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Effect of Basalt Fibers on Properties of Normal and High Strength Concrete Made with Dune Sand

Shahrukh Shoaib[1], Tamer El-Maaddawy[1], Hilal El-Hassan[1], Bilal El-Ariss[1], Marwa Alsalami[2]
[1]United Arab Emirates University
Al Ain, United Arab Emirates
201890010@uaeu.ac.ae; tamer.maaddawy@uaeu.ac.ae; helhassan@uaeu.ac.ae; bilal.elariss@uaeu.ac.ae
[2]Ministry of Energy and Infrastructure
Dubai, United Arab Emirates
Marwa.Alsalami@moei.gov.ae

Abstract – The effect of inclusion of basalt fibers (BF) on properties of normal- and high-strength concrete (NSC and HSC) made with dune sand is investigated in this paper. Dune sand served as fine aggregates to promote environmental sustainability. Test variables included the concrete grade (NSC and HSC) and the BF volume fraction (0, 0.5, 1, and 1.5%). The BF had a length of 43 mm and a diameter of 0.72 mm. The slump, compressive and splitting tensile strengths of the mixes with BF were determined experimentally and compared to those of benchmark plain mixes. The addition of BF resulted in a slump reduction in the range 44 to 79%. The slump of NSC and HSC mixes decreased almost at the same rate with an increase in the BF volume fraction. The compressive strength of the mixes with and without BF were insignificantly different. Normal-strength concrete with and without BF had a cylinder-to-cube compressive strength ratio (f'_c/f_{cu}) of approximately 0.91. The plain HSC mix also showed a f'_c/f_{cu} ratio of 0.91 whereas HSC mixes with BF exhibited a slightly lower f'_c/f_{cu} ratio with an average value of 0.87. The splitting tensile strength increased with an increase in the BF volume fraction. The enhancement in the splitting tensile strength was more pronounced for the NSC mixes. The splitting tensile strength gain caused by the addition of BF was in the range of 10 to 52% for the NSC mixes and 3 to 22% for the HSC mixes.

***Keywords*:** Dune sand, basalt fibers, slump, compressive strength, splitting tensile strength.

1. Introduction

Concrete has been used extensively as a construction material worldwide [1]. Tensile failure in plain concrete is brittle and occurs at very small values of loads [2]. The mechanical properties of concrete, including compressive strength, splitting tensile strength, and flexural strength, can be improved by adding fibers (steel, glass, carbon, basalt, etc.) [3-12]. Although, the addition of steel fibers improves the mechanical properties of concrete, yet they are susceptible to corrosion [13]. Therefore, it is more advantageous to use nonmetallic fibers in concrete to alleviate the risk of corrosion. Of the various types of fibers, nonmetallic basalt fibers have a potential to be used in concrete to improve its mechanical and durability properties. Basalt fibers are extracted from natural basalt rocks and offer good resistance against high temperature and chemical attack.

There is limited information available in the literature on characterization of concrete reinforced with basalt fibers. Iyer et al. [3] reported an optimum length of 36 mm and volume fraction 0.31% for a 16 µm diameter chopped-BF to obtain an improvement in the modulus of rupture. Ayub et al. [6] reported that the addition of 18 µm diameter chopped-BF at a volume fraction of 3% had no effect on the cube compressive strength but improved the splitting tensile strength of high-performance concrete by up to 16.3%. In contrast, Wang et al. [14] indicated that chopped-BF with a 15 µm diameter may be detrimental to the compressive and tensile strengths of natural aggregate concrete.

The conflicting information reported in the literature warrants further research and investigation. Accordingly, this study aims to evaluate fresh and hardened properties of NSC and HSC reinforced with BF. Locally available dune sand was used instead of river sand or crushed stone to promote environmental sustainability. Normal- and high-strength concrete mixes with target cylinder compressive strengths of 30 and 50 MPa, respectively, were used in the present study. Basalt fibers with a length of 43 mm and diameter of 0.72 mm were incorporated into the concrete mixes in volume fractions of up to 1.5%. The workability of fresh BF-reinforced NSC and HSC was characterized by the slump. The compressive and splitting tensile strengths of the NSC and HSC mixes were measured at 28 days and compared to those of control plain mixes.

2. Materials and Methods

2.1. Materials

ASTM Type I ordinary Portland cement (OPC) [15] was used as a cementitious binding material in the preparation of all concrete mixes. Locally available desert dune sand was employed as a sustainable fine aggregate. Its dry rodded density, specific gravity, and fineness modulus were 1663 kgm^{-3}, 2.77, and 1.45, respectively. The coarse aggregates (CA) were obtained from crushed limestone rocks possessing nominal maximum size (NMS) of 19 mm. The CA included in the mixes had water absorption of 0.22%, dry rodded density of 1635 kgm^{-3}, abrasion mass loss of 16%, specific gravity of 2.82, and fineness modulus of 6.82. The CA were used in saturated surface dry (SSD) condition to account for their water absorption capacity. Basalt fibers having 43-mm length, 0.72 mm diameter, 900 MPa tensile strength, 2100 kgm^{-3} density, and 44,000 MPa elastic modulus were used [16]. The physical appearance of materials used in this study is shown in Fig. 1. Also, a polycarboxylic ether polymer-based superplasticizer (SP) was employed to improve workability of concrete.

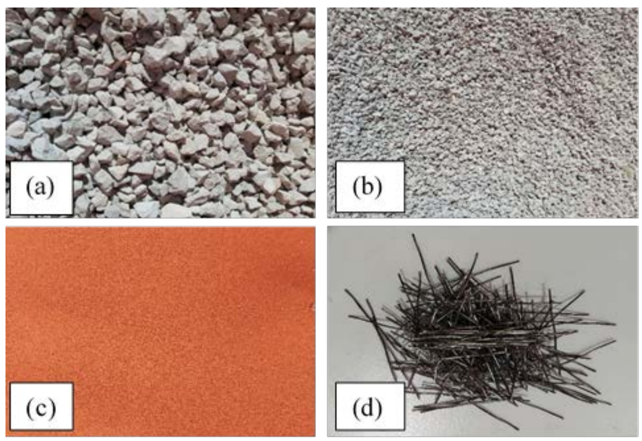

Fig. 1: Physical appearance of materials (a) 19 mm CA (b) 10 mm CA (c) Dune sand (d) 43-mm MBF

2.2. Mix Proportioning

Eight concrete mixes were prepared following the provisions of ACI 211.1 [17] to attain 28-day target cylinder compressive strengths of 30 and 50 MPa for NSC and HSC, respectively. Plain concrete samples (i.e. samples without BF) served as control benchmark mixes. Proportions of concrete mixes are listed in Table 1. Superplasticizer (SP) was added in all concrete mixes to improve concrete workability without compromising mechanical properties. Concrete mixes were labelled as x-BFy, where x denotes the concrete grade, and y represents the volume fraction of BF. For instance, NSC-BF1.5 is a concrete mix with a target cylinder compressive strength of 30 MPa reinforced with BF volume fraction of 1.5%. Also, it should be noted that other than the inclusion of BF, all NSC and HSC had the same mixture proportions.

2.3. Sample Preparation

Concrete mixes were prepared in the laboratory at an ambient temperature of 24±2ºC and a relative humidity of 50±5%. Dry components of the concrete mixes including cement, coarse aggregates, and dune sand were first added into a mechanical concrete mixer. They were then mixed for about 3 minutes. Meanwhile, the required quantity of water to achieve the specified water-to-cement ratio was mixed with the superplasticizer, which, in turn, was incorporated into the dry components. Basalt fibers were added at the last stage of mixing to avoid fiber breakage and clumping. Fresh concrete was sampled into cubes (150 × 150 × 150 mm) and cylinders (150 × 300 mm). The concrete samples were cast in five layers to facilitate proper compaction of concrete, which was performed on an electric vibrating table. Specimens were covered with thick polythene plastic sheets for 24 hours to prevent water evaporation followed by demolding. Demolded specimens were placed in a curing tank until the day of testing.

Table 1: Mix proportion of different concrete mixes

Mix No.	Mix ID	Mass (kgm^{-3})					
		Cement	Sand	CA	Water	BF	SP
1	NSC-BF0.0	470	659	1080	230	0.0	0.47
2	NSC-BF0.5	470	659	1080	230	10.5	0.47
3	NSC-BF1.0	470	659	1080	230	21.0	0.47
4	NSC-BF1.5	470	659	1080	230	31.5	0.47
5	HSC-BF0.0	617	513	1079	216	0.0	0.92
6	HSC-BF0.5	617	513	1079	216	10.5	0.92
7	HSC-BF1.0	617	513	1079	216	21.0	0.92
8	HSC-BF1.5	617	513	1079	216	31.5	0.92

2.4. Performance Evaluation

Concrete specimens were tested in the laboratory to determine the effect of BF addition on the workability, compressive strength, and splitting tensile strength of NSC and HSC. Workability of the fresh concrete was measured using a slump cone test according to the procedure of ASTM 143 [18]. For the compressive strength, cubes of 150×150 mm and cylinders of 150×300 mm (diameter x height) were tested as per BS EN 12390-3 [19] and ASTM C39 [20], respectively. The compressive load was applied using a 2000-kN compression testing machine at rate of 7 kN/s. The splitting tensile strength test was conducted on cylindrical specimens having a size of 150×300 mm according to of ASTM C496 [21] at a loading rate of 1 kN/s. Compression tests included five replicate samples whereases the splitting tensile test included three replicate samples. The average results of the replicate concrete samples were used in analysis.

3. Experimental results and discussion

3.1. Slump

Fig. 2 shows the slump of NSC and HSC mixes. The slumps of plain control concrete mixes (0% BF) for NSC and HSC were 22 and 21.5 cm, respectively. The addition of basalt fibers resulted in a significant decrease in the concrete workability. The addition of 0.5, 1, and 1.5% BF resulted in 61, 70, and 77% reductions in slump compared to that of the control NSC mix. For the HSC mixes with BF volume fractions of 0.5, 1, and 1.5%, the concrete slump reduced by 44, 72, and 79%, respectively. Although, the addition of BF significantly reduced the workability of the concrete, the loss in workability does not seem to be linked to the target compressive strength.

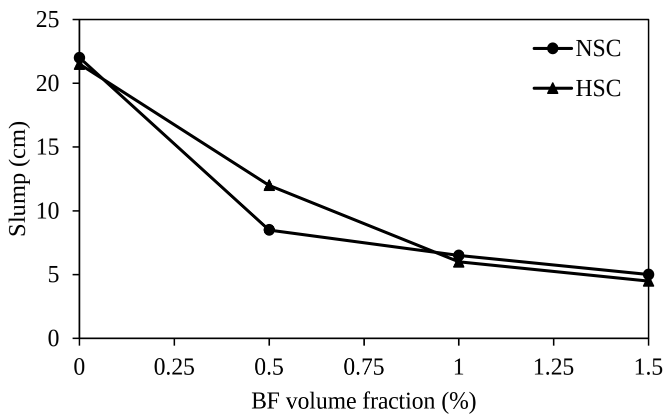

Fig. 2: Slump of concrete with different BF volume fractions

3.2. Compressive Strength

Cube and cylinder compressive strength results, f_{cu} and f'_c, respectively, are depicted in Fig. 3 and summarized in 2. The standard deviation and coefficient of variation values of the five replicate samples were within the limits specified BS EN 12390-3 [19] and ASTM C39 [20] for cubes and cylinders, respectively.

The cube and cylinder compressive strengths of the plain NSC mix were 40 MPa and 36.5 MPa, respectively, with f'_c/f_{cu} of 0.91. The addition of BF insignificantly increased the compressive strength of the NSC mixes by up to 5%. The addition of BF had no effect on the f'_c/f_{cu} ratio of NSC mixes.

The plain HSC control mix had cube and cylinder compressive strengths of 58.6 MPa and 53.6 MPa, respectively, with f'_c/f_{cu} of 0.91. The cube and cylinder compressive strengths of the HSC mixes with BF were on average 96 and 92% of that of the corresponding HSC plain mix. High-strength concrete mixes exhibited and average f'_c/f_{cu} ratio of 0.87. It seems that the compressive strength of NSC and HSC mixes was predominantly affected by the cementitious matrix with no significant impact due to incorporation of BF.

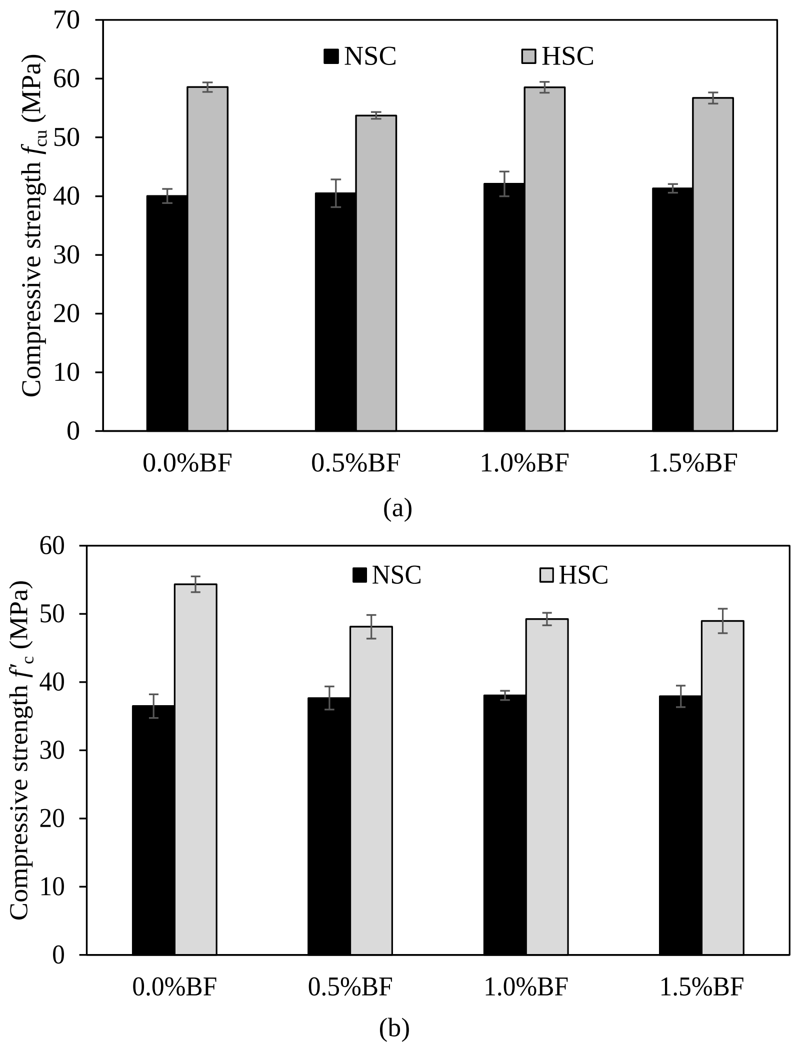

Fig. 3: Compressive strength results (a) f_{cu} (b) f'_c

Table 2: Cylinder and cube compressive strength results

Mix	Avg. f_{cu} (MPa)	StDev (MPa)	COV (%)	Avg. f'_c (MPa)	StDev (MPa)	COV (%)
NSC-BF0.0	40.0	1.2	3.0	36.5	1.7	4.7
NSC-BF0.5	40.5	2.4	5.9	37.7	1.7	4.5
NSC-BF1.0	42.1	2.1	5.0	38.0	0.7	1.8
NSC-BF1.5	41.3	0.7	1.8	37.9	1.6	4.2
HSC-BF0.0	58.6	0.8	1.4	53.6	1.2	2.2
HSC-BF0.5	53.7	0.6	1.1	48.3	1.7	3.6
HSC-BF1.0	58.5	0.9	1.6	50.0	0.9	1.8
HSC-BF1.5	56.7	1.0	1.7	49.5	1.8	3.6

3.3. Splitting Tensile Strength

The 28-day splitting tensile strengths, f_{sp}, of the concrete mixes are shown in Fig. 4. Plain NSC and HSC mixes exhibited splitting tensile strength values of 2.39 and 3.62 MPa, respectively, with a corresponding standard deviation of 0.17 MPa. The addition of 0.5, 1.0, and 1.5% BF volume fractions to the NSC mixes improved the splitting tensile strength by approximately 10, 24, and 52%, respectively, compared to that of the control NSC plain mix. High-strength concrete mixes experienced respective increases of 3, 10, and 22% in the splitting tensile strength compared to that of the HSC control plain mix. It is evident that BF were effective in enhancing the splitting tensile strength of both NSC and HSC mixes. The splitting tensile strength increased with an increase in the BF volume fraction. The increase in the splitting tensile strength was more pronounced for the NSC mixes. Also, NSC mixes exhibited higher rate of increase in the splitting tensile strength than that of the HSC mixes. This is possibly due to the stronger cementitious matrix in the latter that contributes to the splitting tensile strength to the extent that BF inclusion has a less prominent impact on the splitting tensile strength.

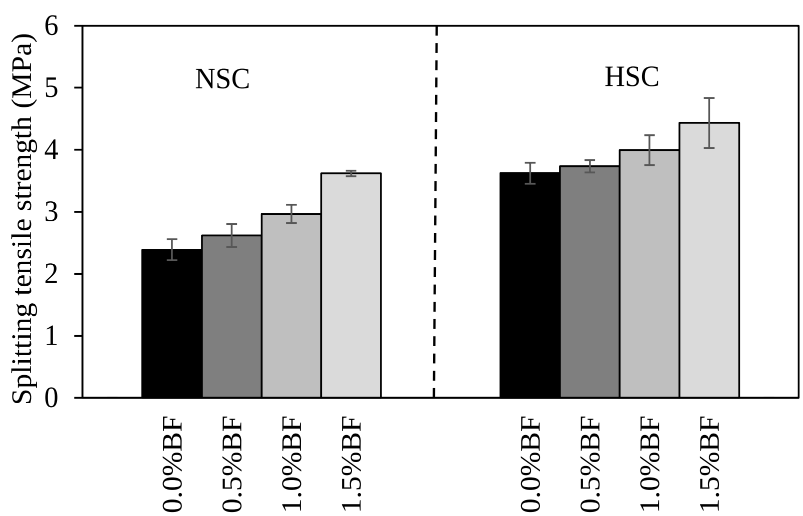

Fig. 4: Splitting tensile strength of BF-reinforced NSC and HSC at different volume fractions

4. Conclusion

The slump, cube compressive strength, cylinder compressive strength, and splitting tensile strength of NSC and concrete mixes with up to 1.5% BF volume fraction were evaluated experimentally in this study. Based on test results, following conclusions are drawn.

(i) The addition of BF reduced workability of the concrete. The addition of 0.5% BF volume fraction reduced the slump of NSC and HSC mixes by 61 and 44%, respectively. The slump further decreased by increasing the BF volume fraction. The inclusion of 1.0 and 1.5% BF to NSC resulted in slump reductions of 70 and 77%, respectively. High-strength concrete mixes exhibited similar respective slump reductions of 72 and 79%.

(ii) The addition of BF had insignificant effect on the compressive strength of NSC and HSC. The cube compressive strength of the NSC mixes with BF was in the range of 40.5 to 42.1 MPa whereases the NSC control mix had a cube compressive strength of 40 MPa. Similarly, HSC mixes with BF had cube compressive strength in the range of 53.7 to 58.5 MPa whereas that of the HSC control mix was 58.6 MPa. The ratio of f'_c/f_{cu} was 0.91 for the plain NSC and HSC mixes. The addition of BF did not alter the ratio of f'_c/f_{cu} for the NSC mixes. High-strength concrete mixes with BF exhibited a slightly reduced f'_c/f_{cu} ratio of 0.87.

(iii) The addition of BF increased the splitting tensile strength of NSC and HSC mixes. The improvement in the splitting tensile strength was more significant for the NSC mixes. Normal-strength concrete mixes exhibited a splitting tensile strength gain in the range of 10 to 52% whereases HSC mixes had a splitting tensile strength gain in the range of 3 to 22%.

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