the proportions of addition with each specific CEM I cement source to ensure that the conformity criteria for strength are met.

Compared with the *k*-value approach, the UK Combinations Conformity Procedure requires additional testing. In order to parallel the testing regimes used by the cement industry, samples of CEM I and addition have to be taken regularly through the month and testing carried out on the homogenized samples. The UK procedure does however, provide confidence that the behaviour of a specific addition with a specific cement, is tightly controlled and as a result consistent concrete can be produced.

4.3 Irish method

Ireland uses an 'equivalent performance of combinations concept' (EPCC) method, where the strength performance of a particular combination is measured on mortar prism tests and compared to the strength performance requirements (i.e. limits) for standard EN 197-1 cements that have established suitability in I.S. EN 206-1.

The procedure applies for combinations of each GGBS with each CEM II/A and CEM I, for up to 70 % substitution of GGBS. The procedure relies on a pass/fail of the strength of combinations of 50 % and 70 % GGBS. For higher GGBS content (70 %) the strength is determined at 56 days. The combinations are required to meet the following mortar prism strength requirements:

Combination	Lower Strength Limit	
	Early strength (≥20 N/mm^2)	Standard strength (≥42,5 N/mm^2)
50 % GGBS	7 days	28 days
70 % GGBS	7 days	56 days

The method is summarized as follows:

a) Monthly average bulk samples of the GGBS and each cement are obtained from the suppliers, and composite samples of 50 % and 70 % are made up.

b) The composite samples are tested in accordance with EN 196-1 on 7, 28 and 56 day strengths.

c) The monthly average of the 7, 28 and 56 day strengths are compared to the lower limit values in the above table, plus an additional statistical margin of 3 N/mm^2 (7 days) and 5 N/mm^2 (28, 56 days).

d) On meeting the minimum strength criteria, a combination is deemed to be a permitted proportion of GGBS in combination with a cement. Where a permitted proportion is established, combinations of lesser proportions of GGBS are also permitted.

The methodology is described in 4.7.

4.4 Portuguese method

History

An equivalent performance of combinations concept (EPCC) was first introduced in Portugal through LNEC Specification E 378 “Concrete. Guide for the use of hydraulic binders”, published in 1993, called up by the National Annex of NP ENV 206. The permitted combinations are presented in the following table that was similar to the equivalent table for cements, established in Portuguese Standard NP 2064, published in 1991. NP 2064 was based on prENV 197-1 from 1989.

CEM I	Silica fume	Natural pozzolana	Fly ash	Limestone filler	Slag
≥ 90	≤ 10				
≥ 75		≤ 25			
≥ 75			≤ 25		
≥ 80				≤ 20	
≥ 65					≤ 35
20 to 64					36 to 80
≥ 60	≤ 40 [a]				

[a] Silica fume limited to 10 %.

Equivalence was established between the combinations and the corresponding cements of similar composition.

With the implementation of EN 206-1 in Portugal, LNEC Specification E 378 was replaced by LNEC Specification E 464 “Concrete. Prescriptive methodology for a design working life of 50 and of 100 years under environmental exposure”, first published in 2005. This new Specification, also called up by National Annex of NP EN 206-1, allows the use of cements other than CEM I and the simultaneous utilization of more than one addition, as for instance fly ash and slag, in line with the composition of CEM V cement defined in EN 197-1.

It can be said that in Portugal all the ready mixed concrete incorporating additions is now supplied using the equivalent performance of combinations concept.

Basis of the concept

The LNEC Specification E 464, called up by the National Annex of NP EN 206-1, establishes, in Tables 6 to 9, the Portuguese prescriptive requirements related to exposure classes. A minimum concrete compressive strength class is mandatory, which in general controls the mix design of concrete (as an example, Table 7 of the LNEC Specification E 464, containing the prescriptive requirements for XS and XD, is presented in 4.8. It is assumed that concretes made with cements or combinations with similar composition have equivalent performance, provided that they have the same compressive strength.

The designer is aware that, for a certain exposure class, the concrete has always to fulfill a minimum compressive strength. For structural reasons the designer may, of course, specify a higher strength, but never a lower strength. When a certain combination has not enough strength or is less reactive, probably a higher amount of binder has to be used and the durability of concrete will be therefore ensured. In this way, the establishment of the equivalent performance of combinations concept doesn’t include the strength control of the combinations in mortar, as the combinations performance is evaluated trough the compressive strength of the concrete. Furthermore, there is no limitation concerning the source of the cement or addition, and other cements than CEM I or more than one addition may be used, provided that the combination has a similar composition of a cement from EN 197-1. For this purpose, the excess of any addition (or cement constituent) is to be disregarded. The corresponding calculations are quite easy to perform through an iterative process, but a specific methodology may also be applied.

Concerning the use of cements other than CEM I, the concept is by now only enlarged to CEM II/A of strength class 42.5 or higher, but there is no technical reason to not consider other cements.

Rules of application

The equivalent performance of combinations concept may be applied provided that the conditions below are simultaneously fulfilled:

a) the minimum compressive strength of concrete is a mandatory requirement related to exposure classes;

b) the cement is of the type CEM I or CEM II/A and of the strength class 42.5 or higher;

c) the additions are either of type I, complying with LNEC Specification E 466 – "Limestone fillers for hydraulic binders" or of type II;

d) the composition of the combination complies with the limits established in EN 197-1 for the composition of one of the cements allowed in Tables 6 to 9 of LNEC Specification E 464, as well with the pozzolanicity requirement when applicable;

e) the proportion of silica fume (should it exist in the composition of the combination) in relation to clinker is equal or less than 11 %.

f) the prescriptive requirements applicable to the combination are those defined for the correspondent cement.

NOTE A procedure to calculate the composition of the combination is included in Annex A of the LNEC Specification E 464, which equates the combination to the correspondent cement (see 4.8).

4.5 Recommendation for application of EPCC

The principles of the "Equivalent Performance of Combinations Concept" permit a defined range of combinations of cement conforming to EN 197-1 and addition (or additions) having established suitability that may count fully towards requirements for maximum water to cement ratio and minimum cement content which are specified for a concrete.

The elements of the methodology are:

1) identify a cement type that conforms to a European cement standard and that has the same or similar composition to the intended combination;

2) assess whether the concretes produced with the combination have similar strength and durability as concretes made with the identified cement type for the relevant exposure class;

3) a production control that ensures these requirements for the concretes containing the combination are defined and implemented.

4.6 Additional information the UK method

4.6.1 Annexes from BS 8500-2 relating to conformity control of combinations

Annex A (normative)

Conformity procedure for combinations

NOTE 1 This annex sets out a procedure for establishing the suitability of combinations to count fully towards the cement content and *w/c* ratio in concrete. The procedure is applicable to a specific source of addition combined with a specific source of Portland cement, and determines permitted proportions for the addition relative to the cement.

NOTE 2 The specification may place further restrictions on the proportion of fly ash, GGBS or limestone fines, depending on the use of the concrete.

NOTE 3 This annex meets the requirements for establishing suitability for the use of additions in concrete conforming to BS EN 206–1.

A.1 Procedure

NOTE 1 An example of the procedure is given in Annex C.

The procedure shall be used only for combinations of a CEM I cement of standard strength class 42.5 or greater conforming to BS EN 197-1 with one of the following additions:

a) fly ash conforming to BS EN 450-1:2005, category A or B;

b) GGBS conforming to BS 6699 or BS EN 15167-1;

c) limestone fines conforming to BS 7979.

Each month, samples shall be obtained that are representative of each addition and each CEM I cement that are to be evaluated for use in combination. Combinations of these addition and cement samples, in appropriate proportions, shall be tested for compressive strength in accordance with the method for testing cement specified in BS EN 196-1, with all references to “cement” therein, being construed as referring to the “combination”.

NOTE 2 Where third-party certification is required, the certification body might require the proportions selected to be justified.

The strength test results shall be evaluated against the requirements for one of the strength classes in Table A.1.

Table A.1 — Requirements for the compressive strength of combinations

Strength class of combination	**Early strength**		**Standard strength**	
	2 day N/mm^2	**7 day** N/mm^2	**28 day** N/mm^2	
22,5	—	≥ 12	≥ 22,5	≤ 42,5
32,5L 32,5N 32,5R	— — ≥ 10	≥ 12 ≥ 16 —	≥ 32,5N	≤ 52,5
42,5L 42,5N 42,5R	— ≥ 10 ≥ 20	≥ 20 — —	≥ 42,5	≤ 62,5
52,5L 52,5N	≥ 10 ≥ 20	— —	≥ 52,5	—

The running means of the early and standard strengths shall be calculated as the average of the most recent test results, taken over a period of not less than 6 months and not more than 12 months, except in the case of a new combination. In this case, the running means shall be based on all the available data.

NOTE 3 A relationship between compressive strength and combination proportions may be used to extrapolate the running means of strength for proportions other than that tested, provided that the relationship is re-established at least once every 2 years.

The only proportions of the combination which shall be deemed to conform to this annex ("permitted proportions") are those proportions for which the measured or extrapolated running means of the early and standard strengths:

1) exceed the relevant lower limits in Table A.1 by a statistical margin; and

2) do not exceed the relevant upper limit.

The statistical margin added to the lower limits shall be:

i) +5 N/mm^2 on the lower limits for standard strength and +3 N/mm^2 on early strength limits; or

ii) calculated statistically from the testing of spot samples, such that an estimate of the overall percentage of results that are less than the required lower limit does not exceed 5 % for the lot from which the samples are taken.

NOTE 4 The statistical margin allows for variability in the cement and addition. No statistical margin is required on the upper limit because the possibility of a combination occasionally exceeding an upper limit is unlikely to substantially reduce the suitability of the combination for its intended use.

Irrespective of the results obtained by testing, no proportion shall exceed 85 % of the combination for GGBS, 20 % of the combination for limestone fines and 55 % of the combination for fly ash unless higher proportions have been specified.

NOTE 5 It is permissible to specify higher proportions (see BS 8500–1:2006, Table A.6, footnote A), but BS 8500–1 contains no recommendations on how such high proportions should count towards the minimum cement or combination content and *w/c* ratio in concrete.

A.2 Issue of certificates

Where a certificate of conformity to this annex is issued[5)], it shall relate to fly ash, GGBS or limestone fines from a specific source combined with CEM I cement from a specific source. It shall contain:

a) identification of the source of the addition and of the CEM I cement;

b) the means by which composite samples of the addition and CEM I cement were obtained;

c) the month represented by the latest composite samples;

d) the period used for evaluating conformity where this is less than 6 months;

e) the strength test results for the latest combination of composite samples, stating the proportions tested;

f) details of the permitted proportions which conform to the requirements of this annex, stating the combination strength class or classes which apply;

g) the signature of the person responsible for the testing.

5) Marking BS 8500-2:2006, Annex A on or in relation to a product represents a declaration of conformity, i.e. a claim that the product meets the requirements of the annex. The accuracy of the claim is solely the responsibility of the issuer of the certificate. Such a declaration is not to be confused with third-party certification of conformity, which might also be desirable.

Annex C (informative)

Example of the conformity procedure given in Annex A

C.1 General

As an example, Annex C contains a convenient plan for the declaration of conformity to combination strength class 42,5N. It is suitable for one source of addition to be used in combination with several sources of CEM I cement. This plan establishes limits on the proportions of addition with each specific CEM I cement source to ensure that the conformity criteria for strength are met. Four stages are involved.

a) The relationships between compressive strength and proportion of addition are established for each CEM I cement (see C.2).

b) The monthly composite samples of the addition and each CEM I cement are tested in combination, and running means of the early and standard strengths are calculated over not less than 6 months and not more than 12 months (see C.3).

c) The statistical margins are established (see C.4).

d) The relationships, the running means and the statistical margins, together with the requirements for strength class 42,5N in Table A.1, are then used to determine the permitted proportions (see C.5).

C.2 Establishment of the relationship between compressive strength and proportions

A composite sample of the addition is obtained by blending not less than eight spot samples of similar mass obtained at regular intervals over at least one calendar month. A composite sample of each CEM I cement is similarly obtained.

Strength tests are carried out at 2 days and at 28 days, in accordance with BS EN 196-1, on the combinations of the composite samples given in Table C.1.

NOTE This example is for a combination of strength class 42,5N. With some other strength classes, testing at 7 days is required in place of the 2-day testing.

Table C.1 — Mass fraction of addition [a] in combinations for strength testing

ggbs [b] %	Fly ash [b] %	Limestone fines [b] %
0	0	0
30	20	10
50	35	15
70	60	20
90	—	—

[a] The remaining percentage comprises CEM I cement.
[b] Expressed as a percentage of the mass of combination.

C.3 Monthly tests on individual Portland cement with addition

Monthly bulk average samples of the addition and each CEM I cement source are obtained either from the material suppliers or by blending not less than eight spot samples of similar mass, taken regularly throughout the month. These composite samples are combined in the ratios:

50:50 for GGBS to CEM I cement;

15:85 for limestone fines to CEM I cement; or

30:70 for fly ash to CEM I cement.

Tests for strength are carried out in accordance with BS EN 196-1 at 2 days and at 28 days. The mean strength, M, of each combination of addition and a specific CEM I cement is the average of the most recent monthly strength tests taken over a period of not less than 6 months and not more than 12 months.

C.4 Estimation of statistical margin

The statistical margin, m, is either taken as +5 N/mm^2 on the lower limits for standard strength and +3 N/mm^2 on early strength limits (see **A.1**), or calculated by:

$$m = k_A s$$

where k_A is the acceptability constant which depends on the number of samples, n.

Values of k_A corresponding to 5 % of results outside of a required value can be found in BS EN 197-1:2000, Table 6, in the 5 % P_k column. In determining the statistical margin, n is the number of spot sample test results used to calculate the standard deviation.

The standard deviation, s, is determined from data based on the anticipated most variable combination of CEM I cement and addition. The choice of the nominated CEM I cement for the most variable combination is reviewed at least every 2 years. The basis of the review is the variability of the monthly tests of the various combinations given in C.3 or, where no historical data exist for combinations, the variability of the autocontrol data for the various CEM I cements where such information is available.

At least once a week, a spot sample of the addition and a spot sample of the nominated CEM I cement are taken in accordance with BS EN 196-7 and combined in the ratios shown in C.3.The combination is tested in accordance with BS EN 196-1 for strength at 2 days and at 28 days. The standard deviation, s, is calculated from the results of the tests carried out in the test period corresponding to that used in C.3.

C.5 Establishment of limits on proportions

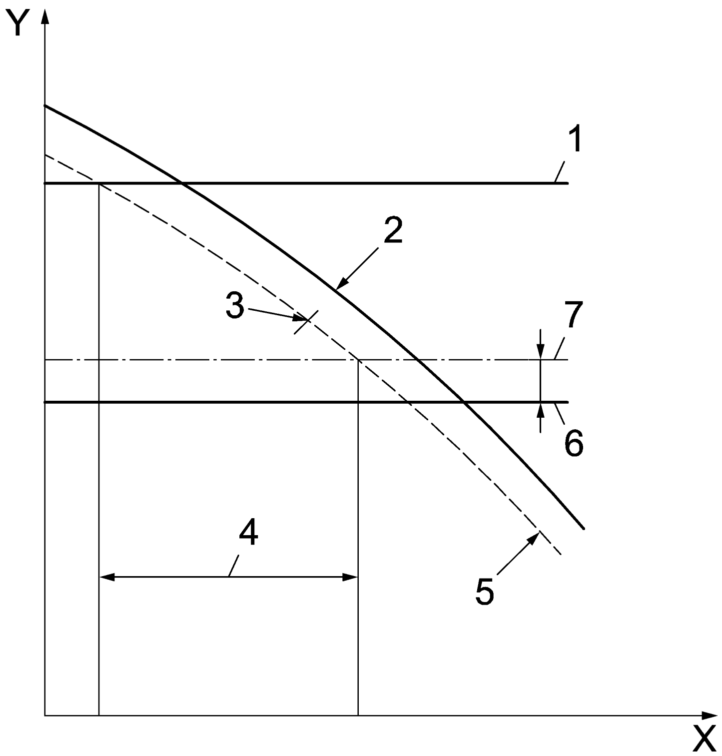
To determine the limits on proportions for the conformity of combinations to strength class 42,5N, construct a diagram showing the relationship obtained in accordance with C.2 between 28-day strength and proportions for the addition with a specific CEM I cement (see Figure C.1). On this diagram, mark a lower limit of 42.5 N/mm^2 + m corresponding to the lower limiting value from Table A.1 plus the margin. Mark an upper limit of 62.5 N/mm corresponding to the upper limiting value.

Then mark the point corresponding to the mean strength, M, determined in accordance with **C.3**. Draw a line through this point, commensurate with the relationship between 28-day strength and proportion.

Conformity with strength class 42,5N is achieved for proportions where this line is between the upper and lower limits.

Carry out a similar exercise for the 2-day strength results (in this case no upper limit is applicable).

The proportions that conform to combination strength class 42,5N are those for which both early and 28-day strength requirements are met, subject to their not exceeding 85 % for GGBS, 20 % for limestone fines or 55 % for fly ash.



Key

1 upper strength limit

2 strength / proportion relationship

3 mean strength

4 range of conforming proportions

5 commensurate relationship

6 lower strength limit

7 lower limits plus the margin

X $\frac{\text{Addition}}{\text{CEM I} + \text{addition}}$ proportion

Y 28-day strength

Figure C.1 — Determination of conformity limits for combinations

4.6.2 How this works when specifying concrete to BS 8500

BS 8500 treats combinations of CEM I and additions as being equivalent to the corresponding factory made cement. The terminology for combinations is identical to that for EN 197-1 cements excepting the prefix is ‘C’ rather than ‘CEM’. Therefore 30 % fly ash factory made cement to EN 197-1 would be a CEM II/B-V and a 30 % fly ash mixer combination tested to BS 8500-2 Annex A is a called a C IIB-V. The full list of notations for combinations is shown below:

Notation		**Composition**
Factory-blended cement	**Within-mixer blend**	
CEM I		Portland cement
CEM II/A-S	CIIA-S	6 to 20 % GGBS
CEM II/B-S	CIIB-S	21 to 35 % GGBS
CEM III/A	CIIIA	36 to 65 % GGBS
CEMIII/B	CIIIB	66 to 80 % GGBS
CEM II/A-V	CIIA-V	6 to 20 % fly ash
CEM II/B-V	CIIB-V	21 to 35 % fly ash
CEM IV/B	CIVB-V	36 to 55 % fly ash
CEMII/A-LL	CIIA-LL	6 to 20 % limestone fines

In BS 8500-1 the permitted cement and combination types are shown in Table A.6, which is reproduced in Figure 2[1)]. BS 8500-1 contains many tables for various exposure conditions as each cement/combinations is treated separately. This is in order to make the best use of a particular cement or combination type for a given durability criteria. Figure 3 is an example for one of the tables within BS 8500 for carbonation, XC. As will be seen the higher ash content mixes have higher Minimum Cement Contents and lower W/C ratios, to compensate for the differing performance of this cementitious type. However, for chloride resistance the benefits of GGBS and fly ash are fully encompassed by the requirements as seen in Figure 4.

1) Figures refer to BS 8500.

Table A.3 — Cements and combinations from BS 8500–1

Table A.6 — Cement and combination types [a]

Broad designation [b]	**Composition**	**Comprises cement and combination types (see** BS 8500–2:2006, Table 1**)**
CEM I	Portland cement	CEM I
SRPC	Sulfate-resisting Portland cement	SRPC
IIA	Portland cement with 6 % to 20 % fly ash, ground granulated bastfurnace slag, limestone, or 6 % to 10 % silica fume [c]	CEM II/A-L, CEM II/A-LL, CIIA-L, CIIA-LL, CEM II/A-S, CIIA-S, CEM II/A-V, CIIA-V, CEM II/A-D
IIB-S	Portland cement with 21 % to 35 % ground granulated blastfurnace slag	CEM II/B-S, CIIB-S
IIB-V	Portland cement with 21 % to 35 % fly ash	CEM II/B-V, CIIB-V
IIB+SR	Portland cement with 25 % to 35 % fly ash	CEM II/B-V+SR, CIIB-V+SR
IIIA [d, e]	Portland cement with 36 % to 65 % ground granulated blastfurnace slag	CEM III/A, CIIIA
IIIA+SR [e]	Portland cement with 36 % to 65 % ground granulated blastfurnace slag with additional requirements that enhance sulfate resistance	CEM III/A+SR [f], CIIIA+SR [f]
IIIB [e, g]	Portland cement with 66 % to 80 % ground granulated blastfurnace slag	CEM III/B, CIIIB
IIIB+SR [e]	Portland cement with 66 % to 80 % ground granulated blastfurnace slag with additional requirements that enhance sulfate resistance	CEM III/B+SR [f], CIIB+SR [f]
IVB-V	Portland cement with 36 % to 55 % fly ash	CEM IV/B(V), CIVB

[a] There are a number of cements and combinations not listed in this table that may be specified for certain specialist applications. See BRE Special Digest 1 [1] for the sulfate-resisting characteristics of other cements and combinations. See IP 17/05 [7] for the use high ggbs content cement.

[b] The use of these broad designations is sufficient for most applications. Where a more limited range of cement or combinations types is required, select from the notations given in BS 8500–2:2006, Table 1.

[c] When IIA or IIA-D is specified, CEM I and silica fume may be combined in the concrete mixer using the k -value concept; see BS EN 206–1:2000, 5.2.5.2.3.

[d] Where IIIA is specified, IIIA+SR may be used.

[e] Inclusive of low early strength option (see BS EN 197–4 and the “L” classes in BS 8500–2:2006, Table A.1).

[f] See BS 8500–2:2006, Table 1, footnote D.

[g] Where IIIB is specified, IIIB+SR may be used.

Table A.4 — The XC requirements in BS 8500–1

Table A.5 — Durability [a] recommendations for reinforced or prestressed elements with an intended working life of at least 100 years

Nominal cover [b] mm	Compressive strength class where recommended, maximum water-cement ratio and minimum cement or combination content for normal-weight concrete with 20 mm maximum aggregate size										Cement/ combination types
	15 + Δc	25 + Δc	30 + Δc	35 + Δc	40 + Δc	45 + Δc	50 + Δc	55 + Δc	60 + Δc	55 + Δc	
Corrosion induced by carbonation (XC exposure classes)											
XC1	C20/25 0,70 240	C20/25 0,70 240	C20/25 0,70 240	C20/25 0,70 240	C20/25 0,70 240	C20/25 0,70 240	C20/25 0,70 240	C20/25 0,70 240	C20/25 0,70 240	C20/25 0,70 240	All in Table A.6
XC2	—	C25/30 0,65 260	C25/30 0,65 260	C25/30 0,65 260	C25/30 0,65 260	C25/30 0,65 260	C25/30 0,65 260	C25/30 0,65 260	C25/30 0,65 260	C25/30 0,65 260	All in Table A.6
XC3/4	—	—	C40/50 0,45 340	C35/45 0,50 320	C30/37 0,55 300	C28/35 0,60 280	C28/35 0,60 280	C28/35 0,60 280	C28/35 0,60 280	C28/35 0,60 280	All in Table A.6 except IVB-V
	—	—	—	C40/50 0,45 340	C35/45 0,50 320	C30/37 0,55 300	C28/35 0,60 280	C28/35 0,60 280	C28/35 0,60 280	C28/35 0,60 280	IVB-V

[a] Where appropriate, account should be taken of the recommendation to resist freeze–thaw damage (see A.4.3, Table A.8), aggressive chemicals (see A.4.4, Table A.11) and abrasion (no guidance).

[b] Expressed as the minimum cover to reinforcement plus an allowance in design for deviation, Δc, e.g. to allow for workmanship. Check the appropriate design code to see whether it is recommended that the minimum cover to prestressing steel is adjusted by a factor (NOTE Factor see NOTE B of BS 8500–1).

Table A.5 — The XD and XS requirements in BS 8500-1

Corrosion induced by chlorides (SX from sea water, XD other than see water)

Also adequate for any associated carbonation induced corrosion (XC)

XD1	—	—	C45/55 0,40 380	C40/50 0,45 340	C35/45 0,50 320	C32/40 0,55 300	C28/35 0,60 280	C28/35 0,60 280	C28/35 0,60 280	C28/35 0,60 280	All in Table A.6
XS1	—	—	—	—	—	0,35 380 (C45/55)	0,40 380 (C40/50)	0,45 360 (C35/45)	0,45 360 (C35/45)	0,45 360 (C35/45)	CEM I, IIA, IIB-S, SRPC
	—	—	—	0,40 380 (C35/45)	0,45 360 (C32/40)	0,50 340 (C28/35)	0,55 320 (C25/30)	0,55 320 (C25/30)	0,55 320 (C25/30)	0,55 320 (C25/30)	IIB-V, IIIA
	—	—	—	0,45 360 (C35/45)	0,50 340 (C32/40)	0,55 320 (C28/35)	0,60 300 (C25/30)	0,60 300 (C25/30)	0,60 300 (C25/30)	0,60 300 (C25/30)	IIIB, IVB-V
XD2 or XS2	—	—	—	—	0,40 380 (C40/50)	0,50 340 (C32/40)	0,55 320 (C25/35)	0,55 320 (C25/35)	0,55 320 (C25/35)	0,55 320 (C25/35)	CEM 1, IIA, IIB-S, SRPC
	—	—	—	—	0,40 380 (C35/45)	0,50 340 (C28/35)	0,55 320 (C25/30)	0,55 320 (C25/30)	0,55 320 (C25/30)	0,55 320 (C25/30)	IIIB-V, IIA
	—	—	—	—	0,40 380 (C32/40)	0,50 340 (C25/30)	0,55 320 (C20/25)	0,55 320 (C20/25)	0,55 320 (C20/25)	0,55 320 (C20/25)	IIIB, IVB-V

4.7 Additional information to the Irish method

Annex to the Irish method from I.S. 206-1:

Annex NE (informative)

Conformity procedure for cement – GGBS combinations in accordance with I.S. EN 206-1

Introduction

This annex sets out a procedure for establishing the suitability of a range of combinations of a specific cement of the strength class 42.5 with a specific GGBS, which can count towards limiting values.

Specific suitability has been established for the combination of a certified GGBS and CEM I, CEM II/A-L (LL), CEM II/A-S, CEM II/A-V cement up to a total replacement level of 70 % GGBS, where the GGBS content of CEM II/A-S shall count towards this total replacement level of 70 % GGBS.

I.S. EN 206-1 may place further restrictions on the proportion of GGBS depending on the exposure class in which the concrete is to be used.

This annex meets the requirements for establishing suitability for the use of GGBS in concrete conforming to I.S. EN 206-1.

NE.1 General

The procedure shall be used only for combinations of cements of standard strength class 42.5 certified to I.S. EN 197-1 with GGBS conforming to I.S. EN 15167-1.

The procedure applies to proportions of GGBS to cement up to 70 % GGBS, and determines a pass/fail on the basis of a particular combination meeting the strength requirements in Table NE.1.

Table A.6 (NE.1) — Requirements for the compressive strength of combinations

Combination	Lower Strength Limit	
	Early Strength ≥ 20 N/mm^2	Standard Strength ≥ 42,5 N/mm^2
50 % GGBS	7 Days	28 Days
70 % GGBS	7 Days	56 Days

NOTE The standard strength of a 70 % GGBS replacement combination is tested at 56 days due to its recognized slower strength development to 28 days and continued strength development thereafter.

NE.2 Procedure

NE.2.1 Sampling

Monthly bulk average samples of each cement source are obtained from the material supplier. A composite sample of GGBS is obtained by blending not less than eight spot samples of similar mass, taken at regular intervals throughout the month. These cement and GGBS samples are combined at 50 % and 70 % GGBS replacement levels.

NE.2.2 Testing

The monthly combined samples are tested for early and standard strength in accordance with I.S. EN 196-1 at 7, 28 and 56 days, as noted in Table NE.1. These test results are termed ‘monthly averages’.

NE.2.3 Assessment

NE.2.3.1

The monthly averages for early and standard strength are compared to the lower strength limit requirements in Table NE.1.

NE.2.3.2

The running mean of not less than six months and not more than one year of the monthly averages are compared to the lower limit strength requirements in Table NE.1 plus the statistical margin. The statistical margin added to the lower limits shall be +3 N/mm^2 for early strength limits and +5 N/mm^2 for standard strength (28 or 56 day) limits.

NE.2.4 Conformity

On meeting the minimum strength criteria, a combination is said to be a “permitted proportion” in combination with cements of the strength class of 42.5. If a permitted proportion is established, combinations of lesser proportions of GGBS are also permitted proportions.

NE.3 Issue of certificates

Certificates of conformity to this annex are to be issued. The certificates shall contain the following information:

a) the source of certified GGBS to be tested as a combination;

b) the source of cement to be tested as a combination;

c) the means by which samples of the GGBS and cement were obtained;

d) the month represented by the latest samples;

e) details of the permitted proportions which conform to the requirements of this annex;

f) the signature of the person responsible for the testing.

4.8 Additional information to the Portuguese method

Annex to the Portuguese method form LNEC specification E 464:

The prescriptive requirements for XS and XD are presented in the following table. As can be seen, in addition to the requirements for concrete, a minimum nominal cover (minimum cover + 10 mm) is also established.

Table A.7 — Limits for the composition and the compressive strength class of the concrete under the action of chlorides, for a design working life of 50 years

Type of cement	**CEM IV/A (Reference); CEM IV/B; CEM III/A; CEM III/B; CEM V; CEM II/B [a]; CEM II/A-D**			**CEM I; CEM II/A [a]**		
Exposure class	XS1/ XD1	XS2/ XD2	XS3/ XD3	XS1/ XD1	XS2/ XD2	XS3/ XD3
Minimum nominal cover (mm)	45	50	55	45	50	55
Maximum water/cement ratio	**0,55**	**0,55**	**0,45**	**0,45**	**0,45**	**0,40**
NE. 4 Minimum cement content, C (kg/m^3)	**320**	**320**	**340**	**360**	**360**	**380**
Minimum strength class	**C30/37 LC30/33**	**C30/37 LC30/33**	**C35/45 LC35/38**	**C40/50 LC40/44**	**C40/50 LC40/44**	**C50/60 LC50/55**
[a] Not applicable to cements II-T, II-W, II/B-L and II/B-LL.						

Usually, when combining a cement with an addition, a simple calculation allows us to quantify the composition of the combination, even if an amount of a constituent has to be disregarded in order to comply with Table 1 of EN 197-1. However, a general systematic procedure is presented below, where the word “binder” is used to designate the part of the combination that equates to the correspondent cement and that should be used in verifying the prescriptive requirements. It has to be noted that the calcium sulfate content is not considered in this calculations for simplification reasons.

Procedure to quantify the composition of combinations

Let us consider a combination of mass D_0, consisting of one or several cements and additions. In order to determine the amount of binder, DL, and its composition, the following procedure shall be adopted:

A.1 The content, CS_i, and the preliminary percentages of each constituent material included in the total of the combination of the mass D_0 are determined. In the cement(s) used, its constituents shall be considered separately, by assuming the minimum clinker percentage foreseen in the EN 197-1 or declared by the manufacturer.

In cements with an indistinct set of constituents, e.g. CEM II/A-M, one should obtain information (e.g. from the manufacturer) of the relative amount of each constituent and consider them separately when determining their contents.

A.2 The cement, of which the equivalence is to be established, is selected from Table 1 of the EN 197-1, so that its constituents have a correspondence in the combination considered. If the selected correspondent cement has an indistinct set of constituents, this set shall be considered together as a single constituent.

If the percentage of each constituent of the combination fulfils the composition of the selected cement, the value of D_0 will be taken as binder content, DL, by considering the binder equivalent to the selected cement. Otherwise, the prescriptions given in A.3 are to be followed.

A.3 For each constituent i of the combination included in the main constituents of the cement selected in the previous clause, the maximum $D_{\text{max\_i}}$ and minimum $D_{\text{min\_i}}$ binder amount is determined by considering the upper $\text{lim}_{\text{upp\_i}}$ and lower $\text{lim}_{\text{low\_i}}$ limits of each constituent in the selected cement, in accordance with Table 1 of the EN 197-1. Therefore, from content CS_{i} of constituents, determined in A.1, a set of n intervals is defined $[D_{\text{min\_i}}, D_{\text{max\_i}}]$, in which:

$$D_{\text{max\_i}} = \frac{CS_{\text{i}}}{\text{lim}_{\text{low\_i}}} \tag{1}$$

$$D_{\text{min\_i}} = \frac{CS_{\text{i}}}{\text{lim}_{\text{upp\_i}}} \tag{2}$$

The preliminary binder content DL_{p} will be the lower of all the $D_{\text{max\_i}}$ determined by Formula (1).

If $DL_{\text{P}} > D_0$ the prescriptions given in A.4 and A.6 will be followed; if $DL_{\text{P}} < D_0$, the recommendations given in A.5 and A.6 shall be observed.

A.4 For each constituent i of which the $D_{\text{min\_i}}$ is higher than D_0, it will be necessary to consider a lower CSi_{alt} content, which will simultaneously fulfil the conditions as follows:

$$CSi_{\text{alt}} = \text{lim}_{\text{upp\_i}} \times \left[\left(\sum_{i}^{n-1} \text{remaining } CS_{\text{i}} \right) + CSi_{\text{alt}} + CM_{\text{mist}} \right] \tag{3}$$

$$CM_{\text{mist}} \leq \frac{\left(\sum_{i}^{n-1} \text{remaining } CS_{\text{i}} \right) + CSi_{\text{alt}}}{0{,}95} \times 0{,}05 \tag{4}$$

$$CM_{\text{mist}} \leq D_0 - \left[\left(\sum_{i}^{n-1} \text{remaining } CS_{\text{i}} \right) + CSi_{\text{alt}} \right] \tag{5}$$

Therefore, CSi_{alt} is the lower value of the determinations presented below:

$$CSi_{\text{alt}} = \frac{\text{lim}_{\text{sup\_i}}\, x \sum_{i}^{n-1} \text{remaining } CS_{\text{i}}}{0{,}95 - \text{lim}_{\text{upp\_i}}} \tag{6}$$

$$CSi_{\text{alt}} = \text{lim}_{\text{upp\_i}} \times D_0 \tag{7}$$

In the case of various constituents to be modified, an interval of values is obtained, for each one, which verifies Formula (3).

A.5 For each constituent i of which the $D_{\text{min\_i}}$ is higher than DL_{P}, it will be necessary to consider a lower CSi_{alt} content, thus:

$$CSi_{\text{alt}} = \lim_{\text{sup\_i}} \times DL_{\text{p}} \tag{8}$$

$$\text{If, } \left(\sum_{i}^{n-1} \text{remaining } CS_{\text{i}} \right) + CSi_{\text{alt}} \geq DL_{\text{P}} \text{ is observed} \tag{9}$$

then, DL = DL_{P} and there is no place for minor constituents in the combination, CM_{mist}, thus:

$$CSi_{\text{alt}} = DL_{\text{P}} - \left(\sum_{i}^{n-1} \text{remaining} CS_{\text{i}} \right) \tag{10}$$

$$\text{If } \left(\sum_{i}^{n-1} \text{remaining } CS_{\text{i}} \right) + CSi_{\text{alt}} < DL_{\text{P}} \text{ is observed} \tag{11}$$

then, there is a place for minor constituents in the combination, CM_{mist}, thus:

$$CM_{\text{mist}} \leq \frac{\left(\sum_{i}^{n-1} \text{remaining } CS_{\text{i}} \right) + CSi_{\text{alt}}}{0{,}95} \times 0{,}05 \tag{12}$$

$$\text{and } \left(\sum_{i}^{n-1} \text{remaining } CS_{\text{i}} \right) + CSi_{\text{alt}} + CM_{\text{mist}} = DL_{\text{P}} \tag{13}$$

A.6 The binder content DL to be considered corresponds to the sum of all the constituents (both main and minor), selected in A.2 of which the amounts were determined in A.1 and A.4 or A.5:

$$DL = \left(\sum_{i}^{n-1} \text{remaining } CS_{\text{i}} \right) + CSi_{\text{alt}} + CM_{\text{mist}} \tag{14}$$

If the selected correspondent cement has an indistinct set of constituents and the total amount of this set cannot count fully to the binder content, then the excess of less reactive constituent(s) shall be disregarded.

Examples

<u>Example 1</u>

Let us consider the following combination:

— 300 kg/m^3 of cement CEM II/A-L 42.5 R, 70 kg/m^3 of fly ash and 130 kg/m^3 of ground granulated blastfurnace slag. Thus D_0 = 500 kg/m^3.

NOTE The calcium sulfate content is not taken considered in this calculations for simplification reasons.

A.1 The combination constituents and the corresponding contents are as follows:

Clinker – CS_{k} = 0,80 × 300 = 240 kg/m^3 → 48,0 % of D_0 (the minimum content was considered).

Limestone – CS_{l} = 0,20 × 300 = 60 kg/m^3 → 12,0 % D_0.

Minor constituents – CS_{m} = 0 → it is considered that they are included in the limestone.

Fly ash – CS_{v} = 70 kg/m^3 → 14,0 % D_0.

Slag – CS_{s} = 130 kg/m^3 → 26,0 % D_0.

That combination does not correspond to any cement of Table 1 of the EN 197-1. Therefore, the binder composition shall be re-calculated.

A.2 The CEM V/A is selected, by taking into account that the combination has a large quantity of fly ash and ground granulated blastfurnace slag, thus excluding the limestone.

A.3 For each constituent CS_{i_mixt} we have:

a. Clinker - D_{max_k} = 240 / 0,40 = 600,0 kg/m^3

D_{min_k} = 240 / 0,64 = 375,0 kg/m^3

b. Fly ash - D_{max_v} = 70 / 0,18 = 388,9 kg/m^3

D_{min_v} = 70 / 0,30 = 233,3 kg/m^3

c. Slag - D_{max_s} = 130 / 0,18 = 722,2 kg/m^3

D_{min_s} = 130 / 0,30 = 433,3 kg/m^3

Thus, $DL_P = \min(D_{max\_i}) = D_{max\_v}$ = 388,9 kg/m^3 < D_0.

A.4 Not applicable.

A.5 It is observed that for ground granulated blastfurnace slag $D_{min\_s} > DL_P$, i.e. the content of that constituent shall be modified. By taking the upper limit for ground granulated blastfurnace slag and according to (8), we have CS_{s_alt} = 388,9 × 0,30 = 116,7 kg/m^3. Since condition (9) is observed (240 + 70) + 116,7 ≥ 388,9 kg/m^3 we have $DL = DL_P$ and there is no place for minor constituents, according to (10) CS_{s_alt} = 388,9 - (240 + 70) = 78,9 kg/m^3.

A.6 The binder content to be considered as equivalent to cement CEM V/A is 388,9 kg/m^3, with the combination as follows:

Clinker – 240,0 kg/m^3 → 61,7 %.

Fly ash – 70,0 kg/m^3 → 18,0 %.

Slag – 78,9 kg/m^3 → 20,3 %.

Thus, 111,1 kg/m^3 of the initial combination could not be considered as binder.

Example 2

Let us consider the combination as follows:

— 200 kg/m^3 of cement CEM I 42.5 R containing 80 kg/m^3 of fly ash and 140 kg/m^3 of ground granulated blastfurnace slag. Then D_0 = 420 kg/m^3.

A.1 The combination constituents and corresponding contents are as follows:

Clinker – CS_k = 0,95 × 200 = 190 kg/m^3 → 45,2 % D_0.

Minor constituents – CS_m = 0,05 × 200 = 10 kg/m^3 → 2,4 % D_0.

Fly ash – CS_v = 80 kg/m^3 → 19,0 % D_0.

Slag – CS_s = 140 kg/m^3 → 33,3 % D_0.

That combination does not correspond to any cement of Table 1 of the EN 197-1:2011. Therefore, the binder composition should be re-calculated.

A.2 The CEM V/A is selected, by taking into account that the combination has a large quantity of fly ash and ground granulated blastfurnace slag.

A.3 For each component CS_{i_mist} we have:

a. Clinker - D_{max_k} = 190 / 0,40 = 475,0 kg/m^3

D_{min_k} = 190 / 0,64 = 296,9 kg/m^3

b. Fly ash - D_{max_v} = 80 / 0,18 = 444,4 kg/m^3

D_{min_v} = 80 / 0,30 = 266,7 kg/m^3

c. slag - D_{max_s} = 140 / 0,18 = 777,8 kg/m^3

D_{min_s} = 140 / 0,30 = 466,7 kg/m^3

Therefore:

DL_P = min(D_{max_i}) = D_{max_v} = 444,4 kg/m^3 > D_0.

A.4 It is observed that for ground granulated blastfurnace slag $D_{min\_s} > D_0$, i.e. the content of that constituent should be modified. Thus, according to (6) and (7)

CS_{s_alt} = min [0,30* (190 + 80) / (0,95 – 0,30); 0,30*420] = min[124,6 ; 126,0] = 124,6 kg/m3.

Consequently, the content of minor constituents is the higher value that verifies the conditions (4) and (5). Therefore CM_{mixt} = 20,8 kg/m^3.

A.5 Not applicable.

A.6 The binder content to be considered as equivalent to cement CEM V/A is 415,4 kg/m^3, with the combination as follows:

Clinker – 190,0 kg/m^3 → 45,7 %.

Fly ash – 80,0 kg/m^3 → 19,3 %.

Slag – 124,6 kg/m^3 → 30,0 %.

Minor constituents – 20,8 kg/m^3 → 5,0 %.

Thus, 4,6 kg/m^3 of the initial combination could not be considered as binder, 10,8 kg/m^3 of ground granulated blastfurnace slag being considered as part of minor constituents.

List of symbols

CM_{mixt}	—	Quantity of minor constituents in the combination	DL_{P}	—	Preliminary binder content
CS_{i}	—	Quantity of constituent i of the combination	$D_{\mathrm{max\_i}}$	—	Maximum binder amount for constituent i considering $\lim_{\mathrm{inf\_i}}$
CSi_{alt}	—	Modified quantity of constituent *i* of the combination	$D_{\mathrm{min\_i}}$	—	Minimum binder amount for constituent i considering $\lim_{\mathrm{sup\_i}}$
D_0	—	Mass of the initial combination to be verified	$\lim_{\mathrm{low\_i}}$	—	Lower admissible limit for constituent i in the cement or in the equivalent binder
DL	—	Binder content	$\lim_{\mathrm{upp\_i}}$	—	Upper admissible limit for constituent i in the cement or in the equivalent binder

Annex A
(informative)

Replies to the k -value questionnaire of CEN/TC 104/SC 1/TG 5

A.1 General questionnaire

This is a compilation of answers to the TG5 questionnaire on the determination of the k-value in the member countries of TG5.

The following countries have answered to the questionnaire. (status 04.08.2011)

- AT Austria
- BE Belgium
- DK Denmark
- FI Finland
- FR France
- DE Germany
- IE Ireland
- NL Netherlands
- PT Portugal
- ES Spain
- SE Sweden
- UK United Kingdom

The answers to the questionnaire are given question by question. Ireland, Portugal and the UK has answered as follows:

IE	The k-value concept is not applied for GGBS and silica fume is not used in Ireland
NL	Additions are used with the k-value concept as well as with the equivalent concrete performance concept
PT	The k-value concept is not used in Portugal
UK	The k-value clauses for fly ash and silica fume in EN 206–1 have never been used in the UK for the design of a concrete structure. A k-value concept for GGBS has never been used in the UK for the design of a concrete structure Therefore, we cannot report any supplies of additions using this concept. However, the Combinations concept was introduced into British Standards in 1982.

TG 5 Questionnaire

How has the *k*-value been established?	Literature review Research Experience in concrete usage Other (specify)
What age compressive strength is used?	28 56 90 Other
What type of specimen?	Mortar prism Concrete
Which method of calculation has been used to determine the *k*-value (if any)?	
With which cement types can the addition be used?	
What is the maximum % of addition permitted to be used?	
What *k*-value(s) are applied in concrete practice?	
Have durability measurements been taken into account in determining the *k*-value?	Y/N If yes, specify.
Describe the method of calculation employed by the concrete manufacturer in applying the *k*-value.	
How many tonnes per year of addition are currently used under the *k*-value(s)?	
For how long has the *k*-value(s) been used?	

1. How has the *k*-value been established?		
AT	Literature review Research Experience in concrete usage Other (specify)	— X X —
BE	Literature review Research Experience in concrete usage Other (specify)	X X X —
DK	Literature review Research Experience in concrete usage Other (specify)	X X X Study of performance of 4 – 6 years old concrete in real structures.
FI	Literature review Research Experience in concrete usage Other (specify)	X X X —
FR	Fly ash Silica fumes	Research (depending of activity index) Concrete experience

	GGBS	Experts consensus
DE	Literature review Research Experience in concrete usage Other (specify)	— X X —
IE	Literature review Research Experience in concrete usage Other (specify)	— — — k-value is given in IS EN 206–1:2002+NA 2007, 5.2.5.2.2 + NA 2.7
NL	Literature review Research Experience in concrete usage Other (specify)	— X X —
ES	Literature review Research Experience in concrete usage Other (specify)	— — — (no k-value is accepted for additions)
SE	Literature review Research Experience in concrete usage Other (specify)	X X — —

2. What age compressive strength is used?		
AT	28	
BE	28	
DK	28	
FI	28 90	for GGBS, PFA and Silica Fume in special cases 91 d (for GGBS only!)
FR	Fly ash Silica fumes GGBS	28 and 90 days 28 days 7 and 28 days
DE	28	
IE	28	
NL	28	
ES	-	
SE	28 Other:	—Some research has been done at both shorter (1–14 days) and longer (1 year) ages

3. What type of specimen?		
AT	Mortar prism Concrete	X —
BE	Mortar prism Concrete	— X

DK	Mortar prism Concrete	— X
FI	Mortar prism Concrete	Quality control of fly ash and GGBS Quality control of concrete
FR	Mortar prism Concrete	Tests for activity index on mortar —
DE	Mortar prism Concrete	— X
IE	Mortar prism Concrete	— X
NL	Mortar prism Concrete	— X
ES	Mortar prism Concrete	— —
SE	Mortar prism Concrete	X X

4. Which method of calculation has been used to determine the *k*-value (if any)?	
AT	Activity index
BE	none
DK	none
FI	—
FR	No direct tests for *k*-value Tests for activity index depending of relevant addition standard's
DE	Relationship of compressive strength and water/cement ratio of reference concrete and concrete with addition as described in CEN report "*k*-value for powder coal fly ash, Method 2 [TG5-07]
IE	none
NL	Relationship of compressive strength and water/cement ratio of reference concrete and concrete with addition as described in CEN report "*k*-value for powder coal fly ash, Method 2 [TG5-07]
ES	—
SE	By equalizing strength for a certain w/c-ratio for CEM I and the strength for the w/(c+k*a) for the cement + addition

5. With which cement types can the addition be used?		
AT	CEM I CEM II/A 32,5 CEM II/A 42,5 CEM II/B 32,5 CEM II/B 42,5	30 % of (CEM+Addition) 15 % of (CEM+Addition) 20 % of (CEM+Addition) 0 % of (CEM+Addition) 10 % of (CEM+Addition)
BE	Fly ash	CEM I CEM III/A CEM III/B (with k = 0) CEM III/C (with k = 0). Remark: In near future, if code revisions are accepted, also in combination with CEM II/A-LL and CEM II/B-LL (with k = 0), and with CEM II/A-S and CEM II/B-

		S.	
	Silica fume	CEM I	
	Approved GGBS	CEM I	
DK		Cement strength > 42.5	Cement strength > 32.5
	Fly ash	CEM I CEM II/A-L CEM II/A-LL	CEM II/A-M – *Only for X0 and XC1* CEM II/B-M – *Only for X0 and XC1*
	Silica fume	CEM I CEM II/A-L CEM II/A-LL CEM II/A-V CEM II/B-V	CEM II/A-M – *Only for X0 and XC1* CEM II/B-M – *Only for X0 and XC1*
	GGBS	not allowed	
FI	All types taking into account the additions already used in the cement		
FR	CEM I		

DE	Fly ash acc. EN 450–1 and GGBS acc. EN 15167–1:	CEM I CEM II/A-D CEM II/A-S or CEM II B-S CEM II/A-T oder CEM II/B-T CEM II/A-LL CEM II/A-P CEM II/A-V CEM II/A-M with main constituents S, D, P, V, T, LL CEM II/B-M (S-D, S-T, D-T) CEM III/A CEM III/B with up to 70 % for blast furnace slag
	Silica fume acc. EN 13263–1 (class 1)	CEM I CEM II/A-S or CEM II B-S CEM II/A-T or CEM II/B-T CEM II/A-P or CEM II/B-P CEM II/A-V CEM II A-LL CEM II/A-M with main constituents S, P, V, T, LL CEM II/B-M (S-T, S-V) CEM III/A CEM III/B
IE	Fly ash	CEM I, CEM II A-L(LL) and CEM II A-V
NL	Fly ash acc. EN 450–1 (cat. A and N)	CEM I CEM III/A CEM III/B
	Silica fume acc. EN 13263–1	CEM I

ES	Fly ash Silica fume GGBS	CEM I CEM I not allowed
SE	CEM I and CEM II	

6. What is the maximum % of addition permitted to be used?		
AT	CEM I CEM II/A 32,5 CEM II/A 42,5 CEM II/B 32,5 CEM II/B 42,5	30 % of (CEM+Addition) 15 % of (CEM+Addition) 20 % of (CEM+Addition) 0 % of (CEM+Addition) 10 % of (CEM+Addition)
BE	Fly ash	CEM I 33 % CEM III/A 25 %. Remark: — in case of XF-classes: For FA with LOI between 5 % and 7 %: maximum addition is 25 %. — in near future, if code revisions are accepted: CEM II/A-S and CEM II/B-S: max 25 % FA
	SF	11 %
	Approved GGBS	normally 30 % and 15 % for XS1, XS2, XS3, XD2, XD3, XF4, 0 % for XA3
DK	Fly ash	X0 and XC1: No limitation *CEM I:* XF: 33 % of the cement weight XC, XS, XD and XA: 67 % of the cement weight *CEM II:* XC, XS, XD, XF and XA: 33 % of the cement weight
	Silica Fume	X0 and XC1: No limitation XC, XS, XD, XF and XA: 11 % of the cement weight
	GGBS	Not allowed
FI	Fly ash	Depending on the environmental class 23 – 50 % of the total binder content
	Silica fume	10 % of the total binder content
	GGBS	Depending on the environmental class 50 – 95 % of the total binder content (see Annex 1).
FR	see Annex 2	
DE	Fly ash acc. EN 450–1	33 % (f/c ≤ 0,33) with CEM I CEM II/A-[S, T, LL] CEM II/B-[S, T] CEM II/A-M [(S-T),(S-LL),(T-LL)] CEM II/B-M (S-T) CEM III/A CEM III/B with up to 70 % for blast furnace slag 25 % (f/c ≤ 0,25) with CEM II/A-P CEM II/A-V

		CEM II/A-M [(S-P)*,(S-V),(P-V)*,(P-T)*,(P-LL)*,(V-T),(V-LL)] 15 % (f/c ≤ 0,15) with CEM II/A-D CEM II/A-M [(S-D), (D-T, (D-LL), (D-P)*, (D-V)*] CEM II/B-M [(S-D), (D-T)]
	Silica fume acc. EN 13263–1 (class 1)	11 % (s/c ≤ 0,11) with cements given above for silica fume *excluded from application in XF2 and XF4

	GGBS acc EN 15167-1	Same rules like for fly ash but excluded from application in XF2 and XF4 NOTE for GGBS of specific sources and cement of specific sources also an “exchange concept” was developed which is applied by national approval.
IE	Fly ash	33 %
NL	Fly ash acc. EN 450-1	33 % (f/c ≤ 0,33)
	Silica fume acc. EN 13263-1	11 % (s/c ≤ 0,11)
ES	Fly ash	Pre-stressed concrete: 20 % High stress concrete: max. 20 % + max. 10 % silica fume Other concretes: 35 %
	Silica fume	Pre-stressed concrete: 10 % High stress concrete: max. 10 % + max. 20 % fly ash Other concretes: 10 %
	GGBS	not allowed
SE	The figures below are valid for CEM I. (For CEM II the max % of addition shall be related to the minimum clinker content for type A and B.) Maximum % of addition to be used with the k-value. Expressed as addition/cement:	
	Fly ash	25 % for XS3, XD3 and XF4 33 % for other exposure classes
	Silica fume	5 % for XF3 and XF4 11 % for other exposure classes
	GGBS	100 % for XC1 and XC2 and XA1 25 % for XS3, XD3 and XF4 50 % for other exposure classes

7. What k-value(s) are applied in concrete practice?		
AT	0,4 0,8	additions according EN 450, EN 15167 additions with higher quality according ÖNORM B 3309–1,-2, −3
BE	Fly ash	CEM I 32.5: k = 0,2 CEM I 42.5 and higher: k = 0,4 CEM III/A: k = 0,2 CEM III/B and III/C: k = 0

		Remark in case of XC3 and XC4: for CEM I, if amount of fly ash > 33 %, then $k = 0$ (for the entire fly ash content). Similar remark if fly ash > 25 % in case of CEM III/A.
	Silica fume	w/c up to 0,45 $k = 2$, w/c above 0,45 $k = 2$ except for XC and XF for which $k = 1$
	Approved GGBS	0,9
DK	Fly ash	0,5
	Silica fume	2,0
	GGBS	n.a.
FI	Fly ash	0,4
	Silica fume	2,0 when w/c < 0,45 and 1,0 when w/c > 0,45
	GGBS	0,8 and 1,0
FR	Fly ash	0,4; 0,5 and 0,6 (mostly 0,6)
	Silica fume	2,0
	GGBS	0,9 (but the k-concept is seldom used – see GGBS concrete productions figures)

DE	Fly ash acc. EN 450–1	$k = 0,4$ $k = 0,7$ for bored piled concrete and under water concrete
	Silica fume acc. EN 13263–1 (cl. 1)	$k = 1,0$ (except for XF2 and XF4)
	GGBS	$k = 0,4$ (as for fly ash; but no concrete praxis)
IE	$k = 0,4$ with CEM II/A cements	
NL	Fly ash acc. EN 450–1 (Cat A and N)	— CEM I 32.5: $k = 0,2$ — CEM I 42.5: $k = 0,4$ — CEM III A: $k = 0,2$ — CEM III B: $k = 0,2$
	Silica fume acc. EN 13263–1	$k = 2,0$ $k = 1,0$ (for XC and XF if w/c > 0,45)
ES	Fly ash $k1$ =	max. $k1 = 0,20$ if cement 32,5 strength max. $k1 = 0,40$ for other strength
	Silica fume $k2$ =	max. $k2 = 2$ for all strengths max. $k2 = 1$ if w/c > 0,45 and XF exposure classes
	GGBS	N.a.
SE	Fly ash	Normally 0,4
	GGBS	Normally 0,6
	For a comprehensive compilation of Swedish rules, see the document TG5–76	

8. Have durability measurements been taken into account in determining the *k*-value?		
AT	Y/N	yes for each addition product during initial test
	If yes, specify	equal quality (CEN/TS 12390-9 slab test an CEN/TR 15177 beam test) with Binder (CEM I+addition) and CEM I alone
BE	Y/N	N
DK	Y/N	Y
	If yes, specify	Comparison between nominal identical concrete types (same 28 days strength) made with CEM I or CEM I + additions. Comparison was made both on laboratory specimens as well as on cores taken from 4 – 6 years old structures. The judgement of the *k*-factors was based on studies of strength, carbonation, freeze/thaw, chloride penetration, ASR and microstructure.
FI	Y/N	Yes
	If yes, specify	different *k*-values in different environmental classes
FR	Y/N	N
DE	Y/N	Y
	If yes, specify	— freeze-thaw-resistance and freeze-thaw resistance with deicing agent — carbonation — corrosion — alkalinity
IE	Y/N	N
NL	Y/N	Y
	If yes, specify	— Freeze-thaw-resistance and freeze-thaw resistance with deicing agent — Carbonation — Corrosion
ES	Y/N	Y
	If yes, specify	to assure that the durability of the concrete with addition is the same of the concrete without any addition.
SE	Y/N	N (only indirectly)

9. Describe the method of calculation employed by the concrete manufacturer in applying the *k*-value.	
AT	Table in concrete standard ÖNORM B 4710–1
BE	See NAD
DK	Equivalent w/c-ratio $(w/c)_{eq} = w / (c + k_{FA} * FA + K_{MS} * MS)$
FI	Cement content = CEM I + *k* * addition > minimum Water / (CEM I + *k* * addition) < maximum
FR	The “equivalent binder” content = $c + kA$ should verify Table NA F 1 (see annex) water ratio = $w/c + kA$
DE	Normal mix calculation based on EN 206–1 and DIN 1045–2 for use of additions
IE	Max w/c Ratio = *w*/(cement + (K*PFA))
NL	Normal mix calculation based on EN 206–1 and NEN 8005 for use of additions
ES	<u>Fly ash</u> $w/c_{equiv} = w / (c + k1*FA)$ max. $k1$ = 0,20 if cement 32,5 strength

	max. $k1$ = 0,40 for other strengths Silica fume $w/c_{equiv} = w / (c + k2*SF)$ max. k 2 = 2 for all strengths max. k 2 = 1 if w/c > 0,45 and XF exposition classes
SE	The k-value is used to calculate the w/c_{eq} value according to the expression $w/c_{eq} = w / (c + k * A)$ The requirement on w/c eq ratio depends on the exposure class.

10. How many tonnes per year of addition are currently used under the k-value(s)? Information removed for competition reasons!		
AT		
BE		
DK	Fly ash	
	Silica fume	
	GGBS	
FI	Fly ash	
	Silica fume	
	GGBS	
FR	Fly ash	
	Silica fume	
	GGBS	
DE	Fly ash	
	Silica fume	
	GGBS	
IE	Fly ash	
NL	Fly ash	
	Silica fume	
	GGBS	
ES		
SE	Fly ash	
	Silica fume	
	GGBS	
11. For how long has the k -value(s) been used?		
AT	10 Years (20 Years guideline)	
BE	Fly ash	for w/c since 1992, for Cmin since 2006
	Silica fume	since 2006

	Approved GGBS	since 2002
DK	Fly ash and Silica fume (Micro Silica) have been used in Denmark since 1975/-76. For the first app. 10 years, *k*-factors solely based on strength were used; k_{FA} = 0,3 and k_{MS} = 3,0 *k*-factors of 0.5 and 2.0 respectively for Fly Ash and Microsilica have been used since April 1987, according to The Danish Society of Engineers advice on "The Use of Fly Ash and Microsilica in Structural Concrete".	
FI	Since early 1980s	
FR	1994	
DE	> 40 years	
NL	25 years	
IE	Since 2006	
ES	- -	
SE	25 years	

A.2 Addition to answer of Finland

Additional comment of Finland to the maximum amount of GGBS permitted to be used.

We have just agreed on a new National Annex of EN 206:2013. This has not yet been published so today we are still using the old NA. In the old version GGBS has a *k*-value of 0,8 in all environmental classes except in the case of sulfate attack where *k* = 1,0 is applied. The maximum % of addition is 375 % of CEM I amount ie. ca. 80 % of total binder content. When using CEM II or CEM III cements the additions in the cement are taken into account and the slag content has to be less than 80 % of the slag + clinker content.

The new NA gives GGBS *k*-values depending on the environmental class. In X0, XC1, XS1, XS2, XS3, XD1, XD2, XD3, XF1 and XF3 the *k*-value is 1,00. In XC2, XC3, XC4, XF2 and XF4 *k* = 0.80. In XA1, XA2 and XA3 *k* = 0,80, but in case of sulfate attack *k* = 1.00. The maximum % GGBS addition with CEM I cement is 1900 % in X0 and XC1, 375 % in XC2, XC3, XC4, XS1, XS2, XS3, XD1, XD2, XD3, XF1, XF3 and XA1 and 100 % in XF2 and XF4. In XA2 and XA3 the designer has to specify the binder taking into account the nature of the chemical attack. In sulfate attack cases SR cement has to be used or when using GGBS the addition % has to be > 70 %.

The above is valid when the concrete is designed according to minimum cement content, maximum water/cement-ratio and minimum compressive strength. For XF-classes calculation methods have been developed to estimate the service life of a structure. When these methods are applied one doesn't need to fulfil the tabled requirements in EN 206:2013. In XF2 and XF4 the so called *P*-value is calculated.

The formulae for *P*-value are:

$$Q_{\text{total}} = Q_{\text{CEM I}} + 2{,}0\, Q_{\text{silica}} + 0{,}80 * Q_{\text{GGBS}} + 0{,}40 * Q_{\text{PFA}}$$

$$WAS = \left(Q_{\text{water}} + 10 * \left(Air\ \% - 2\right)\right) / Q_{\text{total}}$$

$$k_{\text{binder}} = 1 - \left(\left(Q_{\text{water}} / Q_{\text{total}}\right) \text{^} 1{,}5\right) * \left(0{,}05 * Q_{\text{silica}} / Q_{\text{total}} + 0{,}02 * Q_{\text{GGBS}} / Q_{\text{total}} + 0{,}01 * Q_{\text{PFA}} / Q_{\text{total}}\right)$$

$$k_{\text{curing}} = 0{,}85 + 0{,}17 * \text{LOG}_{10}\left(t_{\text{curing}}\right)$$

$$P = 46 * k_{\text{curing}} * k_{\text{binder}} / (((10 * WAS\text{^}1.2) / SQRT(\text{Air}\%)) - 1)$$

These formulae have been developed based on laboratory and field tests on concrete with different binders. A Nordic field test on freeze–thaw resistance under road conditions has been carried out in Sweden (SP in Borås). The test specimens with different cements, water/binder-ratios and air contents have been situated along a highway for more than 12 years. In those tests a Dutch CEM III cement with slag content ca 70 % was scaling much more than the other cements tested. A doctor’s thesis has also proved that the carbonation of slag concrete results in a coarser void structure in the hardened cement paste and thus can worsen the freeze–thaw resistance when also carbonation happens together with freeze–thaw attack.

Addition to answer of France
The amount of addition given is A / A + C

Cendres volantes = Fly ashes; Fumées de silice = Silica fumes; Laitier moulu = GGBS;

Addition calcaires = Limestone filler; Addition calcaires = Siliceous filler

Tableau NA.F.1 — Valeurs limites applicables en France pour la composition et les propriétés du béton en fonction de la classe d'exposition

		Classes d'exposition																	
		Aucun risque de corrosion ou d'attaque	Corrosion induite par carbonatation				Corrosion induite par les chlorures						Attaque gel / dégel				Environnements chimiquement agressifs		
							Eau de mer			Chlorures autres que l'eau de mer									
		X0	XC1	XC2	XC3	XC4	XS1	XS2	XS3	XD1	XD2	XD3	XF1	XF2	XF3	XF4	XA1	XA2	XA3
	Rapport E_{eff}/liant éq maximal	—	0,65	Valeurs numériques identiques à XC1	Valeurs numériques identiques à XF1	Valeurs numériques identiques à XF1	Valeurs numériques identiques à XS2	0,55	0,50	Valeurs numériques identiques à XF1	0,55	0,50	0,60	0,55	0,55	0,45	0,55	0,50	0,45
	Classe de résistance minimale	—	C20/25					C30/37	C35/45		C30/37	C35/45	C25/30	C25/30	C30/37	C30/37	C30/37	C35/45	C40/50
	Teneur mini en liant éq (kg/m^3)	150	260					330	350		330	350	280	300	315	340	330	350	385
	Teneur minimale en air (%)	—	—					—	—		—	—	—	4	4	4	—	—	—
Rapport maximal A/(A+C)	Cendres volantes	0,30	0,30					0,15	0,15		0,15	0,15	0,30	0,30	0,30	0,15	0,30	0,30	0,00
	Fumées de silice	0,10	0,10					0,10	0,10		0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10
	Laitier moulu	0,30	0,30					0,15	0,15		0,15	0,15	0,30	0,30	0,30	0,15	0,30	0,30	0,00
	Addition calcaire	0,25	0,25					0,05	0,05		0,05	0,05	0,25	0,25	0,25	0,05	0,00	0,00	0,00
	Addition siliceuse	0,20	0,20					0,15	0,15		0,15	0,15	0,20	0,20	0,20	0,05	0,00	0,00	0,00

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