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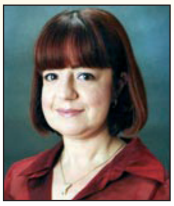
Guidelines for the development of concrete performance-based specifications in Brazil

Diretrizes para o desenvolvimento de especificações por desempenho para concretos no Brasil



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Abstract

Guidelines to develop performance specifications of concrete, including suggestions for performance requirements, are presented. This paper proposes changes to the Brazilian specifications and standards in order to follow the international trend and to move from prescription to performance. Although, the implementation of performance specifications may pose some challenges, it brings an opportunity to increase the service life of concrete structures. The strategic, tactic and operational aspects of performance specification's implementation in Brazil are presented, as well. These guidelines are based on specifications already adopted by other countries, on mathematical modeling and on experimental work.

Keywords: specification, performance-based, hybrid, concrete.

Resumo

A implementação de especificações por desempenho, apesar de apresentarem alguns desafios, trazem uma oportunidade para o aumento da vida útil das estruturas de concreto. Este trabalho apresenta sugestões para a modificação das especificações e normas brasileiras a fim de que sigam a tendência mundial e passem de prescrição ao desempenho. São também apresentadas diretrizes para a criação de especificações por desempenho de concretos, incluindo sugestões para os requisitos de desempenho, bem como os aspectos estratégicos, táticos e operacionais de sua implementação no Brasil. Estas diretrizes têm como base especificações adotadas em outros países, modelagem matemática e trabalhos experimentais.

Palavras-chave: especificação, desempenho, híbrida, concreto.

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1. Introduction

In 2009, following an international trend, Brazil approved its first performance specification for residential buildings (NBR 15 575/2008 [1]). It became effective in 2010 and aims to promote a paradigm shift, representing the evolution of the mindset of the construction industry in Brazil. This specification deals with performance of various systems of residential buildings of up to five floors but not especifically with concrete as a material. There is no consensus for the definition of performance specification and performance-based specifications (Tanesi [2]). In the present paper, performance specifications are those specifications that describe how the finished product should perform over time, while performance-based specifications are specifications that describe the desired levels of engineering properties (e.g., compressive strength and diffusion coefficient) that are predictors of performance and appear in mathematical models that can be used to predict the performance from combinations of predictors over the service life of the structure (TRB [3], Tanesi [2]).
On the other hand, hybrid specification can be defined as a specification that does not apply mathematical modeling to determine the performance criteria or to predict the service life. These specifications may be a combination of prescriptive recommendations and performance requirements and some of the performance criteria are chosen based on technical recommendations (Tanesi [2]).
The development and implementation of concrete performance-based specifications are not easy tasks, especially in Brazil, due to the lack of experience selecting the durability requirements and criteria.
Nevertheless, some requirements widely used in prescriptive specifications are in reality performance-based requirements, such as slump (workability requirement related to constructability), compressive strength and elastic modulus (requirements related to structural safety).
In the past years, some papers have been published addressing performance specification in the Brazilian context (Tanesi et al. [4], Silva et al. [5]). This paper is a follow up to the previously published papers and intends to provide guidelines for the development of performance specifications in Brazil.

2. A critique on the prescriptive approach in NBR 6118/2003

NBR 6118/2003 (ABNT [6]) brings exposure classes in the same way as other international standards and specifications, such as EN 206-1/2000 (EUROCODE [7]), CSA A23.1-04 (CSA [8]) and ACI 318-08 (ACI [9]). According to these classes, the Brazilian standard makes recommendations for maximum water-cement ratio, minimum compressive strength and minimum cover.
Nevertheless, unlikely CSA A23.1-04 (CSA [8]) and EN 206-1/2000 (EUROCODE [7]), the exposure classes in NBR 6118/2003 (ABNT [6]) are very subjective and there are no clear parameters to guide the specifier on how to choose the correct exposure class.
In NBR 6118/2003 (ABNT [6]), the concrete quality is understood as directly related to water-cement ratio and compressive strength. The Brazilian standard does not take into account the type of cement used, the presence of supplementary cementitious materials, specified service life, curing quality, among other things. Despite the proven importance of water-cement ratio with regard to durability, this is not the only factor that governs the various deterioration mechanisms in concrete. Moreover the maximum allowed water-cement ratios allowed by NBR 6118/2003 (ABNT [6]) are relatively high, especially for the case of exposure class III. In this case, despite being a high risk exposure class, a 0.55 water-cement ratio is allowed. Since, unlikely in the USA, in Brazil, almost every single cement readily available in the market contains different contents of blast furnace slag, it is surprising that the use of supplementary cementitious materials and their influence on the matrix microstructure quality are not contemplated.
Finally, an important point is that the limits presented by NBR 6118/2003 (ABNT [6]) were determined on the basis of experience, empirical or not and not based on the understanding and modeling of the deterioration mechanisms. Moreover, since it does not specify a minimum service life, it is not possible to forecast what service life could be achieved if the NBR 6118/2003 (ABNT [6]) criteria are used. In this context, performance-based specifications appear as a solution to achieve the desired service life.

Figure 1 – Action plan for the creation and implementation of concrete performance-based specifications in Brazil

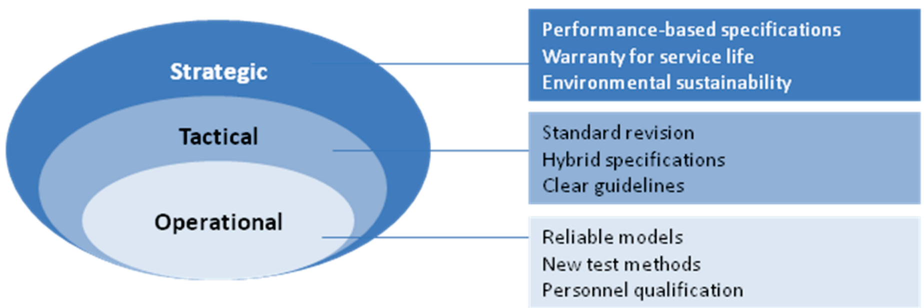


Table 1 – Suggested alternative method for specifying concrete based on CSA A23.1-04 (CSA)

Specification type	Requirements
Hybrid or performance-based	■ requirements and criteria for structural safety ■ requirements and criteria for durability ■ environmental requirements ■ other requirements (color, texture, etc.)
Prescriptive	Same requirements in the current NBR 6118, provided the requirements for exposure classes III and IV are revised.

3. Action plan for the creation and implementation of concrete performance-based specifications in Brazil

Figure 1 shows a schematic of the action plan in the strategic level (long-term), tactical (medium term) and operational (short term) for the creation and implementation of concrete performance-based specifications in Brazil.

3.1 Strategic analysis

The current situation of the Brazilian specifications is still far from a performance-based approach, but should be redirected in that way in order to obtain more durable concrete structures.
Environmental sustainability is another aspect to be considered. The scarcity of raw materials and new environmental policies increasingly stress the importance of the adoption of more innovative solutions for the use of materials and resources available, without, however, sacrificing the performance of the structure. Environmental sustainability also requires the move in the direction of performance-based specifications with the adoption of performance indicators.
However, there is still a long way to reach a concrete performance-based specification, as it requires mathematical modeling of deterioration mechanisms in order to the estimate the service life of the structure. This modeling should aim to guarantee the service life of the project under the specific exposure conditions.
The specification of performance criteria which were not determined with the use of mathematical models to predict the structure service life does not constitute a performance-based specification, but rather a hybrid specification. This is because, as with prescriptive specifications, the criteria become subjective and not necessarily bound to a particular service life or performance over time (Tanesi [2]).
The construction industry is a conservative industry, especially in Brazil, that opposes to radical changes. It is also an industry that is influenced by the interests of large corporations. The implementation of performance-based specifications requires a change of the mindset of all involved in the process, mainly regarding technical responsibilities.
This means that there should be a redistribution of risks and each professional should have their responsibilities clearly defined. However, if the producer and the contractor are expected to take new risks, they anticipate to be given more freedom in the production of the product that meets the criteria of the specification (Bickley et al. [10]).

3.2 Tactical analysis

3.2.1 Standards' revision

The definition and selection of performance requirements have a determining role in the durability of the structure because, simply specifying the maximum water-binder ratio, compressive strength and minimal cement content is not sufficient to guarantee the desirable service life of the structure.
A clear example of the inadequacy of prescriptive specifications is the minimum cement content requirement. It is not a requirement in NBR 6118/2003 (ABNT [6]) but in NBR 12 655/2006 (ABNT [11]). Not only this requirement is not sufficient to ensure the durability, but could be even detrimental to it. This is because when a minimum cement content is specified, the tendency is to exceed it significantly, which could cause shrinkage and cracking issues, in addition to neither being a sustainable nor a cost-effective decision. Some American agencies have already started the discussion about the possibility of replacing the minimum cement content by the maximum cement content (Simons [12]).
However, in Brazil, it is known that if the minimum content is not specified, there is a risk that mixtures with cement content lower than the technically appropriate would be used. That is why, in performance-based specifications, there is a total change of technical responsibility, causing all involved to seek the best long-term solution.
In order to develop a performance-based specification in Brazil, it is imperative to change the current standards, in particular NBR 6118/2003 (ABNT [6]) and NBR 12 655/2006 (ABNT [11]).
The first suggested change would be the option to use three different types of specification: prescriptive, hybrid and performance-based (Table 1), similar to the one presented in the Canadian standard CSA A23.1-04 (CSA [8]), which allows the use of two types of specifications: performance and prescriptive. Nevertheless, in the opinion of the authors what the CSA A23.1-04 (CSA [8]) calls for performance specification is actually a hybrid specification. It is also important to highlight that currently there is no real concrete performance-based specification.
Performance-based specifications require the creation of more detailed exposure classes than the existing classes in NBR 6118/2003 (ABNT [6]). In this case, a combination of current

classes in NBR 6118/2003 (ABNT [6]) and the classes in EN 206/2000 (EUROCODE [7]) is suggested (Table 2).

3.2.2 Selection of performance requirements for performance-based specifications

Several aspects should be considered when creating a performance-based specification for concrete: structural safety requirements (mechanical properties), constructability requirements (fresh properties), durability requirements (physical properties and durability) and sustainability requirements (particularly environmental and lifecycle cost). These requirements should be represented by a set of measurable properties. Moreover, the intended service life must be defined.
The performance requirements can be specified for two distinct phases: those related to properties that must be observed during the mixtures design (pre qualification of mixtures) and those that will be checked on the quality control during construction. However, the quality control requirements should only be a tool to ensure that the concrete received in the job site is the same mixture that was chosen during the mixture design or pre qualification stage and possesses the same properties. For that reason, a correlation between the mixture pre-qualification and the quality control requirements is needed.
In most cases, a single requirement is not sufficient to characterize the behavior of concrete dominated by complex physical and chemical mechanisms which may be subjected to synergistic effects, where several mechanisms are present (Baroghel-Bouny [13]). These requirements must be measurable through reliable test methods, with good repeatability. In addition, quality control test costs should be taken into consideration and long-term tests are not recommended.
This paper focuses on requirements and specific performance criteria based on analysis of specifications of other countries, mathematical modeling and experimental work performed by Tanesi [2]. The quality control requirements exceed the goals of this work and will not be object of discussion.

3.2.2.1 Requirements related to constructability and structural safety

The constructability requirements (fresh properties) depend on the

Table 2 – Proposed exposure classes

Exposure Class	Type of exposure	Subclasses 1
I	Insignificant risk of corrosion	1. Rural[2] 2. Submerged[2] 3. Indoors with low relative humidity
CB	Corrosion induced by carbonation	1. Dry (indoor areas with low humidity) or permanently submerged 2. Wet, rarely dry (surface in constant contact with water, foundations) 3. Moderately humid (indoor areas with high relative humidity and outdoor areas sheltered from rain) 4. Wetting and drying cycles
CAM	Corrosion induced by chlorides	1. Exposed to airborne salts but not in direct contact with sea water (coastal structures)[3] 2. Permanently submerged (marine structures)[3] 3. Tidal, splash and spray zones (marine structures)[4]
AQ[5]	Chemical attack	1. Slightly aggressive 2. Moderately aggressive[3] 3. Highly aggressive[4]
AND	Special exposure not covered in other classes	1. Alkali-silica 2. Alkali carbonate 3. Concrete mass 4. Other

[1] Specific limits should be defined for each sub class.
[2] Exposure class I of NBR 6118/2003.
[3] Exposure class III of NBR 6118/2003.
[4] Exposure class IV of NBR 6118/2003.
[5] Specific limits for SO^{42-}, Mg^{2+}, NH^{4+}, CO_2, pH should be specified for each sub class.

type of structure, the reinforcement ratio, placing and consolidation. It is usually specified in terms of slump, however, in some cases, other requirements could be used such as slump loss over time, segregation and initial set, as they may directly affect the construction, concrete quality and its durability.

The requirements related to structural safety also depend on the specific use and structure design, and among them are the compressive strength, flexural strength, modulus of elasticity and creep. When using mixtures with high level of supplementary cementitious materials, the 28 day compressive strength may not be a proper requirement, since such mixtures may develop strength slower than plain mixtures. In this case, a 56 or 63 day compressive strength may better represent the strength characteristics of these mixtures.

3.2.2.2 Durability requirements

Specifying durability requirements is a much more difficult task than specifying structural safety requirements. Those requirements should be selected based on the exposure class of the structure. Figure 2 shows the sequence for the selection of durability performance requirements and criteria.

- **Step 1:** the owner must choose the service life. Internationally, some structures are already being designed for a minimum service life of 100 years. However, not all structures need to last the same period of time. Structures with higher repair and reconstruction costs, which may cause more disturbances to the environment and offer a greater risk to society typically, require higher service life.
- **Step 2:** the owner must specify whether or not special requirements are needed, such as color, texture, skid resistance, aesthetics, reflectance, flatness and lifecycle cost analysis, among others. In this stage, the owner must specify any sustainability requirement, as well. The definition of sustainability requirements at this stage is important because besides being required for the performance criteria selection (step 7), it may also influence the definition of exposure classes (step 4).

  In case sustainability requirements are incorporated into Brazilian specifications, it is necessary to establish performance indicators and tools for calculating the life-cycle inventory for conditions and materials available in Brazil.
- **Step 3:** the structural designer must specify the structural safety requirements, such as compressive strength and flexural strength and modulus of elasticity, among others. In addition, depending on the reinforcement spacing, dimensions of structure elements, the designer should define the slump or other parameter related to workability.

  In this stage, the contractor should consider construction issues related to environment, such as the temperature at the time of construction, and then specify any property required to handle slump loss, setting time and strength development.
- **Step 4:** the specifier must choose the exposure classes. Several classes of exposure may be necessary to characterize a structure, because multiple mechanisms of deterioration may be involved, as, for example, in a structure that, in addition to being subject to seawater chloride induced reinforcement corrosion (class CAM), has also the risk of alkali-aggregate reaction (class E).

  If concrete with high levels of blast-furnace slag is used, which could potentially provide a greater susceptibility to carbonation, in some cases, it may be advisable to incorporate CB exposure class, so that any mixture used is investigated with respect to carbonation and, if necessary, measures are taken to prevent carbonation induced reinforcement corrosion.

  In addition, different parts of the structure may be subject to different levels of severity. For example, a bridge deck could be classified as CAM-1, while the columns could be classified as CAM-3. Different subclasses, despite having the same performance requirements, may have very distinct performance criteria.

  At this point, it is important to establish the performance requirements related to durability. The requirements should be chosen taking into account what models will be used to predict the service life, because these requirements should be the inputs in these models or should have a clear correlation with them. Furthermore, the durability requirements should be able to reflect the deterioration mechanisms to which the structure is going to be subjected to.

  The following are some of the durability requirements that could potentially be specified. They were divided into requirements related to seawater chloride induced corrosion, carbonation induced corrosion, general and special requirement

3.2.2.2.1 Discussion on possible requirements related to chloride induced corrosion

- **Apparent chloride diffusion coefficient** – this is one of the most important durability requirements as it has a direct relationship with the ingress of chlorides and thus with reinforcement corrosion. Most mathematical models for the service life prediction, when considering chloride induced corrosion, use the diffusion coefficient as one of its inputs.

  The test used to determine this coefficient is the ASTM C 1556-04 (ASTM [14]) (Chloride bulk diffusion test). This test takes approximately three months and is relatively difficult to be carried out. Grinding 1-2 mm layers of concrete is a very delicate task that can lead to a high variability of test results. So, it is necessary to develop another test that can give an indication of the diffusion coefficient.

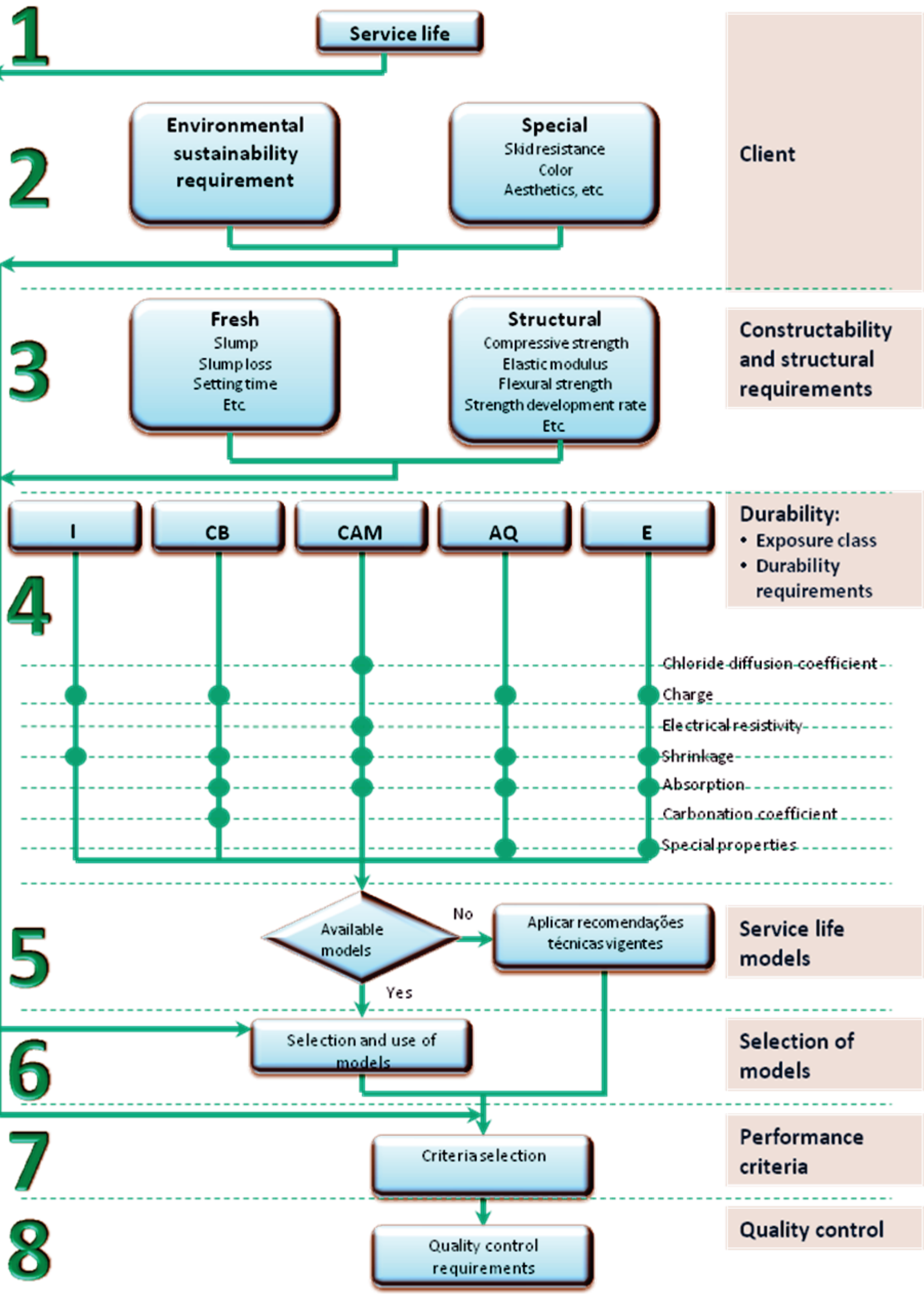
  The rapid migration test NT Build 492: 1999 (NORDEST [15]) was developed based on the research of Tang and Nilsson [16] and presents an equation for calculating the chloride migration coefficient, which is commonly used as diffusion coefficient. However, the coefficient calculated on the basis of this standard is not the apparent diffusion coefficient used by most mathematical models. In reality, this coefficient is not even the chloride diffusion coefficient but an approximation. This is because diffusion is the movement of ions due to a concentration gradient or chemical potential, while the migration test actually measures the movement of ions under an external electric field.

  If the diffusion coefficient is chosen as a requirement, it is recommended that models, such as Life-365, are used to estimate the maximum acceptable diffusion coefficient for the specific conditions of the structure under study that would guarantee that the desired service life is achieved. Selected mixtures should be tested and should comply with these limits.
- **Total charge** – ASTM C 1202-05 (ASTM [17]) is the most widely durability requirement used in hybrid specifications. This

test method provides an evaluation of resistance to penetration of chlorides with electrical conductance of material.
Each specification has a maximum acceptable total charge, which usually lies between 1000 and 3000 Coulombs at 56 days or after the accelerated cure proposed by Ozyildirim [18]. Choosing the maximum total charge relies on the specifier's experience and not on some quantitative relationship with a particular service life under a specific exposure condition. Nevertheless, this might be a good quality control test.

- **Electrical resistivity** – Electrical resistivity in conjunction with the oxygen access to the reinforcement are the main drivers of electrochemical mechanism that leads to corrosion (Ferreira

Figure 2 – Diagram for the selection of performance-based requirements related to durability



[19], Cascudo [20]). Furthermore, it is an easy test to run. Although, CEB 192 (CEB [21]) proposes guidelines for the corrosion risk assessment using electrical resistivity, there is no mathematical model that uses electrical resistivity as an input to predict service life. As a consequence, electrical resistivity cannot be understood as a performance-based specification requirement but as a requirement for hybrid specifications.
Since the current is carried by the ions in the pore solution, several factors can influence the electrical resistivity, such as the size and quantity of pores (for example, with increased water-binder ratio), moisture, degree of hydration, concrete carbonation and salt ingress (Millard; Gowers [22]). Therefore, the electrical resistivity should be analyzed in conjunction with other techniques (Andrade; Alonso [23]).

3.2.2.2.2 Discussion on possible requirements related to carbonation induced corrosion

- **Carbonation coefficient** – Carbonation is not the direct cause of concrete deterioration, but its effects can significantly impact the durability of the structure. For example, shrinkage due to carbonation and the reinforcement despassivation can decisively contribute to reinforcement corrosion.
  The carbonation depth is usually measured by spraying phenolphthalein over the concrete surface. A very simple mathematical model (model Ushida-Hamada, 1928) may be used to obtain the carbonation coefficient k. In this case, a maximum k can be specified in order to prevent the carbonation to reach the reinforcement.
  The natural carbonation is a very slow process that may take years. In addition, several factors can influence the natural carbonation test, such as internal humidity of concrete, the environmental conditions (temperature and humidity) and curing condition. As a consequence, it is practically impossible to reproduce in the laboratory the conditions to which the structure is expected to be subjected to, so the performance presented in laboratory studies may not necessarily represent the concrete behavior in service.
  The accelerated carbonation can reduce testing time, but does not represent the exposure conditions in service and does not correlate with natural carbonation exposure.
  Sanjuán et al [24]; Bier et al. [25] and Tanesi [2] observed that different mixtures respond differently to accelerated testing. In other words, there seems to be different degrees of microstructure change for different concentrations of CO_2. Although coefficient of carbonation is in theory a good requirement, the fact that the accelerated carbonation is not necessarily comparable with the natural carbonation, makes its use basically impractical.

3.2.2.2.3 Discussion on possible general durability requirements

- **Absorption** – mass transport plays an important role in various deterioration mechanisms, such as corrosion, carbonation, sulfate attack, chloride penetration and alkali-aggregate reaction. Nevertheless, this property is not recommended as a requirement since there are no clear criteria for this property neither a mathematical model for service life prediction that uses this property was found. Nevertheless, this property can be used only as a tool to compare mixtures.
- **Drying Shrinkage** – free drying shrinkage can be measured by NBR 8 490/1984 (ABNT [26]) and ASTM C 157-08 (ASTM [27]). These standards are similar. Since they measure the free shrinkage, they do not represent the behavior of the structure, which is normally restrained. NBR 8 490/1984 (ABNT [26]) only provides a limited indication of volume stability.
  No service life prediction model was found that includes shrinkage as one of its inputs. However this can be a useful tool for mixture comparison.
- **Cracking** – cracking is usually due to restrained shrinkage. There are two standardized test methods to assess cracking susceptibility ASTM C 1581-04 (ASTM [28]) and AASHTO PP 34-99 (AASHTO [29]), both ring tests, which was originally developed by Coutinho in 1954 (Tanesi [30]). These test methods present high variability and do not measure a fundamental material property. They do not simulate the conditions that may be encountered in the field. This test method typically presents the age for the onset of the first crack. No recommendation for cracking was found in the current Brazilian specifications.

3.2.2.2.4 Special requirements

- **Sulfate resistance** – NBR 13 583/1996 (ABNT [31]) assesses sulfate resistance of mixtures. There is no recommendation in the Brazilian specifications with respect to a maximum allowed expansion that would guarantee the mixture to be resistant to sulfate attack.
- **Abrasion** – in special cases, as in floors and pavement, it may be necessary to specify abrasion resistance. Abrasion resistance is usually indicated by means of the mass loss or the depth of abrasion. Several test methods have been used for the evaluation of this property, as for example, ASTM C 779-05 (ASTM [32]) and ASTM C 944-05 (ASTM [33]).
- **Alkali-silica reaction** – when the aggregates to be used in the job are prone to alkali-silica reaction, recommendations should be provided in the specification in order to avoid the reaction, either by changing the aggregate source or by adopting preventive measures, such as the addition of blast-furnace slag.
  There are several test methods for the detection of the potential for the alkali-silica reaction, such as ASTM C 1260-07 (ASTM [34]), ASTM C1293-08 (ASTM [35]), ASTM C289-07 (ASTM [36]) and ASTM C 1567-08 (ASTM [37]).
- **Step 5**: the applicability and reliability of the available service life predictive models should be reviewed. Table 3 presents a summary of some requirements relating to durability that are used as inputs for the prediction of the service life.
  If no models are available for some of the selected requirements, the criteria should be chosen according to the existing technical recommendations.
- **Step 6**: The service life model should be selected according to appropriate technical principles and should be consistent with the deterioration mechanisms expected to affect the structure. Then, the models should be applied, incorporating the minimum service life established in step 1.
- **Step 7**: The performance criteria is determined by applying the desired minimum service life to the models. In addition, the criteria for the special requirements should be determined.
- **Step 8**: Requirements for quality control have to be specified. They should correlate with the performance requirements se-

Table 3 – Mathematical models for performance requirements related to durability

Requirement	Are there mathematical models to correlate this requirement with service life?
Chloride diffusion coefficient	Yes
Charge (ASTM C 1202)	No
Electrical resistivity	No
Carbonation coefficient	Yes
Absorption	No
Shrinkage	No
Cracking	No
Expansion due to sulfate attack	Yes
Expansion due to alkali silica reaction	Yes
Abrasion resistance	No

lected previously. Since assessing performance of in-place concrete may not be always practical, surrogate tests may be used for acceptance. In addition, another set of tests may be specified to verify the concrete delivered is similar to the pre-qualified mixture. The acceptance criteria should be statically based and tolerance or minimum /maximum values should be specified. The actions to be taken, in case the criteria are not met, should be clearly stated. The point of sampling should be clearly defined, as well (ACI [38]).

3.2.3 Hybrid specifications

A transition in the direction of performance specifications is necessary. For such, an intermediate stage should be implemented, where the maximum allowed water-binder ratio should be decreased and other requirements should be specified. This can be an efficient and relatively simple way to guarantee a better microstructure and, as a consequence, increase the service life of the structures, before the Brazilian industry is ready for the implementation of performance-based specifications.

An example of hybrid specification is a document that specifies the compressive strength and maximum total charge in Coulombs as requirements instead of water-binder ratio. One of the most commonly specified requirements in hybrid specifications is the maximum total charge.

ASTM C 1202-05 (ASTM [17]) presents a qualitative classification regarding the risk of chloride penetration. However, since this classification is very broad, it can potentially put quite different mixtures at the same level of risk of chloride penetration. This classification, therefore, is not sufficiently sensitive to microstructural differences that may occur, nor it is appropriate to ensure durability and does not consider the exposure conditions of the structure.

The current hybrid specifications normally do not use the C 1202-05 (ASTM [17]) classification but stipulate a maximum total charge passed at particular age. A value of 1500 Coulombs to 56 days has been shown to be appropriate for most cases with similar exposure conditions of exposure classes III and IV of NBR 6118/2003 (ABNT [6]).

3.3 Operational analysis

As previously presented, implementation of performance-based specifications in Brazil requires a change of mentality in the industry. In order to promote this change, it is recommended the creation of workshops and seminars so that the performance-based concepts, as well as their implications, advantages and disadvantages can be presented to engineers, contractors and owners.

In addition, according to Bickley et al. [10], it is necessary:

- creation of qualification/certification programs that establish requirements for a quality control management system, qualification of personnel and requirements for the concrete plants;
- Producers and contractors partner to ensure the right mixture is developed, delivered and installed;
- Performance requirements be measured by a set of tests at the various stages of the process (pre- qualification of mixture and quality control);
- A clear set of instructions is created presenting actions to be taken when concrete does not meet the performance criteria, including penalties and bonuses;
- Reliable mathematical models are developed and calibrated based on data from long-term exposure to the Brazilian conditions (environment and materials).

4. Conclusions

This paper proposed the creation of performance-based specifications, as well as hybrid specifications in Brazil. In order to accomplish it, the current Brazilian standards, especially NBR 6118/2003 and NBR 12655/2006 must be changed.

Among the necessary changes, NBR 6118/2003 should allow the use of performance-based specifications and, in this case, the requirement for maximum water-binder ratio should be eliminated.

New exposure classes were proposed, taking into consideration various mechanisms of deterioration.

The need of mathematical modeling to predict service life and some of the challenges related to performance-based specifications implementation were analyzed.

The process of choosing performance requirements and criteria was discussed. The constructability, structural safety, durability, sustainability and special requirements were analyzed. In addition, a methodology to determine the performance criteria was proposed.

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