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Research Article

An Experimental Study on the Effectiveness of Chopped Basalt Fiber on the Fresh and Hardened Properties of High Strength Concrete

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Abstract: This research aimed to investigate the suitability of chopped basalt fibers for inducing ductility in High Strength Concrete (HSC). HSC offers a sustainable option to the rapidly growing construction industry particularly in long span bridges, high-rise structures together with other infrastructures. Until near past, efforts were made to achieve much higher compressive strength of HSC, which causes HSC being more brittle. In view of high brittleness of HSC many researchers focused on fiber reinforced concrete to induce ductility. In this study two series of mixes, one with 100% cement and the other with 80% cement with 20% fly ash were studied. In the both of series mixes, fiber content was varied as 0, 0.25, 0.75, 1, 2 and 3%, respectively. Concrete with 0% fibers is known as the control mix. Since, water/binder ratio and super-plasticizer content was kept constant. The tests result indicated that, slump of concrete mixes showed decline with the increment in the fiber content. The addition of chopped basalt fibers did not help to improve the compressive strength of HSC. However, fibers have improved tensile and flexural tensile strength of HSC, also the area under the stress strain curves increased, which are an indication of ductile mode of HSC as well as its toughness. Similarly, tensile to compressive strength and flexural to compressive strength ratio observed a continuous increment with the increase in fiber content as well as the areas under compressive stress-strain curves. In conclusion, chopped basalt fibers have shown their potential for producing ductile HSC.

Keywords: Brittle, chopped basalt fiber, compressive strength, ductility, flexural tensile strength, splitting tensile strength, toughness

INTRODUCTION

Use of HSC is continuously increasing due to improvement in its strength and durability characteristics. This kind of concrete is needed in high rise buildings, long span bridges and hydraulic structures. Utilization of HSC fatalistically reduces the structural cost and weight by reducing the member sizes. With the rapid increase of HSC in the construction industry, gradually its drawbacks have realized, such as a low tensile and flexural strength, short term cracks and high brittleness (Mazloom *et al*., 2004). Despite of HSC popularity, the above discussed shortcomings have restricted its application in some situations.

Collapse of HSC will happen suddenly, it will not show any warnings like cracks deformation due to high brittleness of HSC. This will involve high level of risk to the users of HSC structures. Recently, many attempts have been conducted to solve the tensile strength deficiencies of HSC properties using traditional reinforcement even by providing restraining techniques. HSC reinforced by steel is not friendly with the environmental conditions as well as its cost. Therefore, these shortcomings have been controlled by an addition of small closely spaced and uniformly dispersed fibers to the concrete. Fibers can be prevent macro crack and can act as a bridge to transfer the load. It can also be effective in increasing the static and dynamic properties of the plain concrete. This kind of concrete in the literature is defined as a Fiber Reinforced Concrete (FRC). FRC is a composite material consisting of mixtures (Rajeshkumar *et al*., 2010). Fiber reinforced composites satisfy more than other composites materials even the traditionally reinforcement published by Padmarajaiah and Ananth (2004), Rahimi and Kelser (1979), Alsayed and Alhozaimy (1999), Emadi and Hashemi (2011) and Balendran *et al*. (2002).

Fiber reinforced HSC was developed to become an active area of study due to its excellent properties such as flexural tensile strength; resistance impact and good permeability to provide good concrete for HSC structures. Recently, a number of studies have been conducted using E-glasses, AR-glass a boron-free type of E-glass, steel and basalt fibers (Micelli and Nanni, 2004). Distribution and right orientations in the matrix,

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bonding properties of the fiber and matrix and its quantity are led to significant enhancement in the brittleness and toughness of HSC reported by (Padmarajaiah and Ananth, 2004; Punmia *et al*., 2005a, b). Fibers act as a control and/or prevent the opening and growth of macro cracks which is the desire to increase the energy, ductile, toughness of HSC and its meet the growth of multi cracks. Furthermore, post-cracking can be improved, enhances of mechanical and durability of the material but there was no effect on the linear elastic behavior of the matrix reported by Micelli and Nanni (2004).

Basalt fiber is a common term used for a variety of volcanic rocks, which is gray and dark in color, formed from the molten. There are large areas of this type of rock in the world (Sahibin *et al*., 2001). Continuous fibers were classified as inert and natural, friendly to environment and nonhazardous material. Basalt fibers are helpful materials to improve the properties of HSC because it has good mechanical properties. Moreover, it is cheaper, available and chemically more stable than the other fibers. Also, it can be work in a wide range of temperatures (-269 to 650°C) (ASTM, 2005; Li and Xu, 2009).

Basalt fibers can be support the tensile properties of concrete as internal strengthening materials by two systems. Firstly wideness requires a high amount of fibers well distributed inside the mixture to avoid or prevent any existing number of micro-crack. Second one is a crack bridge, high length fibers and adequate bond of concrete. A few studies in the available literature have been done to assess this new kind of the fibers. Dias (2005) geopolymeric concrete had better characteristics than normal concrete using the basalt fiber and less sensitive to the presence of cracks. Li and Xu (2009) studied the effect of the Basalt Fiber Reinforced in the mechanical properties of Geopolymeric Concrete (BFRGC). Their results showed that impact characteristics of BFRGC exhibit strong strain and it was increased linearly as an expected. Moreover, use of basalt fiber can be improving the deformation and energy absorption properties of HSC.

Using Fly Ash (FA) with CBFS here in this study can be partially substituted the reduction of the slump and compressive strength of HSC. FA as an addition or partially replacement material of cement is very well documented in the literature. It has several contributions on the properties of concrete such as slump, long term compressive strength, durability and the cost of HSC (Mehta and Burrows, 2001; Vengata, 2009; Adams, 1988; Naik and Ramme, 1989). These benefits are depending on the type of FA, proportion used, mixing procedure and field conditions reported by Raju *et al*. (1994), American, Coal Ash Association (1995) and Kosmatka *et al*. (2003).

Last years, several studies have been done to improve the toughness and brittle of HSC using basalt Fiber reinforced as an external Reinforcement Plate (FRP). However, there is the shortage in the literature review to improve the mechanical properties of HSC using a chopped basalt fiber as internal strengthening materials. The overall objective of this study was to investigate the feasibility of utilizing the CBFS as internal strengthening materials to improve the tensile strength, toughness and brittleness of HSC.

Scope of study: This work studied the effect of CBFS on the basic fresh and mechanical characteristics of HSC, by changing the content of CBFS. Water and super-plasticizer were kept constant, all specimens are left in the potable water tank until the tests day at room temperature. Tests are proceeding according to American standards testing materials ASTM.

METHODOLOGY

Materials:

Cement: In order to produce HSC mixture while maintaining a good fresh property of mixture, it is required to investigate carefully the composition, fineness's and its compatibility of cement with the chemical admixtures. In this study the cement used was ordinary Portland cement type I according to ASTM with specific surface area of 3960 cm^2/g and a density of 3.15 g/cm^3, which was supplied by Tasek Cement Company limited in Malaysia.

Fly ash: Using the fly ash FA with CBFS on HSC can be partially substituted the reduction of the slump and compressive strength of HSC. FA as an addition or replacement material for cement is very well-known in available literature. It has several contributions on the properties of concrete such as low slump, long term compressive strength, durability and the cost of HSC, (Hong and Shin, 2003; Mehta and Burrows, 2001; Vengata, 2009; Adams, 1988). The mineral admixture used was FA class F, its from a local source, which was supplied by Mahjung, Panven, Perak, Malaysia. Table 1 shows the chemical compositions of the cement and fly ash.

Coarse aggregate: Coarse aggregate used in this investigation was hard, dense, non-reactive and durable crushed granite with nominal size range of 9 to 20 mm. The specific gravity of the coarse aggregate was found to be 2.65. The coarse aggregate had water absorption of 0.92% and the unit of weight was found to be 1560 kN/m^3. Furthermore, in according to ASTM, C136 (2005) the sieve analysis of coarse aggregate was preformed related to test result coarse aggregate classified as well gradation coarse aggregate as shown in Table 2. Coarse aggregate was washed by water to take out all the dust or small particle size which effect on the properties of HSC and coarse aggregate used in Saturated Surface Dry (SSD) condition.

Table 1: Compositions of the cement and fly ash

	Binder	
Chemical composition	OPC	Fly ash
SiO_2	20.3	56.39
Al_2O_3	4.2	17.57
Fe_2O_3	3.0	9.07
CaO	62.0	11.47
MgO	2.8	0.98
SO_3	3.5	0.55
K_2O	0.9	1.98
Na_2O	0.2	1.91

Table 2: Sieve analysis of coarse aggregate

Sieve size (mm)	Retained Wt/gm	Cumulative retained mass fraction wt (%)	Passing mass fraction wt (%)
25.00	0	0.0	100.0
20.00	63.0	3.2	96.9
13.20	1033.0	51.7	48.4
10.00	1521.7	76.1	23.9
5.00	1957.5	97.9	2.1
4.75	1958.4	97.9	2.1
3.35	1998.7	99.9	0.1
2.36	1999.1	100.0	0.0

Table 3: Sieve analysis of fine aggregate

Sieve size (mm)	Retained Wt/gm	Cumulative retained mass fraction wt (%)	Passing mass fraction wt (%)
4.750	0.0	0.0	100.0
2.360	0.1	0.1	99.9
2.000	0.3	0.3	99.7
1.180	5.8	5.8	94.2
0.600	48.6	48.6	51.4
0.300	80.8	80.8	19.2
0.212	85.6	85.6	14.4
0.150	87.7	87.7	12.3
0.063	97.5	97.5	2.5

Table 4: Chemical and physical component of CBFS

Component	Result (%)
Combustible matter content	0.5200
Water content	0.0025
SiO_2	51.6500
AL_2O_3	15.5800
Fe_2O_3	3.9700
FeO	6.1500
CaO	9.3500
MgO	6.1000
K_2O	1.4300
Na_2O	2.0500
TIO_2	1.3300
Other oxides	2.3900

Fig. 1: Chopped basalt fiber stands

Fine aggregate: Well graded natural river sand supplied from a local Malaysian source with maximum size particle of 5 mm is considered to complete this study. Fine aggregate was cleaned separated from any impurity and dried under the sunlight, it is had fineness modulus of 2.2, specific gravity of 2.63 and water absorption of 1.04%. Its particles gradation was tested using sieve analysis test as per ASTM C 136 01 (2005), Table 3 shows the test result.

Water: Water used in all mixes was clean and free from injurious of oils, acids, alkalis, salts and organic materials to prevent any deleterious quantity of chloride ion. It was drinkable water supplied from the lab source.

Chopped basalt fiber stands: A new type of continuous nature fibers used was a chopped basalt fiber stands its natural materials coming from melting the basalt rock. The CBFS manufactured in China, it has length as 25 mm and diameter as 18 µmm, tensile strength range of 4100-4840 MPa and density range of 2.63-2.8 g/m^3 as shown in Fig. 1, it was added by weight of cement. Table 4 shows the chemical composition of CBFS.

Mix proportion and mixing: In available literature, there are no guide lines to provide HSC mix design, but there are the basic concepts from the experts. These concepts involve quantity of materials, improvement of paste cement as well as the aggregate, enhancing the bond between aggregate surface and cement paste and lastly denser packing between the both components (Liping *et al*., 2010). Many trial mixes have been tested accordingly by these experts concept from criteria mentioned above. Two HSC design mixes are achieved which labelled as M and MF, each one of them will be considered as a control mix for its own group. Table 5 shows the proportion of mixes.

A plain mixer was considered for mixing. All specimens were mixed at room temperature of 26±2°C. Fine aggregate and coarse aggregate which are placed and mixed about one minute firstly, then half of the water content added and approximately one more minute for mixing. It is flowed by adding the powder content; remaining water and super-plasticizer are placed and mixed again until concrete becomes fully homogenous. Lastly, the CBFS was feed gradually to the mixture and continuous mixing maintaining the workability and homogeneousness.

Preparing, casting and curing of specimens: A total of 14 mixes have been made to complete this study. Properties of fresh HSC are tested according ASTM C 172. A number of 210 cubes having dimensions 100×100×100 mm each were cast using oiled steel

Table 5: Mixes proportion of materials

No. of mix	Cement (kg/m^3)	Fly ash (kg/m^3)	C.B.F (%)	C.A (kg/m^3)	F.A (kg/m^3)	W/C ratio	S.P (%)
M	550	0	0.00	975	740	0.275	0.8
M1	550	0	0.25	975	740	0.275	0.8
M2	550	0	0.50	975	740	0.275	0.8
M3	550	0	0.75	975	740	0.275	0.8
M4	550	0	1.00	975	740	0.275	0.8
M5	550	0	2.00	975	740	0.275	0.8
M6	550	0	3.00	975	740	0.275	0.8
MF	440	110	0.00	975	740	0.275	0.8
MF1	440	110	0.25	975	740	0.275	0.8
MF2	440	110	0.50	975	740	0.275	0.8
MF3	440	110	0.75	975	740	0.275	0.8
MF4	440	110	1.00	975	740	0.275	0.8
MF5	440	110	2.00	975	740	0.275	0.8
MF6	440	110	3.00	975	740	0.275	0.8

(a) (b)

(c) (d)

Fig. 2: Tests producers, (a) slump test, (b) compressive strength, (c) flexural strength (d) splitting tensile test

moulds to calculate the compressive strength of HSC. 28 cylinders having a dimension 100 diameter×200 mm were cast to determine the tensile splitting strength of HSC. Also, to obtain the flexural tensile strength a number of 28 beams having a dimension 100×100×500 mm were cast. All samples were cast using three compacting layers of filling by electrical vibrating hammer to remove the entrapped air. For documentation issues the free surfaces of the cubes were labelled after a while from the cast and they were kept for 24 h in mould at lab temperature. After that all of the specimens were remolded and immersed in potable water for curing, at the lab temperature, maintained at 26±2°C up to the date of tests.

Testing:

Slump: The standard slump test apparatus were used to measure the slump of fresh HSC. Slump value was measured immediately after the mixing according to ASTM C 172 as shown in Fig. 2a.

Compressive strength, splitting and flexural tensile strength: Both of the compressive strength, splitting and flexural tensile strengths were calculated using a compressive machine test according to ASTM C 39, 496 and 78, respectively. Compressive strength, splitting and flexural tensile strengths samples were loaded under control load of pace rate of 3, 0.94 and 0.2 kN/s, respectively until the sample failure. Figure 2b to d shows the preparation of those tests. Compressive strength tests were done on the 3th, 7th, 28th, 56th and 90th day and the 28th and 90th day for splitting and flexural. To measure the compressive strain of HSC, electrical resistance strain gauge was used. The strain gauge was fixed in the middle of the plain concrete cube. Nevertheless, stress was recorded from compressive machine test directly and the strain was recorded using data logger computer through the compressive strength machine.

RESULTS AND DISCUSSION

This study was an experimentally investigation to improve the tensile strength, toughness and brittleness, flexural and tensile strength of 100% OPC HSC and 80% OPC with 20% replacement of cement by fly ash HSC mixes utilizing a different amount of CBFS as internal strengthening materials. (0.25, 0.5, 0.75, 1, 2 and 3%, respectively) CBFS by weight of binder materials for each group mix were considered to complete this comparison. All the results are presented and discussed in the flowing paragraphs.

Properties of fresh HSC: High workability is required as an important property for high productivity of HSC. Therefore, high effective chemical admixture with low dosage was used to get a good slump test results without compromise on the strength of HSC. After mixing the basic components up to full homogenous the

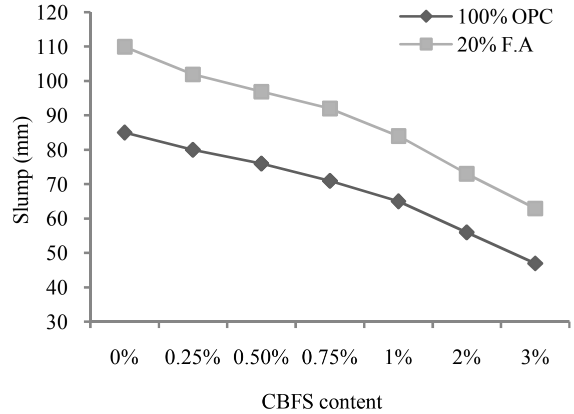
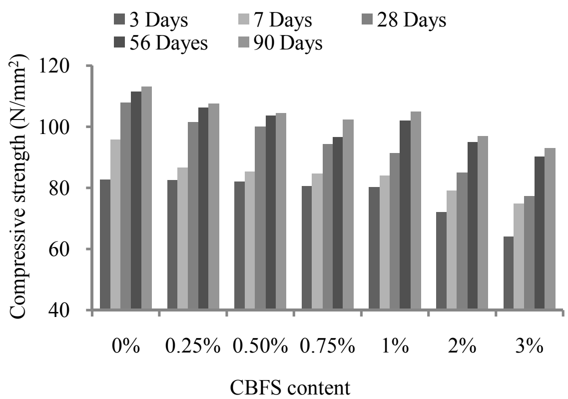
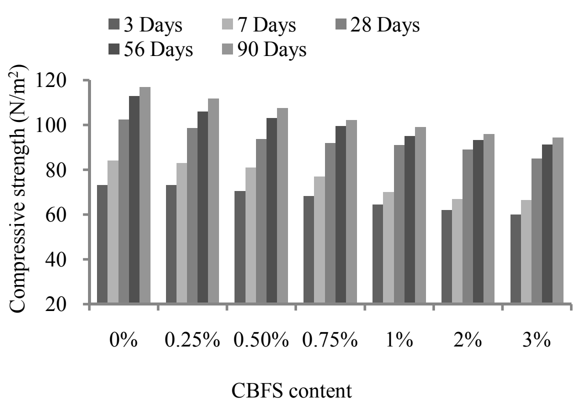


Fig. 3: Effect of CBFS on the workability of HSC



(a)



(b)

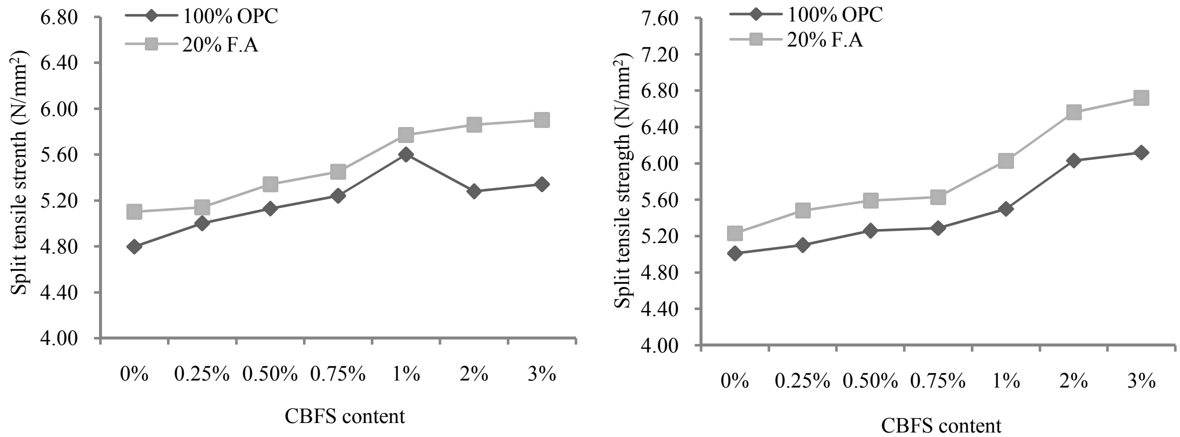
Fig. 4: Compressive strength of HSC with CBFS, (a) 100% OPC and (b) 20% fly ash

CBFS initially was feed gradually. The time of mixing increases as an increasing the quantity of CBFS as well as providing good distribution fibers and prevent the fiber balling. Addition of CBFS by this system was provided more friction force between the components of the mixes and absorbed some of water from the designed water of mixing. However, the test results showed that the workability of HSC decreased with increasing of CBFS as shown in Fig. 3. Whereas, small particle size and spherically shaped particles of FA decreased the resistance friction between paste of cement and aggregates. Consequently, an improvement of fresh properties of concrete is observed as reported by Naik and Ramme (1989) and Raju *et al*. (1994). Thus from the tests results can be obtained that the loss of the workability was potentially substituted using 20% replacement of cement by fly as shown in Figure. There was no aggregate segregation happen and full homogenously mix was observed from tests. Also test results showed that 0.25, 0.5 and 0.75%, respectively of CBFS showed a little effect on the slump of the two group mixes.

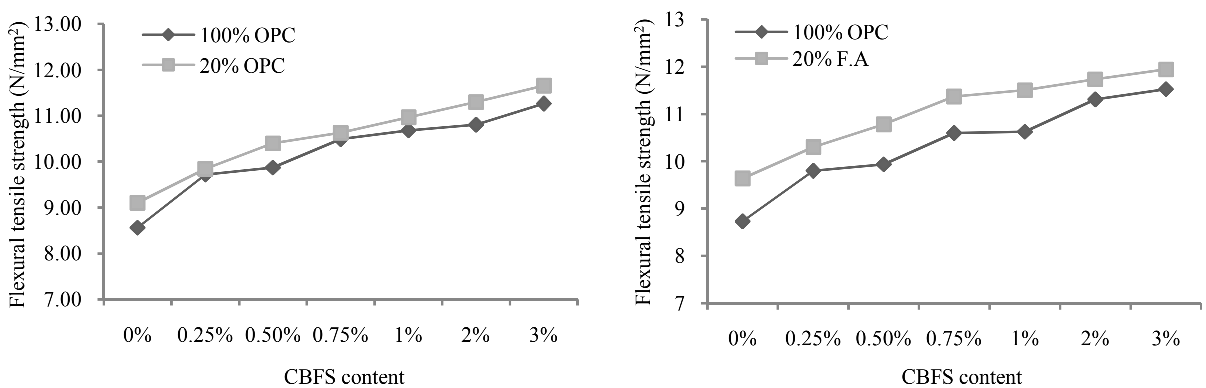
Properties of harden HSC:

Compressive strength: Figure 4a and b shows the variation of compressive strength of specimens of early and long term strength with different content of CBFS for the both mixes. Each result of compressive strength reported is an average of three samples. The results showed that the compressive strength reduced with an increasing the CBFS content. There were two reasons which may have led to these findings results, firstly using the CBFS might make some poor areas in harden concrete. First collapse may happen through these voids regions. Secondly, Fibers after mixing had absorbed too much of the mixing designed water, cement around them may not get sufficient water for hydration. Therefore, small particle size of fly ash can be fill those voids areas and provide some help to the cement hydration. However, the reduction of compressive strengths of 20% replacement of cement by fly ash HSC mix was less than that of 100% OPC HSC mix. Also from the test results it can be pointed out that, 0.25, 0.5 and 0.75%, respectively of CBFS showed a little effect on the compressive strength HSC mixes.

Tensile strength: Figure 5 presents the indirect tensile strength test results conducted to evaluate of splitting and flexural tensile strength of HSC using various contents of CBFS at 28 and 90 days. From the test results are observed that, CBFS acts as the arrester of the cracks which growth when HSC specimens were loaded and bridged deformation of HSC cracks the load was transferred to around concrete. The results showed that Splitting and flexural tensile strength at 28 and 90 days significantly increased as increasing of CBFS content. However, 20% replacement of cement by fly ash specimens showed better splitting and flexural tensile strength than 100% OPC specimens. (10, 18 and 20%, respectively) increase of splitting tensile strength for 100% OPC HSC and 15, 25 and 28 for 20%,

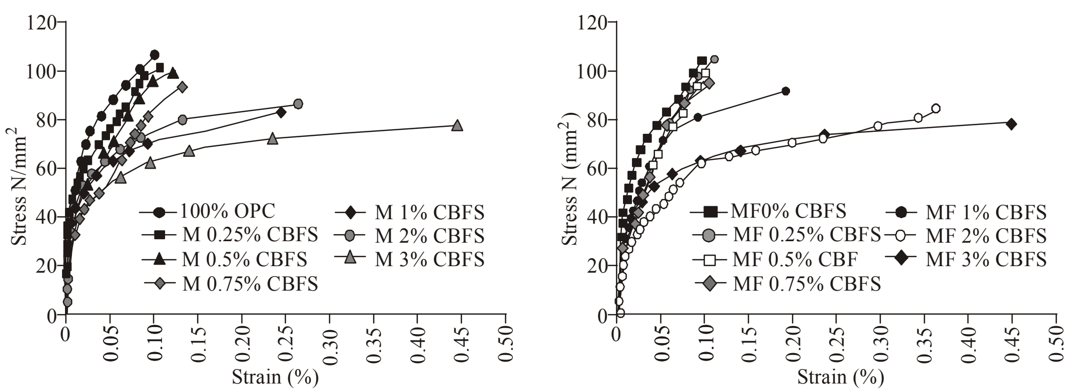


(a)



(b)

Fig. 5: Splitting and flexural strengths of 100% OPC (a) and 20% fly ash (b) of HSC at 28 and 90 days

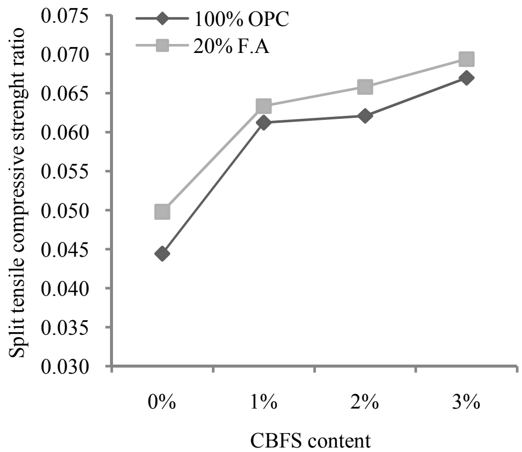


(a) (b)

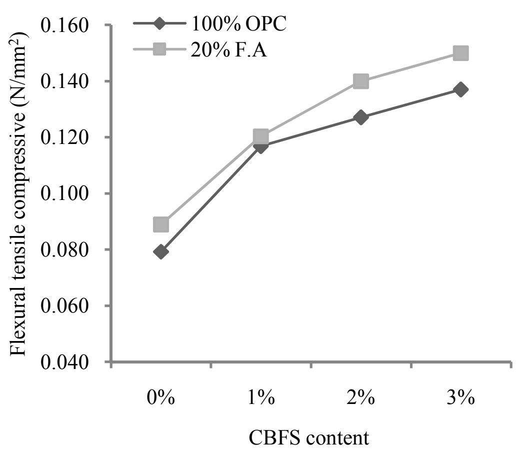
Fig. 6: Stress-strain relationship of 100% OPC (a) and 20% fly ash (b) HSC at 28 days

respectively replacement of cement by fly ash with 1, 2 and 3% of CBFS at 90 days respectively. Thus, the toughness of both of HSC mixes was steadily improved as well as its ductility and the shape of failure changed from brittle to ductile pattern.

Compressive stress-strain relationship of HSC: Figure 6 presents the behavior of compressive stress-strain relationship of HSC. From the plot it can see that the ascending parts of the curves were linear, which flowed by non-linear shape up to failure point as second



(a)



(b)

Fig. 7: Tensile compressive strength ratio of HSC, (a) splitting strength to compressive strength (b) flexural strength to compressive strength

Fig. 8: Comparison the pattern of failure in HSC with and without CBFS in compressive strength, splitting and flexural tests

parts of curves. Compressive l Basalt fiber is B strain increases as increasing of CBFS content that was changing the curves shapes. The areas under the compressive stress-strain curves increased as increasing of CBFS content, that is reflects the improvement of the toughness of HSC using CBFS as internal strengthening materials. The reason is the characteristics of fibers which help to carry out the compressive tensile stress. However, 20% replacement of cement by fly ash mixes provided a better toughness than 100% OPC. Furthermore, in the second hand, the test results presented that all the fiber reinforced specimens failure happened after reach the ultimate load. Also these specimens showed crack deformation before its collapse. There was no any significantly effect of 0.25, 0.5 and 0.75%, respectively CBFS on the compressive stress-strain curves.

Tensile strength to compressive strength ratio of HSC: The test results showed that tensile strength to compressive strengths ratios of HSC were clearly increased as an increasing of CBFS content as shown in Fig. 7. This is most important indicators of the brittleness and toughness of concrete which is a percentage between its own tensile and compressive strength ratio. Reduction of this percentage value reflecting to increases the brittleness and improvement the toughness of HSC reported by Liping *et al*. (2010). Based on these finding results and the shape of failure it can say that pattern of compression of HSC collapse was moving from brittle style failure towards the ductile as shown Fig. 8.

CONCLUSION

Recently, natural basalt fiber is being a published as the alternative for the steel reinforcement, glass, steel and carbon fiber. The experimental application of the randomly distributed CBFS as an internal addition strengthening was evaluated herein through various lab tests on fresh and mechanical properties of HSC. CBFS manufactured in China from nature rock by melting, with 25 mm length and 18 μmm diameter was used by different amount by weight of cement. The conclusions of the study can be summarized as flowing.

More time of mixing needed which increases as an increasing of CBFS content, full homogenous, no balling of fibers and there was no aggregate segregation that were observed during the mixing time. Using a high effect of super-plasticizer and fly ash as the mineral admixture controlled the negative effect of CBFS on the workability of HSC.

The randomly distribution CBFS was not supported the compressive strengths of HSC events it decreased as an increasing the content of CBFS on the both of two groups of mixes. Furthermore, there was little or ignore effect of 0.25, 0.5 and 0.75%, respectively of CBFS on the compressive strength of HSC.

Tensile to compressive strength and flexural to compressive strength ratio observed a continuous increment with the increase in fiber content. Also compressive stress-strain curves showed an increase in the areas under curves. Therefore, toughness and ductility of HSC were remarkably improved using the CBFS as an internal strengthening material. Furthermore, the type of collapse had moved from the brittle failure to the ductile failure. Finally, the CBFS as an internal strength material can be considered as an alternative to among of the fiber reinforced for producing ductile HSC.

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