Microstructure and mechanical properties of basalt fibre reinforced concrete

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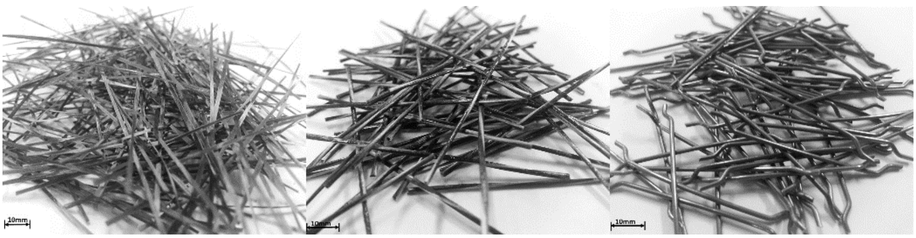
INTRODUCTION

Over the decades, several methods have been used to improve the mechanical properties of concrete as demand in tensile and flexural applications evolve. Steel reinforcement has been the conventional material used to those properties. However, with increasing awareness in sustainability, there is a need for the replacement of steel with greener alternatives. The use of steel reinforcement is considered not sustainable due to its production process, which emits large amounts of carbon dioxide into the environment, consumes high amounts of energy, and deteriorates the environment physically. On the other hand, the use of fibres has also gained huge popularity in recent years for their ability in improving the ductility of concrete. These types of concrete are referred to as fibre reinforced concrete (FRC). However, similar to conventional reinforcements, the most commonly used fibres are steel fibres, which still embody the detrimental environmental impact of steel reinforcements despite their positive effect on ductility properties of concrete. In addition, steel reinforcement and fibres are prone to corrosion and are expensive. Therefore, the use of alternative sustainable fibres that are durable and capable of resulting in similar properties as steel fibres will help to reduce the overall embodied energy of FRC and increase its service life. Glass fibre reinforced concrete (GFRC) is a common alternative to steel fibres. However, due to the alkalinity of the concrete's pore solution, glass fibres are subject to degradation, leading to the loss of mechanical integrity of GFRC in aggressive environments. Nonetheless, the FRC industry is moving towards the use of basalt fibres due to its advantage over other fibres in terms of sustainability, cost, and mechanical properties [1]. This focus has led to the development of different basalt fibres such as chopped basalt fibre (CBF) and basalt minibars (BMB). This study focuses on understanding the effect of basalt fibres on the mechanical properties of FRC and the behaviour of the fibres in an alkali environment.

EXPERIMENTAL PROGRAM

Material

General use type 1 Portland cement conforming to CSA A3001 [2] was used as the binder in all mixtures, alongside tap water. Fine aggregate with a fineness modulus of 2.7 and coarse aggregate with a maximum nominal size of 19 mm was used for all mixtures. Superplasticizer was used to achieve the desired workability for each mixture. Basalt minibars (BMB) and two different lengths of chopped basalt fibres (CBF) were used as reinforcement for the concrete mixtures. The two lengths of CBF were 36 mm (36CBF) and 50 mm (50CBF). The BMB is an epoxy-based resin reinforced with 17 μm diameter basalt fibres. Conventional steel fibres (CSF) were also used to compare its performance with BMB and CBF. Figure 1 shows the fibres employed in this study.



(a) (b) (c)

Figure 1: Fibres used in the experimental work, CBF (a), BMB (b), and CSF (c) [3].

Tab

le 1: Test matrix.

Mixture ID	Fibre Type	Length (mm)	Dosage		Plasticizer (mL)
			kg/m^3	vol. (%)	
C	No fibre		0	0	0
CBF 36-4	Bundle dispersion	36	4	0.15	0
CBF 36-8			8	0.31	30
CBF 36-12			12	0.46	60
CBF 50-4		50	4	0.15	0
CBF 50-8			8	0.31	30
CBF 50-12			12	0.46	100
BMB 43-6	Minibar	43	6	0.31	0
BMB 43-20			20	1	0
BMB 43-40			40	2	0
CSF 38-40	Steel	38	40	0.51	0

Mixture Proportion and Testing

All mixtures were made with a water-cement ratio of 0.5, and fine aggregate to coarse aggregate ratio of 1:2. The test matrix followed is presented in Table 1. The mixture ID indicates the type of fibre used, fibre length, and dosage. "C" represents the control mixture with no fibre.

Compressive strength tests and flexural strength tests were performed at the age 28 days according to ASTM C39 [4] and ASTM C1609 [5]. A FEI Quanta 200 FEGS scanning electron microscope (SEM) was used to collect secondary electron images to evaluate the interfacial properties between the matrix and the fibres.

RESULT AND DISCUSSION

Mechanical Properties

The compressive and flexural properties of the cementitious composites reinforced with basalt fibres are presented in Figures 2 and 3. It was observed from Figure 2 that concretes reinforced with 36CBF exhibited similar strengths compared to the control when the fibre dosage is greater than 4 kg/m^3. Likewise, all mixtures containing 50CBF have similar compressive strength to the control. Specimens containing BMB experienced a significant reduction in the compressive strength, regardless of the fibre dosage. Similar to CBF, CSF had compressive strength comparable to the control.

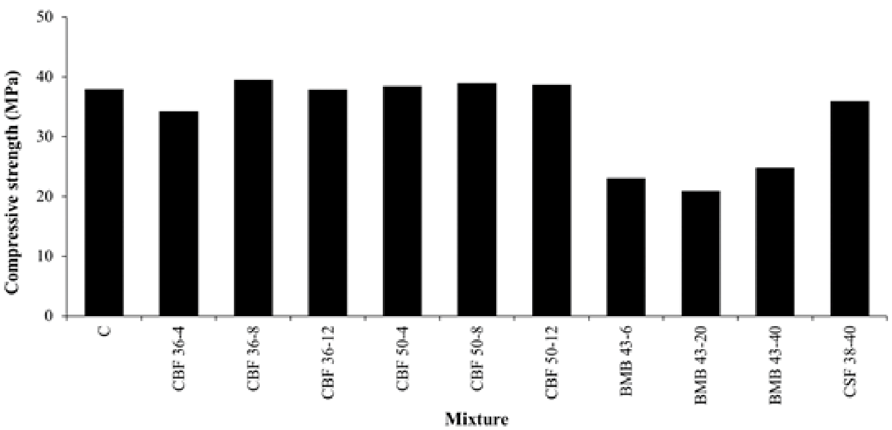


Figure 2: Effect of fibres on compressive strength of concrete

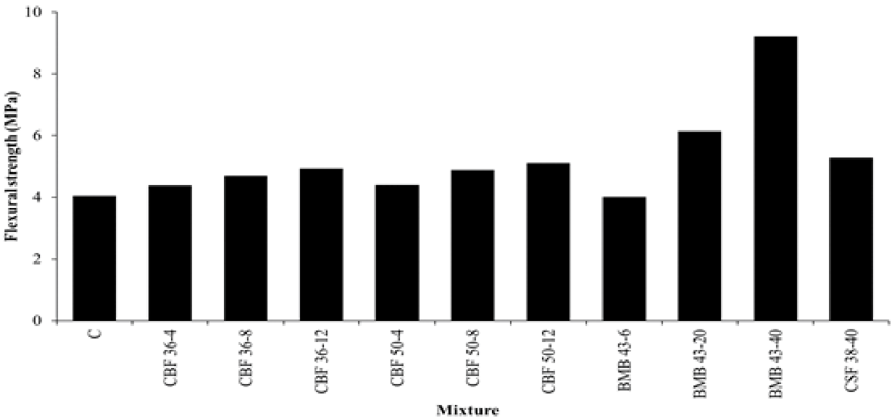


Figure 3: Effect of fibres on flexural strength of concrete

On the other hand, the effect of the fibres on flexural strength were different from the trends observed for compressive strength. The incorporation of the fibres resulted in an increase in flexural strength for all mixtures except BMB 43-6, which contained 0.31% fibre (i.e. 6 kg/m^3). Mixtures reinforced with 2% BMB was found to yield the highest flexural strength of 9.2 MPa, which is more than twice as that of the control. Increase in the BMB content from 0.31% to 2% showed a corresponding increase in the flexural strength. The increase in flexural strength with increasing fibre content is also true for CBF mixtures. However, at the same fibre content, CBF of 50 mm length exhibited a slight increase in flexural strength of about 4% when compared to CBF of 30 mm length. Observations showed that basalt fibres can be used to successfully enhance the flexural strength of concrete. However, it is paramount to ensure that the incorporation of the fibres do not have a significant negative impact on the compressive strength.

Interfacial Properties

SEM was used to observe the effect of the fibres on the interfacial transition zone between the fibres and the matrix. Figure 4 shows the presence of hydration products between CBF filaments in the cementitious matrix. Furthermore, Figure 5a shows a fractured CBF specimen in which no fibres were visible on the failure surface. From this image, it is apparent that that CBF is brittle in nature since the failure mode of the specimen was controlled by fibre rupture. Figure 5b shows the failure surface of a BMB specimen. It is evident that debonding of the fibres governs the failure of the specimen.

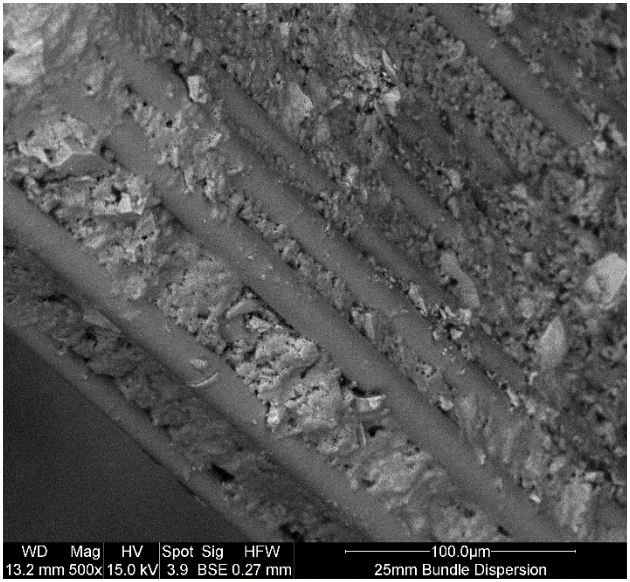


Figure 4: Presence of hydration products on CBF filaments [3]

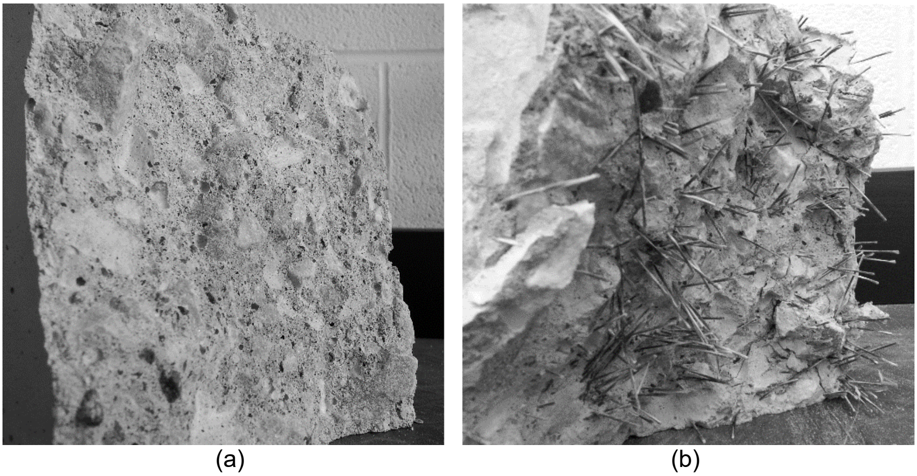
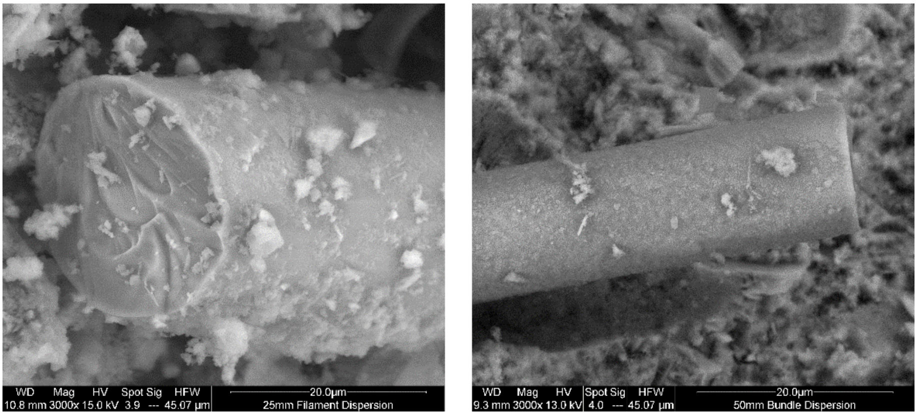


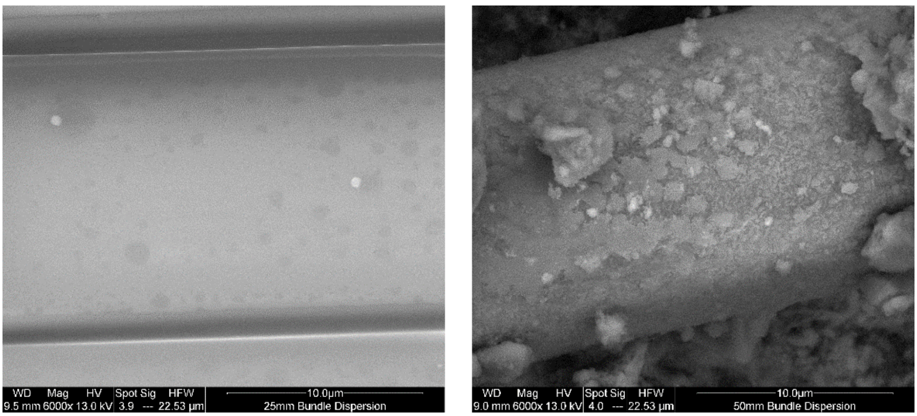
Figure 5: Failed cross-section of samples, (a) CBF 36-12, and (b) BMB 43-40 [3]

The hydration product formed on the CBF were further investigated at 7 days, 28 days, and 9 months to observe changes in the density of the hydration product and morphology of the fibre. No significant difference was found at 7 and 28 days; however, at 9 months, there was a significant decrease in the density of the hydration products as presented in Figure 6.



(a) (b)

Figure 6: Change in cement density on fibre surface over time, (a) 7 days, and (b) 9 months [3]



(a) (b)

Figure 7: Change in fibre surface after 9 months of exposure to the concrete matrix, (a) plain fibre, and (b) fibre in concrete [3]

Figure 7 shows a comparison between virgin CBF and CBF in concrete for 9 months. From the figure, it appears that the CBF in the concrete mixture has undergone a chemical reaction due to its roughened surface. Past studies have shown possible deterioration of CBF in alkali solution, which results in the loss of mechanical strength with time [6,7]. Therefore, the inferior performance of CBF in this current study might be a result of its possible degradation with time. Therefore, the use of the epoxy resin in the production of BMBs is effective in overcoming the deterioration effect, thereby resulting in higher flexural capacity compared to those with CBF.

CONCLUSION

In this study, the viability of using two types of basalt fibres as a sustainable alternative to conventional steel fibres was investigated. Based on this experimental study, the following conclusions can be drawn.

No significant loss in compressive strength was observed when CBF was incorporated into concrete. However, no significant improvement in flexural strength was also observed due to the possible degradation of CBF in the concrete's high alkali pore solution. Consequently, a decrease in compressive strength of about 38% was observed when BMB was used but considerable improvement in flexural strength was achieved at BMB contents greater than 6 kg/m^3.

The roughness of the CBF after 9 months indicates the possible degradation of the CBF which resulted in its poor flexural performance when compared to that of BMB.

Long term durability properties of concrete reinforced with BMB should be carried out to determine its overall performance. In addition, a study should be carried out on the possibility of reducing the concrete's pore alkalinity using supplementary cementitious material or alternative cement, thereby creating an opportunity to utilize CBF in concrete.

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