11th International Conference on Fracture Mechanics of Concrete and Concrete Structures
FraMCoS-11
J. M. Chandra Kishen, A. Ramaswamy, S. Ray and R. Vidyasagar (Eds)
https://doi.org/10.21012/FC11.092360

SIZE AND SHAPE EFFECTS ON THE COMPRESSIVE FATIGUE OF SFRC

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Key words: Size and Shape Effects, Steel-Fiber Reinforced Concrete (SFRC), Fatigue-Induced Autogenous Self-Healing.

Abstract: The size and shape of concrete specimens influence their compressive strength due to their effect on the development of fracture processes before the maximum load. Small specimens yield higher strengths than larger ones, so the size effect becomes an issue since material properties in structural elements may be smaller than those measured in the laboratory. Analogously, cubes resist more compression than cylinders (of slenderness 2) due to the constraints exerted by the load platens, which may also affect fatigue results. Regarding fatigue, there are very few studies on the effect of the size and shape of the specimen in the resisted number of cycles, especially in fiber concrete, which justifies our work on this topic. We tested cubes of 40 mm, 80 mm, and 150 mm in edge length and cylinders of 75 mm (S), 100 mm (M), and 150 mm (L) in diameter (all of slenderness 2). All the specimens were of the same self-compacting steel-fiber reinforced concrete and were loaded from 20% to 85% of their corresponding quasi-static strength. L and M cylinders endure a smaller number of cycles than S cylinders on average. Likewise, 150 mm and 80 mm cubes live shorter lives than 40 mm cubes (many of them are runouts). Cubes endure longer fatigue lives than cylinders of comparable size. Some of the reasons explaining these effects are: L and M cylinders have a larger maximum pore size due to the pouring process in the molds; cylinders show wall-effect (fiber alignment and porosity decrease close to the walls); load platens constraint is weaker in cylinders; and this material shows an autogenous self-healing due to the cyclic loads, which is especially noticeable in the small cubes. These results indicate that careful selection of the correct testing specimen is crucial when determining the constitutive laws for the fatigue of steel-fiber concrete.

1 INTRODUCTION

The compressive strength of concrete depends on the size and shape of the specimens used to perform the tests [1]. Besides, compressive properties are also affected by fibers when they are used to reinforce the concrete matrix. Their distribution in the specimen is highly conditioned by the shape of the mold and the casting protocol. Fibers tend to align in parallel to the mold walls, and, in cylinders, this leads to a type of tubular reinforcing region whose thickness depends on the fiber length and the radius of the cylinder. This wall effect interacts with those of the size and shape in fiber-reinforced concrete specimens. We are particularly interested in how these effects influence the fatigue behavior of steel-fiber concrete and in determining which type of specimen yields reliable constitutive equations for structural elements. Therefore, we did tests on cubes of 40 mm, 80 mm, and 150 mm in edge length [2] and on cylinders of three sizes, namely 75 mm × 150 mm, 100 mm × 200 mm, and 150 mm × 300 mm (diameter × height), which results are presented here and described detailly in [3].

2 EXPERIMENTAL PROCEDURE

The experiments consisted firstly in determining the compressive strength of each shape and size, followed by immediate testing of 15 specimens of each type in compressive fatigue, with cycles of 0.25 Hz going from 20% to 85% of the respective compressive strength. The material was the same in all the specimens, cubes, and cylinders [3, 4], and the fatigue setup was analogous for cubes and cylinders. Figure 1 shows cubes of the three sizes and the set-up used in the tests, which included scaled ball-and-socket hinges to minimize load eccentricity. Figure 2 shows computed tomography (CT) scans of the fiber distributions in the small and intermediate cylinders. Porosity distribution in the specimens' volume was determined as well by CT.

3 RESULTS AND DISCUSSION

Figure 3 shows the cumulative probability of the fatigue life for the specimens of the three sizes and the Weibull fit to each case. Triangles pointing to the right represent 40 mm cube runouts.

Large and intermediate cubes have similar behavior, but 40 mm cubes resist significantly more cycles than the others, 1.5 orders of magnitude above their larger counterparts for the 50% probability. Interestingly, all the cubes follow Sparks and Menzies' law regardless of their size, that is, the secondary strain rates of all broken specimens fall aligned with the corresponding number of cycles in a log-log plot [3], which attests to the ability of strain-based methodologies to predict the life to failure [5]. Large

Figure 1: (a) Cubes and (b) ball-and-socket hinges of the three sizes; (c) large cube being tested.

and medium cylinders stand fewer cycles than the small ones, roughly two orders of magnitude less for the 50% probability case, whereas small cylinders roughly match the results obtained for the 80 mm and 150 mm cubes.

The reason behind this size effect can be partially attributed to the constraining effect of the platens, which affects the contact side differently, causing different crack patterns for the various sizes. However, the constraint is weaker in the cylinders due to their bigger slenderness, which results in shorter fatigue life for them.

In the case of cylinders, CT scans showed that maximum pore size is higher in larger cylinders, which leads to shorter number of resisted cycles; contrariwise, porosity gets reduced with size when close to the cylinder walls, which originates an inverse size effect in the static compressive strength, i.e., larger cylinders yield higher strengths, which may be influencing the fatigue results since absolute stress limits result to be higher for larger specimens.

The research shows that the effect of the size couples with the effect of fatigue-induced autogenous self-healing, which is fully activated in the case of small cubes [3, 6]. Indeed, the residual compressive strength of runouts was 43% higher than the corresponding quasi-static strength [3]. This phenomenon is also taking place in the small cylinders, as described in [4], although not to the extent of getting runouts like in cubes.

4 CONCLUSIONS

The self-compacting steel-fiber reinforced concrete tested in this work exhibits a strong size effect coupled with autogenous self-healing induced by cyclic loading, which is apparent in the case of small cubes.

Fatigue life is very sensitive to the shape and size of the specimens used in the fatigue tests. These effects mix with those of the porosity and fiber distribution.

Finally, a careful selection of the correct testing specimen is crucial when determining the constitutive laws for the fatigue of steel-fiber concrete.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the financial support from the *Ministerio de Ciencia e Innovación*, Spain, through grant PID2019-110928RB-C31.

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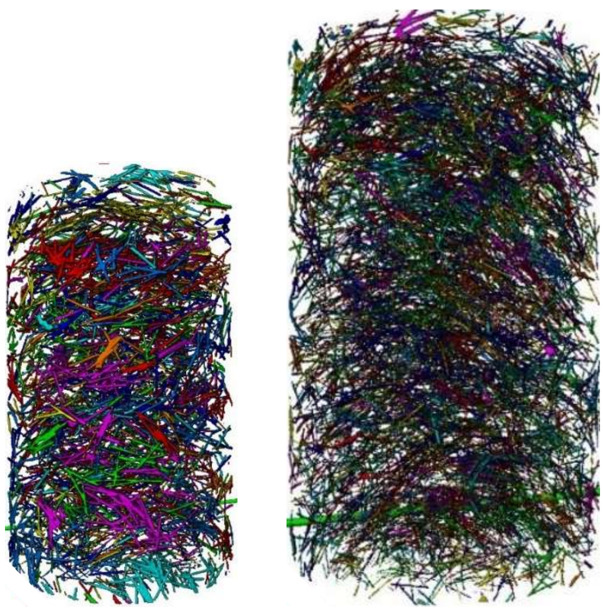

Figure 2: CT scans showing the fibers within the small and intermediate cylinders.

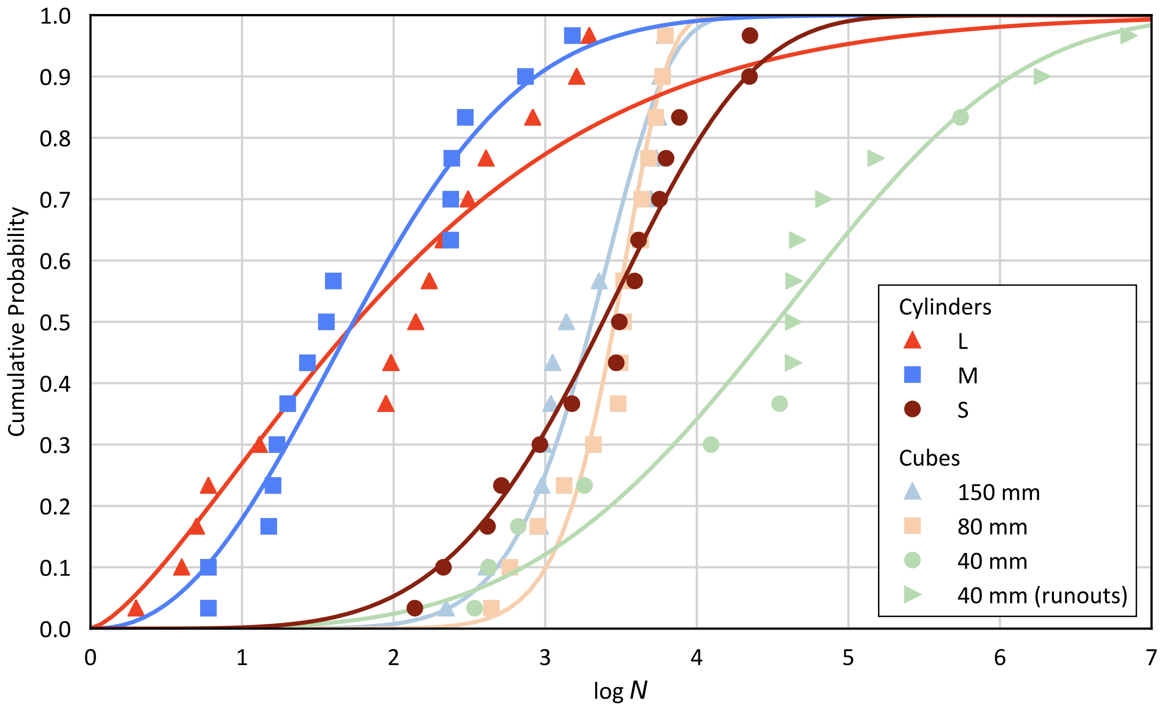

Figure 3: Fatigue life in the six series of specimens.

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