MULTISCALE TOUGHENING MECHANISM IN HYBRID FIBER REINFORCED CEMENT-BASED NANOCOMPOSITES

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Abstract

In this study a thorough evaluation of the toughening mechanism in cement-based nanocomposites reinforced with hybrid networks of carbon nanofibers (CNFs) and polypropylene microfibers (PPs) took place. The critical values of fracture toughness/stress intensity factor, K_{IC}^{S}, were experimentally determined on prismatic notched specimens of nano and micro scale fiber reinforced cementitious composites using the two parameter fracture model (TPFM). The post-crack energy absorption capacity of the hybrid-composites was assessed by evaluating the dimensionless toughness index, I_{20}, calculated through linear elastic fracture mechanics (LEFM) tests. The addition of CNF/PP networks at low volume fractions of about 0.1 vol% in cementitious matrix results in a significant improvement in the K_{IC}^{S} (85-240%) and 1.6 – 10x higher I_{20} compared to the CNF or PP reinforced materials. Relative to the single-scale fiber reinforcement, the synergy between the nano- and micro- scale fibers results in a multi-scale crack arresting distinctively increasing the toughening effect in the hybrid fiber-cementitious mortar nanocomposites.

1. Introduction

The use of fibers for reinforcing the cementitious matrix results in a crack arresting mechanism that range from subtle to substantial, depending upon the scale of fibers. The advantageous effect of combining micro- and macro- scale fibers has the potential to improve the post-crack flexural behavior of cementitious materials. Introducing nanoreinforcement, such as carbon nanofibers (CNFs), that can control or even prevent nano-cracking can lead to significant improvements in the first-crack strength and toughness of the cementitious nanocomposites by 120%. This study shows for the first time that the introduction of a hybrid reinforcement combining high stiffness CNFs with ductile polypropylene microfibers (PPs) significantly enhances the pre- and post- crack load carrying capacity and energy absorption capability of cement-based nanocomposites. The CNF/PP reinforced cement mortars exhibit 240% increased fracture toughness and up to 10x higher toughness index compared to the materials reinforced with CNFs or PPs.

2. Results

The hybrid fiber-mortar nanocomposites were prepared using ordinary Portland cement (OPC) 42.5 R and standard sand according to ASTM C 778-17. Uniformly dispersed/individual CNFs and PPs at a volume fraction of 0.1% were used as hybrid reinforcement. Fracture mechanics tests were conducted on 28d notched 20x20x80 mm prismatic specimens using a crack mouth opening displacement (CMOD) as the feedback signal, following the two parameter fracture model (TPFM) and linear elastic fracture mechanics (LEFM). The experimental determination of the critical values of fracture toughness, K_{IC}^{S}, of hybrid CNF/PP mortar nanocomposites was based on the load versus CMOD curve for a loading-unloading cycle of 28d notched specimens according to TPFM (Fig. 1a). CNF/PP – mortar exhibits a remarkably increased by 240% K_{IC}^{S}, than the plain or PP-mortar, 1.8x higher compared to the CNF reinforced material. This is the effect of an enhanced nano and micro scale crack arresting mechanism that allows the hybrid fiber-mortar to greatly improve its resistance to crack propagation and toughening efficiency. The size and geometry independent toughness index I_{20} that indicates the material's post-crack energy absorption capacity was calculated by the load-CMOD curves of the LEFM test (Fig. 1b). The I_{20} values, presented in Fig. 2, indicate that the incorporation of CNFs in the PP reinforced mortar results in a hybrid fiber-material that is able to absorb 60% higher strain energy. Nanoscale carbon fibers contribute to a more effective crack bridging mechanism from nano- to micro- scale controlling this way the debonding process of the polypropylene fibers from the matrix, thus increasing the demand of energy for crack propagation at all levels of mechanical deformation.

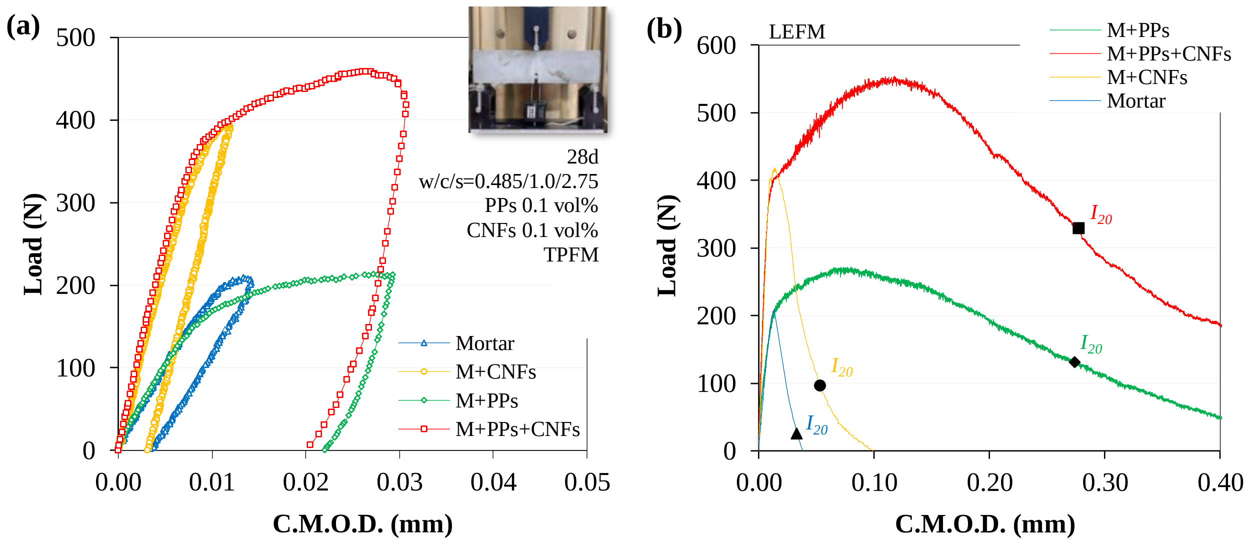

Fig.1 – Load-CMOD curves for the 28d PP, CNF and hybrid CNF/PP reinforced mortars from the (a) TPFM and (b) LEFM tests

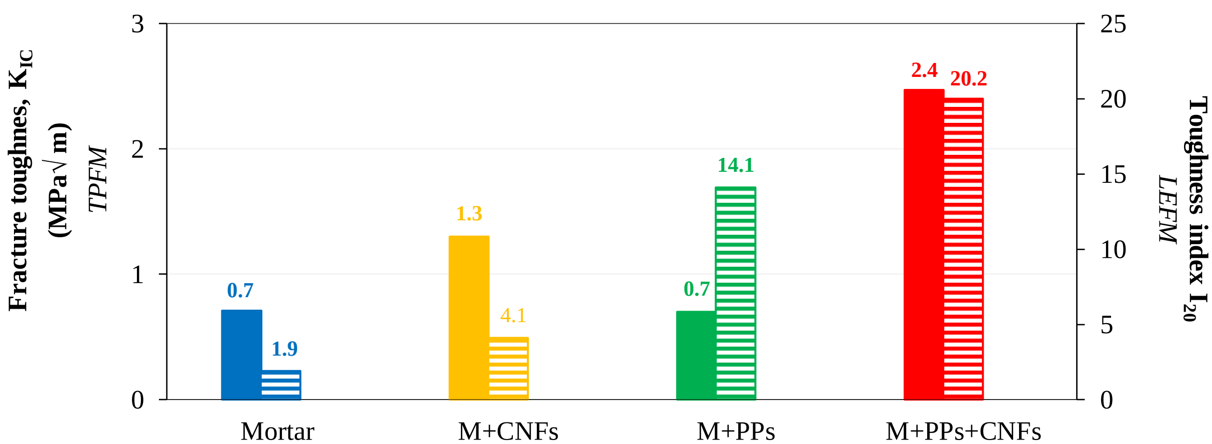

Fig.2 – Fracture toughness and toughness index I_{20} results for the 28d PP, CNF and hybrid CNF/PP reinforced mortars

3. Conclusions

The reinforcing and toughening efficiency of CNFs, PPs and their combination in mortar matrix was evaluated by conducting fracture mechanics tests following the two parameter fracture model and the linear elastic fracture mechanics. The positive synergistic interaction between nano- and micro- scale fiber networks is reported that results in a notably improved, by 240%, fracture toughness and up to 10x higher post-cracking energy absorption capacity of the hybrid cementitious nanocomposites. Such exceptionally increased toughening effect, an important performance factor for serviceability, is interpreted in terms of the mechanism of a synergistic interaction between the nano- and micro- scale fiber reinforcement.

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