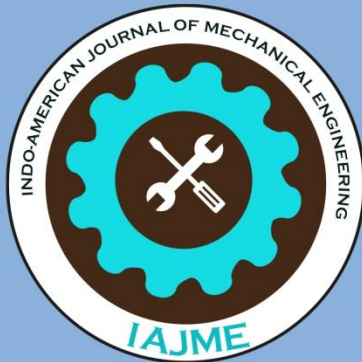




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THE EFFECT OF THE INTERFACE IN CONTROLLING THE FRACTURE WIDTH OF HYBRID SHCC CONCRETE BEAMS

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Abstract

Crack width may be reduced by using a combination of normal concrete and a Strain Hardening Cementitious Composite (SHCC). In order to verify the theory and investigate the impact of interface treatment on crack width control, an experimental and numerical investigation is presented in this work. Surfaces that are smooth, profiled, partly debonded, or entirely debonded are all options for a given interface. Four-point bending tests are performed on the beams. The maximum crack width of 0.3 mm at the surface is used as a criteria for the analysis of the fracture development under the loading. The lattice model is used to simulate the hybrid and control beams. Stronger interfaces permit composite action in hybrid beams and give better fracture width control than artificially weakened interfaces, as demonstrated both experimentally and numerically.

Introduction:

Because of its tremendous compressive strength and versatility in casting, concrete is the most widely used building material in the world. Low strength and brittle strain-softening behaviour [1] contribute to failure when concrete is subjected to uniaxial tensile stresses. Concrete buildings are reinforced with steel reinforcement to increase their tensile strength (ULS) so that they can handle their design tensile loads. Surface crack widths must be kept to a minimum in concrete under serviceability conditions (the Serviceability Limit State, SLS) so that harmful chemicals can't get in and concrete structures can last long enough. Criterion for crack width management is often the driving factor in structural applications, leading to more reinforcement than necessary for the design loads. Despite the fact that this reinforcement is necessary for crack-width management, it does not add to the

structural capacity of the design, making it uneconomical.

For uniaxial tensile stresses, a novel form of fibre reinforced concrete has been created in the last several decades that shows strain-hardening response. Strenuous Cementitious Composite is the name given to this material (SHCC). By engineering micromechanical design, the strain hardening ability of SHCC may be realised [3]. When compared to conventional concrete, SHCC has a ductility that is two orders of magnitude more and may produce many fractures (microscopic fissures with a width of less than 100 m). When compared to traditional rein-forced concrete, certain studies [4] demonstrate that reinforced SHCC displays better durability. It's also not a cost-effective alternative to completely replace ordinary reinforced concrete with reinforced SHCC, owing to the higher material costs of SHCC.

A mix of SHCC and conventional concrete may provide the best solution, as long as the SHCC is only used where it is required, such as on the tension side of a flexural part to reduce crack widths. For example, shear and flexural strengthening may be achieved by inserting SHCC on the sidewalls of a beam [5,6] and by placing SHCC on the tension side [7]. There have been many research that have studied these methods. In [8], an overview of strengthening applications may be found.

It is clear from these and other recent research [9, 10] that the increased load-bearing capability of hybrid structures is a viable application for these structures. In SLS and ULS, minimal consideration

is given to factors such as maximum fracture widths and the qualities of the interface between the two forms of concrete. a crack was found in a recent research [10]

The ability of hybrid SHCC concrete beams with embedded reinforcement to control their width is being studied. The crack width control is reported to be eliminated as a governing design parameter when a 70 mm thick layer of SHCC is provided in the tensile zone of a 200 mm beam.

It's also limited to one type of interface preparation between SHCC and conventional concrete.

As long as the cracks around it remain small, the reinforcement can be activated in tension, ensuring that the reinforcement is adequately protected. A straining SHCC behaviour is not possible in hybrid systems because the SHCC layer is also restrained along one edge (the interface with the concrete). Because of this, it's not uncommon for cracks to form in the SHCC directly adjacent to the interface. SHCC with embedded reinforcement's ability to control crack widths is still unknown due to this interfacial boundary condition. Current design codes and standards provide limited information for the safe design of hybrid structures, particularly the design calculation of the interface..... Typically, the interface strength is estimated from the mean roughness of the interface profile [11,12]. Interfacial treatment is well known for enhancing the strength of the interface, but little is known about how it affects the width of cracks in hybrid systems [11,13,14].

For repair applications where SHCC is applied to pre-cracked concrete surfaces, the effect of interface treatment on crack width control has been studied [15–17]. Because a larger portion of SHCC is activated around the pre-existing crack in concrete, the repair system is more ductile with a weak interface (represented by a smooth profile or local debonding), according to the studies. In contrast, a strong interface prevents SHCC from debonding and causes cracks to appear sooner (see Fig. 1).

Interaction treatment effects on hybrid SHCC concrete cracking behaviour are explored in this study. The initial hypothesis is that a weaker interface would result in more cracks with smaller crack widths in SHCC, and thus better control of crack width. Because the SHCC cracking behaviour is dependent on the fibres included in the mix [18], Polyvinyl Alcohol (PVA) and High

Modulus Polyethylene (HMP) are two of the most commonly used SHCC fibre types (HMPE).

Modeling hybrid concrete structures and developing reliable models for structural interfaces has been widely acknowledged [19,20]. The difficulty of obtaining reliable interface behaviour has been widely acknowledged. Researchers in this study used a discrete-type lattice model, a simple fracture model, in order to gain an understanding of the physical phenomena taking place at the interface and determine the governing parameters and their role in the behaviour and dynamics of the hybrid systems.

1.1. The importance of the research

SHCC concrete hybrid beams' crack width development is examined in this study to determine the impact of interface treatment on SHCC and concrete, highlighting the benefits and drawbacks of lattice modelling in simulating these complex structures. Fibre-specific roles in SHCC are also examined. The information gleaned from this study will aid in the development of hybrid SHCC concrete structures that use SHCC to regulate crack width.

Methods of investigation

2.1. Planning and execution of experiments

There are six beams to be tested, one of which is a traditional reinforced concrete beam for comparison. Using a 70 mm thick SHCC layer, PVA fibres and embedded reinforcements are used to construct four hybrid beams. The interface treatment is ensured because the crack width development is studied in the constant moment region of the beam (central 500 mm in Fig. 2). Surfaces that are smooth, profiled, partially debonded, or completely debonded are all options for constructing an interface. Figure 2 depicts the beams' longitudinal and cross sections. Due to mechanical interlock between the grooves, the profiled beam is meant to represent a strong interface, whereas the completely debonded interface is meant to represent a weaker one. It is intended that the beams with smooth surfaces and partial debonding represent intermediate behaviour. HMPE fibres are used to create a hybrid beam with a smooth interface so that the effect of different

fibres types can be studied. The hydrophilic nature of PVA fibres and their ability to form a strong chemical bond with the matrix have made them a popular choice for textiles. The fiber–matrix adhesion bond must be broken in order for slippage of the fibres to occur, which can reduce the ductility of SHCC due to early fibre rupture. By treating the PVA fibres with oil prior to use in this study, the fibres were less bonded to their matrix and more dispersed in the cement matrix. HMPE fibres, on the other hand, are twice as strong in tension as PVA fibres despite having a weaker adhesion bond. There are two reasons why HMPE fibres are superior to PVA fibres in SHCC: the friction caused by fibre slippage and the greater ductility they provide.

Reinforced Concrete is the name given to the reference beam, and Smooth(PVA) or Smooth(HMPE) is the name given to the hybrid beams with the smooth interface, depending on the type of fibres incorporated into SHCC. Based on the interfacial treatment, the remaining hybrid beams contain PVA fibres and are classified as such. Profiled, Partial, and Complete Debonds are all depicted schematically in Fig. 2.

The preliminary study's specimen geometry is used.

All of the beams have the same dimensions of 1900 mm in length, 150 mm in width, and 200 mm in height. For the hybrid beams, the bottom 70 mm of concrete is replaced with SHCC. Beams have the same reinforcement configuration with 3

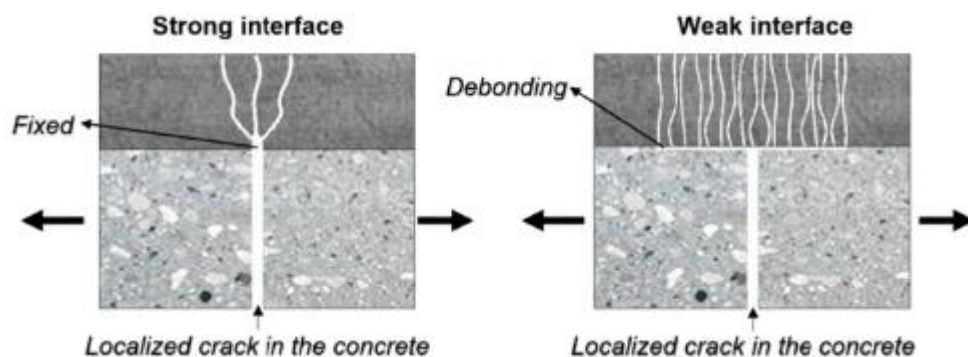


Fig. 1. Distribution of a pre-existing crack in concrete to SHCC for repair applications.

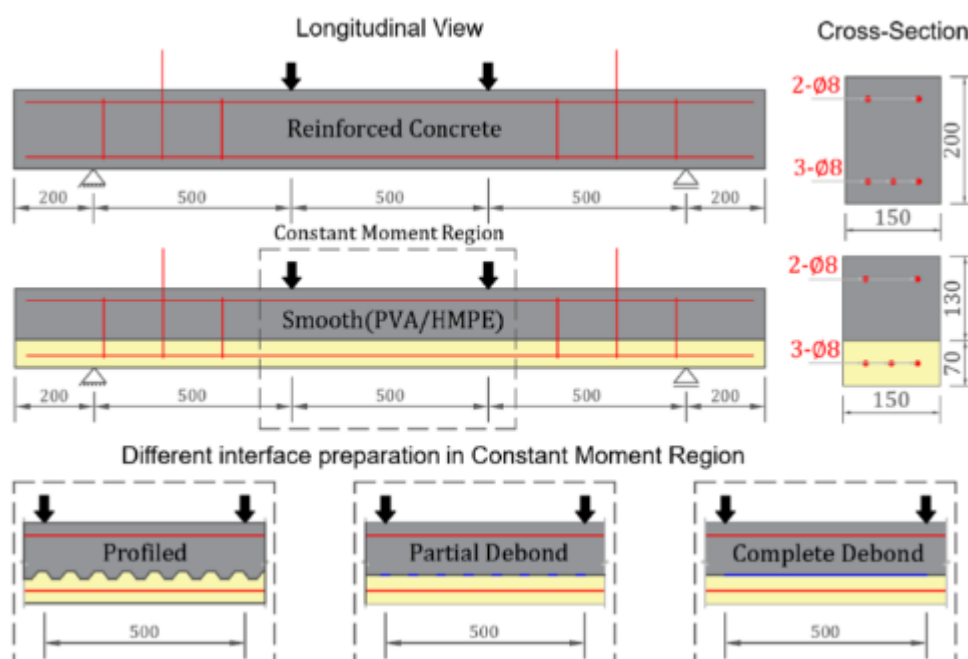


Fig. 2. Longitudinal and cross sections of the reference and hybrid beams with varying treatment of interface within the constant moment region. Concrete (Grey),

The reference beam's constant moment area has high fracture widths, therefore longitudinal reinforcing is maintained to a minimum. The stirrups of 8@150 in the shear span guarantee that the beams collapse in flexure. Both sides of the centre stirrup have been expanded higher and protrude out of the beam to aid with sample handling.

Preparation and casting of specimens, as well as materials

We use two-phase casting for all of our hybrid beams. There is an initial layer of 70 mm thick

SHCC put in the plywood moulds utilising spacers in the first phase. A vibrating table is then used to condense this layer. The surface is levelled using a trowel immediately upon compaction, and for contoured surfaces, a plastic sheet with 18 mm grooves at a spacing of 70 mm is pushed over the newly cast SHCC and kept in place with tiny weights. Before pouring the concrete layer, the beams are allowed to cure for 14 days in a sealed state. Afterwards, the debonded and partly debonded beams are cleaned and prepped for use.



Fig. 3. Interface preparation of the hybrid beams before casting the concrete top layer.

Table 1
Properties of the fibres used in SHCC.

Property	PVA
Tensile Strength (MPa)	1640
Young's Modulus (MPa)	41,100
Density (kg/m ³)	1300
Diameter (mm)	0.04
Length (mm)	6

Fibers made from HMPE are used in the testing of materials. Specimens 30 mm 8 mm 180 mm in size are cast and allowed to cure for 14 days under tight seals. The specimens are then put through a series of four-point flexural tests with a loading rate of 0.01 mm/sec utilising a displacement controlled

analysis (Fig. 4a). Compressive strength of concrete is measured using 150 mm cubes that are cast at each step of the beam construction and tested in accordance with NEN-EN 12390-3

Testing and monitoring of the structure

A four-point bending test configuration is used to test all of the beams indicated in Figs. 2 and 4b. The specimens are loaded at a rate of 0.01 mm/sec using a displacement-controlled technique. Linear Variable Differential Transformers (LVDTs) are used on one side of the beam and Digital Image Correlation (DIC) on the other to quantify the deformation of the beams in the constant moment zone. In order to get stresses and deformations throughout the whole field, DIC utilises a non-

contact optical method called pixel tracking [23]. This is done by coating the beam surface with white paint and then applying a black speckle pattern to the surface using a roller brush. Loading images are taken per 5 kN increment in applied load. Only the in-plane deformations of the beam are of relevance, hence a single camera is used to capture the data needed. Measurement of crack widths is done using DIC and a microscope. Measurements made using an optical microscope and images processed by ImageJ [24] are used to compare DIC findings with other methods of crack width measuring, which yields a resolution of 0.025 millimetres. Here are the findings of the verification and a short description of the experiment in [10,25].

Results of the experiment

Properties of the materials

It was shown that samples with HMPE fibres were more durable than those with PVA fibres in four-point bending tests on SHCC. Figure 5a displays the bending stress (assuming linear elastic stress distribution) versus the mid-span deflection of the samples as a summary of the findings. Figure 5a Fiber–matrix adhesion and frictional resistance at the fiber–matrix contact contribute to greater ductility in HMPE fibres. HMPE fibres have a greater ultimate strength than SHCC fibres, as can be seen from the deflection hardening curve. The matrix cracking stress is equivalent for both fibre

types, but the ultimate strength of SHCC with HMPE fibres is higher. There is more variation in the findings of the SHCC with HMPE fibres compared to samples with PVA fibres, even though HMPE fibres exhibit improved deformation hardening. Once these fibres have been analysed, they will be used to explore how the structural behaviour and crack development of SHCC hybrid beams are affected by the embedded steel reinforcement, restraints at the interface and cracking of neighbouring concrete.

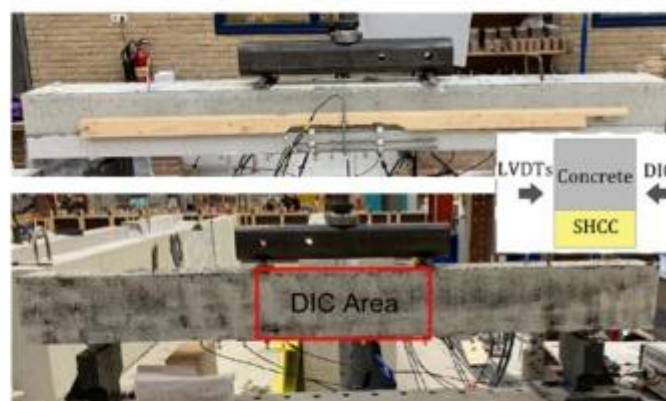
During the beam testing, the concrete's average compressive strength was measured to be 49.4 2.2 MPa, which is in accordance with the previously recorded value of 46 MPa [10].] SHCC's average compressive strength is 49.3 5.3 MPa.

Anatomy and physiology

It is necessary to compare the load deformation relationship and crack width response between the reference (Reinforced Concrete) beam and the hybrid beams while conducting structural tests and analysis. Beams' capacity to restrict maximum crack width down below the SLS criterion is a major consideration in crack formation and pattern. It is suggested for reinforced concrete under quasi-permanent stress for all exposure classes except for X0 to have a maximum fracture width of 0.3 mm at the surface, which is the limit used in this work.



(a)



(b)

6. Conclusion:

Experimental and numerical studies are conducted to determine how fibres used in a SHCC might

affect a hybrid SHCC concrete beam's capacity to limit fracture width. As a result, we may say the following:

To ensure that the SLS criterion no longer governs for reinforcement design, the 70 mm thick SHCC

layer on the tension side of a 200-mm flexural member has been proven to be effective in providing appropriate crack width control, so that cracks exceed the SLS limit after longitudinal reinforcement yields, i.e.

- The substitution of PVA fibres with HMPE fibres did not enhance crack width control for the provided evaluation criteria of restricting SHCC crack widths to less than 0.3 mm. However, when the reinforcement has yielded, the SHCC fractures for both fibre types surpass this limit.

Hybrid beams' crack control is influenced by the treatment of the interface between SHCC and concrete. While a stronger interface offers better support for the concrete, it also leads to more fractures in the material, reducing the crack width on the SHCC surface. This results in an early fracture localisation in the SHCC because of a strong interface. In hybrid SHCC concrete systems, the former is found to be the controlling mechanism. According to the DIC, the SHCC is loaded more evenly, in tension, if there is a stronger link between the SHCC and the concrete. SHCC, on the other hand, is more prone to bending and crack localization because of this.

As a result, enhancing the connection between concrete and SHCC results in improved crack width control, i.e., crack widths on SHCC's surface exceeding the 0.3-millimeter limit at higher loads.

- The lattice model is proven to be useful in predicting and obtaining insight into the fracture behaviour of hybrid systems with very basic interface inputs. Accurately simulates fracture formation, peak load, crack distributions, and final patterns of cracks.

Because of this, the failure mode is missing. The hybrid beams' stiffness is overestimated, while their deformation capacity is underestimated. As a result, crack spacing in reality is substantially smaller than in the model due to the mesh size constraint and inherent microcracking behaviour of SHCC. In order to construct a model that captures both the crack width control and the deformation capacity of hybrid beams, more study is needed.

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