ENHANCING THE POST-CRACK TENSILE STRAIN CAPACITY OF CEMENT-BASED COMPOSITES USING FIBRILLAR WASTE BYPRODUCTS

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Abstract
The objective of this study is to assess the positive effect of fibrillar waste byproducts, such as biochar, on enhancing the tensile strain capacity and ductile behavior of cementitious composites by evaluating their fracture energy and fracture process zone length through the Work of Fracture Method (WFM). Cementitious mortars enriched using a low amount of biochar of 1 wt% exhibit 100% higher fracture energy over the OPC mortar indicating that the incorporation of the byproduct significantly increases the composite's ability to absorb strain energy at the post-peak/strain softening area. As indicated by the 1.9x higher characteristic length of fracture process zone, l_{ch}, of biochar-mortar, the effective incorporation of the fibrillar byproduct holds a great potential to increase the post-crack tensile strain capacity that leads to a significantly improved ductile behavior of the cementitious composite.

1. Introduction
The cement and concrete industry is continuously researching ways to improve the limited tensile strain capacity of quasi brittle cementitious materials, a decisive property to increase their resiliency and ductility. A common approach to enhance concrete's tensile behavior is to improve its fracture energy through a crack-arresting mechanism using micro- and macro- scale fibers. The mechanical and fracture properties of fiber reinforced concrete are inherently dependent on the proper fiber orientation into cementitious matrix; hence adverse effects in the composite's pre- and post-cracking toughness can be observed in case of a non-uniform fiber distribution within the bulk material. Biochar, a porous byproduct of biomass pyrolysis process, holds a great potential to enhance concrete's toughness due to the angular and fibrillar surface that modifies the linear crack pathway during fracture. In this study it is shown that the use of low amounts of carbon-enriched biochar significantly enhances the post-cracking energy absorption capacity resulting in a composite with 100% higher fracture energy and characteristic length of fracture process zone at high strain rates.

2. Results
In this study, biochar enriched mortars were produced using Type I ordinary Portland cement (OPC) and standard siliceous sand. Commercially available biochar with 90% carbon content was incorporated in mortar matrix at an amount of 1 wt% of cement. Linear elastic fracture mechanics (LEFM) tests were conducted on 28d notched 40x40x160 mm specimens. The fracture energy, G_f, which represents the energy required to create new material surfaces during the fracture process; and the characteristic fracture process zone length of concrete (l_{ch}), a true material property that expresses its ductile behavior, were evaluated following the Work of Fracture Method (WFM) based on the fictitious crack model.
Load-CMOD curves of the 28d plain and biochar-mortars are presented in Fig. 1. The load-CMOD curves exhibit the same pattern with a linear elastic stage before peak load and a nonlinear stage of stable crack propagation up to failure. It is observed however that the load-CMOD curve of the biochar-cementitious sample is markedly elongated at the post-cracking stage as the specimen exhibits a significantly extended strain softening behavior with 300% higher CMOD values at the failure (≈0.47 mm) compared to the reference mortar (≈0.15 mm). Therefore, the fracture energy, G_f, of the biochar enriched composite is 100% higher than the reference sample. Moreover the cementitious composite's characteristic fracture process zone length, l_{ch}, was found to be extended by 1.9x times. The findings indicate that the incorporation of biochar greatly enhances the post-crack energy absorption capability of the composite; hence its ductile behavior. This is attributed to the angular and fibrillar morphology of biochar that contributes to the development of more tortuous and articulated crack paths (Fig. 2); hence to a much less linear crack propagation, a typical brittle fracture pattern for the cementitious materials.

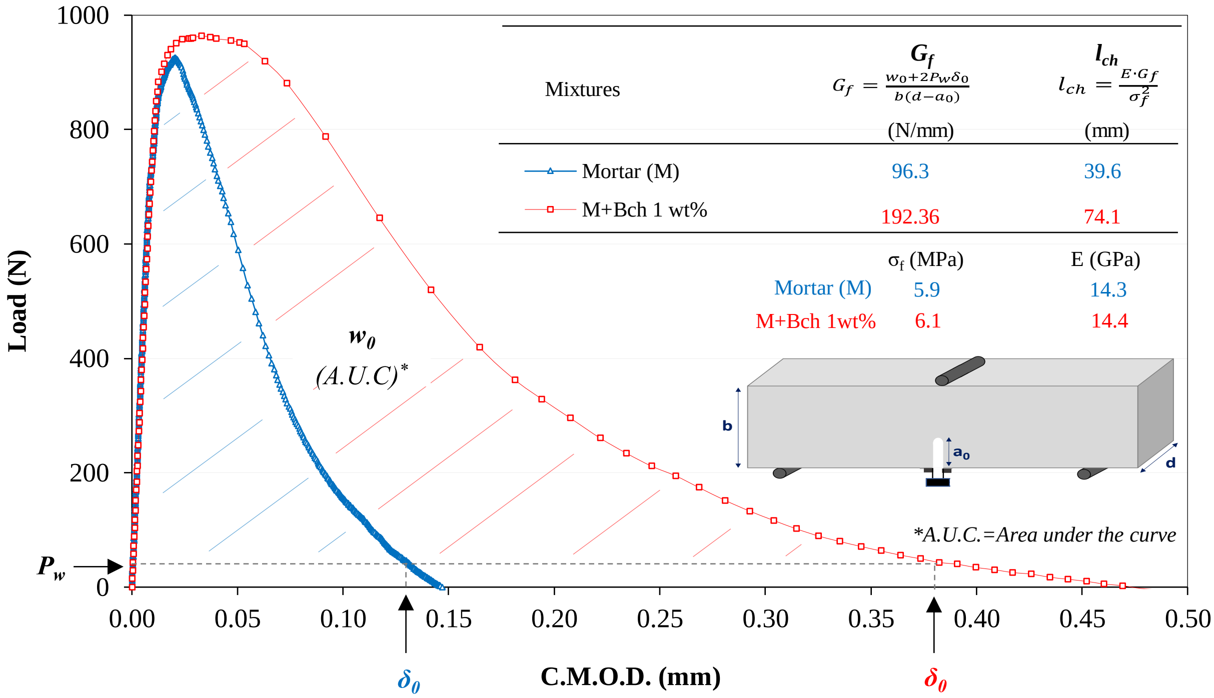

Fig.1 – Load-CMOD curves for the 28d plain and biochar-cement mortars obtained from the LEFM tests

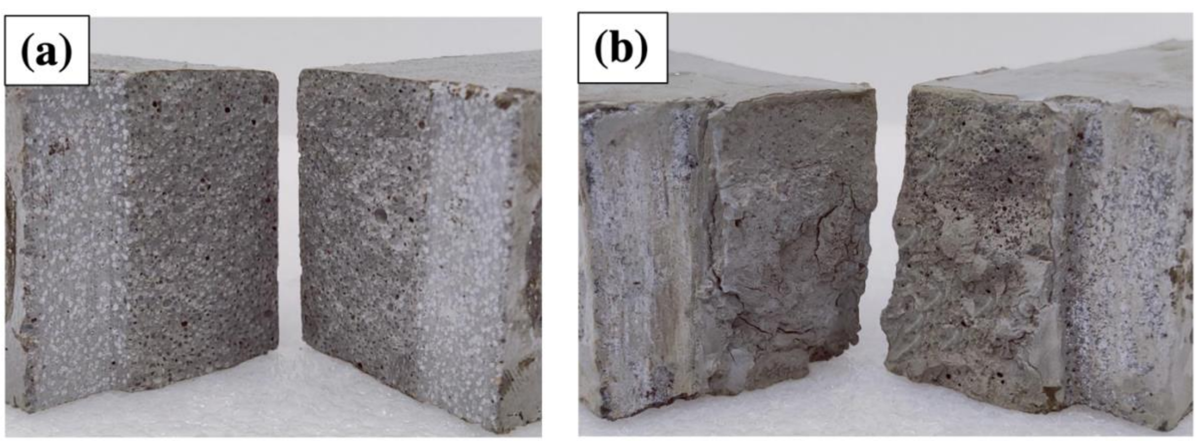

Fig.2 – Fracture surface showing the (a) linear crack propagation of plain mortar and (b) the tortuous crack pathway of biochar enriched cementitious specimens

3. Conclusions

In this study, a substantial enhancement of the post-cracking energy absorption capacity and ductility of cementitious materials, associated with the addition of waste byproducts, was demonstrated. Load-CMOD curves obtained from LEFM tests indicate that the OPC mortars enriched with a low amount of biochar of 1 wt% exhibit a 100% increased fracture energy and 1.9x extended fracture process zone length. The angular and fibrillar morphology of biochar contribute to the development of more tortuous and articulated crack paths resulting in a more ductile behavior of the biochar-cementitious composite.

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