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From prescription to performance: international trends on concrete specifications and the Brazilian perspective

Da prescrição à especificação de concreto por desempenho: tendências internacionais e a perspectiva brasileira




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Abstract

There are two types of specifications: prescriptive and performance based. The prescriptive specifications focus on materials properties, materials proportions, mixing and transporting procedures and on a variety of processes, such as placing and curing. In these specifications, the concrete desired performance it is not necessarily described.
On the other hand, performance specifications stipulate what is required from the product and do not prescribe how the product should be produced. In other words, they focus on the desired performance rather than on the concrete ingredients, materials selection, proportioning or construction methods. These are the responsibility of those individuals who contractually have to comply with the specifications. In this case, concrete is defined in terms of measurable fresh and hardened properties and durability and as there are no restrictions regarding materials and their proportions in the performance specifications, innovative solutions may be used in order to achieve the performance requirements.
Currently, most concrete specifications are predominantly prescriptive with some performance requirements. Nevertheless, there is a consensus that in order to extend the service life of concrete structures, this has to be changed. This paper gives an overview of the international specifications and describes the international efforts on the performance specification implementation in the concrete industry.

Keywords: specification; performance, concrete; durability.

Resumo

Há dois tipos de especificações: prescritivas e por desempenho. As especificações prescritivas focam nas características das matérias-primas, na dosagem do concreto, na mistura e no transporte e numa grande variedade de operações, tais como lançamento e cura. Nestas especificações, o desempenho desejado do concreto não é necessariamente descrito.
Por outro lado, as especificações por desempenho estipulam o que se requere do produto e não prescrevem como o produto deve ser produzido. Em outras palavras, elas focam no desempenho desejado ao invés de focarem nos materiais constituintes, dosagem e métodos construtivos. Esses aspectos são responsabilidade daqueles individuos que devem cumprir contratualmente com as especificações.
Em contraste, as especificações por desempenho tratam daquilo que se requer do
produto, e não prescrevem como esse produto deve ser produzido. Em outras palavras, ao invés de partirem dos materiais que compõem o concreto, partem do desempenho desejado, em termos de suas propriedades mensuráveis no estado plástico,endurecido e em termos de durabilidade, deixando a seleção dos materiais, a dosagem e os métodos construtivos a cargo daqueles que, contratualmente, devam atender às especificações. Nesse caso, como não há restrições dos materiais ou de suas proporções, soluções mais inovadoras podem ser usadas.
Atualmente, a maioria das especificações de concreto é predominantemente prescritiva com alguns aspectos de desempenho. No entanto, há um consenso de que essa realidade deve ser mudada para um aumento de vida útil das estruturas. Esse artigo apresenta um panorama das especificações internacionais e descreve os esforços internacionais para a implementação de especificações por desempenho na indústria do concreto.

Palavras-chave: especificações; desempenho; concreto; durabilidade.

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1. Introduction

ACI 116-00 [1] defines specification as an explicit set of requirements to be satisfied by a material, product or service. In a performance specification, concrete is defined in terms of measurable fresh properties, hardened concrete properties and in terms of durability. According to Souza [2], the performance of a product is equal to its behavior during its service life. Nevertheless, there is no consensus for the term "Performance specification" because it can be interpreted in many different ways [3]. Table 1 shows some of the

Table 1 – Performance specification definitions

CIB Commission W060 (4)	"The practice of thinking and working in terms of ends rather than means".
U.S. Federal Highway Administration (5)	"A performance specification defines the performance characteristics of the final product and links them to construction, materials and other items under contractor control."
NRMCA (National ready mixed concrete association) (3)	"A performance specification is a set of instructions that outlines the functional requirements for hardened concrete depending on the application".
Canadian standard CSA A23-1 (6)	"A performance concrete specification is a method of specifying a construction product in which a final outcome is given in mandatory language, in a manner that the performance requirements can be measured by accepted industry standards and methods. The processes, materials, or activities used by the contractors, subcontractors, manufacturers, and materials suppliers are then left to their discretion."
UK Highway Agency (3)	"**Output measures** define the end product of works carried out on the network. This is usually in the form of a series of outputs that will deliver the desired outcome. For example meeting road surface skid resistance requirements is one output that will help enable the safety outcome to be realized. **Outcome measures** define the benefits that should be delivered as a consequence of the works carried out on the network. This will usually take the form of the level of service required."
Cement Association of New Zealand (3)	"A performance-based specification prescribes the required properties of the concrete but does not say how they are to be achieved."
PIARC – World road association (3)	• "performance specification: one that describes how the finished product should perform over time. • performance-based specification: one that describes desired levels of fundamental engineering properties. • performance-related specification: one that describes desired level of materials and characteristic factors that have been found to correlate with fundamental engineering properties that predict performance.
NBR 15.575/2008, Residential building up to 5 stories– Performance (7)	"Behavior of a product during service life to specific exposure conditions.

definitions for "performance specification". Nevertheless, this concept is not new. Apparently, the roots of performance based project have been planted more than 2000 years ago in an architecture paper written by Vitruvius.
However, the approach normally used in specifications and codes is still based on the achievement of the required performance through a set of prescriptive requirements based on previous experiences [4].
Currently, most concrete specifications are predominantly prescriptive with some performance requirements, such as minimum service life and requirements on compressive strength and at the same time, limitations on the water-cementitious materials ratio (w/cm). Nevertheless, it is common sense that, in order to increase the service life of concrete structures, this practice shouldn't be used [8].
However, concrete specifications are still prescriptive in nature, indicating maximum w/cm, maximum and minimum volume of supplementary cementitous materials, but excluding the requirements the material should comply with in order to guarantee that its service life is achieved. These requirements are the performance requirements, which in the prescriptive specifications, are believed to be indirectly attained through the specification, for example, of the maximum w/cm allowed.
The Nordic model is a procedure that was first conceptually standardized in ISO 6240/1980 [10], ISO 6241/1984 ([11] and ISO 6242/1992 [12]. It has been adopted recently by the ICC Performance Code [13] and by the Australian-NZ Building Code [4]. Most performance specifications in construction currently in use or under development follow this model. The structure of the Nordic model applied to concrete performance specification is, as follows:

- Establishment of the user needs;
- Establishment functional requirements;
- Establishment of the performance requirements. The specification should clearly state the performance requirements for the fresh and hardened concrete, including durability. The performance requirements should not only take into account the characteristics of the structure in service and durability, but its constructability, as well. The performance requirements must be defined in terms of properties with clear limits, through predetermined testing. Regarding durability, performance specifications must take into account the environmental conditions, the service life, the most likely deterioration mechanisms, such as carbonation, chloride ingress, alkali-silica reaction, just to name some.

Nonetheless, in order to guarantee the proper performance of the concrete in service, the general concept of performance specification concrete should be applied as follows [3]:

- There would be a qualification/certification system that establishes the requirements for a quality control management system, qualification of personnel and requirements for concrete plants.
- The specification would have provisions that clearly define the functional requirements of the hardened concrete.

Producers and contractors would partner to ensure the right mixture is developed, delivered and installed.

- The submittal would not be a detailed list of mixture ingredients but rather a certification that the mixture will meet the specification requirements, including pre-qualification test results.
- After the concrete is placed, a series of field acceptance tests would be conducted to determine if the concrete meets the performance criteria.
- A clear set of instructions outlining what happens when concrete does not conform to the performance criteria.

Unfortunately, in the past few years in Brazil, the construction industry concentrated all its efforts on quality management and process rationalization and not much was done regarding the improvement of the final product performance [2]. Some of the actions that should be taken in this direction are:

- Education of designers, contractors, suppliers and owners regarding performance concepts;
- Creation of performance based standards and codes;
- Creation of performance specifications.

2. Opportunities and challenges

It is believed that the implementation of performance specifications could potentially improve the performance of the concrete in service and could offer new opportunities for organizational and technological innovations in the construction industry [4].
The performance specification should guarantee that any unsatisfactory concrete is detected and penalized; no satisfactory concrete is rejected, and should promote an adequate quality control that avoids any concerns about the delivered concrete [14].
The primary advantage to specifying performance is that a knowledgeable concrete producer-contractor team has the flexibility to develop a unique combination of materials and construction methods that will achieve the owner designer's objectives and specific condition of the project. They are an alternative for prescriptive specifications because prescriptive specifications [5; 3; 15]:

- Do not guarantee that the requirements will result in the desired performance;
- Prevent innovations;
- Limit competitiveness;
- Describe the source, composition and proportion of materials;
- The risks are taken by the owner and specifier;
- Must be sufficiently detailed in order to consider all the factors that impact the long term performance;
- Need an intense supervision in order to guarantee that all the requirements are met;
- Do not include requirements of the final product or its performance, such as durability;
- Do not take into account the materials variability during construction and do not allow mixture design changes;
- Can promote workability problems during construction when the requirement for w/cm is very low.
- Eliminate any motivation for the producer to improve the mixture design and the quality control.

It is important to point out once more that the biggest advantage of the performance specifications, in comparison to prescriptive specifications, is that, in the former, the behavior of the concrete during its service life and the properties of the final product are specified, not only the compressive strength as in the prescriptive specifications.
However, the implementation of performance specifications encounters some challenges [3; 8; 9], especially in Brazil:

- Lack of reliable, repeatable test methods that evaluate the required performance characteristics (along with performance compliance limits that take into account the inherent variability of each test method);

- Need to establish reliable service life models, calibrated for the Brazilian conditions and materials, and based on long term results;
- Need to revise standards, specifications and codes, such as NBR 6118-03 [17], as they prevent innovation, by limiting, for example, the w/cm and maximum volume of supplementary cementitious materials;
- The construction industry is conservative and generally opposed to changes and it is an industry easily influenced by the interests of big organizations;
- In Brazil, there is not much trust among the parts involved in a project, and this complicates the changes on the roles and responsibilities of the parties involved in the construction process. In order to overcome this feeling, the ready mixed concrete companies may have to develop quality systems and may have to be certified by independent and reliable entities;
- There is a need to correlate the tests used during pre-qualification of mixtures and those used in the quality control of the construction;
- A quality control process must be implemented in each stage of the product production, when there is a change in the responsibilities, namely, for the delivered concrete, for the placed concrete and for the cured concrete;
- Some specifiers and designers are not yet familiarized with performance criteria;
- As the ability to meet the performance requirements depend on many factors which involve the ready mixed concrete plant, the equipment and the personnel, it is imperative to establish a certification program for the plants, contractors and personnel, as well as the maintenance of a satisfactory quality control system;
- Need for some uniformity verification testing when the concrete is received, which should be much more relevant than the slump test, specific gravity or water content (microwave test).

3. Responsibilities

The implementation of performance specifications requires a change of the mindset in terms of responsibilities, as well. Each professional should have his/her responsibility clearly defined in order to state the exposure condition and the performance to be met. This redefinition of responsibilities creates a new environment for the establishment of bonus and penalties.

4. Initiatives

Although the concept of performance specifications is not new, only recently the international discussion has taken the spotlight, aiming to develop specifications focused on performance, especially regarding durability and as a result provide long lasting structures. A good example of the efforts in the direction of establishing a performance specification in the construction industry is the Superpave (SUperior PERforming Asphalt PAVEments). In 1987, the American congress established a five year research program seeking to improve the performance, durability, safety and efficiency of the highway system in USA. The budget for the research program and the implementation program was 150 million dollars. The research carried out between 1987 and 1993 resulted in a performance specification for asphalt, a mixture design method, test methods and models to predict the performance of the material. This specification is entirely performance based and has being used with success.

Performance specifications have been attracted lots of interest in Europe. The Performance Based Building Network (PeBBu) is a thematic network funded under the European Commission's EU) 5th framework – Competitive and Sustainable Growth and managed by the CIBdf, The Netherlands. More than 70 international organizations are involved in the project. The PeBBU has been facilitating and enhancing the existing performance based building research activities by networking with the main European stakeholders and other international stakeholders. The network has also been producing synergistic results for dissemination and adaptation of performance based building and construction.

It may seem that there is a need for the preparation of a European performance-based Model Code for Buildings, similar to and more comprehensive than the ICC 2003, which will cover all the performance attributes, and for administrative documents, which will address all the links between the four markets when such a code is applied. These attributes have been included in the curricula of professional education of many Building and Civil Engineering departments in universities in Europe, New Zealand, Israel, Canada and USA [4].

Reflecting this European tendency, a joint committee between CIB and RILEM was created in 1996, focusing on service life methodology – service life prediction for construction materials and components (CIB W080/RILEM 175 SLM), which produced a report presenting the tools for performance specifications [18].

The European structural codes (CEN) are a set of project documents based on performance concepts, very detailed and follow a semi-probabilistic approach. Their analysis is based on the user's point of view, namely, the construction must be safe and the user must feel safe. The Eurocodes establish safety targets and service conditions in physical terms related to the factors that impact the building performance under the user's point of view, such as deformations, cracking and vibrations, and establish limits for these physical factors. The Eurocodes do not contain prescriptive requirements, not even for minimum cross section for columns [4].

Structural fire safety engineering is following an approach similar to the Eurocodes, offering a performance design option. The American Society of Fire Protection Engineering, SFPE, is also trying to generalize a performance-based approach to the overall Fire Safety design process [19; 20].

The Energy Codes that were adopted by most American States include two design options. The prescriptive option follows the traditional provisions for thermal resistance of envelope elements, sizing of windows, etc. The performance option requires analysis of energy demand and its comparison to a calculated energy budget. While following the first option does not require highly specified knowledge beyond the regular architectural or building engineering education, the second option can be applied only by professionals who are well versed in the area of energy analysis and engineering [21].

Other design fields that are developing tools for performance-based design include acoustics, moisture protection and Indoor Air Quality.

Both ASTM and ISO already established committees and subcommittees responsible for standards related to performance in construction, such as, ASTM E06, ISO SC 03 and ISO SC 15 [4].

Brazil has also started using the performance based concept, but

focusing on the performance of the building as a whole, not specifically the performance of the concrete. In 2008, ABNT approved the first performance based specification for the Brazilian construction industry, the NBR 15.575/2008 [7], Residential buildings up to five stories – Performance and will be in probation until 2010. This new standard aims at the performance of the system and does not evaluate the quality of each individual component of the system.
More specifically related to concrete, one can mention initiatives such as Prescription to Performance (P2P).This is an initiative promoted by the engineering and standard committee of the National Ready-Mixed Concrete Association – NRMCA. NRMCA is one of the main entity that promotes the performance approach in the concrete industry in USA.
Federal Highway Administration (FHWA) launched the Road Map, that is, a detailed strategic plan for concrete pavements that will guide the research investments for the next ten years. This plan is divided into 13 focus areas and three of them are related to performance: i) Performance based concrete pavement mix design system with expected investment of 68 million dollars; ii) Performance based design guide for new and rehabilitated concrete pavements with anticipated investment of 60 million dollars and iii) concrete pavement performance with projected investment of 4 million dollars [22].
Following this international trend, in 2007 ACI created the committee ITG-8 Performance Criteria for Concrete Materials. Its mission is to develop a report on performance criteria and test methods for concrete materials that could be used in codes and specifications. In 2009 this created another committee ACI 329 (Performance criteria for ready-mixed concrete), which had its first meeting in March 2010. Its mission is to develop and report information on performance criteria for ready-mixed concrete.
RILEM organized a committee AAM (Alkali activated materials) which main objective is to develop performance specifications and recommendations for the creation of performance standards of alkali activated materials, such as slag cement (ground granulated blast furnace slag), fly ash, geopolimers and other emerging technologies.
In 2010, the annual meeting of the Transportation Research Board (TRB) presented a workshop on case studies of projects that implemented performance specifications.

5. Main codes, standards and specifications

5.1 USA

5.1.1 ACI 318-08 (2008)

The ACI 318-08 [16] is a prescriptive specification regarding the durability aspects. Chapter 4 of the ACI 318-08 [16] presents exposure classes and limits the w/cm, entrained air, maximum supplementary cementitious materials content, maximum chloride content and specifies the type of cement to be used in particular exposure conditions (Table 2).
This code also presents provisions to prevent reinforcement corrosion by specifying the minimum cover (Table 3) and the necessary

Table 2 – Recommendations for special exposure conditions in ACI 318-08 (16)

Exposure class	Severity	Subclass	Maximum w/cm	Compressive strength (MPa)
Freezing and thawing	Not applicable	F0	-	18
	Moderate	F1	0,45	31
	Severe	F2	0,45	31
	Very severe	F3	0,45	31
Sulfate	Not applicable	S0	-	18
	Moderate	S1	0,50	28
	Severe	S2	0,45	31
	Very severe	S3	0,45	31
Requiring low permeability	Not applicable	P0	-	18
	required	P1	0,50	28
Corrosion protection	Not applicable	C0	-	18
	Severe	C1	-	18
	Very severe	C2	0,40	35

Table 3 – Minimum cover for reinforced concrete in ACI 318-08 (16)

Exposure condition	Minimum cover in mm
Concrete cast against and permanently exposed to earth	80
Concrete exposed to earth or weather	50
Concrete not exposed to weather or in contact with ground (beams, columns)	40

matrix densification in order to decrease the ingress of ions.
The ACI 318-08 [16] tries to promote the matrix densification, or to improve the properties related to permeability by limiting the w/cm and by the use of supplementary cementitious materials. Nevertheless, ACI 318-08 [16] does not take into account the microstructure differences between mixtures with same w/cm but different cementitious materials. In other words, it considers that independently of what combination of materials is employed, the same level of permeability is achieved for each w/cm.
As it can be observed, this is a simplistic document which does not consider relevant factors regarding the exposure environment and the concrete quality, as they are not only dependent on the compressive strength and w/cm, but also the use of supplementary cementitious materials, cure, among other factors. In its commentaries, ACI 318-08 [16] presents ASTM C 1202 [23] as a performance-based indicator of low permeability.

5.2 Canada

The Canadian standard CSA A23.1 [6] offers two options for specification: prescriptive and performance (in reality a hybrid specification). In Table 5 of the standard annex, the criteria to be specified are presented. The CSA A23.1 [6] standard presents 5 exposure classes and several subclasses, which reflect different levels of exposure (Table 4).
Although it limits the w/cm, requires minimum compressive strength and entrained air, it also specifies the type of cure and, in case there is exposure to chlorides, it limits the maximum Coulombs at 56 days [23], as an indirect way to guarantee a certain level of impermeability of concrete.
The performance requirements are used when the owner requires that the ready-mixed concrete plant assumes the responsibility for the concrete performance. The contractor assumes the responsibility for placing, consolidating and curing the concrete, by meeting the compressive strength and the expected durability.

5.3 Europe

5.3.1 EN 206-1

In 2000, the EN 206-1 – Concrete – Part I: Specification, performance, production and conformity [24] was published. Nevertheless, each country created its own national annex, in order to consider the peculiarities of each country and ease the consensus. As a result, the limits for the concrete components and the cover can vary from country to country.
The committee CEN/TC 104 considered the use of performance specification approach but decided to adopt a prescriptive approach, claiming lack of reliable test methods. Nevertheless, it allows the use of performance requirements when the country has national test methods and feels sufficiently confident in using them. CEN/TC 104 will continue the development of performance test methods related to durability on the European level.
EN 206-1 [24] specifies criteria for the materials, for the fresh and hardened properties and their verification, presents limits for the concrete proportions and specifies the quality control procedure, the conformity criteria and the conformity evaluation.
The main deterioration mechanism considered by EN 206-1 [24] is the corrosion of the reinforcement, no matter if it is the result of chloride ingress, freeze-thawing or chemical attack. The environment effect is classified in terms of exposure classes (Table 5). For each class, only prescriptive requirements are specified, including type and class of materials, w/cm, entrained air, minimum cement content and strength class (Table 6).
Regarding the use of supplementary cementitious materials, only silica fume is mentioned. Ground granulated blast furnace slag is not allowed to be used as a replacement for the Portland cement but can be used if it is part of the blended cement.
Nevertheless, EN 206-1 [24] presents the equivalent performance concept, which allows the modifications of the prescriptive requirements for cement content and w/cm. It is applicable to a specific combination of cement-supplementary cementitious materials, as long as the concrete presents equivalent performance regarding the durability, when compared to the reference concrete for the same exposure class.
Annex J of EN 206-1 [24]: Performance-related design methods with respect to durability, does not present any guidance on how to choose the performance requirements and criteria. It only provides a definition of performance methods and guidelines of when this option should be considered.

5.3.2 Durable concrete structures - design guide [25]

Among the documents which use prescriptive requirements, this is one of the most complete documents. Its recommendations include all the construction process, from the design, identifications of responsibilities and interactions of project planning, to the delivery of the project, maintenance and use.
This guide presents some factors and recommendations in order to guarantee the quality of the concrete:

- Motivation, information and education of staff;
- Design and detailing, with focus on draining, spray, cracking and spalling;
- Materials: cement, aggregates, water, admixtures and supplementary cementitious materials;
- Construction;
- Cure;
- Service conditions;
- Inspection, maintenance and repair.

Table 4 – Exposure classes in CSA A 23.1 (6)

Subclass	Definition
Chloride exposure	
C-XL	Structurally reinforced concrete exposed to chlorides or other severe environments with or without freezing and thawing conditions, with higher durability performance expectations than the C-1, A-1, or S-1 classes.
C-1	Structurally reinforced concrete exposed to chlorides with or without freezing and thawing conditions.
C-2	Non-structurally reinforced (i.e., plain) concrete exposed to chlorides and freezing and thawing.
C-3	Continuously submerged concrete exposed to chlorides but not to freezing and thawing.
C-4	Non-structurally reinforced concrete exposed to chlorides but not to freezing and thawing.
Freezing and thawing exposure	
F-1	Concrete exposed to freezing and thawing in a saturated condition but not to chlorides.
F-2	Concrete in an unsaturated condition exposed to freezing and thawing but not to chlorides.
Exposed to neither chlorides nor freezing and thawing	
N	Concrete not exposed to chlorides nor to freezing and thawing.
Chemical exposure	
A-1	Structurally reinforced concrete exposed to severe manure and/or silage gases, with or without freeze-thaw exposure.
A-2	Structurally reinforced concrete exposed to moderate to severe manure and/or silage gases and liquids, with or without freeze-thaw exposure.
A-3	Structurally reinforced concrete exposed to moderate to severe manure and/or silage gases and liquids, with or without freeze-thaw exposure in a continuously submerged condition.
A-4	Non-structurally reinforced concrete exposed to moderate manure and/or silage gases and liquids, without freeze-thaw exposure.
Sulfate exposure	
S-1	Concrete subjected to very severe sulfate exposures.
S-2	Concrete subjected to severe sulfate exposure.
S-3	Concrete subjected to moderate sulfate exposure.

Table 5 – Exposure classes in EN 206-1 (24)		
Class	Relates to	Number of sub-classes
XO	No risk of corrosion or attack	0
XC	Carbonation induced corrosion	4
XD	Chlorides not from sea water	3
XS	Chlorides from sea water	3
XF	Freeze-thaw with or without de-icing agents	4
XA	Chemical attack	3

This guide also presents a classification related to exposure conditions, based on limits for pH, CO_2 concentration, ammonia, magnesium and sulfate limits. This classification is presented in Table 7. The document presents recommendations for minimum compressive strength, maximum w/cm, minimum cement content, entrained air and permeability (Table 8), minimum cover, rebar spacing and maximum cracking width for each exposure class.

5.3.3 France

Boroghel-Bouny [26] uses the concept of durability indicators. The durability indicator is a material property with a clear physical meaning [3]. These properties are porosity, diffusion coefficient, permeability and calcium hydroxide content and define the durability class of the concrete (Table 9).

5.3.4 United Kingdom

BS 8500 [27] proposes five different approaches when specifying concrete: Designated concrete, Designed Concrete, Prescribed concrete, Standardized prescribed concrete and Proprietary concrete (Table 10). Supplementary cementitious materials (fly ash, ground granulated blast furnace slag and silica fume) are allowed only as part of the blended cement, not as a replacement for the Portland cement. UK Highway Agency has been developing a performance specification since 2003. This specification comprises three options:

Table 6 – Carbonation induced corrosion class in EN 206-1 (24)					
Class	Environment	Example	Maximum w/mc	Compressive strength class (MPa)	Minimum cement (kg/m^3)
XC1	Dry or constantly wet	Indoor environment with low relative humidity	0,65	20	260
XC2	Wet or rarely dry	Foundations and concrete surfaces subject to long term water contact	0,60	25	280
XC3	Moderately wet	Indoor environment with high or moderate relative humidity or outdoor structures sheltered from rain	0,55	30	280
XC4	Wet-dry cycles	Outdoor structures in contact with water, not within exposure XC2	0,50	30	300

Table 7 – Exposure classes (25)

Exposure class		Environmental conditions
1		Dry, RH ≤ 70%
2	A	Constant humidity variations and occasional risk of condensation
	B	Constant humidity variations and high risk of condensation
3		Wet and subjected to freezing-thawing
4		Marine environment
5	A	Low chemical exposure
	B	Moderate chemical exposure
	C	Severe chemical exposure

i) development of specifications with low risk and low benefits; ii) performance specification for maintenance; iii) performance specification that transfers the risk from the agency to the producer, and allows him to implement innovative solutions.

5.4 Brazil

5.4.1 NBR 15.575/2008

The first Brazilian performance standard in the building industry,

Table 8 – Durability recommendations (25)

Recommendation		Exposure class 1	2a	2b	3	4a	4b	5a	5b	5c
Strength ISO 4012 (MPa)	concrete	≥ 12/15								
	CA	≥ 16/20	≥ 20/25	≥ 20/25	≥ 20/25	≥ 25/30	≥ 25/30	≥ 20/25	≥ 25/30	≥ 30/35
	CP	≥ 20/25								
w/cm	concrete	-	≤ 0,70							
	CA	≤ 0,65	≤ 0,60	≤ 0,55	≤ 0,55	≤ 0,55	≤ 0,50	≤ 0,55	≤ 0,50	≤ 0,45
	CP	≤ 0,60	≤ 0,60							
Cement content (kg/m^3)	concrete	≥ 150	≥ 180	≥ 180	≥ 180					
	CA	≥ 270	≥ 300	≥ 300	≥ 300	≥ 300	≥ 300	≥ 300	≥ 300	≥ 300
	CP	≥ 300	≥ 300	≥ 300	≥ 300					
Air entr. % (DMC)	≤ 32mm	-	-	If there is a risk of saturation same as item 3	≥ 4	-	If there is a risk of saturation same as item 3	-	-	-
	≤ 16mm				≥ 5					
	≤ 8mm				≥ 6					
Water penetration ISO 4848		-	-	≤ 50	≤ 50	≤ 30	≤ 30	≤ 50	≤ 30	≤ 50
Aggregate recommendation		-	-	Frost resistant	Frost resistant	-	Frost resistant	-	-	-

Table 9 – Potential durability classes related to corrosion and limits associated to the performance requirements for concrete cured under water for not more than 90 days (26)

Potential durability	Classes and limits				
	Very low	Low	Medium	High	Very high
Porosity accessible to water (%)	>16	14 a 16	12 a 14	9 a 12	6 a 9
Effective chloride diffusion coefficient (10^{-12} m^2 s-1)[1]	>8	2 a 8	1 a 2	0,1 a 1	<1
Apparent chloride diffusion coefficient (10^{-12} m^2 s-1)[2]	>50	10 a 50	5 a 10	1 a 5	–
Apparent chloride diffusion coefficient (10^{-12} m^2 s-1)[3]	>50	10 a 50	5 a 10	<5	<5
Apparent gas permeability (10^{-18} m^2)[4]	>1000	300 a 1000	100 a 300	30 a 100	<30
Liquid water permeability (10^{-18} m^2)[5]	>10	1 a 10	0,1 a 1	0,01 a 0,1	<0,01
Ca(OH)2 content (% by mass of cement)[6]	<10	10 a 13	13 a 20	20 a 25	≥25

[1] related to Fick's 1st law
[2] related to Fick's 2nd law and measured by means of a migration test
[3] related to Fick's 2nd law and measured by means of a diffusion test
[4] measured by means of a constant head permeameter at Pinlet = 0.2 MPa and after oven drying at T = 105 ± 5 °C
[5] by direct flow measurement, after saturation
[6] plain mixtures.

NBR 15.575/2008 [7], Residential buildings up to 5 stories– Performance, deals with the overall performance of the system and does not evaluate the quality of each individual part of the system, such as the concrete structure. It is a provisional standard and will be under probation until May 2010. It is based on ISO 6241/1984 [11].
NBR 15.575/2008 [7] aims to promote a paradigm shift and repre-

Table 10 – Five approaches to the specification of concrete per BS 8500-2006 (3)

Designated concrete – for specific uses. Concrete is specified using a number of tables which are intended to guide de process. This is an only applicable where third-party certification is selected as the option in specifying the concrete.

Designed concrete – This approach offers more flexibility to the specifier than designated concretes, which do not cover every application and every constituent material. Using the intended working life and the minimum cover to reinforcement, the limiting values of composition are determined for each of the identified exposure classes.

Prescribed concrete – This approach allows the specifier to prescribe the exact composition and constituents of the concrete. It is not permitted to include requirements on concrete strength, and so this option has only limited applicability.

Standardized prescribed concrete – This was previously known as standard mixes in BS 5328. This approach is appropriate where concrete is site-batched on a small site or obtained from a ready mixed concrete producer who does not have accredited third-party certification.

Proprietary concrete – This approach is appropriate where it is required that the concrete achieves a performance, using defined test methods, outside the normal performance requirements for concrete. The proprietary concrete is selected in consultation with the concrete producer and the project specification.

Table 11 – Minimum service life in NBR 15.575/2008 (7)

Service life (years)	
Structure	40
Indoor floors	13
External walls	40
Internal walls	20
Roofing	20
Hydraulic and sewer	20

sents the evolutions of the mindset of the construction industry in Brazil. It contains 6 parts:
Part 1: General requirements
Part 2: Structure
Part 3: Indoor floors
Part 4: Facades and internal parts
Part 5: Roofing
Part 6: Hydraulic and sewer systems.
The 15.575/2008 [7] part 1 presents several general considerations, including the structural performance and durability. Although it does not address concrete structures specifically, it can represent the basis for the development of a performance specification for concrete. Moreover, it already defines service life, warranties, durability and performance. For example, structural elements which cannot be repaired or maintained, such as foundations, should have the same service life as the building. If no service life is addressed by the specifier, it recommends the minimum service lives in Table 11.

5.4.2 NBR 6118 (2003)

In 2003, NBR 6118 [17] was published and the scope of its previous version was split into two standards, NBR6118/2003 [17] (design) and NBR 14931/2003 [28] (construction); they became effective in 2004.
The NBR 6118/2003 [17] presents exposure classes (Table 12) and for each of them recommends maximum w/cm, minimum compressive strength (Table 13) and minimum cover.
The exposure classes are very subjective and there are no clear parameters to guide the specifier on choosing the correct exposure class. Definitely, a detailed classification, such as the CSA A23.1 [6] and EN 206-1 [24] would be more helpful and convenient.
Table 13 shows explicitly that concrete quality is a function of the w/cm and the compressive strength. It does not take into account the type of cement used, the presence of supplementary cementitious materials, curing quality and other relevant aspects. Although the w/cm importance is indisputable, it is not the only determinant factor that controls the deterioration mechanism in concrete.

Table 12 – Exposure classes in NBR 6118/2003 (17)

Exposure class	Exposure	Deterioration risk
I	Low	negligible
II	Medium	low
III	Severe	high
IV	Very severe	Very high

6. Summary and Conclusions

The performance approach in the construction industry is not a new concept. Nevertheless, it was only in the past fifteen years, when globalization became more important in the construction industry, that the international community has become more aware of the need to create and use performance specifications and started to implement them. Several current international initiatives aim to create the base for the creation of performance specifications.
Many concrete codes, standards and specifications have already included this concept by, for example, defining exposure classes. These documents are mostly hybrid documents, which still present some prescriptive requirements such maximum as w/cm, maximum supplementary materials content and minimum cement content.
The increase need to use recycled materials or by-products, due to sustainability requirements, as well as the use of concretes with very specific purposes, have been promoting the design of more sophisticated concretes which are not a simple mixture of cement, water and aggregates, but also include different blends of supplementary cementitious materials, several different types of admixtures and fillers. Performance specifications open a new perspective for the development of such concretes. There is a consensus that this reality should change in order to achieve longer lasting concrete structures. Nevertheless, performance specifications must be based on scientific evidence that the desired performance can be achieved.

7. References

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Table 13 – Relation between exposure class and concrete quality in NBR 6118/2003 (17)

Concrete	Type	Exposure class I	Exposure class II	Exposure class III	Exposure class IV
Water-cement ratio	CA	≤ 0,65	≤ 0,60	≤ 0,55	≤ 0,45
	CP	≤ 0,60	≤ 0,55	≤ 0,50	≤ 0,45
Strength class NBR 8953	CA	≥ C20	≥ C25	≥ C30	≥ C40
	CP	≥ C25	≥ C30	≥ C35	≥ C40

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