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Mechanical Properties of High-Performance Concrete Reinforced with Basalt Fibers

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Abstract

Knowledge of the concrete properties such as strength, elastic modulus, thermal expansion, heat generation, shrinkage and creepand durability, are important in the pavement designing. High-performance fiber reinforced concrete (HPFRC) is currently being used in the construction of airport runway and highway pavements but mostly it is used forrapid cure patching and where the early opening of the pavement is required. The reason for less use of HPFRC is its high cost as it employs higher cement content whichresults in thermal contraction problems due to high heat release during setting. In this study, material properties of an economical HPFRC containing Basalt fibers are determined which include compressive strength, elastic modulus and tensile strength. Basaltfibers are relatively cheaper and newfibres for concrete whichare recently investigated by a few researchers. In this study, influence of addition of 1, 2 and 3% Basaltfiber volume fraction in three different mixes of high-performance concrete (HPC) is investigated. The first mix was prepared by using 100% cement and other two mixes were prepared by replacing 10% cement content with silica fume and locally produced met kaolin. Experimental results showed that the addition of Basaltfibersup to 2% fiber volume together with mineral admixtures improved the compressive strength. The improvement in the strains corresponding to maximum compressive strength and splitting tensile strength results was observed at all fiber volumes, whereas there is a negligible influence of the fiber addition on the elastic modulus.

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Keywords: high-performance fiber reinforced concrete; Basaltfibers; silica fume; metakaolin; compressive strength;elastic modulus; splitting tensile strength.

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1. Introduction

Alteration and stabilization of airport and highway pavement slabs using fiber reinforced concrete (FRC) is well established. Typically, FRC is used when the pavement is expected to heavywear and tear; therefore, addition of fibers in the concrete mix, due to a uniform distribution, offers substantial benefits including enhanced impact and fatigue resistance [1], increased flexural strength [1], increased toughness and tensile strength [1, 2], ductility [1] as well as shrinkage cracking control [1-3]. A few examples of FRC pavements are shown in Fig.1.

The most commonly used fiber in FRC pavement construction is steel fiber which though performs quite satisfied for a longer period of time, but in tropical countries like Malaysia, use of steel fiber may not be appropriate due to possibility of surface corrosion [1]. Therefore, it is necessary to look for alternate construction materials offering substantial applications in Pavement Engineering.

During the last decade, Basaltfiber is investigated by few researchers [4-8] due to its characteristics which include good mechanical characteristics particularly high strength, high elastic modulus, high thermal and chemical stability [9], good sound insulation and electrical characteristics [10]. The first use of Basaltfiberin normal strength concrete was reported in 1998 in a report published for Highway Innovations Deserving Exploratory Analysis (IDEA) Project 45 [11] in which performances of 3-D Basalt fiber reinforced concrete (using fiber volume as 0.1, 0.25, 0.4, and 0.5%) and Basalt rod reinforced concrete were investigated. The prominent features endorsed to Basalt fiber reinforced concrete included higher energy absorption capacity after attaining the optimum load and increased ductility. Beside this, it is also mentioned in [11] that Basalt fibers easily disperse in the concrete mix without segregation and lose their shape due to flexibility unlike other fibers which cause difficulty in handling and therefore form balls such as steel and Polyvinyl Alcohol PVA fibers. Similar conclusions are also mentioned in other studies [5, 7] which showed encouraging effect on the concrete strength and its cracking resistance [9]. So far, the optimum Basalt fiber dosage used to produce best mechanical properties is reported as 0.1% in a study [6] (after using 0.1 to 0.3% of Basalt fiber volume) and 0.3% in a study [8] (after using 0.1 to 0.5% of Basalt fiber volume [8]) in the concrete mix. However, the use of higher volume of Basalt fibers in either normal or HPC is not reported in the literature yet. Other than concrete pavements, bridge deck slabs are mostly subjected to reverse cyclic loading and in the study [6], the dynamic behavior of Basalt fiber reinforced concrete is investigated, which showed good results. Therefore, use of FRC incorporating Basalt fibers is one of the good substitutes of conventional steel fibers.

Certainly, to investigate the influence of several important new engineering material parameters on the long-term performance of pavement, it is essential to have sufficient knowledge about material properties including compressive strength, flexural strength, elastic modulus, tensile strength, as well as the coefficient of thermal expansion [12]. Therefore, in this study, the authors used higher fiber volume of Basalt fiber ranging from 1 to 3% in three different HPC mixes to determine the material properties included compressive strength, modulus of elasticity and splitting tensile strength.The first HPC mix was prepared using 100 percent cement content, and other two mixes were prepared by using 10% silica fume and 10% locally produced met kaolin as partial cement replacing materials.

a.Concrete floor,driveway and warehouse built by Macro polymeric Synthetic FRC [13]

b. Pavement with Steel FRC [1]

c. Concrete pavement grade replaced by FRC at Hex ham, Australia [14]

Fig. 1. Examples of the use of FRC in the pavement slabs

2. Experimental Program

Experimental program including selection of material for the preparation of high-performance concrete (with and without fibers), specimen sizes and their preparation and specimens testing setup, for determining the mechanical properties, is described in afterwards sections.

2.1. Materials and mixing of high-performance fiber reinforced concrete

Detailed literature was reviewed by the authors before finalizing the materials and mix proportion for HPFRC (Refer [15]). Type I ordinary Portland cement (OPC), river sand (as fine aggregate with a fineness modulus of 3.55) and two sizes of coarse aggregates were used as basic constituents to produce high-performance concrete (HPC). Among two sizes of the coarse aggregates, first coarse aggregate was passed through a 20 mm (3/4") opening sieve and retained on 10 mm (3/8"), whereas the second aggregate was passed through a 10 mm (3/8") opening sieve. The reason for using two sizes in the concrete mix is that crushed rock aggregates of 10 to 20 mm in size are not too angular and elongated; therefore, they should preferably be used as recommended in [16]. Two types of mineral admixtures, silica fume and locally produced met kaolin, were also used to replace 10% cement content use of silica fume and met kaolin improves the pore structure of the concrete by reducing the total porosity which ultimately improves the material properties, as reported in [17]. The physical and chemical properties of cement and mineral admixtures are presented in Table 1.

Table 1. Physical and Chemical Composition of OPC, silica fume and locally produced met kaolin

	OPC	Silica fume	Locally produced met kaolin
Specific gravity	3.05	--	--
BET Surface Area (m^2/g)	0.392	16.455	12.174
Loss on ignition (%)	--	2.0	1.85
Average Particle Size (μm)	--	--	2.5-4.5
SiO_2 (%)	20.44	91.40	53.87
Al_2O_3 (%)	2.84	0.09	38.57
CaO (%)	67.73	0.93	0.04
MgO (%)	1.43	0.78	0.96
SO_3 (%)	2.20	--	--
Na_2O (%)	0.02	0.39	0.04
K_2O (%)	0.26	2.41	2.68
TiO_2 (%)	0.17	--	--
MnO (%)	0.16	0.05	0.01
Fe_2O_3 (%)	4.64	--	1.40
TiO_2 (%)	--	0.04	0.95
P_2O_5 (%)	--	0.38	0.10

Note: Properties were determined by X-Ray Fluorescence (XRF) and Brunauer–Emmett–Teller (BET) Specific surface area analysis

A constant water cement ratio of 0.4 was used to mix the concrete constituents and to improve the workability of concrete, high range water reducing admixture (super plasticizer) was used. In order to achieve the target slump of 50±10 mm (with and without fiber addition), the dosage of super plasticizer was kept as varied. The chemical composition and the technical indexing characteristics of Basaltfiber used in the current study are described in Table 2 and Table 3, respectively. Detail of the mix design of HPFRC along with the quantities of the concrete ingredients is given in Table 4 and it can be seen that slight lower cement content of 450 kg/m^3 has been used to avoidthermal contraction problems, as mentioned earlier. All ingredients were mixed in a pan mixer in compliance to BS 1881- 125: 1986 standard [18]. It is important to mention that for concrete mixes with fibers, extra time was utilized to ensure proper mixing and this duration was increased as the fiber volume increased. Fig. 2 and Fig. 3 show the Basalt fiber used in the current study and the quality of the concrete mix with 3% Basaltfibers, respectively.

Table 2. Chemical composition of Basaltfibers chopped strands provided by the supplier

Chemical composition of Basaltfibre (%)							
SiO_2	Al_2O_3	CaO	MgO	FeO+ Fe_2O_3	TiO_2	Na_2O+K_2O	Others
51.6-59.3	14.6-18.3	5.9-9.4	3.0-5.3	9.0-14.0	0.8-2.25	0.8-2.25	0.09-0.13

Table 3. Properties of Basalt fibers

Fiber type	Diameter (*μm*)	Cut length (*mm*)	Tensile strength (*MPa*)	Elastic modulus (*GPa*)	Specific gravity	Elongation (%)
Filament type	18	25	4100-4840	93.1-110	2.63-2.8	3.1

Table 4. Mix detail for HPFRC

Series	Sample	Mix ingredients (kg/m^3)						Weight proportion	Basaltfibre	High range water reducing admixture
		Cement	Mineral additive type and content	Fine aggregate (*FA*)	Coarse aggregate (*CA*) <10 mm	Coarse aggregate (*CA*) 10 to 20 mm	Water	(*Cement*: *FA* *CA*)	(%)	(super plasticizer)
"P"	P0	450	--	670	500	600	180	1.0: 1.5: 2.4	0	Variable, target slump 50 ± 10 mm
	P1								1	
	P2								2	
	P3								3	
"S"	S0	405	45 (silica fume)	670	500	600	180	1.0: 1.5: 2.4	0	
	S1								1	
	S2								2	
	S3								3	
"M"	M0	405	45 (met kaolin)	670	500	600	180	1.0: 1.5: 2.4	0	
	M1								1	
	M2								2	
	M3								3	

* "P" represents a plain concrete, "S" and "M" represent mixes in which 10% cement content is replaced with silica fume and met kaolin, respectively

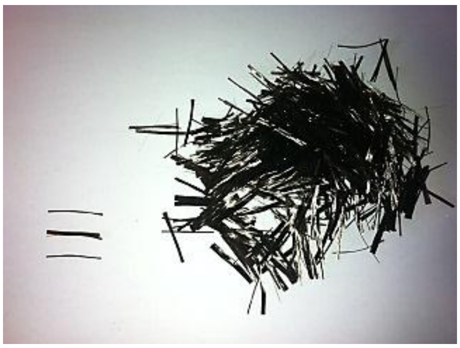

Fig. 2. ChoppedBasalt fiber.

Fig. 3. Concrete mix quality with Basaltfibers.

As mentioned in Table 4, total three series of high-performance concrete mixes were prepared and named as Series "P", Series "S" and Series "M". Series "P" represents plain concrete mix prepared in accordance with the quantities of the concrete ingredients described in the Table 4 and no cement content was replaced with any of the mineral admixture listed in the Table 4. Series “S” and Series “M” were also prepared similar to Series “N” except that 10% cement content was replaced by silica fume and locally produced met kaolin, respectively. In other words, label “S” and “M” represent those series in which silica fume and met kaolinwere added to partially replace the cementcontent.For each three series of HPC, four types of mix samples were prepared including one control sample (containing no fiber) and three mix sample containing 1%, 2% and 3% of Basalt fiber added by volume of the concrete mix. For example, in Series “P”, Sample label “P0” represents mix sample containing 0% fiber volume, whereas samples label “P1”, “P2” and “P3” represent plain concrete mix containing 1%, 2% and 3% Basalt fiber volume, respectively. Similar labels were also used for the mix samples of Series “S” and Series “M”. Overall, twelve mix samples for all three series were prepared. The detail of the samples is also given in Table 4.

2.2. Sizes and casting details of the specimens

From each mix sample as described in the previous section and as mentioned in Table 5, total six cylindrical specimens of size 100×200mm were cast and cured according to BS 1881-3:1970 standard [19]. After 24 hours, formwork of all specimens was removed and specimens were left to wet cure for 28 days.Before pouring, slump of the concrete was also determined in compliance with BS 1881-102 standard [20] and it was found that slump is within the limit of 50 ± 10 mm.

2.3. Specimens testing

After the completion of curing period, specimens were air dried for few hours and then tested. Compressive strength of HPFRC was determined by testing three (03) cylinders of size 100×200 mm using compression testing machine of 1000 kN capacity. To obtain the strain measurements, LVDT was also installed. Average compressive strength of cylinders along with the strain results are presented in the Table 5. Splitting tensile strength test of three 100×200 mm sized cylinders was carried out according to BS 1881-117:1973 [21], respectively using compression testing machine of 3000 kN capacity ata loading pace of 0.3 kN/sec.

ab

Fig. 4.100×200 mm cylinder testing for (a) splitting tensile strength; (b) compressive strength.

3. Experimental results and discussion

Table 5 shows the 28 days cylindrical compressive strength, modulus of elasticity and splitting tensile strength of the specimens without fibre reinforcements and those reinforced with 1, 2 and 3% of Basaltfibres (added by volume of the concrete).

Table 5. Results of the mechanical properties at 28 days

Samples	Compressive test results				Elastic modulus (GPa)	Splitting tensile strength results	
	Max. cylinder strength (MPa)	Strength increase with respect to control (%)	Strains (μm/m) Peak	Strains (μm/m) Ultimate		Strength (MPa)	Strength increase with respect to control (%)
Series "P": *Plain* concrete reinforced with 0, 1, 2 and 3% Basaltfibres							
P0	71.87	--	2412	14630	40.76	5.26	--
P1	73.52	2.29	2781	19512	42.01	5.40	-4.78
P2	74.16	3.19	2832	18335	41.88	5. 524	-2.24
P3	65.08	-9.45	2969	16662	42.54	6.00	8.62
Series "S": Concrete with 10% *silica fume* as partial replacement of cement and reinforced with 1, 2 and 3% Basaltfibres							
S0	80.87	--	2599	14548	42.99	6.65	--
S1	81.31	0.62	2902	12820	41.35	6.71	0.90
S2	82.34	1.82	2905	15359	45.55	6.72	1.05
S3	68.66	-15.1	3033	15125	37.82	7.99	20.15
Series "M": Concrete with 10% *met kaolin* as partial replacement of cement and reinforced with 1, 2 and 3% Basaltfibres							
M0	82.74	--	2640	10499	42.03	5.27	--
M1	84.05	1.58	2749	13477	41.90	5.49	4.17
M2	84.08	1.62	2819	15582	41.26	5.86	11.20
M3	80.78	-2.37	3412	15989	39.16	7.18	36.24

3.1. Compressive Strength

The results of maximum cylindrical compressive strength, as presented in Table 5, show that in each series, slight increase in the compressive strength was observed up to 2% fibre volume; however at 3% fibre volume, compressive strength observed to be decreased from 2.37% (in Series "M") to 15.1% (in Series "S").

Comparing the results of compressive strength of all series on the basis of fiber volume added in concrete mixes of each series (i.e. Series "P", Series "S" and Series "M"); it was found that highest compressive strength was achieved in Series "M" at all Basalt fiber volumes compared to Series "P" and Series "S" (Refer Fig. 5).

When no fiber was added, the compressive strength of mix sample "M0" was obtained as 15.12% and 2.31% higher than mix "P0" and mix "S0", respectively; whereas the strain gain of mix sample "S0" was observed as 12.52% higher than mix sample"P0" (Refer Fig. 5).This shows the use of met kaolin is not only beneficial in terms of highest strength gain and economical compared to imported silica fume also as it is locally produced from locally available Kaolin.

At 1% Basalt fiber volume, the strength increase of mix sample "M1" was about 14.32% and 3.37% compared to the mix samples "P1" and "S1", respectively (Refer Fig.5). The strength increase of mix sample "S1" was 10.6% higher than mix sample "P1". Similar behavior was observed at 2% Basalt fiber volume i.e. the strength increase in mix sample "M2" was 13.38% and 2.11% higher than mix sample "P2" and "S2", respectively (Refer Fig.5). The strength increase of mix sample "S2" was 11.03% higher than mix sample "P2". Opposite to 1 and 2% Basalt fiber volume, the results of compressive strength at 3% Basalt fiber volume werequite improved. The strength increase of mix sample "M3"was 24.12% and 17.65% compared to mix sample "P3" and mix sample "S3", respectively. The strength increase of mix sample "S2" was 5.5% higher than mix sample "P3".

The results of strain corresponding to maximum compressive strength (referred as Peak strains in Table 5) show an increase in strains at all fibrevolumes in all series. Comparison of strains across the series is shown in Fig. 6 and it can be seen that at 0 and 3% fibre volume, higher strains were obtained with met kaolin comparing to silica fume, whereas at 1 and 2% fibre volume higher strains were obtained with silica fume. This shows that the use of mineral admixtures as partial replacement of cement is highly beneficial and improves the performance of the concrete. Locally produced met kaolintogether with the Basaltfibres performed very well at higher fibre volume.

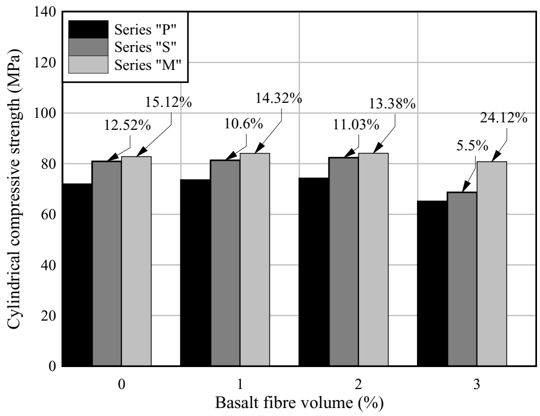

Fig. 5. Variation in compressive strength.

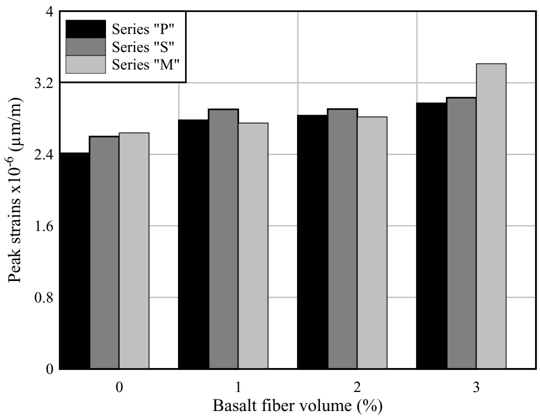

Fig. 6.Variationin peak strain.

3.2. Elastic Modulus

Elastic modulus is interdependent on the concrete compressive strength. It can be seen in Fig. 5 that there is slight improvement in the compressive strength results with respect to the increase in fibre volume. Similarly, results of elastic modulus, presented in Fig. 7, show no significant variation in the elastic modulus due to the addition of fibre. Therefore, it may be inferred that the addition of Basaltfibredoes not influence the elastic modulus.

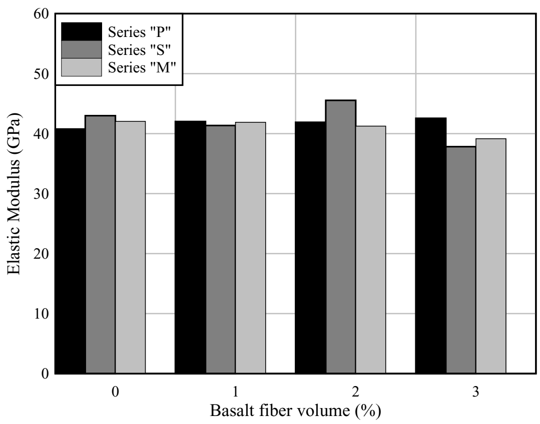

Fig. 7.Variation in elastic modulus

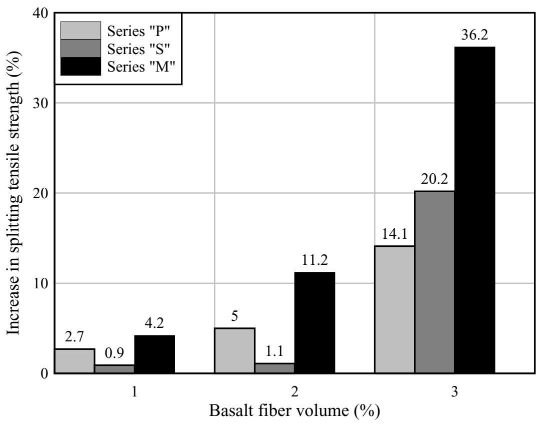

Fig. 8. Increase in splitting tensile strength with respect to control

3.3. Splitting tensile Strength

Results of splitting tensile strength are presented in Fig. 8 which shows that the addition of 1, 2 and 3% volume of Basaltfibres improved the tensile characteristics of the concrete (with and without containing mineral admixtures). Comparing the results of splitting tensile strength across the series, it was found that high-performance concrete containing 10% silica fume better improved the splitting tensile properties for all fibrevolumes (i.e. 1, 2 and 3% Basaltfibres) and these results are better than normal concrete as well as the concrete in which met kaolin was added as partial replacement of cement.

4. Conclusions

In this study, HPFRC incorporating mineral admixtures as partial replacement of cement were found to be beneficial to improve the properties of concrete. Further conclusions are as follows:

1. In each of the three series of HPFRC (i.e. plain concrete containing no mineral admixture (Series "P", concrete containing 10% silica fume (Series "S") and 10% locally produced met kaolin (Series "M")), the optimum compressive strength at 2% Basalt fibre volume was found to be higher, whereas at 3% fibre volume compressive strength reduced probably due to the presence of voids caused by the use of higher fibre volume of Basalt fibres. Across the series, though combined use of mineral admixtures and Basalt fibres (i.e. Series "S" and Series "M") significantly increased the compressive strength in comparison to the plain concrete (i.e. Series "P") at each fibre volume, but the compressive strength results in Series "M" (for each fibre volume) were found to be higher than in Series "S" and in Series "P", showing that the use of locally produced met kaolin is better.
2. In each of the three series of HPFRC, strains corresponding to the maximum compressive strength as well as splitting tensile strengths were found to be increasing with the increasing fibre volume and this increment was significantly higher than control mix samples (containing no fibre), showing the ductile behavior of the concretes with the use of Basalt fibres. The results of strains corresponding to the maximum compressive strength and splitting tensile strength in Series "S" were higher than Series "M" at each fibre volume.
3. Additions of Basaltfibres did not significantly influence the results of elastic modulus.

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