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Influence of Different Lengths and Volumes of Basalt Fibre on Mechanical Properties of Concrete

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Abstract In this research work, the influence of basalt fiber lengths and volumes on mechanical properties of concrete such as compressive strength, flexure strength and split tensile strength are studied. 12 and 24 mm lengths of basalt fiber having the same diameter (13 µm) were used in the experimental work. The influence of 0.10%, 0.15%, 0.20%, 0.25%, 0.30%, 0.35%, 0.4% and 0.5% volume of basalt fiber on mechanical properties of concrete have been studied. The results of conventional concrete and basalt fiber reinforced concrete were compared. Normal strength concrete M30 grade was considered in the work and the mechanical properties were measured at 3, 7 and 28 days of hydration period. The experimental investigation shows that high dosage of fibers creates workability problems such as mixing, clumping and balling effects. Experimental results show that there is no improvement in the compressive strength of concrete when basalt fibers were added in plain concrete mix at all ages of concrete. Moreover, the compressive strength values become unstable when basalt fibers are added to concrete. Maximum value of split tensile strength and flexure strength was obtained for 0.35% (9.275 kg/m^3) basalt fiber content for both 12mm and 24mm length of basalt fiber at all ages of concrete. Comparing both 12mm and 24mm basalt fiber lengths, the 24 mm length of fiber has shown superior performance in relation to flexure strength and split tensile strength. Overall, the optimum length of basalt fiber is 24 mm and the optimum volume fraction of basalt fiber is 0.35%.

Keywords Normal Strength Concrete, Conventional Concrete, Basalt Fiber, Compressive Strength, Split Tensile Strength, Flexure Strength

1. Introduction

This is a well-known fact that plain concrete is strong in compression but weak in tension. On the other side, the strength of plain concrete decreases as the plastic and drying shrinkage cracks develop in concrete. These problems can be minimised or eliminated by incorporating fibers in the plain concrete. Large scale research work has been done in the area of synthetic, polypropylene, glass, carbon and steel fiber concrete. The application of fiber reinforced concrete is more in industrial flooring, pavements, marine structures and underground tunnel structures. Generally, the long steel fibers are effective and can replace conventional steel reinforcement, because it increases tensile and flexure strength of plain concrete, but at the same time, it creates workability problem and balling effect. Nowadays, the application of fibre usage is extended to building structures also. Overall, the fibre increases the structural performance of concrete. Steel fiber concrete used in tunnel lining may get corroded due to the chemical attack and after some years failure of lining may happen due to corrosion of steel fibers. Also, steel fiber is not fire safe. Therefore, there may be a chance of spalling and damage of tunnel lining because of fire accident. On the other side, polypropylene fibers improve the resistance against spalling and damage of lining in tunnel compared to steel fiber, but it will not increase the structural performance as that of steel fiber. Glass fiber improves the aesthetic look of concrete. At present also research is going on in above-mentioned fibers in order to minimise the disadvantages incurred as discussed above. Parallelly, the research into new fibers and fiber reinforced concrete continues today. One such new fiber is basalt fiber, because of the excellent strength properties, resistance to thermal, resistance to high alkaline environment, resistance to corrosion, makes basalt fiber as a promising new fiber material to reinforce concrete to enhance mechanical properties and to minimise dry and plastic shrinkage cracks. Chemical composition of basalt fiber is the same as that of glass fiber but has superior strength properties. Basalt fiber is resistant to acidic, alkaline and salt attack, therefore a good alternative than other types of fibers for concrete bridges and concrete shoreline structures. Basalt fiber can be easily mixed in concrete without much difficulty and can be used as reinforcement in concrete and crack resistant. Basalt fiber can extend the life of the construction in the area of buildings, bridges, railways, runways, marine structures, ports, tunnel structures and many others. As per Elshafie et al. [1] the optimum basalt fiber dosage is 0.2% by the total volume of concrete and optimum length is 24 mm in order to improve flexure and tensile strength of plain concrete. It is proven that addition of basalt fiber in concrete reduces the compressive strength and workability. A similar kind of trend was observed by A.M.El-Gelani et al. [2], whose work proved that basalt fiber has no significance in improving the compressive strength of conventional concrete. Padmanabhan Iyer et al. [3], done experimental investigation on the effect of short and long basalt fibre of different length and different amounts on mechanical properties of concrete. If improvement in flexure and compressive strength is desirable, then the optimum dosage and optimum length of basalt fiber are 8 kg/m^3 and 36 mm. Whereas, 4 kg/m^3 amount of basalt fiber and 12 mm length of fiber will give maximum compressive strength value. Alike conclusion was stated by Xinzhong Wang [4] who proposed 12 mm length and 0.10% to 0.15% content of basalt fiber for maximum increase in the value of modulus of rupture and compressive strength. Ramakrishna et al. [5] performed experimental investigation on concrete specimens with 13mm long and 12μm diameter basalt fibers in concrete. Results of experimental investigation showed that basalt fiber does not enhance the compressive and flexure strength of plain concrete when fiber volume varied from 0.1% to 0.5% by volume. Borhan's [6] research outcome is different, the compressive strength increased when fiber volume increased up to 0.3% by volume of basalt fibers for 25.4 mm length and 13 μm diameter of basalt fiber. On the other hand, reduction in compressive strength was observed at 0.5% by volume of basalt fiber. A lot of research has been carried out on steel, glass, carbon, polypropylene etc. fiber concrete, but there is very little research and projects done on basalt fiber concrete, especially in India, to understand the behaviour of concrete under different loading conditions. Seeing the excellent properties of basalt fiber, it is needed to do research work in the area of basalt fiber reinforced concrete. Similar to the other types of fibers, basalt fiber lengths and content may also have an influence on flexure, split tensile and compressive strength. Therefore, in the present research work the influence of different lengths of basalt fiber and different volume fraction of basalt fiber on flexure, split-tensile and compressive strengths of conventional concrete has been studied.

2. Experimental Work

The total experimental work has been completed in two phases. In the first phase, the required materials were procured and performed various tests on materials to determine the physical and chemical properties. In the second phase, mix proportioning, casting of specimens, test on fresh properties of concrete and testing of hardened specimens were taken up to find the flexure strength, compressive strength and split tensile strength. In the following sub-headings it is explained in detail.

2.1. Phase I

In Phase one, all the required materials were procured from the local places and performed various tests on materials in order to determine required physical and chemical properties.

Cement

OPC 53 grade cement was used as binder material (confirming to IS: 12269-1987[11]). Physical properties were determined as per IS: 4031 (Part II)-1988 [12]. The particulars of test results are shown in Table 1.

Fine and Coarse Aggregate

Fine aggregate confirming to IS: 383-1970 [13] was procured from locally available sellers. Crushed granite was used as a coarse aggregate. 20 mm is the maximum size of coarse aggregate. As per IS: 2386 [14] code guidelines, the physical properties of coarse aggregate and fine aggregate were determined. The particulars of test results are shown in Table 1.

Table 1. Physical Properties of Cement (OPC 53 Grade), Fine Aggregate and Coarse Aggregate

Property	Cement	Fine Aggregate	Coarse Aggregate
Normal Consistency	33%	-	-
Specific Gravity	3.14	2.62	2.64
Initial Setting Time Final Setting Time	50 min 190 min	-	-
Fineness	9%	-	-
Bulk density i) Loose ii) Compacted	-	1635 Kg/m^3 1766 Kg/m^3	1450 Kg/m^3 1571Kg/m^3
Fineness Modulus	-	2.90	7.16

Water

Portable water without oils, sugar, acids, salts, alkalies and organic materials confirming to IS: 456-2000 [15] was used for mixing of concrete ingredients and curing of concrete specimens.

Basalt Fibers

Basalt fibers supplied by Vaishnavi Composites, Hyderabad, Telangana, India were used in this present study. The physical and chemical properties provided by the supplier are depicted in Table 2. A sample of basalt fiber is shown in Figure 1.

Figure 1. Chopped Basalt Fiber

2.2. Phase II

Under phase two, mix design, proportioning, casting, curing of specimens and testing of hardened specimens was undertaken to know the mechanical properties of conventional concrete and basalt fiber concrete at 3, 7 and 28 days period.

Design and Proportioning of Concrete Mix

Using the various properties of materials as discussed in Phase I, M30 grade of concrete designed according to IS: 10262-2019. Water-cement binder ratio of 0.45 was maintained for all the mixes. Total 17 mixes were considered in the research work, out of which, one conventional concrete mix (MC), eight basalt fiber reinforced concrete mixes with 12 mm length of basalt fiber and the remaining eight basalt fiber reinforced concrete mixes with 24 mm length basalt fibers. Table 3 represents designations of various mixes and proportions of concrete mix ingredients. The name of mix designation denotes fiber type, length, and volume fraction of fiber. For instance, in mix designation MA30, letter M represents mix, letter A stands for 12 mm length of basalt fiber and the number 30 indicates 0.30% (percentage) volume fraction of basalt fiber in plain concrete. Whereas, in MB30 mix designations, letter B represents 24 mm length of Basalt Fiber and all others are same as explained above. Mix designation MC represents the conventional concrete without any fibers in it. Here, MC was taken as reference mix. The flexure, compressive and split tensile strengths of basalt fiber concrete and conventional concrete were compared.

Table 2. Chemical composition and Physical Properties of Basalt Fibers

Chemical Composition	Percentage by mass	Fiber Properties	Particulars
SiO_2	51.6-59.3	Type of Fiber	Chopped
$FeO + Fe_2O_3$	9.1-14.0	Length of Fiber (mm)	12 and 24
CaO	5.9-9.5	Diameter (μm)	13
MgO	3.2-5.3	Density (g/cm^3)	2.65
Al_2O_3	14.7-18.4	Tensile Strength (MPa)	2365
TiO_2	0.8-2.26	Elastic Modulus (GPa)	93.5
$Na_2O + K_2O$	3.62-5.25	Specific Gravity	2.62 – 2.82
Others	0.09-0.132	Elongation at break (%)	2.9

Table 3. Details of various M30 grade concrete mixtures and their corresponding mix designations

Mix Designation	Constituent Materials, kg/m^3				W/C	Basalt Fiber in Concrete		
	Cement	Fine Aggregates	Coarse Aggregate	Water		Weight, kgs	Volume Fraction, %	Length, mm
MC	398	663.2	1137.6	179.1	0.45	0	0	-
MA10	398	663.2	1137.6	179.1	0.45	2.650	0.10	12
MA15	398	663.2	1137.6	179.1	0.45	3.975	0.15	12
MA20	398	663.2	1137.6	179.1	0.45	5.300	0.20	12
MA25	398	663.2	1137.6	179.1	0.45	6.625	0.25	12
MA30	398	663.2	1137.6	179.1	0.45	7.950	0.30	12
MA35	398	663.2	1137.6	179.1	0.45	9.275	0.35	12
MA40	398	663.2	1137.6	179.1	0.45	10.600	0.40	12
MA50	398	663.2	1137.6	179.1	0.45	13.250	0.50	12
MB10	398	663.2	1137.6	179.1	0.45	2.650	0.10	24
MB15	398	663.2	1137.6	179.1	0.45	3.975	0.15	24
MB20	398	663.2	1137.6	179.1	0.45	5.300	0.20	24
MB25	398	663.2	1137.6	179.1	0.45	6.625	0.25	24
MB30	398	663.2	1137.6	179.1	0.45	7.950	0.30	24
MB35	398	663.2	1137.6	179.1	0.45	9.275	0.35	24
MB40	398	663.2	1137.6	179.1	0.45	10.600	0.40	24
MB50	398	663.2	1137.6	179.1	0.45	13.250	0.50	24

Mixing and Casting of Concrete

The weight of concrete ingredients cement, aggregates and water was taken according to mix design. A pan mixer was used to mix all the materials. In the first stage, cement and sand were mixed thoroughly in the dry state for 2 to 3 minutes. Secondly, some quantity of basalt fibers were added to the cement-sand mix uniformly and mixed for 2 minutes, after that while in mixing the remaining amount of basalt fibers were added slowly and dispersed uniformly. It was mixed for nearly 2 minutes in a dry state. In the third stage, coarse aggregate was added to the cement-sand-fiber mix and mixed for 2 to 3 minutes. After getting a uniform mix of all the ingredients in the dry state, then water was added. Mixing was done until a workable mixture of uniform colour was obtained. Also, uniform dispersion of fibers in mix was ensured and maintained. Finally, the mixed concrete was placed in mould specimens and put on the table vibrator for better compaction and to remove air voids. Trowel and straight edge tool were used to level and smooth finish the top surface. All the specimens were then put in a water tank till the specified curing period. After the desired curing period, the specimens are then removed from the water tank and tested to find mechanical properties.

Sample Size

After 3 days, 7 days and 28 days hydration period, the mechanical properties of basalt concrete and plain concrete were determined. A total of 17 mixes were considered in the present study. In each mix and for one particular age total 6 cube, 6 cylinder and 6 prism samples were casted. Therefore, in one mix total of 18 cubes, 18 cylinders and 18 prisms samples were casted. To determine the strengths, an average of six specimens has been considered.

Testing of Specimens

Compressive strength test was carried out on 150 mm x 150 mm x 150 mm cubes, split tensile strength on cylinder having 150 mm diameter and 300 mm length and flexure strength on 150 x 150 mm cross section and 500 mm length. Compressive and flexure strength were determined according to Indian Standard Code IS: 516 and split tensile strength in agreement with Indian Standard Code IS: 5816.

3. Results and Discussions

Fresh State Property of Concrete: Workability

Workability is the fresh state property of concrete which can be measured in terms of compaction factor test and slump test. To assess the workability of concrete mix in fresh state, the slump cone test was carried out in accordance with Indian Standard code specifications IS 1199:1959. Slump values of all 17 mixes are represented in Table 4. Among all mixes, MC mix has shown more workability than other mixes with basalt fiber as represented in Table 4. The decreasing trend of slump values from mixes MA10 to MB50 indicates that as the volume of fibers increased the workability of concrete reduced This may be due to the clumping and balling effect at higher amount of fiber, a similar trend was also observed by the Abulaziz Alaskar [14]. Further reduction in slump values can be observed when the length of basalt fiber increased from 12 mm to 24 mm. The reduction in slump may be because of water absorption by basalt fibers and clumping and balling effect, a similar outcome was observed by Xinzhong Wang [4] in workability when basalt fiber length increased. Even at low slump, the mix was uniform without any segregation. The balling and clumping effect was seen in the mix when basalt fiber was added in the proportion of 0.40% and above. This trend of reduction in workability with increase in fiber content is evident for other types of fibers also and the same is reported by so many authors. There is not much difference between the unit weight of conventional concrete and basalt fiber reinforced concrete even for higher dosage of fibers in concrete because of the light weight of basalt fibers, the findings of M. Yakhlaf [15] work also show similar pattern and decrease in unit weight with increase in fiber content.

Compressive Strength

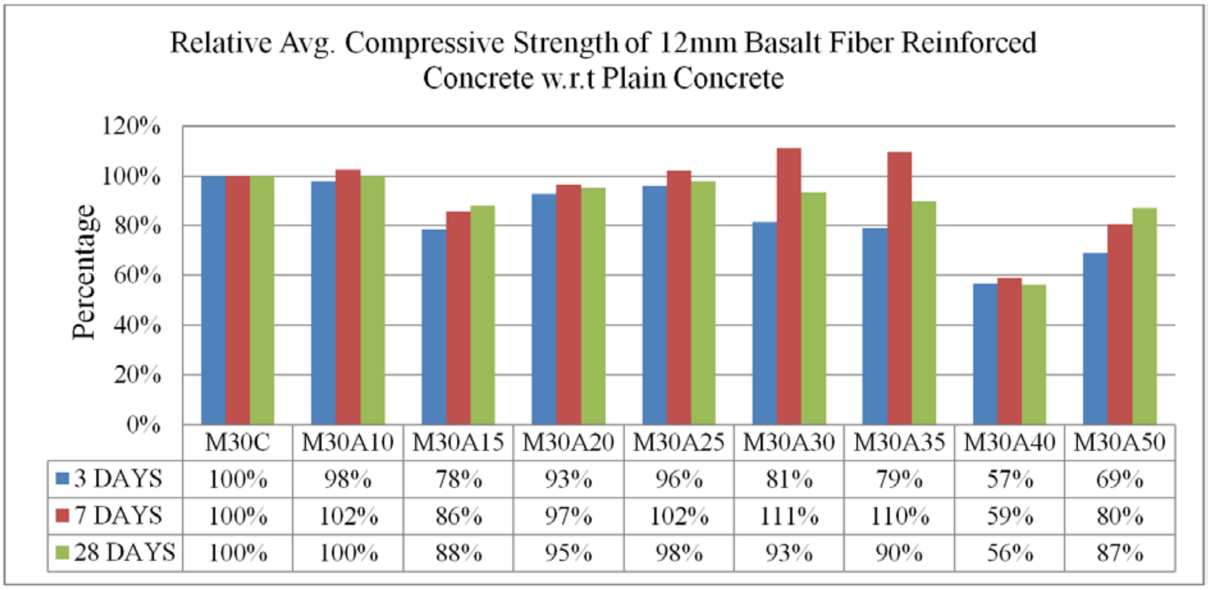
The absolute compressive strength values of plain concrete and fiber reinforced concrete at various curing periods is presented in Table 5. In Figure 2 (a & b), relative average compressive strength of 12 mm and 24 mm long basalt fiber reinforced concrete with respect to corresponding conventional concrete at 3, 7, and 28 days age of concrete has shown. At 3 and 28 days age of concrete, the compressive strength of all concrete mixtures containing fiber is lower than the plain concrete as shown in Figure 2 (a). Maximum decrease in compressive strength was observed to be 43% at 3 days age and 44% at 28 days age of concrete for the mix MA40. At 28 days age, the strength of mix MA10 is nearly equal to the strength of plain concrete (Figure 2 (a)). The scenario is different at 7 days age of concrete, the compressive strength of plain concrete decreases by 14%, 3%, 41% and 20% for the mixes MA15, MA20, MA40 and MA50, whereas compressive strength of plain concrete increases by 2%, 2%, 11% and 10% for the for the mixes MA10, MA25, MA30 and MA35 as depicted in Figure 2 (a). A similar kind of trend can be seen in the case of concrete mixtures with 24 mm long fibers as shown in Figure 2 (b). At 3 and 28 days age of concrete, the compressive strength of all mixes containing fibers is lower than that of plain concrete and the maximum decrease in strength was found to be for mix MB50, 29% at 3 days age and 50% at 28 days age of concrete, respectively. The compressive strength of plain concrete increased by 10% and 12% for the mixes MB20 and MB25 at 7 days age of concrete. Whereas decreased for all other mixes containing fibers. The lowest being for the mix MB15, which is 28% less as shown in Figure 2 (b). Moreover, the compressive strength values are unstable. Overall, the performance of mixes containing 12 mm length of fiber was better than the mixes containing 24 mm length of fiber. Also, from Figure 2 (a & b), it can be seen that the values are not stable i.e., at one particular mix it is increasing while for the next higher amount fiber it is decreasing and then increasing for the next higher percentage of fiber. Instability in compressive strength values was also observed by Ramakrishna et al. [5]. As per Ramakrishna et al. [5], compressive strength does not improve when basalt fiber were added in conventional concrete. Also, the results obtained in the present research work are in line with the authors Parvez Imraan Ansari [12], Elshafie S et al. [1], and Mustapha Abdulhadi [13] who found a similar trend. Figure 3, 4, and 5 shows the relative avg. compressive strength of 12 & 24 mm length basalt fiber reinforced concrete with respect to plain concrete at 3, 7, and 28 days curing periods. At 3 days age, from Figure 3 and 5, it can be observed that none of the mixes with fibers achieved the strength as that of conventional concrete. At 0.10% volume content of fibers in concrete shown better results when compared with other proportions and the value is 98% as that of value of conventional concrete for both 12 and 24 mm dosage. Whereas at 7 days age, for 12 mm length of fiber the maximum value was found at 0.30% which is 11% more than the conventional concrete and for 24 mm length of fiber it is 12% more than the conventional concrete at 0.35% volume fraction. The decrease in compressive strength values with increase in basalt fiber content was also reported by Yury Barabanshchikov [16]. The exact reason was not reported by any of the research. Micro level analysis of basalt fiber concrete is needed to find the reasons behind this. The practical application of basalt fiber concrete where compressive strength is not much important parameter is in basalt concrete composite pipes used to transport corrosive gases and liquids.

Table 4. Details of Slump Test Values for Various M30 Grade Concrete Mixtures

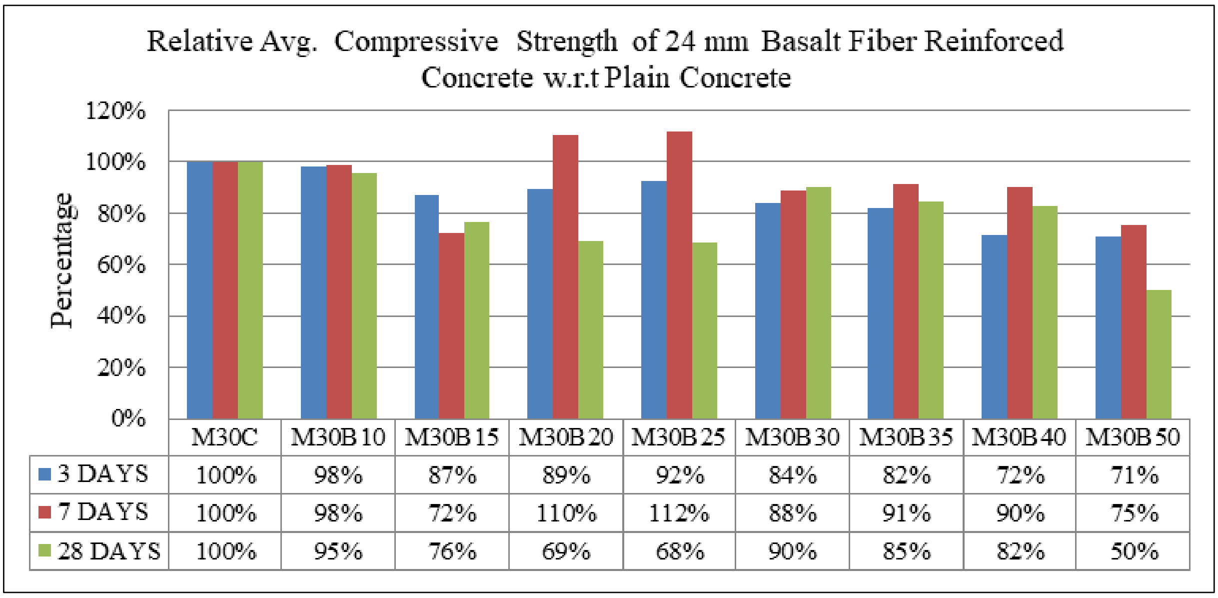
Mix Designation	Slump Value, mm	Mix Designation	Slump Value, mm
MC	82	MB10	70
MA10	75	MB15	66
MA15	69	MB20	52
MA20	58	MB25	38
MA25	42	MB30	28
MA30	33	MB35	24
MA35	25	MB40	16
MA40	18	MB50	5
MA50	8		

Table 5. Absolute Average Compressive Strength of Various Mixtures at Various Ages

MIX IDS	Avg. Compressive Strength in N/mm^2			MIX IDS	Avg. Compressive Strength in N/mm^2		
	3 DAYS	7 DAYS	28 DAYS		3 DAYS	7 DAYS	28 DAYS
MC	26.44	31.85	42.22	MB10	25.96	31.36	40.31
MA10	25.88	32.64	42.24	MB15	22.96	22.96	32.30
MA15	20.74	27.26	37.19	MB20	23.66	35.07	29.04
MA20	24.55	30.81	40.15	MB25	24.44	35.56	28.89
MA25	25.41	32.59	41.33	MB30	22.12	28.18	38.09
MA30	21.53	35.41	39.41	MB35	21.63	29.04	35.70
MA35	20.89	34.96	37.93	MB40	18.96	28.59	34.81
MA40	14.96	18.81	23.70	MB50	18.67	24.00	21.19
MA50	18.22	25.63	36.74				

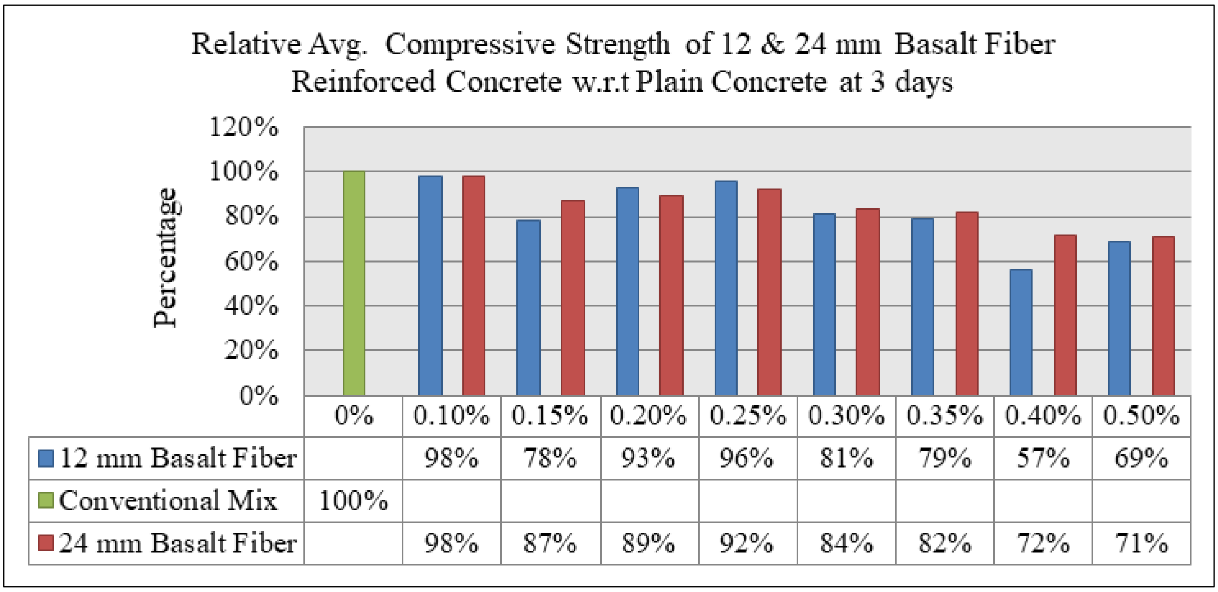


(a)



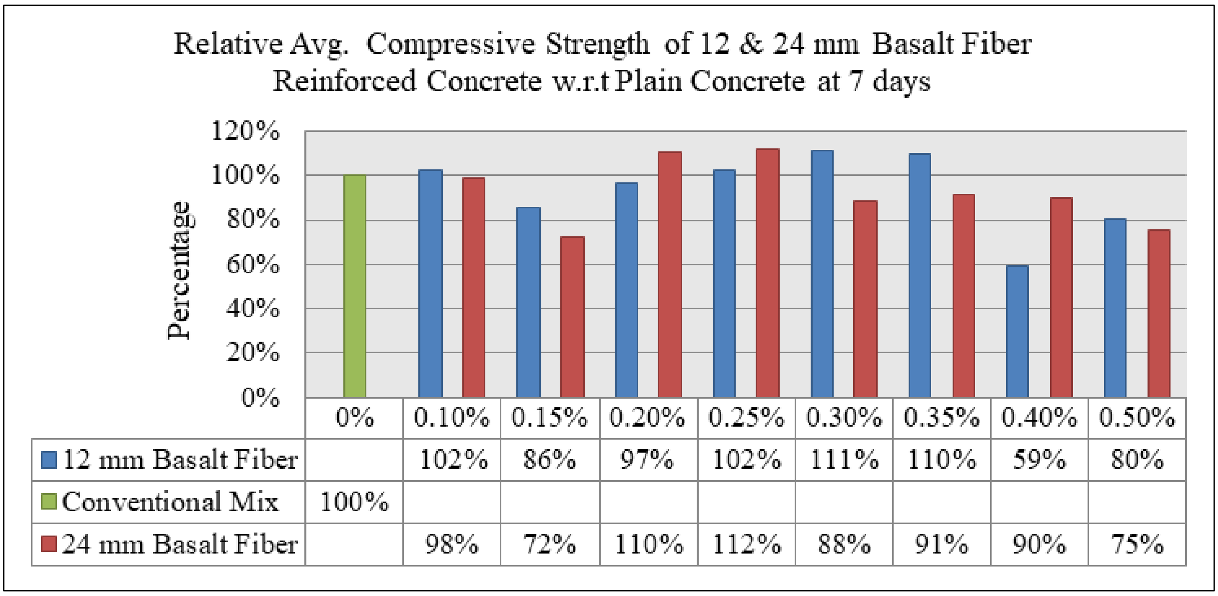
(b)

Figure 2. Avg. Compressive Strengths (a) 12 mm Basalt Fiber Length (b) 24 mm Basalt Fiber Length



	0%	0.10%	0.15%	0.20%	0.25%	0.30%	0.35%	0.40%	0.50%
12 mm Basalt Fiber		98%	78%	93%	96%	81%	79%	57%	69%
Conventional Mix	100%								
24 mm Basalt Fiber		98%	87%	89%	92%	84%	82%	72%	71%

Figure 3. Comparison of Compressive Strengths at 3 days age



	0%	0.10%	0.15%	0.20%	0.25%	0.30%	0.35%	0.40%	0.50%
12 mm Basalt Fiber		102%	86%	97%	102%	111%	110%	59%	80%
Conventional Mix	100%								
24 mm Basalt Fiber		98%	72%	110%	112%	88%	91%	90%	75%

Figure 4. Comparison of Compressive Strengths at 7 days age

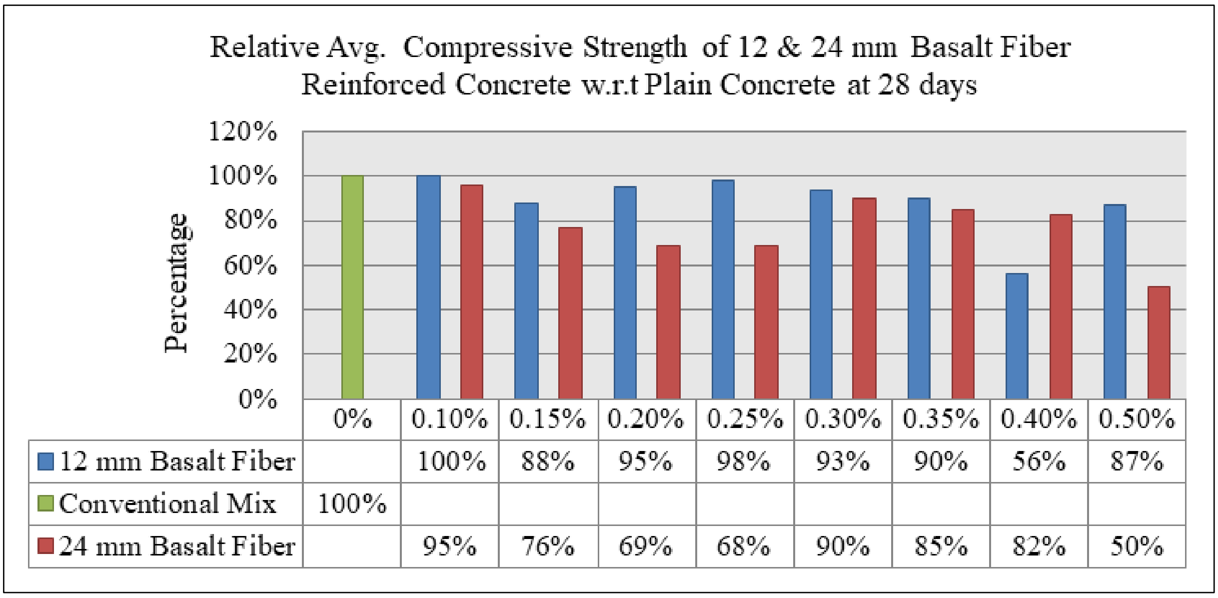


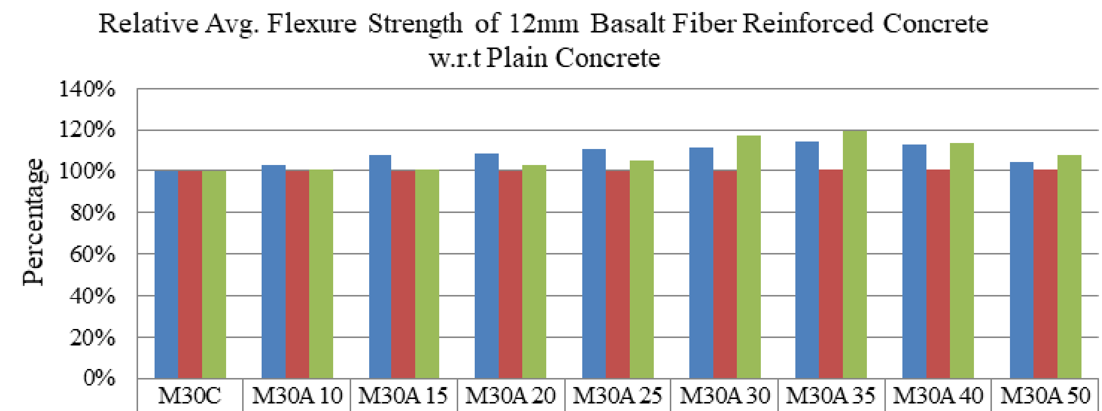
Figure 5. Comparison of Compressive Strengths at 28 days age

Flexure Strength

The absolute flexure strength values of plain concrete and fiber reinforced concrete at various curing periods is presented in Table 6. Figure 6 (a & b) shows the variation of flexure strength values of various mixes at 3, 7 and 28 days age of concrete. From Figure 6 (a & b) it can be observed that early age strength were less than that later age strength. At all ages of concrete, the flexure strength values increased as fiber content increased up to 0.35% volume fraction and thereafter decreased as depicted in Figure 6 (a & b). The maximum percentage increase in value of flexure strength at 3, 7 and 28 days was found to be 14.12, 0.96 and 19.62% at 0.35% fiber volume fraction for 12 mm fiber length as shown in Figure 6 (a). The maximum percentage increase in values of flexure strength at 3, 7 and 28 days was obtained as 30.88, 7.45 and 22.01% at 0.35% volume fraction for 24 mm fiber length as represented in Figure 6 (b). At 3 days age of concrete, when compared the results of 12 and 24 mm basalt fiber concrete mixes, the response is same up to 0.25% volume fraction and thereafter the mixes with 24 mm basalt fiber have shown better performance than the mixes with 12 mm length of basalt fiber. The maximum flexure strength value was found to be 5.17 MPa for MA35 mix whereas for MC the value is 4.53 MPa at 3 days age. Similar development was detected for all the mixes at 7 days age of concrete. The maximum flexure strength value was observed as 5.60 MPa for mix MA35 and 5.96 MPa for mix MB35 which are 0.96% and 7.45% more than the value of 5.55 MPa for mix MC. At 28 days, performance of both 12 and 24 mm basalt fiber concrete mixes was similar with slight increment in the values of 24 mm basalt fiber concrete mixes as depicted in Figure 9. Overall, 24 mm basalt fiber concrete has outperformed than 12 mm basalt fiber concrete in all the mixes. The flexure strength values of conventional concrete were 4.53, 5.55 and 5.57 MPa at 3, 7 and 28 days respectively. The maximum flexure strength values of 12 mm and 24 mm basalt fiber concrete at 3, 7 and 28 days are 5.17, 5.60 & 6.67 MPa and 5.93, 5.96 & 6.80 MPa which were obtained for MA35 and MB35 mixes. Also, it can be seen from Figure 9 (a & b), the values of flexure strength were nearly the same at 7 and 28 days age. Finally, it can be observed from all the figures, 24 mm basalt fiber concrete performed better than 12 mm basalt fiber concrete and conventional concrete. Figure 7, 8, and 9 shows the relative avg. flexure strength of 12 & 24 mm length basalt fiber reinforced concrete with respect to plain concrete at 3, 7, and 28 days curing periods. At all ages, the performance of both 12mm and 24mm basalt length in concrete was similar and the maximum value was observed for 0.35% content. For 12 mm fiber, the percentage increment in the value of flexure strength is 14,1 and 20% at 3, 7 and 28 days, respectively, and for 24 mm fiber, the percentage increment in the value of flexure strength is 31, 7 and 22% at 3, 7 and 28 days age.

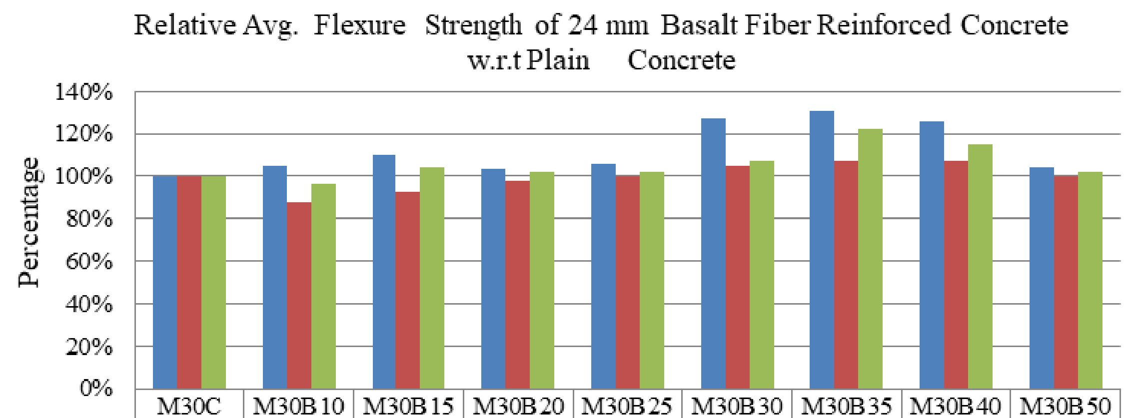
Table 6. Absolute Average Flexure Strength of Various Mixtures at Various Ages

MIX IDS	Avg. Flexure Strength in N/mm^2			MIX IDS	Avg. Flexure Strength in N/mm^2		
	3 DAYS	7 DAYS	28 DAYS		3 DAYS	7 DAYS	28 DAYS
MC	4.53	5.55	5.57	MB10	4.77	4.87	5.37
MA10	4.67	5.56	5.60	MB15	4.97	5.13	5.80
MA15	4.91	5.56	5.60	MB20	4.71	5.44	5.69
MA20	4.92	5.55	5.75	MB25	4.80	5.56	5.71
MA25	5.01	5.56	5.87	MB30	5.77	5.83	5.96
MA30	5.05	5.56	6.55	MB35	5.93	5.96	6.80
MA35	5.17	5.60	6.67	MB40	5.69	5.93	6.41
MA40	5.13	5.59	6.35	MB50	4.73	5.53	5.69
MA50	4.72	5.57	6.00				



	M30C	M30A 10	M30A 15	M30A 20	M30A 25	M30A 30	M30A 35	M30A 40	M30A 50
3 DAYS	100%	103%	108%	109%	111%	111%	114%	113%	104%
7 DAYS	100%	100%	100%	100%	100%	100%	101%	101%	100%
28 DAYS	100%	100%	100%	103%	105%	117%	120%	114%	108%

(a)



	M30C	M30B 10	M30B 15	M30B 20	M30B 25	M30B 30	M30B 35	M30B 40	M30B 50
3 DAYS	100%	105%	110%	104%	106%	127%	131%	126%	104%
7 DAYS	100%	88%	93%	98%	100%	105%	107%	107%	100%
28 DAYS	100%	96%	104%	102%	102%	107%	122%	115%	102%

(b)

Figure 6. Flexure Strengths (a) 12 mm Basalt Fiber Length (b) 24 mm Basalt Fiber Length

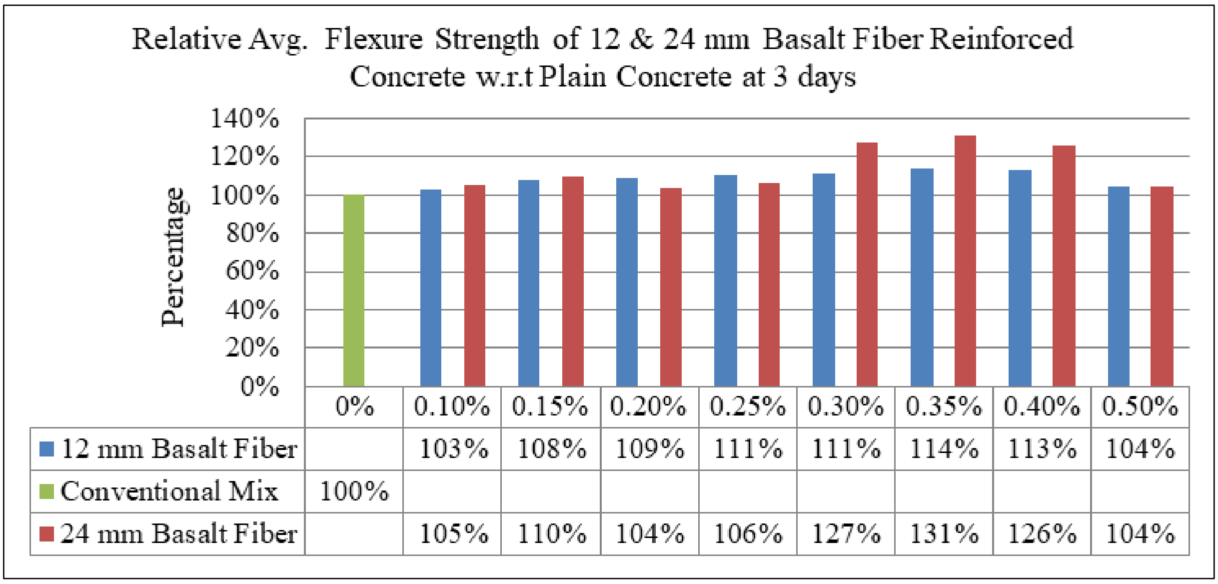


Figure 7. Comparison of Flexure Strengths at 3 days age

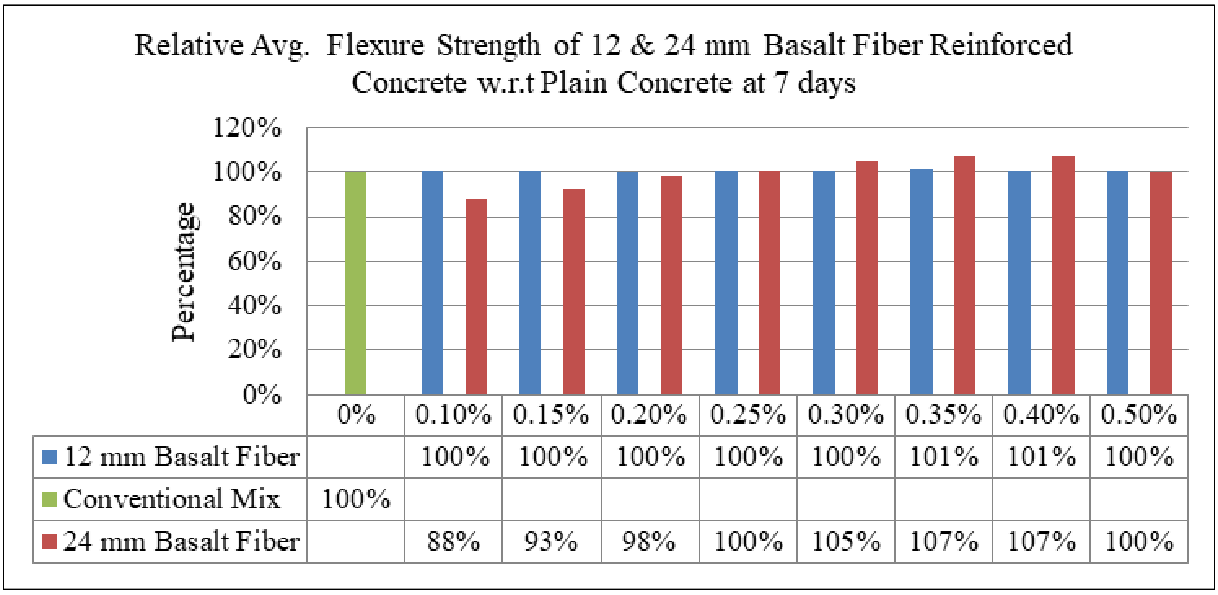


Figure 8. Comparison of Flexure Strengths at 7 days age

Split Tensile Strength

The absolute split tensile strength values of plain concrete and fiber reinforced concrete at various curing periods is presented in Table 7. Figure 10 (a & b) represents the variation of split tensile strength values of various mixes at 3, 7 and 28 days age of concrete with and without basalt fibers. The results of experimental work show that tensile strength increased with the increase in basalt fiber content upto 0.35% and then decreased post 0.35% volume fraction as shown in Figure 10 (a & b). As expected early age strength was less than later age strength observed. The maximum percentage increase in split tensile strength value was observed as 26.48, 30.81 & 15.05% when 0.35% volume fraction was added in concrete for 12 mm basalt fiber mix at 3, 7 and 28 days age. Whereas for 24 mm basalt fiber mix at 0.35% volume fraction, the split tensile value increased by 21.21, 40.10 and 40.59% when compared with convention concrete mix at 3, 7 and 28 days age. The tensile strength values of MC mix are 1.79 MPa at 3 days, 1.93 MPa at 7 days and 2.38 MPa at 28 days age. At 3, 7 and 28 days age, the maximum value of split tensile strength were recorded for the mix MA35 and MB35. The maximum values are 2.26 MPa, 2.52 MPa and 2.74 MPa for mix MA35 and 2.17 MPa, 2.70 MPa and 3.35 MPa for mix MB35 at 3, 7 and 28 days age of concrete, respectively. Later age increment in value was more than the increment in value at early state as shown in Figure 10 (a & b). At 28 days age, the increment in value is nearly 40.59% than the conventional concrete mix, this value is achieved for mix MB35. When compared both 12 and 24 mm basalt concrete, 24 mm basalt concrete mixes performed better than 12 mm basalt fiber concrete mixes as shown in Figures 11, 12 and 13. From Figure 11, 12 and 13, it can be observed that the maximum increase in value in terms of percentage is 26, 31 and 15% for 12mm length fiber than conventional concrete. For 24 mm fiber, the maximum increase is 21, 40 and 41% more than conventional concrete at 0.35% content of fiber.

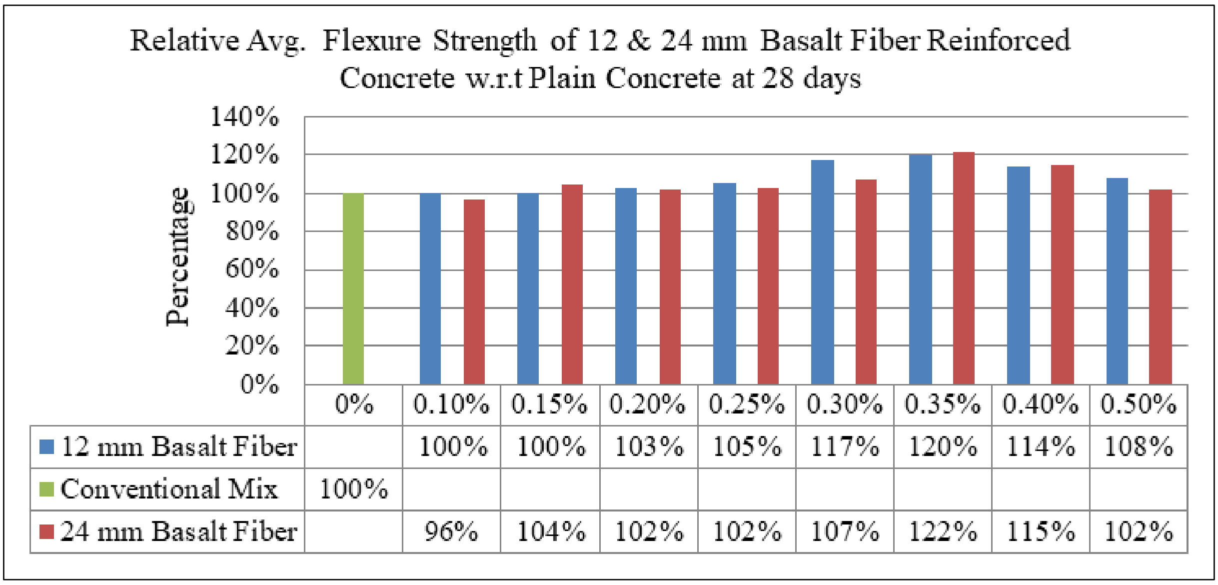
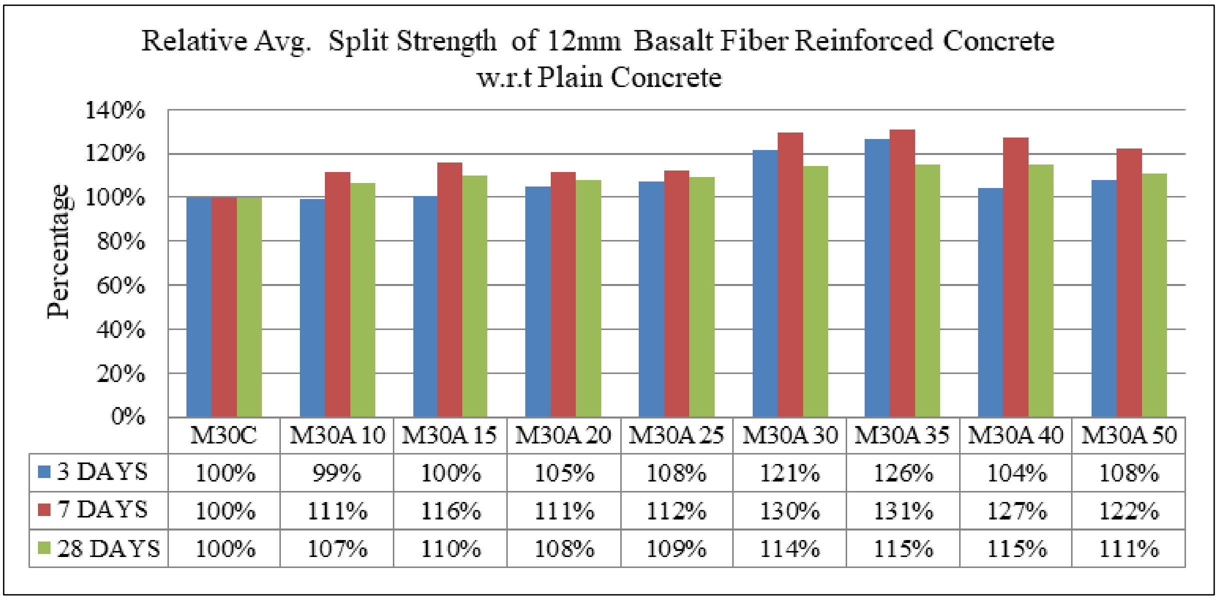


Figure 9. Comparison of Flexure Strengths at 28 days age

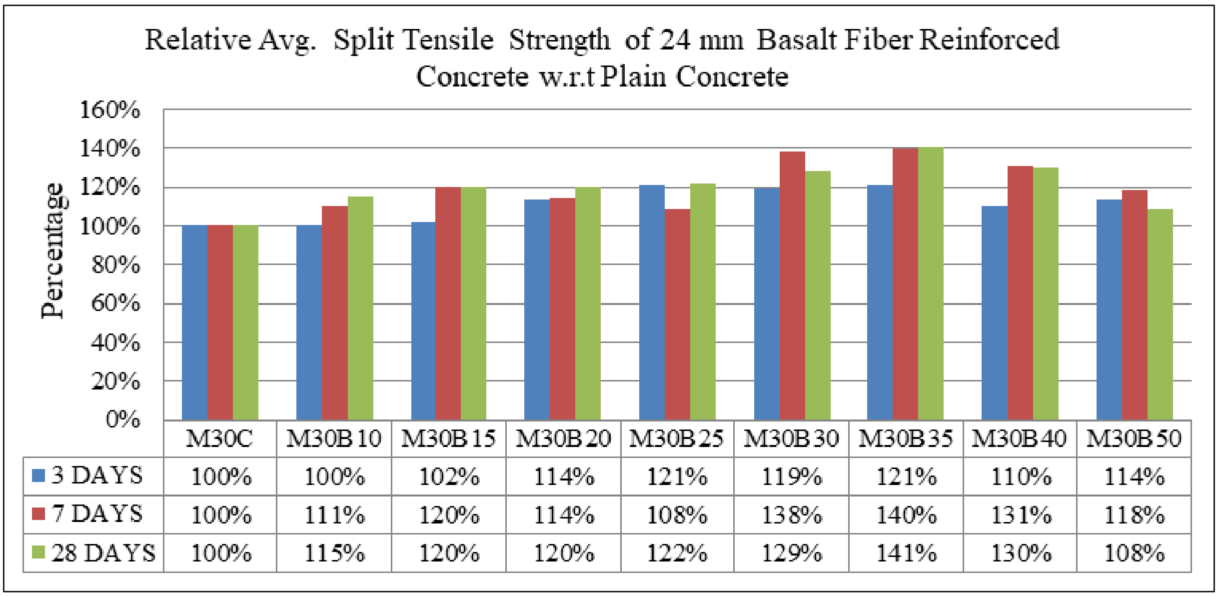
Table 7. Absolute Average Split Tensile Strength of Various Mixtures at Various Ages

MIX IDS	Avg. Split Tensile Strength in N/mm²			MIX IDS	Avg. Split Tensile Strength in N/mm²		
	3 DAYS	7 DAYS	28 DAYS		3 DAYS	7 DAYS	28 DAYS
MC	1.79	1.93	2.38	MB10	1.80	2.13	2.74
MA10	1.78	2.15	2.54	MB15	1.82	2.31	2.86
MA15	1.80	2.23	2.63	MB20	2.03	2.20	2.87
MA20	1.88	2.15	2.57	MB25	2.16	2.09	2.90
MA25	1.92	2.16	2.60	MB30	2.13	2.66	3.06
MA30	2.17	2.50	2.73	MB35	2.17	2.70	3.35
MA35	2.26	2.52	2.74	MB40	1.97	2.52	3.09
MA40	1.86	2.45	2.74	MB50	2.04	2.28	2.58
MA50	1.93	2.36	2.64				



	M30C	M30A 10	M30A 15	M30A 20	M30A 25	M30A 30	M30A 35	M30A 40	M30A 50
3 DAYS	100%	99%	100%	105%	108%	121%	126%	104%	108%
7 DAYS	100%	111%	116%	111%	112%	130%	131%	127%	122%
28 DAYS	100%	107%	110%	108%	109%	114%	115%	115%	111%

(a)



	M30C	M30B 10	M30B 15	M30B 20	M30B 25	M30B 30	M30B 35	M30B 40	M30B 50
3 DAYS	100%	100%	102%	114%	121%	119%	121%	110%	114%
7 DAYS	100%	111%	120%	114%	108%	138%	140%	131%	118%
28 DAYS	100%	115%	120%	120%	122%	129%	141%	130%	108%

(b)

Figure 10. Split Tensile Strengths (a) 12 mm Basalt Fiber Length (b) 24 mm Basalt Fiber Length

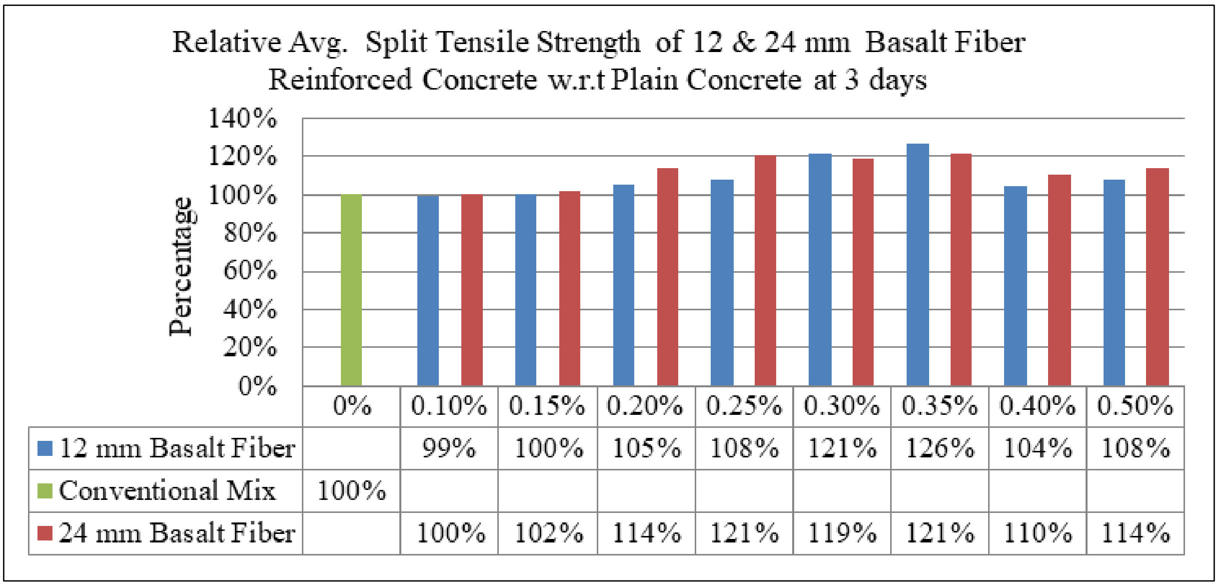


Figure 11. Comparison of Split Tensile Strengths at 3 days age

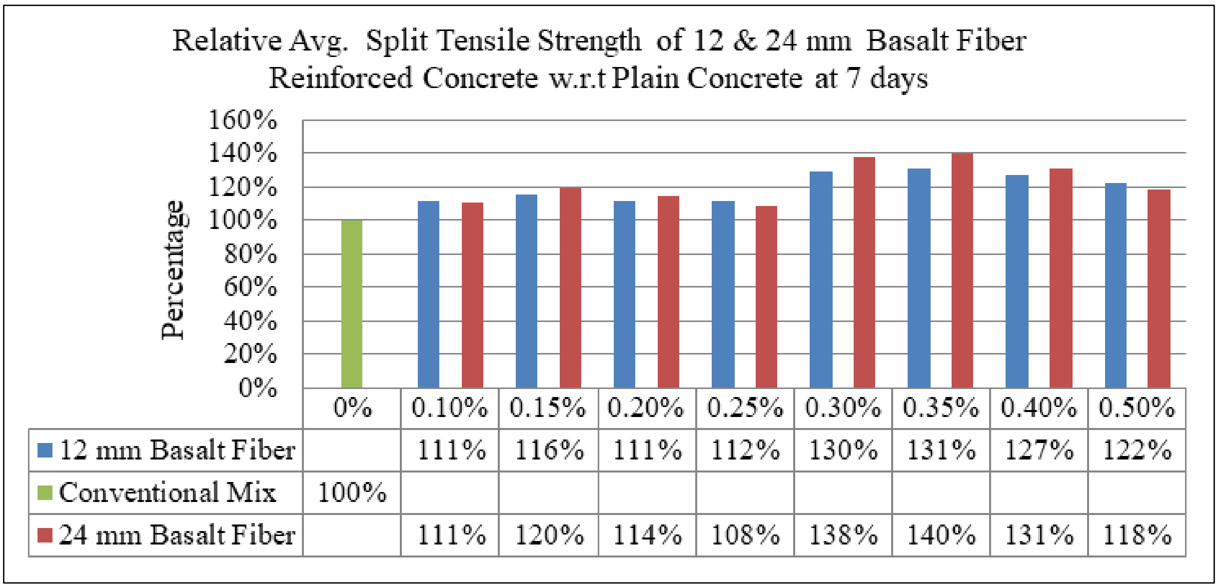


Figure 12. Comparison of Split Tensile Strengths at 7 days age

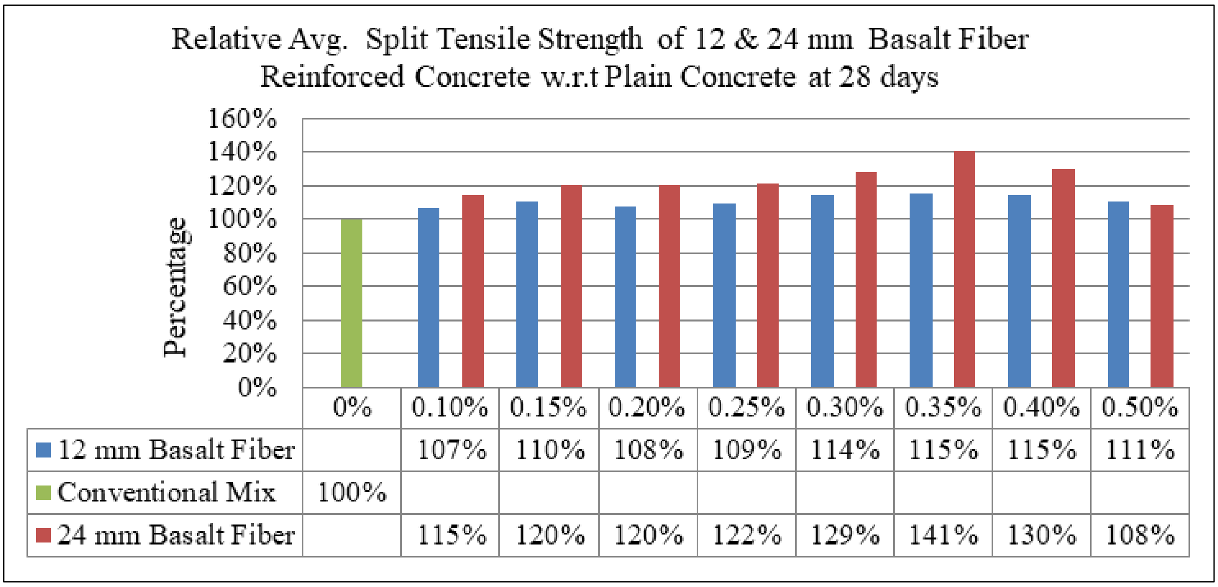


Figure 13. Comparison of Split Tensile Strengths at 28 days age

4. Conclusions

The conclusions given below are drawn from the experimental research work done in the present investigation. As the properties of concrete materials and type of basalt fiber will have influence on results, the results achieved in the present work are limited to the specimen used in this research:

1. Fresh state property of concrete that is workability reduced as the percentage of basalt fiber increased in the concrete. Workability reduced further when long-length fiber is used.
2. Low slump values were recorded for the mixes MA40, MA50, MB40 and MB50. This indicates that for the large volume of fibers, workability reduces.
3. Balling and clumping effect was seen for higher volume fractions of fiber 0.40% and 0.50%. The problem of balling and clumping was more when 24 mm length basalt fiber was used.
4. There is no improvement in the compressive strength values when fibers are added in plain concrete. Moreover, the compressive strength values are unstable.
5. The ideal volume of basalt fiber is 0.10% when compressive strength is to be considered for both 12 mm and 24 mm basalt fiber length.
6. The best volume fraction of basalt fiber is 0.35% when both split tensile and flexure strength is of important parameter to be considered for both 12 mm and 24 mm basalt fiber length.
7. The optimum length and optimum volume fraction is 24 mm and 0.35% when increase in both split tensile and flexure strength are required.
8. Overall, the concrete with 24 mm length of basalt fiber has shown better performance than the concrete with 12 mm basalt fiber length.

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