# FAILURE MECHANISMS OF STEEL FIBERS EMBEDDED IN HSFRSCC

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## Abstract

The bond stress transfer between fibers and matrix is the basic resistant mechanism of fiber-reinforced composite materials. Interfacial bond properties and failure mechanisms of the composite are commonly evaluated through single pullout tests on unreinforced matrices. The small size of the molds used to cast the samples prevents the fibers from being randomly distributed in the matrix and makes it difficult to compact the mixture. Krahl *et al*. (2020) developed an innovative portable pullout machine that allows testing fibers embedded in fiber-reinforced matrices with larger sample sizes. This paper discusses the experimental results of single fiber pullout tests carried out with the portable machine on high-strength fiber-reinforced self-compacting concrete (HSFRSCC). The bond behavior of hooked-end steel fibers and their relationship with the failure mechanisms are analyzed for fiber contents of 0% and 0.75%. The results show that bond and failure mechanisms were influenced by the presence of fibers in the matrix.

## 1. Introduction

Steel fiber reinforced concrete is a material that is becoming increasingly important in several civil engineering applications. Discontinuous and randomly distributed steel fibers in concrete improve properties such as ductility and toughness. The brittleness of high-strength concretes, for example, can be minimized with steel fibers addition. Steel fibers increase the concrete residual strength, after the matrix reaches its tensile strength, the fiber bridging mechanism is activated, allowing the cracks to transfer tensile stresses between their faces. Chemical, mechanical and frictional bond are the mechanisms associated with the fiber pullout process that transfer this stress. The performance in terms of residual strength that SFRC can achieve depends mainly on the added fiber content, fiber orientation, and fiber distribution. These last two parameters can be controlled through the use of self-compacting concrete, which, due to its high fluidity, contributes to better fiber dispersion, avoiding problems like fiber balling.

The characterization of the fiber-matrix interface properties and the failure mechanisms analysis can be carried out through single pullout tests (Fig. 1). The samples used in the test are usually small, which makes it difficult to study matrices that contain large aggregates and fibers with a length greater than 30 mm. These limitations prevent the failure mechanisms associated with the fiber-matrix interaction of concretes with these characteristics have not been fully explored.

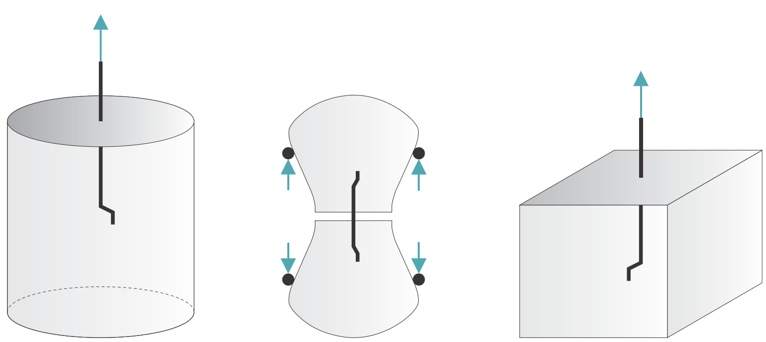
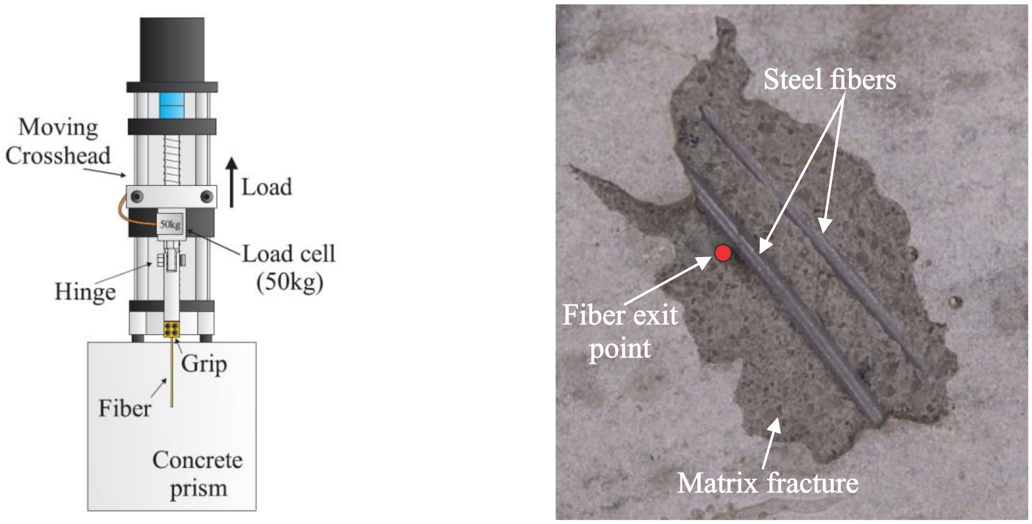


Fig.1 – Typical specimens used for single-fiber pullout tests.

In this paper, the fiber content influence of the matrix on the failure mechanisms (fiber and matrix fracture) of hooked-end steel fibers pulled from high-strength fiber-reinforced self-compacting concrete (HSFRSCC) are studied. A portable pullout machine developed by Krahl *et al*. (2020) is used to perform the tests (Fig. 2a). This allows a greater number of fibers to be tested in the same specimen with larger dimensions than conventional ones. In this way, the presence and random fiber dispersion are guaranteed (Fig. 2b).




(a) (b)

Fig. 2 – (a) Portable single fiber pullout machine developed by Krahl *et al*. (2020) and presence of fiber HSFRSCC matrix.

## 2. Results

The results indicate that the presence of fibers can have an impact on the pullout failure mechanisms. From the pullout tests it was possible to verify that:

a. Fibers close to the exit point of the tested fiber restrict the opening of the spalling crack opening, decreasing matrix damage and promoting a higher stress concentration in the pulled fiber.
b. The importance of considering the fiber's presence in the matrices evaluated by the pullout test was evident since unreinforced matrices may underestimate the fiber fracture probability.
c. The maximum bond strength is enhanced with 0.75% of fibers to the matrix regardless of whether or not fiber fracture occurs.

## 3. Conclusions

The presence of steel fibers in pullout specimens has a beneficial effect on the interfacial properties of the pulled fibers. However, despite the bond strength and the total pullout energy improving with the increase of the fiber content, the failure mechanisms can be altered. The fiber fracture becomes more recurrent with the increase in ductility and toughness of the cementitious matrix. All these aspects reveal the importance of considering the fiber's presence in the matrices when carrying out the pullout test. Pullout tests performed on unreinforced matrices do not reproduce the real behavior of HSFRSCC matrices.

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