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MEASUREMENTS OF INTERNAL ENERGY DISSIPATION IN ULTRA-HIGH PERFORMANCE CONCRETE

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Summary: We are interested in quantifying the toughening the different toughening mechanisms at work during damage and fracture of fiber reinforced ultra-high performance concrete. A number of 3D image processing techniques, used in conjunction with x-ray CT images were developed or adopted towards this end.

1. INTRODUCTION

The overall role of fiber reinforcements in cement-based composites is well known and well documented. In ultra-high performance concrete (UHPC), fibers facilitate an array of energy dissipation mechanisms that transform a highly brittle composite to a relatively ductile one. While some of these dissipation mechanisms, (e.g. fiber pullout, bridging, crack branching) are well known and well documented, less well documented are quantitative experimental analysis of the relative contributions to overall energy dissipation. The objectives of this work are to measure energy dissipation in fiber reinforced UHPC loaded in a split cylinder configuration using x-ray computed tomography (CT). 3D CT images made of the specimen before and after the test can provide a detailed picture of damage accumulation and other internal changes that result from loading.

2. EXPERIMENTAL METHOD

The specimens tested were a particular UHPC[2] with nominally 3.5% by volume steel fibers of two types: 30 mm long by 0.55 diameter hooked ("Z" specimens), or 12 mm long by 0.20 mm diameter straight ("B" specimens). Cylindrical specimens 5 cm in diameter by 10 cm in length were cast. CT scans were made of undamaged cylinders. Of interest in this work was the role of fiber orientation on the fracture properties. While performance models often assume a random fiber orientation, previous work[1] found preferential alignments. The initial CT images were analyzed to evaluate optimum and pessimum fiber orientations, with the optimum orientation being the one that maximizes fiber components orthogonal to the principal tensile stress. Pessimum orientation minimizes those orthogonal components.

Specimens were loaded in split cylinder configuration at a rage of 1 mm/min. Load and platen-to-platen displacement were recorded. From the load-deformation records, peak load and net work of load were determined. A second set of CT scans were done on the damaged specimens. As shown in Fig. 1, the CT scans reveal a complex network of interacting cracks and fibers.

3D image analysis was applied to the CT data to evaluate both the surface area of new cracks in the damage specimen, as well as the degree of fiber pullout of the concrete matrix. In the former, a simplified analysis of solids surface area of before and after damage images was used to estimate the crack area, while length of fiber bridging cracks was used to estimate the degree of fiber pullout. The total energy dissipated by matrix cracking was simply the measured area multiplied by a previously established specific fracture energy of the matrix. Fiber pullout energy dissipation was evaluated by multiplying the pullout length by a previously established fiber pullout curve.

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3. RESULTS

Load-deformation results showed, not surprisingly, that fiber orientation played a significant role in the load-deformation behavior, with peak loads being increased between 10 and 20%, and net work of load being increased as much as 30%.

Energy dissipation results showed that only about 40% of the net work of load could be accounted for by these two mechanisms, with matrix cracking dissipating almost twice that of fiber pullout. However, in a separate study it was found that the work required to pull fibers out of a UHPC matrix increases when the fibers are in a compression field. When the compressive stresses of the split cylinder are taken into account, the work of fiber pullout nearly triples putting the energy dissipation for fiber pullout to be about 65% higher than matrix cracking. Still, only about 70% of the net work of load could be accounted for with these mechanisms, leaving 30% unaccounted for. Three potential reasons for the failure to account for all of the energy dissipation: matrix compaction/plastic deformation of the specimen (as evidenced by the flat section on the damaged specimen of Fig. **??**(a)), friction along the crack faces, and additional matrix cracking that is beyond the resolution of the CT instrument. Further investigation of these mechanisms is ongoing.

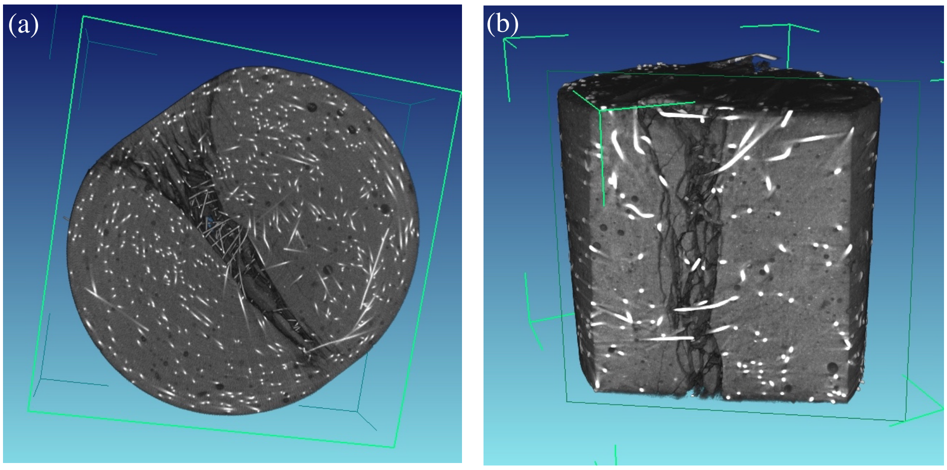

Figure 1: 3D renderings of (a) a B specimen (smaller fibers) and, (b) a Z specimen (larger fibers). Images reveal the internal crack networks, and the fibers that bridge those cracks. Note the flattened "plug" segment that appears on the upper left side of the B specimen (a). This flat side is typical of all the fiber reinforced specimens.

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