

Belgian Implementation of the ECPC-Concept Following EN 206-1

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ABSTRACT

The European Concrete Standard, EN 206-1, defines durability requirements for concrete exposed to different environmental conditions. These requirements are formulated for well-known cement types, like Portland cement and blast furnace slag cement, and taking into account partial cement replacement by pozzolanic additions like fly ash and silica fume. Going beyond well-known solutions, e.g. using new types of binder and/or new type of additions, the European Standard EN 206-1 generally defines the Equivalent Concrete Performance Concept (ECPC). By means of the ECPC-concept, the durability of non-traditional or alternative cementitious materials can be evaluated in comparison with well-known deemed-to-satisfy-solutions. However, the European Standard does not give a detailed method for the implementation of the ECPC concept. In Belgium, a new Standard has been developed for the practical implementation of the ECPC concept, enabling the evaluation and attestation of non-standard cement types and/or pozzolanic additions. The evaluation of the durability is based on comparative tests, comparing the non-traditional concrete composition with standard solutions accepted by EN 206-1. In this paper, this Belgian approach will be outlined, as implemented in the Belgian Standard NBN B15-100.

KEYWORDS

Concrete, Durability, Equivalent concrete performance concept, Standardization.

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1 INTRODUCTION

Although the knowledge is available to make durable concrete structures, it is sad to remark that in reality a lot of concrete structures clearly show durability problems. To a large extent, the durability of concrete structures depends on the structural design, on the mix design, and on the execution (including aspects like concrete cover and casting, compacting, curing).

It is clear that the concrete should have the right composition for the right application. In the actual European concrete code EN 206-1 '*Concrete – Part 1: Specification, performance, production and conformity*', this is implemented by defining exposure classes and by requiring a minimum cement content and a maximum water/cement ratio in function of the considered exposure class. Strength classes are also mentioned within the durability prescriptions, however as an indication only (It is not enough to just satisfy the strength prescription in order to guarantee a durable concrete for the considered exposure conditions). These 'deemed to satisfy' rules enable the concrete industry to easily design the right concrete composition for the considered application.

Clearly, the European concrete code EN 206-1 considers three important parameters in order to guarantee durable concrete structures: water/cement ratio, cement content, and strength. While this approach has the advantage of being practical, it is clear that each of the parameters is being criticized (Fig.1). It is clear that concrete strength is not a satisfying parameter to guarantee durable behaviour [Neville 1997]. A prescribed minimum cement content is also encountering criticisms in literature, as illustrated by Wasserman *et al.* [2008]. And on top of that, while it is commonly considered as the most important practical parameter when considering durability, even the water/cement ratio should be considered cautiously. Neville [1999] states that '*We should remember the limitations on its interpretation*'. Indeed, as long as the concrete binder is made of Portland cement and water, the definition of water/cement ratio is quite clear and not questioned. In this case, there is also a clear link between water/cement ratio and strength, as e.g. illustrated in Feret's law. Nevertheless, it has to be stated that even the historic evolution of cement properties has led to an increased durability risk when only looking at concrete strength and/or cement content, as clearly shown by Neville [1997] and De Schutter [2004].

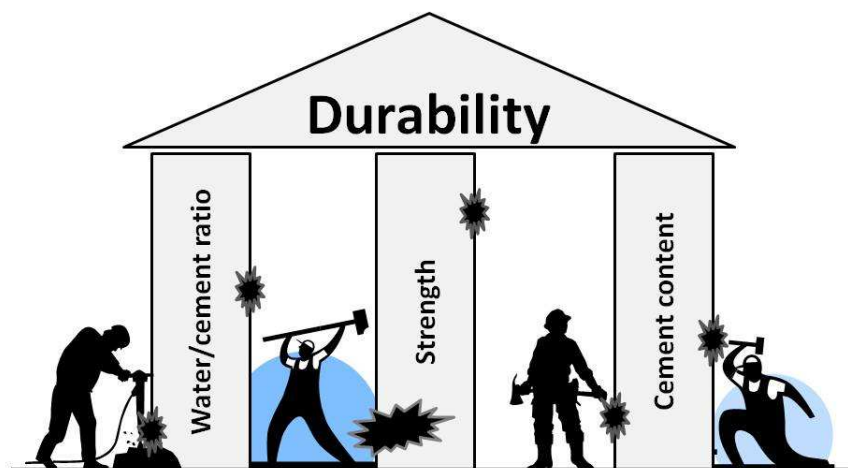


Figure 1. Water/cement ratio, cement content and compressive strength are being questioned as most important durability parameters.

Nowadays, considering the application of various types of supplementary cementitious materials, the definition of water/cement ratio is not straightforward. The European code EN 206-1 considers this problem by adopting the k-value concept, as e.g. explained by Neville [1999]. Although this k-value concept seems to be working for many cases, major discussions are going on about the level of the k-value and about the general validity of the k-value concept. As the k-value concept is principally based on concrete strength, the link with durability behaviour is not always straightforward. In Europe, the defined k-values differ from member state to member state, as listed in the various national application documents related to EN 206-1.

As an example of the European diversity within the application of the k-value concept, it can be mentioned that some countries define a k-value for the case of limestone filler, which in principle is a non-reactive filler (type I). While limestone filler is accelerating the hydration of Portland clinker due to improved nucleation possibilities, it is not chemically active (except for a minor percentage which could be chemically active in the formation of carbo aluminates) [Poppe & De Schutter 2005, Ye *et al.* 2007, Kadri *et al.* 2010]. In this way, limestone filler improves the strength development (hence the definition of a k-value within some countries), while the improvement by limestone filler of the pore structure and the long term durability performance is not always of the same degree [De Schutter & Audenaert 2008].

Considering the criticisms on water/cement ratio, cement content and concrete strength, attempts have been made to rely on other parameters, like water absorption by immersion. This is also implemented in the EN 206-1, as a potential additional requirement. Nevertheless, also the water absorption by immersion can be generally questioned as a governing durability parameter [De Schutter & Audenaert 2004].

In order to go around the discussion about the k-value concept, the European code EN 206-1 includes the possibility to experimentally demonstrate the durability of a concrete containing an alternative binder system, by comparing the durability performance with a well accepted more traditional binder following the prescriptions based on the defined exposure classes. This approach is called the Equivalent Concrete Performance Concept (ECPC). An important practical problem however is that the European code does not give any detail on how the ECPC concept should be practically implemented. For this reason, a new code has been developed in Belgium for the practical implementation of the ECPC concept, enabling the evaluation and attestation of concrete with non-standard cement types and/or pozzolanic additions. The experimental durability evaluation is based on comparative tests, comparing the non-traditional concrete composition with standard solutions accepted by EN 206-1. In this paper, this Belgian approach will be outlined, as implemented in the Belgian code NBN B15-100.

2 EQUIVALENT CONCRETE PERFORMANCE CONCEPT

Paragraph 5.2.5.3 of EN 206-1 reads: *“the equivalent concrete performance concept permits amendments to the requirements in this standard for minimum cement content and maximum water/cement ratio when a combination of a specific addition and a specific cement is used, for which the manufacturing source and characteristics of each are clearly defined and documented”*. Some further details on the ECPC-concept are given in the (informative) annexe E of EN 206-1: *“Testing should show that the performance of the concrete containing the addition should be at least equivalent to that of the reference concrete.”* Annexe E furthermore provides some general guidance, on which a testing and acceptance procedure can be based.

The sequel of this paper presents the Belgian approach followed for the ECPC testing and acceptance procedure. The text is based on the Belgian code NBN B15-100, and on a previous publication on this topic [De Schutter 2009].

3 BELGIAN APPROACH: NBN B 15-100

The Belgian Standard NBN B15-100 determines a reference method for the attestation of the suitability of cements and type II additions (puzzolans), following the guidance of EN 206-1 and NBN B15-001. The suitability evaluation is based upon the comparison with reference concrete with known properties. NBN B15-100 is not questioning the rules given in EN 206-1 and NBN B15-001, neither can it be used to formulate alternative rules. NBN B15-100 only provides a framework to check the equivalence performance for a specific mix in a well-defined application environment.

The methodology of NBN B15-001 can be applied to the following cases:

- Cement normalised according to EN 197-1 and EN 197-1/A1, but normally not used in Belgium (The commonly used cement types in Belgium are listed in NBN B15-001, section 5.1.2)
- Cement normalised according to another standard than EN 197-1 and EN 197-1/A1.
- Non-normalised cement
- Blends of different cements
- Blends of cement and additions of type II

All constituent materials need to have an attestation (CE-mark or alternative).

While the Belgian code NBN B15-100 is intended to test new binder systems based on cement(s) and reactive powder materials, it is investigated at this moment whether the code could be extended to non-reactive powder materials which could be included into the binder system (fillers type I). As an example, the methodology described in NBN B15-100 could be applied without any problem to binder systems containing limestone filler. Showing the equivalent performance of limestone filler based systems would be a more coherent and safer way to show the beneficial effects of limestone filler, instead of applying the k-value concept without fundamental background in this case.

The standard NBN B15-100 considers two important terms: ‘general suitability’ and ‘specific suitability’. General suitability refers to the fact that a constituent material can be successfully used within concrete. Materials having a CE-mark (or alternative) are considered to be generally suitable. For non-certified materials, the general suitability first has to be evaluated experimentally (e.g. composition, alkali content, chloride content, mechanical properties, stability, heat of hydration, setting, loss on ignition, residue, sulphate content). The general suitability will not be focused upon in this paper, as it is quite comparable to other certification procedures for constituent materials.

The most important part of the standard NBN B15-100 is dealing with specific suitability. This refers to the suitability of a specific mix for a specific field of application and exposure conditions. The specific suitability has to be checked by means of Initial Type Testing (ITT) on real concrete mixes.

4 DETERMINATION OF THE SPECIFIC SUITABILITY

4.1 General Prescriptions

The specific suitability can only be evaluated after attestation of the general suitability. For each field of application, requirements have to be defined concerning the following items: cement and addition (identification, quantities, minimum contents), aggregates (type, grading curve), admixtures (type, dosage, restrictions in order to avoid side effects), water (content), mixing (guidelines for the mixing procedure of the concrete).

Within the procedure for the evaluation of specific suitability, several types of performance can be evaluated:

- mechanical properties: this part is optional. Information on mechanical properties is often already available from the evaluation of the general suitability.
- Durability: this part is compulsory. Durability performance has to be evaluated for an individual mix (level 1) or for the application within a certain exposure class as defined in EN 206-1 and NBN B15-001 (level 2). The methodology will be described in detail hereafter.
- properties related to casting and placement: all relevant properties have to be determined. This concerns properties related to workability, setting and hardening (consistency, density, setting, air content, strength development).

During the experimental investigation, all relevant guidelines concerning production, transport, casting and curing have to be determined and documented.

The evaluation of specific suitability consists of comparing the performance of the real mix with the performance of a reference mix which complies with the normalised prescriptions for the considered application. In case of level 1, the experimental investigation only concerns one composition for a given exposure condition. In case of level 2, the investigation can be performed for all exposure classes defined in EN 206-1 and NBN B15-001, except for classes EA1, EA2 and EA3 (aggressive environments) for which only a verification at level 1 is allowed.

4.2 Reference Concrete and Mortar

For a level 1 evaluation, the reference concrete should have a composition as normally prescribed for the considered application. The reference cement type is clearly indicated in some tables within NBN B15-100, depending on the exposure conditions. The mix to be evaluated has the same composition as the reference concrete, except for the binder system. If required, the workability of both mixes will be adjusted to the same level by means of plasticisers.

For level 2, limestone aggregates and quartzite sand have to be used. Also in this case, the reference cement type is listed in tables within NBN B15-100, depending on the exposure conditions. The reference concrete has to meet the requirements given in EN 206-1 and NBN B15-001 depending on the considered exposure classes. The mix to be evaluated has an identical composition, except for the binder. The binder composition has to be defined by the demander of the tests, in form of some tables similar to the F-tables within NBN B15-001, giving maximum water/cement ratio and minimum cement content for each exposure class considered. Also in this case, the workability of both mixes can be adjusted to the same level by means of plasticisers.

For some specific tests (see further), a reference mortar is also needed, made with high sulphate resisting cement. The water/cement ratio has to be defined in function of the considered application.

4.3 Curing

Two different curing regimes have to be considered:

- ideal curing, consisting of 55 days storage under water at $(20\pm 2)^{\circ}\text{C}$. Storage under water can be replaced by storage at a relative humidity of 95% or higher.
- non-ideal curing, consisting of 55 days storage in a climate room at $(20\pm 2)^{\circ}\text{C}$ and $(60\pm 5)\%$ relative humidity.

The results obtained with the ideal curing conditions will be decisive for the evaluation of equivalent performance. The results obtained with non-ideal curing are informative only. In case non-equivalence would be obtained with the non-ideal curing, the user shall be informed in order to follow an accurate curing system in practice.

4.4 Durability Test Methods

The standard NBN B15-100 gives the test method to be followed, as well as the evaluation criteria to be applied. The test methods to be applied are listed in the standard, depending on the considered exposure conditions. As a general rule, alternative test methods can be used, however only after motivation.

The test methods are dealing with:

- **Carbonation:** in a carbonation chamber with 1% CO₂, at (20±2)°C and (60±10)% relative humidity. Higher concentrations of CO₂ can be considered if desired. The determination of the carbonation depth is performed after 28 days and 56 days, following the guidelines given by RILEM CPC-18. Taking into account the accuracy of the test method, the evaluation criterion at 56 days states that the carbonation depth of the concrete to be evaluated should not exceed 1.2 times the carbonation depth of the reference concrete.
- **Frost resistance:** 14 frost-thaw cycles following the European standard EN 1367-1. As an evaluation of the performance, the tensile splitting strength before and after frost testing is considered. The strength reduction of the concrete to be evaluated should not exceed 1.2 times the strength reduction obtained for the reference concrete.
- **Scaling resistance** (frost in combination with de-icing salts): 28 cycles according to EN 1339. The mass loss of the concrete to be evaluated should not exceed 1.2 times the mass loss of the reference concrete.
- **Chloride diffusion:** the non-stationary chloride diffusion coefficient is determined according to the standard NT Build 443. As an alternative method, NT Build 492 can be used. Considering the accuracy of the method, the evaluation criterion states that the chloride diffusion coefficient of the evaluated concrete should not exceed 1.4 times the diffusion coefficient of the reference concrete.
- **Resistance against sea water:** the test is performed on mortar specimens according to the French standard NF P18-837. The expansion of the evaluated mortar should not exceed 1.2 times the expansion of the reference mortar. The results are also accepted if the expansion of the tested mortar is below 0.05%.
- **Sulphate resistance:** the expansion of mortar specimens stored in sulphate solution is determined according to the prescriptions given in the Dutch document 'CUR Aanbeveling 48'. The evaluation criterion is identical as for resistance against sea water.
- **Acid attack:** 20 cycles of 1 day submerging in aggressive solution and 1 day drying at (20±2)°C and (60±10)% relative humidity. After drying, each exposed surface should be brushed twice (if the surface is exposed to erosion). The composition of the solution has to be defined in function of the considered application. The PH-value of the solution has to be maintained constant throughout testing. The mass loss of the evaluated concrete should not exceed 1.2 times the mass loss of the reference concrete.
- **Alkali Silica Reaction (ASR):** In case the new binder approaches the composition of a known cement type, the alkali content of the binder has to be compared to limit values prescribed for the known cement type. Otherwise, testing according to the French Standard NF P18-594 is recommended. Testing of ASR is not compulsory according to NBN B15-100.

4.5 Equivalent Performance

For each test to be considered, the code NBN B15-100 defines acceptance criteria, as briefly indicated before, when explaining the test methods. Within these criteria, the experimental results obtained with the new binder type are compared with the experimental results obtained on the reference concrete.

As an example, when testing the carbonation performance of the new binder type, the following acceptance rule is defined, after 56 days of exposure in the carbonation chamber:

$$d_{\text{new}} \leq 1.20 d_{\text{ref}}$$

with d_{new} the carbonation depth of the concrete with the new binder type, and d_{ref} the carbonation depth of the reference concrete.

The coefficient of 1.20 is introduced into the acceptance rule in order to consider the accuracy of the test method and the statistical variations on the test results.

When all relevant tests have been performed, in function of the considered exposure class(es), and when all criteria have been fulfilled, the evaluated concrete will be accepted as having 'equivalent concrete performance'. This concrete, with the evaluated binder system, will thus be accepted for applications within the considered exposure classes.

5 CONCLUSION

By means of the Equivalent Concrete Performance Concept (ECPC) as described in the European Standard EN 206-1, the durability of non-traditional or alternative cementitious materials can be evaluated in comparison with well-known deemed-to-satisfy-solutions. However, the European Standard does not give a detailed method for the implementation of the ECPC concept. In Belgium, a new Standard has been developed for the practical implementation of the ECPC concept, enabling the evaluation and attestation of non-standard cement types and/or pozzolanic additions. The evaluation of the durability is based on comparative tests, comparing the non-traditional concrete composition with standard solutions accepted by EN 206-1.

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