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Correlation between the Barcelona test and the bending test in fibre reinforced concrete

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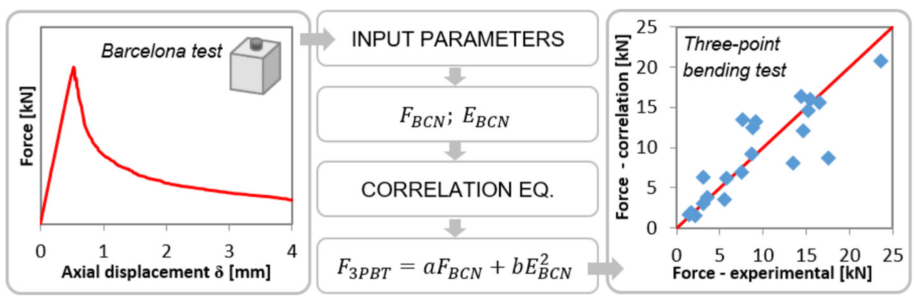
HIGHLIGHTS

- A methodology to correlate the bending and the Barcelona test is described.
- The Barcelona test is presented as an alternative method to the bending test.
- The correlations calculated are able to predict the results with accuracy over 75%.
- Confidence intervals are defined due to the inherent scatter in the results of FRC.
- Several parameters are involved in the correlation to maximize R^2.

GRAPHICAL ABSTRACT



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ABSTRACT

The Barcelona test (BCN) is an alternative method to characterize the post-cracking behaviour of fibre reinforced concrete (FRC). Given its simplicity, the reduced scatter of the results and low material consumption, the BCN may represent a suitable method for the quality control of FRC. For that, a correlation between the results of the BCN and the bending test is currently required since the latter is considered the reference for the characterization of the material and for deriving the constitutive design equations. The objective of this paper is to propose such correlation following an approach that takes into account the intrinsic variability of FRC. An experimental program involving 21 mixes of conventional and self-compacting FRC with either steel or plastic fibres was performed. Several analyses were conducted both for selecting the most relevant parameters and for maximizing the degree of correlation between the tests. The highest correlation coefficient between tests was obtained for the mixes with plastic fibres. In such case, the formulation proposed is able to predict the results with accuracy up to 75%. The correlation found is an interesting tool towards a simple and reliable quality control of FRC based on the BCN mainly oriented to large scale concrete production.

1. Introduction

The quality control of fibre reinforced concrete (FRC) used in structural applications should include tests for the assessment of the post-cracking response of the material. The selection of suitable testing methods for this purpose becomes particularly relevant given the high intrinsic scatter associated with the post-cracking response [1]. In this context, it is important to count with simple and fast methods that may provide enough repetitions for a reliable statistical analysis of the results that could lead to representative average and characteristic values of the post-cracking strength of the material.

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The most extended method applied nowadays is the three-point bending test (3PBT) according to EN 14651:2007 [2]. It presents a coefficient of variation usually above 20% [3,4] and a complex setup if compared to other tests, requiring special equipment and relatively big specimens. For these reasons, as suggested by the Belgian standard NBN B 15–238 [5], the 3PBT is not considered suitable for the systematic quality control of FRC. Thereby, alternative tests were developed in an attempt to overcome the drawbacks previously mentioned [6–8]. In this context, the *fib* Model Code 2010 [9] allows the use of alternative tests to obtain the residual strength of FRC if appropriately correlated to the results of the 3PBT. Therefore, in case such correlations are achieved, the substitution of the bending test by an alternative approach may be accepted.

The use of correlations between concrete properties measured in different test methods is a common and widely accepted procedure, even when the cracking mechanisms involved in each of them are completely different. For example, equations relating the compressive strength and the tensile strength are present in the majority of structural concrete codes and guidelines. Moreover, several equations are available to transform the indirect tensile strength measured in the Brazilian Test into the indirect flexural strength measured with bending tests [10]. In the case of FRC, Minelli et al. [11] already proposed a correlation between the Round Panel Test and the UNI flexural test based on the energy released and the residual strength. Correlations between different typologies of tests also provide an opportunity for developing new simplified stress-crack width laws for FRC [12,13].

Another alternative to characterize the tensile residual strength of FRC is the Barcelona test (BCN) proposed by Molins et al. [4] and included in the standard UNE 83515:2010 [14]. Recently, it has been improved by Pujadas et al. [15,16] and a constitutive equation based on the results of the test was proposed by Blanco et al. [17]. The BCN is simpler than the 3PBT in terms of execution since 75% lighter specimens are used and no closed-loop is required. It also presents smaller scatter [15] with a coefficient of variation of the results below 13% [4]. Despite these advantages, the use of the BCN for the characterization of FRC is hindered by the lack of correlations with the 3PBT.

Taking that into account, the objective of this paper is to correlate the results of both tests so the BCN may be used as a complementary method to characterize the properties of FRC. The approach presented here aims to obtain simple and reliable correlations taking into account the typical variability of the material. In this regard, the correlation proposed represents a tool towards a simpler, faster and less expensive quality control of FRC based on the BCN. This approach is in line with the *fib* Model Code 2010 and may also serve as an example for future correlations with other tests applied to FRC.

2. Methodology to correlate the tests

The approach proposed to determine the correlation between the BCN and the 3PBT consists of three stages, as indicated in Fig. 1. In the first stage, an experimental program with a wide variety of concrete types was performed. In the second stage, linear regressions are performed considering different variables included in the study. This helps determining whether a universal correlation between both tests is possible or if different formulations are needed depending on the type of concrete, the type of fibre or the fibre content.

In the third stage a multi-variable parametric study is conducted in order to obtain the final correlations. To account for the variability of the FRC, an approach similar to that used in sprayed concrete is applied. Instead of proposing a single equation,

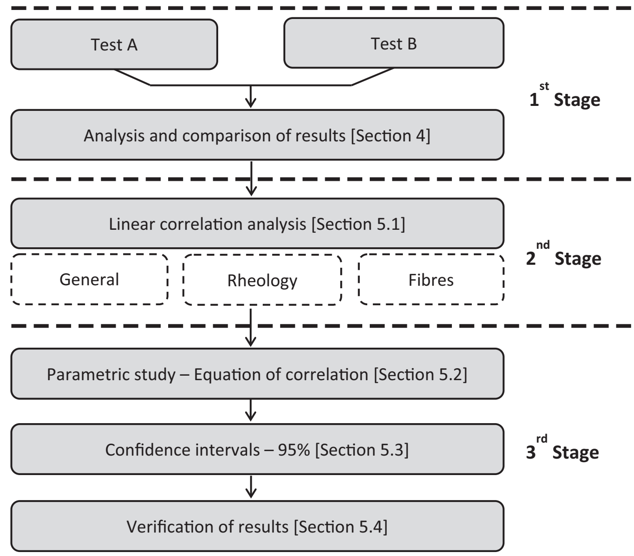

Fig. 1. Methodology used to derive the correlation between tests.

a correlation zone defined by confidence intervals is derived through a statistical analysis of the results. Equations for the 50% and 95% confidence are proposed.

3. Experimental program

3.1. Materials and mixes

Mixes with conventional concrete (CC) and self-compacting concrete (SCC) were produced. The flowability of concrete may influence the residual strength of FRC since it affects the orientation of the fibres [18–23]. In total, 21 concrete mixes were designed with water-to-cement ratios ranging from 0.19 to 0.56. Different types of cements were used, with total contents between 275 and 700 kg/m^3. Hooked-end steel fibres (SF) were added in contents from 30 to 60 kg/m^3, whereas the content of 3 types of plastic fibres (PF1, PF2 and PF3) varied from 3.5 to 25 kg/m^3.

Table 1 summarizes the mixes depending on the main variables of the study. The compressive strength in each mix is the average of 3 specimens of $\phi 150 \times 300$ mm tested under compression according to EN 12390-3 [24]. The nomenclature includes the type of fibre and the content used. Table 2 shows the main characteristics of each type of fibre.

3.2. Specimens and test procedure

As shown in Fig. 2, the BCN consists of a double punch test on a cylindrical ($\phi 150$ mm $\times$ 150 mm) or cubic (150 mm) specimen. The test is performed by placing, concentrically above and below the specimen, cylindrical steel punches with a height of 25 mm and a diameter equal to ¼ of the smaller dimension of the cross-section of the specimen. The hydraulic press applies a load to the punches at a constant displacement rate of 0.5 ± 0.05 mm per minute. In the process, a conical triaxial state is formed from the centre to the edges of the specimen, leading to internal tensile stresses that increase with the load. Cracks appear (Fig. 2) when the stresses reach the tensile strength of the concrete matrix. After that, the fibres bridge the crack, providing a residual strength. The results obtained may be represented through a Load-Total Circumferential Opening Displacement (TCOD) curve or Load-Axial Displacement relationship depending on the equipment used in the test, as depicted in Fig. 2.