Construction and Building Materials 124 (2016) 722–731

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Shear behaviour of sprayed concrete

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HIGHLIGHTS

- Shear behaviour of sprayed concrete under controlled laboratory conditions.
- Selection of shear test compatible with the production of sprayed concrete samples.
- Experimental program on reference concrete mix and sprayed mixes.
- Evaluation of the influence of porosity, humidity and anisotropy in the results.
- Validation of the test for future studies or quality control.

ARTICLE INFO

Article history:
Received 5 February 2016
Received in revised form 22 June 2016
Accepted 15 July 2016

Keywords:
Sprayed concrete
Shear
Luong test
Set-accelerator

ABSTRACT

Shear in sprayed concrete (SC) may govern the design criteria in certain applications subjected to seismic loads or in bolted areas. However, it has been scarcely studied given the complexity of reproducing the production conditions in the laboratory and the lack of standardized tests. The paper focuses on the shear characterization of SC using a shear test compatible with the sample production. For that, an experimental program is performed analysing the influence of several parameters and comparing the results to those of a reference concrete. Furthermore, the outcome validates the shear test selected for the characterization of SC.

1. Introduction

Sprayed concrete (SC) is a material extensively used worldwide for underground support, slope stabilization and the construction of domes, façades or reservoirs. Despite that, it has been scarcely studied under controlled laboratory conditions if compared with other types of concrete. The main reason for that is the difficulty to emulate in laboratory the production conditions found in practice, which would imply the use of big facilities and equipment to spray and pump concrete. Among the properties of SC that require further studies is the shear behaviour. Especially in elements subjected to seismic loads or in bolted areas, the shear strength might play an important role on the ultimate limit state verifications, as well as on the partial or complete failure of the structure.

The formulations available nowadays in codes and guidelines to conduct the structural verification in shear are derived from extensive studies on either conventional or high performance concrete. Even though all these types of concrete share similarities in terms of composition, relevant differences arise due to the casting procedure in the case of SC. For instance, to assure a good pumpability and decrease the incidence of blockages, a reduction of the relative amount and the maximum size of coarse aggregate is necessary in SC mixes [1]. During the spraying process, the introduction of compressed air and set-accelerator admixtures at the nozzle modify the microstructure of the cement paste, affecting the hydrated compounds formed and leading to higher porosity [14,22,23]. Moreover, part of the components rebound when the concrete impacts against the substrate. This rebound is higher for bigger particles, like the coarse aggregates. In other words, an additional reduction on the content of this fraction is observed.

Studies on conventional concrete show that aggregate interlock is one of the main mechanisms governing the shear behaviour. Consequently, the higher porosity of the concrete matrix together with the smaller aggregate size and content must affect the shear behaviour. In this context, the direct use of formulation for conventional concrete for the design of SC elements might lead to unsafe predictions. In order to overcome this drawback and promote the efficient use of SC, it is necessary to conduct rigorous experimental studies on the shear behaviour of the material in comparison with equivalent conventional concrete.

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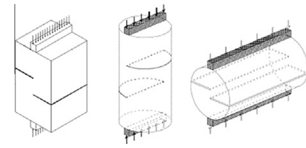
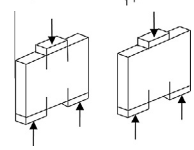
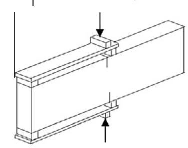
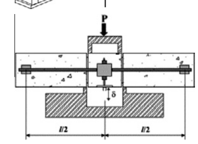
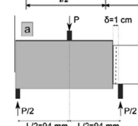
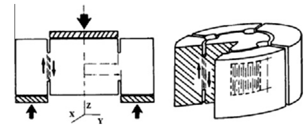
http://dx.doi.org/10.1016/j.conbuildmat.2016.07.050
0950-0618/

Table 1
Summary of shear characterization tests.

Shear test	Reference	Specimen	Setup
Push-off test	[3,2]	Z-shaped specimens	
Punch shear test	[3,26]	Deep beams or panels with notches	
Iosipescu shear test	[15]	Iosipescu beam	
Japanese test	[16,20]	Beam	
LCB shear test	[18,19]	Cylindrical specimen	
Luong test	[17,21]	Cylindrical specimen with diametrical notch	

The assessment of pure shear behaviour of concrete is a complex task. No standardized tests are available and most of the tests found in the literature require special sample preparation and setups hardly compatible with the execution of SC structures. The selection and adaptation of a simple shear test to these conditions might represent an additional contribution since the results obtained could be used for the quality control of the variability of the material.

Taking that into account, the primary objective of this paper is to evaluate the shear behaviour of SC under controlled laboratory conditions and in comparison with a reference concrete (REF). The secondary objective of this study is to define a simple test to evaluate the shear behaviour in SC, considering the condition found in most worksites. For that, first an in depth evaluation of the setup of the shear tests available in the literature is performed. Then, an experimental program with a reference concrete mix (manually poured) is conducted to define the parameters used in the test and to obtain reference values for the comparison with SC. Next, an experimental program with SC that is sprayed in laboratory and characterized with the proposed test setup. The influence of the porosity, of the humidity and of the type or content of set-accelerator on the microstructure are evaluated. The results not only shed light on the reductions expected on the shear behaviour in comparison with the reference concrete mix, but also validate a test setup for future studies or for the quality control.

2. Shear characterization tests

A common issue in these tests is the difficulty to achieve a situation of pure shear. Most of the setups available in the literature present an eccentricity in the application of the load. As a result, other phenomena such as bending may also appear, leading to a combination of tensile and shear failure. In order to reduce variability and obtain reliable results, it is important to select tests that minimize this effect. Table 1 summarizes the main shear tests reported in the literature.

The push-off tests is the most frequently used to characterize shear [3]. They are usually conducted on Z-shaped prism or cylinders with two notches in opposed faces that resemble two L-shaped blocks joined by a common plane. A compression load applied at the top and bottom surfaces generates shear stresses in the common plane. The setup may vary depending on the geometry of the specimens and the location of the notches [3,2]. Other procedures reported in the literature are performed in deep beams or panels [3,26] with aligned or eccentric notches on the top and bottom surfaces (in some cases the notches are only on the bottom surface) that are subjected to punching.

The Iosipescu shear test was originally proposed for metals and welded joints [15]. Barr (1990) and Schlangen [24] applied it to concrete and concluded that a failure mode with mixed shear and tensile stress was normally observed. Alternatively, the shear test proposed in the Japanese recommendations JSCE-SF6 [16] is conducted on a beam with two notches. The load is applied by a steel block with two wedges close to the mouth of the notches, generating a stress field [20] that favors the shear failure. The LCB test was developed to evaluate the bond between pavements layers of bituminous materials through the shear strength [18,19] based on the Spanish standard NLT-328/08 [4]. A study performed by Segura and Aguado [25] to assess the bond between SC and conventional concrete with the LCB showed that a mixed failure was also commonly observed.