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EFFECT OF NATURAL SANDS ON THE TENSILE BEHAVIOR OF SHCC UNDER DIFFERENT STRAIN RATES

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One of the key factors affecting the successful production of strain-hardening cement-based composites (SHCC) is the nature of fine quartz aggregates. The elevated cost of SHCC preparation is considered as a limiting parameter. The incorporation of natural fine aggregates of different particle sizes can be one of the most cost-effective methods to produce SHCC locally. Two different types of local natural sands abundantly available in the Arabian Peninsula were used in the preparation of SHCC. The effect of these sands on the tensile response of SHCC under the effect of different strain rates was investigated. Three strain rates of $7.7x10^{-5}$, $1.5x10^{-4}$ and $1.5x10^{-3}$ s^{-1} were applied during the assessment of the direct tensile properties of SHCC samples made of natural sands. The results have shown that the use of natural sands provides an effective strain capacity. Microstructural analysis of SHCC mixtures has revealed the existence of two reaction mechanisms during PVA pullout of SHCC mixture with natural sands under direct tensile tension. Therefore, the incorporation of natural sands was proven to carry potential properties to SHCC mixtures that reduce their cost and encourage their production in a broad scale.

Keywords: Sustainability, Microstructural analysis, Uniaxial tension, Strain capacity.

1 INTRODUCTION

It is an established fact that the cost of repairing for many construction projects worldwide is surprisingly increasing. The main drawback of concrete construction is the inability to control crack formation. In general, this issue was initially solved by the introduction of fiber bars into concrete to improve its tensile properties after crack formation. Specifically, the development of the strain hardening cement-based composites (SHCC) is the state-of-the-art of the advancement in the cementitious composites and fibers production. The introduction of SHCC characterized with low short fiber volume has enabled the control of crack formation and lowering its width. SHCC have become an effective method of repairing and an effective unit in structures that absorbs different types of energies created by various forms of stresses. This leads to the multiple formations of fine cracks while controlling tensile properties. Successful mix design including the cementitious materials and fibers is the key factor that produces effective SHCC mixtures for repair and improved mechanical properties. SHCC is characterized also with their fracture toughness that relying on the fiber as well as on the stress loading rate (Schänzel *et al.* 2013). Previous studies have shown that the strain rate is greatly affected by the constituents of SHCC (Mechtcherine *et al.* 2011, Yang and Li 2005). It is reported that tensile strength increases with an increase in the strain rate, while strain capacity increases in an inverse manner (Mechtcherine *et al.* 2013). Two mechanisms were reported to dominate during the rate dependent strain capacity: chemical bond and/or slip-hardening (Yang and Li 2005, Boshoff *et al.* 2009). The aim of the current study was to investigate the effect of three different strain rates of $7.7*10^{-5}$, $1.5*10^{-4}$, and $1.5*10^{-3}$ s^{-1} (with corresponding displacement rates of 0.005, 0.01 and 0.1 mm/sec, respectively) on the strain capacity of SHCC, with two types of natural sands, in a direct tensile test. The results have shown that with an increase in the stain rate there is a remarkable increase in the tensile strength while the strain capacity slightly decreased. Moreover, the incorporation of natural sands was proven to carry potential properties to SHCC mixtures that reduce their cost and encourage their production in a broad scale.

2 EXPERIMENTAL INVESTIGATION

2.1 Materials

General-use Portland cement (PC), complying with the requirements of ASTM C150 specifications, was utilized as a binder to which class F fly ash (FA) was added. PC and FA have median grain sizes of 14 µm and 10 µm, respectively. Two types of natural sands of different particle sizes, i.e., local white sand (WS) and dune sand (DS), were used. WS and DS have median grain sizes of 270 µm and 210 µm, respectively. Both WS and DS originally have a spherical structure rather than angular, which should improve the rheological properties of SHCC mixtures. DS is the finest while WS is the coarsest in accordance with particle-size analysis.

A polycarboxylic ether (PE) polymer was used in the production of SHCC. PE has a specific gravity of 1.1 and dry extract of 36%. It is expressed as a dry extract (DE) per cement weight. The optimized PE dosage of 0.20 % (DE, per cement weight) was used, which proved to have acceptable workability.

Poly vinyl alcohol fibers (PVA) were used in this investigation. PVA have an average length of 12 mm and median diameter of 40 µm, and consequently have an aspect ratio of 266. PVA have a tensile strength and young's modulus of 1.8 GPa and 46 GPa, respectively.

2.2 Methods

2.2.1 SHCC mix proportions

Fixed amounts of cement, class F fly ash and optimized PE dosage were used. The amount of fiber added was equivalent to 2.2% (volume based). PE dosage of 0.2% (DE, per cement weight) was used for the preparation of SHCC mixtures to be tested for the effect of different strain rates of $7.7*10^{-5}$, $1.5*10^{-4,}$ and $1.5*10^{-3}$ s^{-1}. The mix design proportion of SHCC constituents of PC:FA:FS:water was 1:1.21:1.06:0.64, respectively. A W/B ratio of 0.29 was used throughout. The test setup used in this study is shown in Figure 1.

Figure 1. Direct tensile stress test setup with a displacement rate of 0.4 mm/min.

2.2.2 Mixing procedures and testing

The protocol of mixing was to pour PC pre-homogenized with fly ash over FS (WS and DS), then the whole mixture was homogenized for few minutes. The final homogenized mixture was gently poured over water premixed with the optimized PE dosage in a Hobart bowl run at speed # 1 within 4 minutes. The mixer was stopped for 30 sec to clean the wall of the ball by pushing down the flushed mix. The mixer was put on again for 5 minutes, during which the required amount of fibers was slowly added while pressing fibers by fingers to disperse into separate strands. At the end of 5 minutes, the mixer was stopped and shifted to speed # 2 for 2 minutes. The final mix was then cast into the mould, pushing the different layers over each other, followed by finishing the surface. Special dumbbell-shape moulds with a dimension of 40 mm x 40 mm x 240 mm were used (Figure 1). After 24 hours, samples were demoulded and standard cured for 56 days. The samples were tested for direct tensile stress using the tensile machine (Figure 1). The effect of three strain rates of 7.7×10^{-5}, 1.5×10^{-4}, and 1.5×10^{-3} s^{-1} with corresponding displacement rates of 0.005, 0.01, and 0.1 mm/s, respectively. The gauge length for testing the specimens was 65 mm. The tensile load and accompanied displacement were retrieved and continuously plotted using a recording system.

3 RESULTS AND DISCUSSION

3.1 Effect of Strain Loading Rate and Strain Capacity

At the end of curing age of dumbbell-shape samples, their tensile behavior at different stain rates of 7.7×10^{-5}, 1.5×10^{-4}, and 1.5×10^{-3} s^{-1} was determined using the test setup shown in Figure 1. The results are shown in Figures 2-4. The effect of high strain rate of 1.5×10^{-3} s^{-1} (short time frame) on the tensile response of the SHCC mixtures with DS and WS are shown in Figure 2. All samples showed reduced strain responses with notably higher tensile strength. The SHCC mixture with DS showed a significant improvement in strain response of approximately 2 times that of other SHCC mixtures. This indicates that the matrix fracture toughness is in the direction of matching with fiber-bridging force. The same results and observations become consistent with lower strain rates of 1.5x10^{-4} s^{-1} and 7.7x10^{-5} s^{-1} (longest time frames), as shown in Figures 3 and 4, respectively.

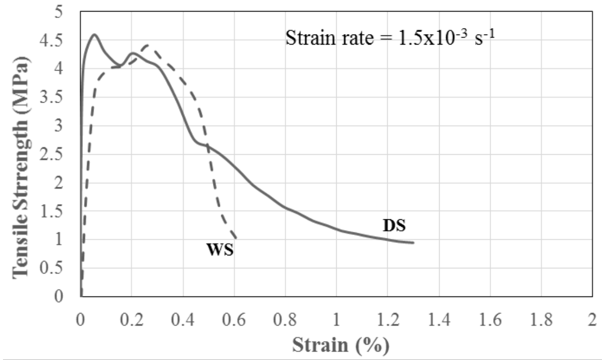


Figure 2. Effect of strain rate of 1.5x10^{-3} s^{-1} on tensile strength and strain capacity of SHCC mixtures with different sands.

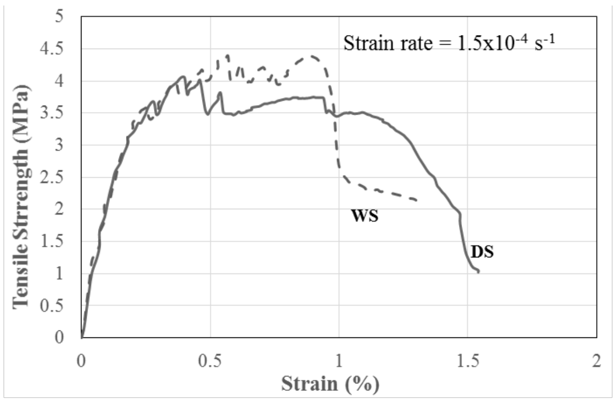


Figure 3. Effect of strain rate of 1.5x10^{-4} s^{-1} on tensile strength and strain capacity of SHCC mixtures with different sands.

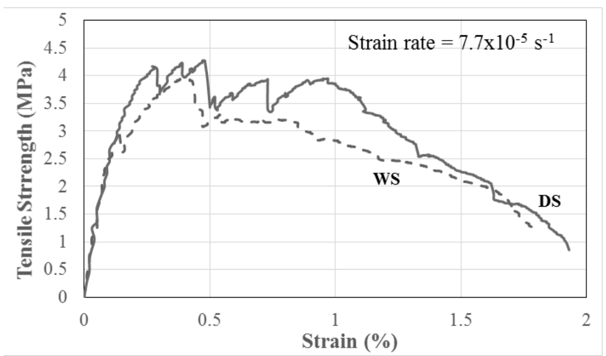
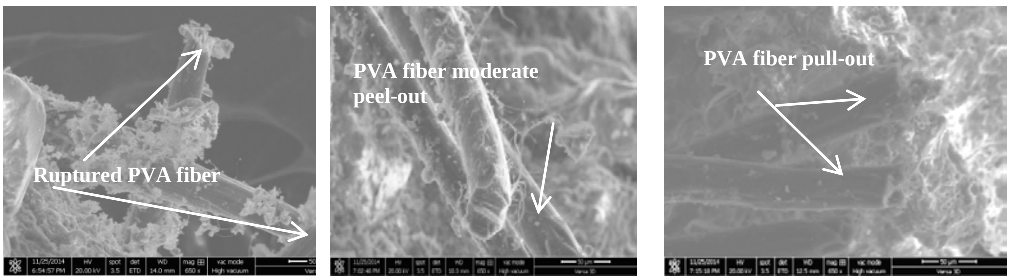


Figure 4. Effect of strain rate of 7.7x10^{-5} s^{-1} on tensile strength and strain capacity of SHCC mixtures with different sands.

3.2 Effect of Strain Rate on PVA Pullout SHCC Mixture with DS and WS

For SHCC mixtures containing DS subjected to strain rate of $1.5x10^{-3}$ s^{-1}, the dominant mechanism is the rupture of PVA fiber, as shown in Figure 5. At strain rates of $1.5x10^{-4}$ and 7.7 $x10^{-5}$ s^{-1}, the dominant mechanism was moderate peel-out-to-pull-out of PVA fiber followed by fiber pull-out. The mechanism of moderate peel-out was due to a moderate bonding force between PVA fibers and the cementitious matrix.



0.1 mm/s ($1.5x10^{-3}$ s^{-1}) 0.01mm/s ($1.5x10^{-4}$ s^{-1}) 0.005 mm/s ($7.7x10^{-5}$ s^{-1})

Figure 5. Effect of strain rate on PVA fiber/matrix interaction mechanism of SHCC mixture containing DS.

For SHCC mixtures containing WS subjected to strain rates of 1.5 $x10^{-3}$ s^{-1} and 1.5 $x10^{-4}$ s^{-1}, the dominant mechanism was the typical rupture of PVA fiber, as shown in Figure 6. At strain rate of 7.7 $x10^{-5}$ s^{-1}, the dominant mechanism is the peel-out of PVA fiber due to a strong bonding force between PVA fibers and the cementitious matrix.

0.1 mm/s ($1.5x10^{-3}/s^{-1}$) 0.01mm/s ($1.5x10^{-4}/s^{-1}$) 0.005 mm/s ($7.7x10^{-5}/s^{-1}$)

Figure 6. Effect of strain rate on PVA fiber/matrix interaction mechanism of SHCC mixture containing WS.

The fiber peel-out mechanism is not preferred, as it reflects that the bonding force between fiber and the cementitious matrix is at borderline but still slightly weaker than the fiber tensile strength, which should be lowered by tailoring this bonding force. The fiber-rupture mechanism is an indication to the strong extreme bonding force between the fiber and the cementitious matrix. The pull-out mechanism is the most preferable one that represents the driving force the formation of multi-cracks.

4 CONCLUSIONS

Particle size distribution of the abundantly available WS and DS as crystalline fine quartz and their nature not only affect the mechanical properties but also the bonding with PVA fibers. Therefore, the compatibility of the cementitious matrix and PVA fibers is of great importance that affects the tensile properties. DS has special type of bonding with PVA fibers that allow fiber pull-out mechanism under tensile force. The strain rate of the SHCC mixture with DS is greatly affected by strain capacity in contrast to the WS mixtures. The effect of strain rate on tensile strength of different SHCC mixture with DS is obviously notable. At lowest strain rate of 7.7×10^{-5} s^{-1}, the dominant mechanism is fiber pull-out and mostly found in DS mixture, which has moderate bonding with PVA fibers. DS is proved to be a good candidate for the use as fine quartz in the production of green and cost-effective SHCC mixtures.

Acknowledgements

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