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Shape factors of self-compacting concrete specimens subjected to uniaxial loading

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ABSTRACT

One of the problems encountered when comparing the mechanical properties of self-compacting concrete (SCC) is the use of different specimen sizes all over the world. For vibrated concrete (VC), conversion factors are defined to convert the obtained compressive strength on one specimen type to another. In order to investigate the applicability of these factors for SCC, a total of 2 VC and 10 SCC mixtures were selected varying in cement type, cement content, water-to-cement ratio and water-to-powder ratio. Beside cubes with sides of 100 mm, 150 mm and 200 mm, cylinders with a diameter of 100 mm and diameter 150 mm were cast and cores with a diameter of 100 mm, 80 mm and 50 mm were drilled. A significant difference of about 10% in the shape factors between SCC and VC has been found. Mix design parameters, such as the fraction of powder, the cement-to-powder ratio and the water-to-cement ratio, seem to have little influence on the obtained shape factors.

1. Introduction

Using the proper shape factors, it is possible to relate the compressive strength of concrete as being measured from a standard specimen to the strength of specimens with a different size and/or shape. The standard specimen used world-wide is varying. Most European countries have listed a cylinder with a diameter of 150 mm and a height of 300 mm as reference specimen in their standards, whereas North-American countries opt for a cylinder with a diameter of 100 mm and height of 200 mm and other European countries prefer cubes with sides 150 mm. Cylindrical cores with a diameter of 100 mm and a height of 200 mm are often used to determine the onsite concrete strength, but some results determined from cubes with sides of 100 mm or 200 mm and cores with a diameter of 50 mm and a height of 100 mm are also reported. Table 1 summarizes the most cited shape factors of some of the specimen types, as determined on vibrated concrete (VC) [1–10].

During the compressive test, the Poisson effect causes a lateral expansion of the specimen. Because the friction between the end faces of the specimen and the platens of the compression test machine partially hinders the lateral expansion of the area near the end faces, a multiaxial stress state as illustrated in Fig. 1 arises inside the specimens [11]. In a specimen with a height comparable to the lateral size, the multiaxial stress states originating from both end faces overlay in the center of the specimen and allow a higher compressive strength measurement compared with a specimen with a higher height-to-diameter ratio [6,12–14]. Therefore, the compressive strength as measured on cubes or cylinders with a height-to-diameter ratio smaller than 2 is higher than as measured on a cylinder with the same lateral dimension but a height-to-diameter ratio of 2. If the friction is eliminated with the use of a friction-reducing interlayer (e.g. Teflon), the compressive strength is independent of the slenderness of the specimen [15,16].

Because, the voids of the granular skeleton in a specimen are larger near the walls of the specimen than in the interior, a specimen with a higher surface-to-volume ratio uses more paste to fill the voids at the walls of the specimen and has a more compact packing density of the granular skeleton inside the specimen, which causes an increase in the measured compressive strength of the specimen [6,12–14]. Therefore, as the size of a specimen with a certain shape increases, the surface-to-volume ratio decreases and a decrease in the strength of the specimen is observed. Due to the higher powder content and the smaller content of coarse aggregates, self-compacting concrete (SCC) has a more uniform stress distribution, a denser microstructure and an enhanced bond between the paste and the aggregates [17–20]. The more uniformly distributed stresses lead to a decrease in the maximum stresses in the specimen.

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Table 1
Reported shape factors for vibrated concrete.

	$f_{c\ 150\times300}/f_{c\ 50\times100}$	$f_{c\ 150\times300}/f_{c\ 100\times200}$	$f_{c\ 150\times300}/f_{c\ cub\ 100}$	$f_{c\ 150\times300}/f_{c\ cub\ 150}$	$f_{c\ 150\times300}/f_{c\ cub\ 200}$
Gonnerman [1]	1.08	0.99	–	0.86	0.87
RILEM [2]	–	0.97	0.75	0.80	0.80
Kuczynski [3]	–	–	0.76	0.89	0.96
Lyse and Johansen [4]	–	0.96	0.86	–	0.86
C.E.B. [5]	–	0.97	0.80	0.80	0.83
Neville [6]	0.93	0.97	0.83	0.89	0.94
NBN B15 220 [7]	0.93	0.97	0.74	0.79	0.83
UNESCO [8]	0.97	0.80	0.80	0.83	–
Tokyay and Özdemir [9]	–	0.95	0.94	0.81	0.87
Yi et al. [10]	0.91	0.97	0.87	0.93	0.98

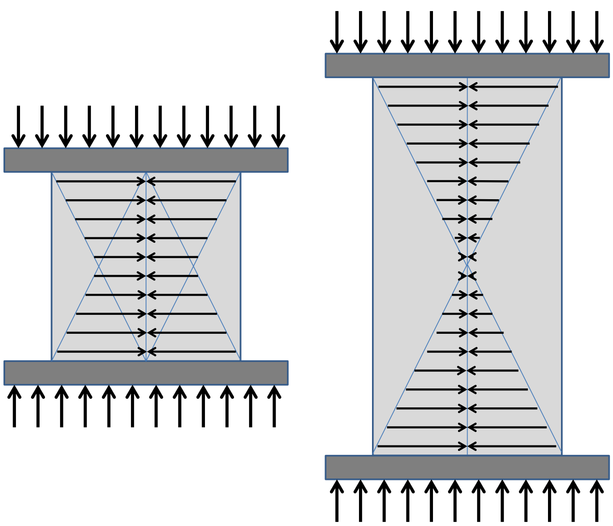

Fig. 1. The multiaxial stress state inside a specimen.

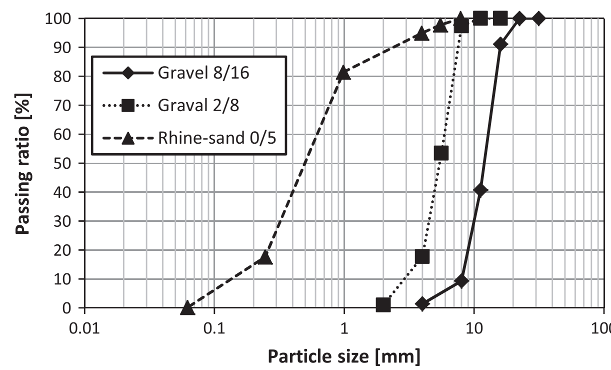

Fig. 2. The grading curves of the used aggregates.

For VC, the coefficient of variation (C.V.) of the compressive strength doubles when the diameter of the cylindrical test specimen is divided by two [12,21–27], although the difference in C.V. between cylinders with a diameter of 150 mm and 100 mm is also reported to be small [22,28]. The spread of the compressive strength determined from cylinders is smaller than that from cubical test specimens, because the circular shape of the end faces allows a more homogenous compactation in fresh state and during the compression test [11]. The C.V. of the compressive strength as determined on drilled cores is reported to be twice as big as the compressive strength determined on a casted cylinder with the same diameter [24,29,30]. According to Bartlett and MacGregor [31], the length-to-diameter ratio of drilled cores has no influence on their C.V. Because of the less amount of coarse aggregates and the denser structure of SCC, the C.V. of the compression strength test is expected to be lower compared to VC. However, no investigation has been conducted on this subject.

This paper discusses the results of an experimental program conducted at the Magnel Laboratory for Concrete Research on the shape factors of different specimens, varying in size, shape and concrete composition. Special attention is paid to the used materials and laboratory apparatus so as to reduce the influence of secondary effects on the obtained test results.

2. Materials and methods

In order to study the influence of the powder content, water-to-cement ratio and cement-to-powder ratio on the shape factors, 10 SCC mixtures are considered, allowing each parameter to vary independently. Additionally, two VC mixtures have been studied, one containing an ordinary Portland cement CEM I 52.5 N (according to European classification EN 197-1) and one other containing cement CEM III 42.5 N LA. All SCC mixtures contain cement CEM I 52.5 N.

2.1. Material properties

Fig. 2 shows the grading curves of the used coarse aggregates Gravel 8/16 and Gravel 2/8 (both with a specific weight of 2620 kg/m^3) and fine aggregate Rhine-sand 0/5 (specific weight 2640 kg/m^3). The grading curves of the cements CEM I 52.5 N, CEM III 42.5 N LA and the inert limestone filler (density 2650 kg/m^3) were determined with a laser diffraction meter and are shown in Fig. 3. The chemical composition, density and Blaine index of the cements are summarized in Table 2. The SCC mixtures contain a polycarboxyl ether superplasticizer with a concentration of 35%. As all materials, the tap water was added at 20 °C.

2.2. Mix proportions

The compositions of all mixtures are summarized in Table 3. The corresponding water-to-cement ratio, water-to-powder ratio, cement-to-powder ratio and powder content of the SCC mixtures are summarized in Table 4.

2.3. Mix procedure

To exclude additional influencing factors, each time the same mixing procedure is applied:

(1) The coarse and fine aggregates are mixed for 15 s.
(2) After adding half of the amount of water, the mixing continues for 1 min.