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DYNAMIC MIXED-MODE FRACTURE OF SELF-COMPACTING STEEL-FIBER REINFORCED CONCRETE

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Abstract: This work studies the influence of fiber content and loading rate on the mixed-mode dynamic fracture of self-compacting steel-fiber reinforced concrete. The specimens were prismatic beams for three-point bending tests, plain and reinforced with three fiber ratios (up to 0.6% in volume). They were sawn a notch cutting half of the depth at 1/4 of the span. Tests were performed at four loading rates: 2.2×10^{-3} and 2.2 mm/s in a servo-hydraulic machine; 1.7×10^{3} and 2.7×10^{3} mm/s in a drop-weight device. The latter ones were recorded with a high-speed video camera. Results show that both the peak load and the inclination of the crack increase for faster rates. Besides, highly reinforced beams exhibit profuse crack branching for all the rates. As the fiber ratio increases, it is also observed that the main crack may either bifurcate or abruptly change its path when it gets closer to the loading point.

1. INTRODUCTION

The mechanical response of steel-fiber reinforced concrete is sensitive to the rate of loading [1-4]. In particular, the peak load and the fracture energy may exhibit dynamic increase factors of 3.5 and 2.5 respectively for loading velocities of 1.0×10^{3} mm/s in a drop-weight device [3]. Similarly, the rate effect on the crack propagation speed is pronounced. In the interval between 0.9×10^{3} and 2.7×10^{3} mm/s the early-stage crack velocity almost keeps constant around 500 m/s, though later on the main crack propagates with

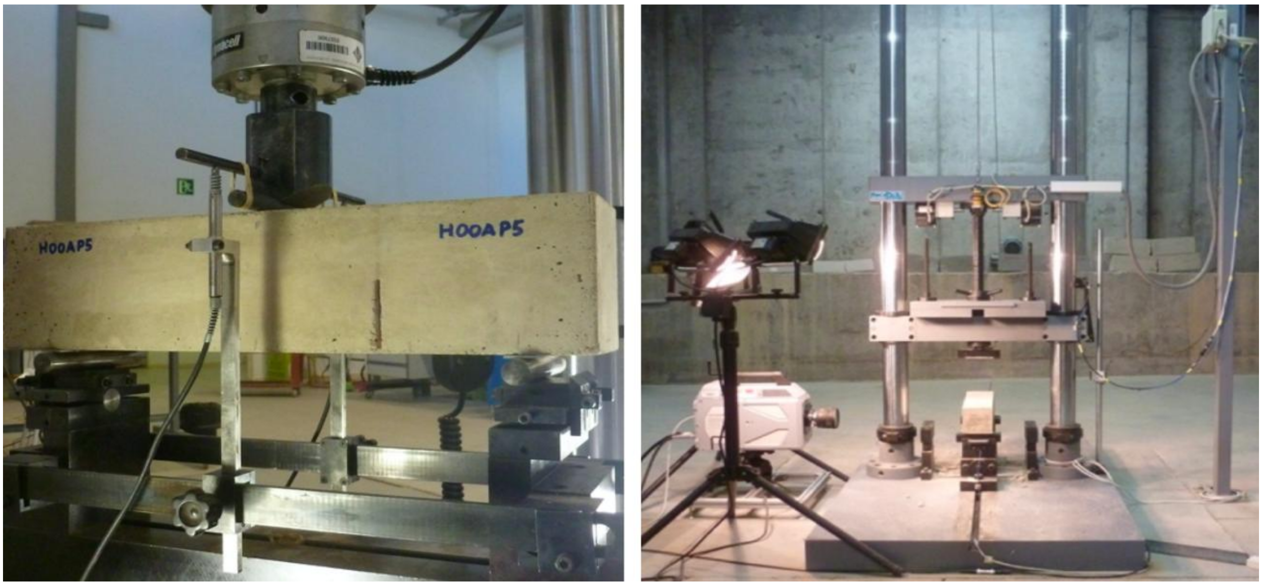

Figure 1. Specimens ready to be tested in the servo-hydraulic nachine (left) and the drop-weight test device (right).

decreasing velocity [4]. These studies are performed in mode I, whereas dynamic mixed-mode propagation of cracks in fiber-reinforced concrete have received little attention so far. This is why here we focus on the influence of the fiber content and of the rate of loading on the mixed-mode fracture [5].

2. EXPERIMENTAL PROCEDURE

The specimens were prismatic beams, plain and reinforced with three fiber ratios: 15, 30 and 45 kg/m^3, which correspond to 0.2, 0.4 and 0.6% in volume; the steel fiber used is HE 55/35 of ArcelorMittal, with a length of 35 mm and a diameter of 0.55 mm. Beams were made of self-compacting mixes sharing exactly the same matrix. They were sawn a notch cutting half of the depth at 1/4 of the span. Three-point bending tests were performed at four loading rates: 2.2×10^{-3} and 2.2 mm/s in a servo-hydraulic machine; 1.7×10^{3} and 2.7×10^{3} mm/s in a drop-weight device (they are the same machines used and described in [3, 4] and can be seen in Fig. 1). The impact tests were recorded with a high-speed video camera (FASTCAM SA-Z 2100K-M-8Gb) at 25×10^{3} frames per second.

3. RESULTS AND DISCUSSION

Figure 2 shows a selection of pictures of tested specimens. The first row corresponds to the four types of concrete tested at 2.2 mm/s, whereas the second row shows identical beams but tested at 1.7×10^{3} mm/s (the images are taken from the slow-motion videos). Figure 3 plots the anvil load-displacement curves that correspond to the specimens in Fig. 2.

The cracks generated at low impact velocities are stable, i. e. they need of external energy to propagate. Stable cracks are slightly inclined and the post-mortem surface analysis indicates that stable propagation is mainly transgranular, although there is also some intergranular fracture, as can be seen in the upper row of Fig. 4. As the fiber content is higher, more energy is needed for the crack to propagate and, eventually, for 45 kg/m^3 there appears a second unstable crack. Unstable cracks are more inclined and propagate always through the aggregates (Fig. 4, lower row). The leftmost picture of the second row in Fig. 2 shows that the crack starts to propagate stably but at some point, once the specimen stores a sufficient amount of energy, it dissipates in the crack and the propagation turns to be unstable. The crack propagation in reinforced specimens at this impact speed is mainly unstable, but for the highest fiber content there is an initial stable stretch. Besides, note that cracks bifurcate as they get close to the loading point. This is caused by bending of the ligament, since fibers sew the crack in spite it be opening [6]. Figure 3 shows that the maximum impact load is achieved with an intermediary fiber content (30 kg/m^3). In addition, dynamic increase factors go from

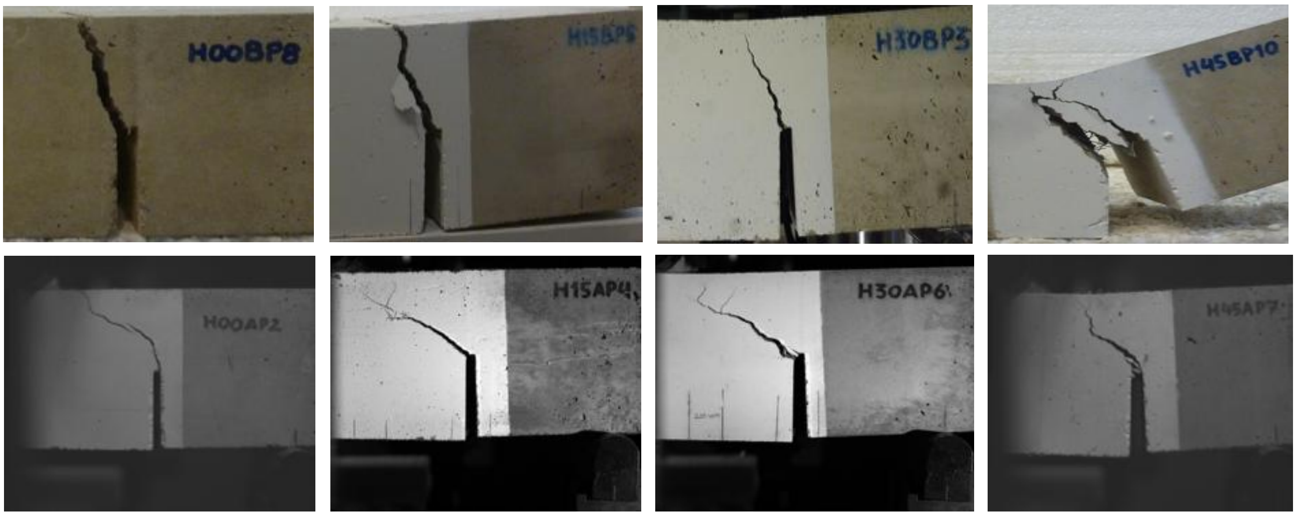

Figure 2. Crack path for beams reinforced with 0, 15, 30 and 45 kg/m^3 of fibers tested at 2.2 mm/s (top row) and 1.7×10^3 mm/s (bottom row).

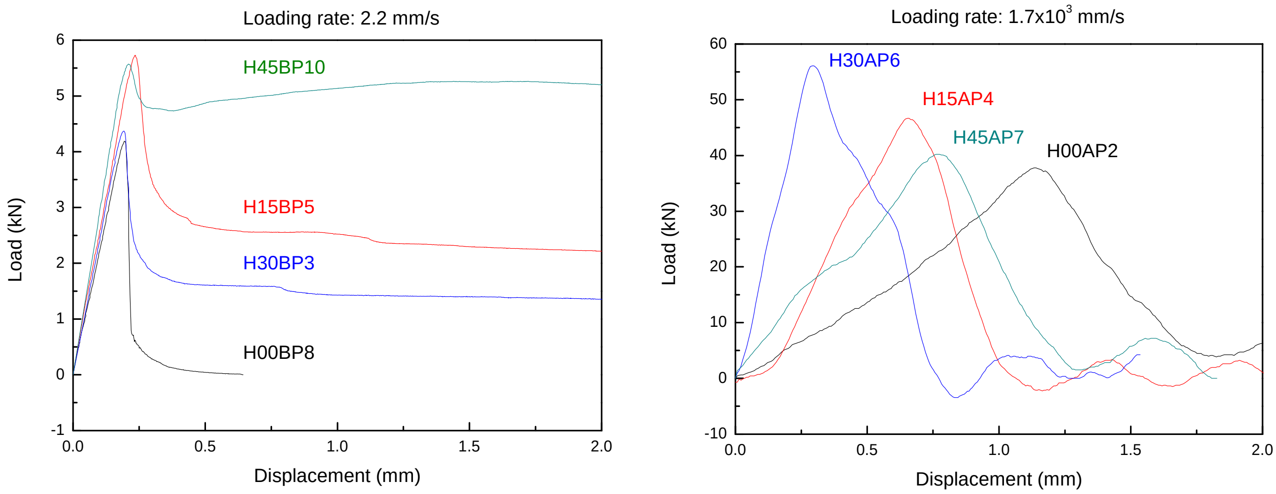

Figure 3. Load-displacement curves corresponding to the beams in Fig. 1.

7 to 11 and thus are 3 to 4 times bigger than in mode I [5].

3. CONCLUSIONS

Mixed mode propagation may be stable or unstable depending on the impact velocity and fiber content. As the fiber ratio increases, it is observed that the main crack may either bifurcate or abruptly change its path when it gets closer to the loading point.

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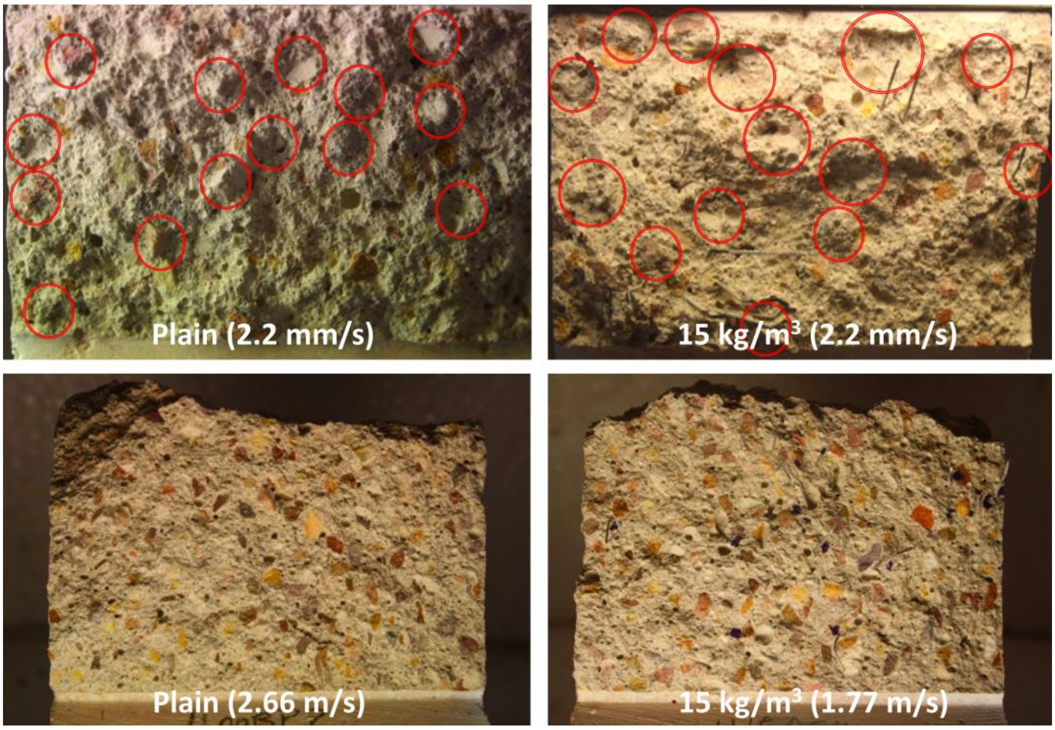

Figure 4. Crack surfaces. There is evidence of transgranular fracture at slow loading rates.

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