Inclusion of Metakaolin and Basalt Fiber with High Strength Concrete

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Abstract: This research work is carried out to study the different proportion effects on mechanical and chemical properties of high strength concrete (HSC) with the inclusion of Basalt fiber (BF) and Metakaolin (MK). As per IS-456:2000 a concrete which Characteristic compressive strength is greater than 55 N/mm^2 is called High strength concrete. The expected growth of cement consumption as per the Indian brand equity foundation is 328 Million Newton (MN) ton but as per the existing development of infrastructure growth, it increased up to 337 MN ton which represents how our infrastructure framework develops definitely. A chopped basalt fiber (BF) is a single material made from melting crushed basalt rocks. And calcination clay in the form of metakaolin (MK) are used for this research work in this research BF cast with supplementary cementitious material MK. Cement is replace in the range accordingly in 3 different concrete sets using 0.5% BF with MK 0%, 5%, and 10%, 1.0% BF with MK 0%, 5%, and 10%, 1.5% BF with MK 0%, 5%, and 10% by weight of cement were designed at single water cement ratio (w/c ratio) is 0.33. The research focuses on compressive strength and water absorption test that how quality improvement in the concrete mixes with BF & MK is improved. Besides, a decrease within the compressive strength was observed in the specimens with fiber addition, even though a significant variation of water absorption was taken note when compared with the conventional concrete.

***Index Terms* - Chopped Basalt Fiber, Compressive Strength, High Strength Concrete, Metakaolin, Water Absorption**

1. INTRODUCTION

Civil engineering means construction, maintenance, planning, and rehabilitation for humanity. It represents the redesign of our daily life in unique ways. It is one of the world's largest consumers of raw materials and resources. For several decades, concrete is a versatile material due to casting in any shape and provides good workability. The construction industry produced a high carbon footprint of 7% of the world's total CO2 emissions. According to Ponnada, M., and P. Kameswari [26], India is responsible for 10-12% of the construction and demolition (C&D) waste generated annually. While various construction items such as wood, brick, and glass, etc. they are recoverable while some materials such as concrete and masonry waste consume approximately more than 50 percent of the total consumption is not used. According to N. Gopi, P.Baskar, B.Dharani, and P.Abinaya. [23] Fibers and pozzolanic material minimize the cost of concrete and maximize the mechanical and chemical properties of concrete. Later it was discovered that the inclusion of basalt fiber in concrete changes the failure behavior from delicate failure mode to flexible failure mode when subjected to compression, tilt, and affect. MK is a high-quality pozzolanic material, which is mixed with cement to improve the durability of concrete. When used in concrete, it will fill the void space between the cement particles resulting in a more impermeable concrete. Metakaolin is a generally modern material in the concrete industry, it is viable to increase quality, reduce sulfate attack, and decrease porosity. Therefore, the main objective of this research is to advance and increase the amount of concrete cementitious supplementary material and summarizes its results and useful results.

2. EXPERIMENTAL MATERIALS

The materials utilized during the present research are as follows

2.1. Basalt Fiber

Basalt is a medium-grained dense volcanic rock when it is heated above 1400ºC. It is melted and converted into the superfine fiber. It is 100% inorganic. Basalt fiber is lies between 6 to 13 microns. This gives better durability and stability. Basalt fiber has no created any harmful response with water and air and no side impacts on human health.it encompasses a great fire-resistant capacity, low cost and more available than any other material so, considerably this makes lower the basalt fiber cost. Basalt fiber replaces all applications of asbestos, so it will decrease human health problems. It has three-time thermal insulation capability. It is very good material for bridge, shoreline structures, very good fire-resistant capability and prevent seepage. Figure 1 and Table 1 shows physical and chemical properties of basalt fiber which procured from Vadodara, Gujarat.

Table 1 Chemical and physical properties of basalt fiber

Chemical properties	Values (%)	Physical properties	Values
SiO_2	69.51	Tensile strength	2.8 - 3.1Gpa
Al_2O_3+Fe_2O_3	18.1	Elastic modulus	85 - 87 Gpa
CaO	5.62	Elongation at break	3.15
MgO	2.41	Density	2.67 gm/cm^3
K_2O	1.01		
Na_2O_3	2.74		

2.2. Cement

The broadly and most generally utilized cement in all types of construction works is Ordinary Portland Cement (OPC). The OPC 53 Grade cement conforming to IS: 12269-1987 was utilized for all concrete mixes. Whereas the water is included in the Portland cement, chemical reactions happen between the cement and water and thus coming about within the energy release and the cement paste event which is mindful for making hardened substance. This process of response happens between cement and water is named as the hydration process and the help of the energy during this process is named as the heat of hydration. For the research work, the Ordinary Portland Cement of 53-grade use. Figure 1 and Table 2 shows properties of cement which procured from local market, Anand, Gujarat.

Table 2 Physical properties of cement

Property	Values for Cement	IS:12269:1987
Initial setting time	35 min	30 minutes min
Final setting time	178 min	600 minutes max
Specific Gravity	3.15	3.10-3.15

2.3. Coarse aggregate 10mm (Grit)

As per IS 383:1970, an aggregate which is retained on IS 10mm sieve is called coarse aggregate. A material that has utilized in a drain, retaining wall, prevents differential setting, works as a low-cost binder in the road and giving base material in rail/road base. Concurring to expectations, size of 10mm has more strength as compared to 20mm aggregates. Just because of the measure of 10mm easier to fill little spaces and simple to compact. According to Limbachiya, M. C., Leelawat, T., & Dhir, R. K [20] in addition it is also consider as a light weight material. It is economical to put as much aggregate into a concrete blend as possible whereas not sacrificing other properties. However, Economy isn't the only reason for utilizing total; it too confers greater volume stability and superior durability than cement paste alone. Figure 1 and Table 3 shows properties of 10mm graded coarse aggregate (grit) which procured from local market, Anand, Gujarat.

Table 3 Physical properties of coarse aggregate (Grit)

Property	Values
Source	Sevaliya, Gujarat
Fineness modulus	6.08
Specific gravity	2.87

2.4. Coarse aggregate 20mm

As per IS 383:1970 an aggregate which is retain on IS 20mm sieve is called coarse aggregate. Coarse aggregates are responsible for providing 70-75% bulk within the constituents of concrete.it is the prime ingredient within the concrete. When it blended with cement and water it gets to be glued and therefore the entire strong matrix is bound during a strong mass which called concrete. Coarse aggregates are larger size filler materials in construction. As the name indicates, they are classified depending on the sizes of aggregate particles. The surface area of the coarse aggregate is less than fine aggregates. Coarse aggregates are utilized in concrete, railroad track ballast, etc. Coarse aggregate size 20 mm graded as per IS 383:1970 locally available is utilized for HSC. Figure 1 and Table 4 shows properties of 20mm graded coarse aggregate which procured from local market, Sevaliya, Gujarat.

Table 4 Physical properties of coarse aggregate

Property	Values
Source	Sevaliya, Gujarat
Fineness modulus	6.94
Specific gravity	2.81

2.5. Fine aggregate

As per IS 383:1970 an aggregate which is retain on IS 4.75mm sieve is called fine aggregate. Sand is shining yellow, off white, and rounded. The cost of Construction Sand is nil due to its normal availability but its transportation cost is more. Processing is easy by normal machines without using and Blast materials or any Crushing machines. Sand is free of any Organic Materials or any radiation or big blocks or concrete stones. Sand is utilized for backfilling, mortar, and concrete, road paving, Plastering, Filling under Foundations, reinforced ready-mix concrete, Building Blocks, and manufacturing masonry blocks. Figure 1 and Table 5 shows the properties of fine aggregate which procured from the local market, Bodeli, Gujarat.

Table 5 Physical properties of fine aggregate

Property	Values
Source	Bodeli, Gujarat
Fineness modulus	3.16

2.6. Fly ash

Fly ash (Class C) is the foremost broadly utilized material in this world The utilize of fly ash as concrete admixture not as it expanded specialized focal points to the Properties of concrete but moreover contributes to environmental pollution control. Since the significant commitment to environmental pollution and the tall consumption of characteristic resources like limestone etc., able to not go on producing more and more cement. There's a need to economize the utilization of cement. One of the down to earth arrangements to economize cement is to cement replaced with supplementary cementitious materials like fly ash. Major utilization of fly ash is a partial replacement, manufacturing of cement, blocks, bricks, wasteland development, and pavement construction. Figure 1 and Table 6 shows properties of fly ash which procured from, Vadodara, Gujarat.

Table 6 Chemical and physical properties of fly ash

Chemical properties	Values (%)	Physical properties	Values
SiO_2	46.38	Specific gravity	2.07
Fe_2O_3	8.26	Fineness (m^2/kg)	290
Al_2O_3	13.9	Bulk density (kg/m^3)	1100-1200
CaO	15.1	Colour (Visual observation)	Light grey
MgO	6.68		
SO_3	4.26		
Free-CaO	0.15		

2.7. Metakaolin

Metakaolin is not a by-product.it is a refined kaolinite clay at a temperature between 600^o C to 750^o C. MK gives effective packing at the cement paste-aggregate molecule interface, and produces a dense concrete, decreases the quantity of bleeding and made homogeneous concrete.MK improved significantly the pore structure of the concretes and diminished the substance of the harmful large pores, consequently made concrete more impervious. Calcium hydroxide could be a by-product of the hydration reaction of cement. When cement partially replaced with metakaolin; C-S-H gel is formed. That C-S-H gel could be a sole cause for the development of strength in cement-based concrete and cement. Utilization of metakaolin will help within the enhancement in long term strength, provide and develop a better resistance of diffusion harmful ions and water which leads to degradation of the matrix. Figure 1 and Table 7 shows properties of high reactive metakaolin which procured from Kapadvanj, Gujarat.

Table 7 Chemical and physical properties of Metakaolin

Chemical properties	Values in Percentage (%)	Physical properties	Values
SiO_2	51.52	Specific gravity	2.6
Al_2O_3	40.18	Bulk density (g/cm^3)	0.3-0.4
Fe_2O_3	1.23	Physical form	Powder
CaO	2.00	Colour	Off-white
MgO	0.12	GE brightness	79-82
K_2O	0.53		
SO_3	0.00		
TiO_2	2.27		
Na_2O	0.08		
L.O.I	2.01		

2.8. Silica fume

Silica fume is a next generation construction material. Silica fume is an industrial by-product primarily delivered from ferrosilicon and silicon metal. It reacts promptly with the calcium hydroxide, which is delivered during cement hydration. Silica fume as substitution of cement not only makes the concrete more strong against the environmental agencies but too diminishes the emission of CO_2 during the generation of cement its little angular particles improve workability, helping to diminish the water-cement ratio. The expansion of silica fume refines pore structure and produces concrete of improved mechanical strength. Silica fume contains an exceptionally high specific surface area and acts as a reactive pozzolanic. Normally, silica fume is utilized in small amounts compared to other pozzolanic materials. Figure 1 and Table 8 shows properties of silica fume which procured from, Kapadvanj, Gujarat.

Table 8 Chemical and physical properties of silica fume

Chemical properties	Percentage (%)	Physical properties	Value
SiO_2	93.8	Specific gravity	2.26
Al_2O_3	0.206	Specific surface (mw/gm)	18
Fe_2O_3	0.096		
CaO	0.426		
MgO	0.222		
K_2O	0.337		

2.9. Superplasticizer

Super plasticizing admixture based on selected sulfonated naphthalene polymers-based brown solution that immediately disperses in water. Superplasticizer disperses the fine particles within the concrete mix, empowering the water substance of the concrete to perform more viably. Superplasticizer essentially progress the workability of site mixed and precast concrete without expanding water demand. To give fabulous acceleration of strength pick up at early ages and major increments in quality at all ages by essentially lessening water demand in a concrete mix. To provide improved durability by expanding ultimate qualities and reducing concrete permeability. Figure 1 and Table 9 shows properties of Superplasticizer which procured from Infra build tech, Anand, Gujarat.

Table 9 Typical properties of Superplasticizer

Typical properties	
Appearance	Brown liquid
Specific gravity	1.18 @ 25°C

Chloride content	Nil to BS 5075 / BS:EN934
Air entrainment	Less than 2% additional air is entrained at normal dosages

2.10. Water

Water is a universally adopted key ingredient liquid for all types of work.in this research potable water is utilized for casting and curing purposes respectively. When water is mixed with cement it forms a paste that binds all aggregate together. The role of water within the concrete is most critical because of the water-cement ratio (w/c proportion). In this research w/c ratio is 0.33 taken out. Figure 1 Shows experimental materials used in this research are shown in below.

3. Design Mix

The mix proportion of HSC is not as same as conventional concrete. There are no exact codal provisions for preparation for mix design. This research depends on trial and error so the mix proportion is based on the literature review and guideline given by IS: 10262-2009. For all mix proportions, the water-cement ratio (w/c ratio) 0.33 is adopted for all mix proportions. Supplementary cementitious material in the form of fly ash, metakaolin, silica fume and fiber in the form of chopped basalt fiber are added in a proportion of 0.5% BF with MK 0%, 5%, and 10%, 1.0% BF with MK 0%, 5%, and 10%, 1.5% BF with MK 0%, 5%, and 10% by weight of cement were designed at single water cement ratio (w/c ratio) is 0.33.The Design mix nomenclature are shown in Table 10 and Design mix properties for 1m^3 concrete mix shown in Table 11.

Figure 1. Various experimental materials used in research

Table 10 Shows Nomenclature for design mix properties

Meaning	Description
A0	Control Mix design for M60 grade of concrete
B1-BF(0.5) M(0)	0.5% Basalt fiber and 0.0% Metakaolin as a replacement of cement in HSC
B2-BF(0.5) M(5)	0.5% Basalt fiber and 5.0% Metakaolin as a replacement of cement in HSC
B3-BF(0.5) M(10)	0.5% Basalt fiber and 10.0% Metakaolin as a replacement of cement in HSC
C1-BF(1) M(0)	1.0% Basalt fiber and 0.0% Metakaolin as a replacement of cement in HSC
C2-BF(1) M(5)	1.0% Basalt fiber and 5.0% Metakaolin as a replacement of cement in HSC
C3-BF(1) M(10)	1.0% Basalt fiber and 10.0% Metakaolin as a replacement of cement in HSC
D1-BF (1.5) M(0)	1.5% Basalt fiber and 0.0% Metakaolin as a replacement of cement in HSC
D2-BF (1.5) M(5)	1.5% Basalt fiber and 5.0% Metakaolin as a replacement of cement in HSC
D3- BF(1.5) M(10)	1.5% Basalt fiber and 10.0% Metakaolin as a replacement of cement in HSC

Table 11 Design Mix Properties in 1 m^3 concrete (kg)

Concrete mixes	Design mix for concrete (Kg)									
	Cement	Fine Agg.	Coarse Agg.10 mm	Coarse Agg.20 mm	Water	MK	BF	FA	SF	Superplasticizer (lit.)
A0	377.07	541.92	751.25	1252.08	153.17	0.00	0.00	70.70	23.57	0.71
B1	375.18	541.92	751.25	1252.08	153.17	0.00	1.89	70.70	23.57	0.71
B2	356.33	541.92	751.25	1252.08	153.17	18.85	1.89	70.70	23.57	0.71
B3	337.48	541.92	751.25	1252.08	153.17	37.71	1.89	70.70	23.57	0.71
C1	373.30	541.92	751.25	1252.08	153.17	0.00	3.77	70.70	23.57	0.71
C2	354.45	541.92	751.25	1252.08	153.17	18.85	3.77	70.70	23.57	0.71
C3	335.59	541.92	751.25	1252.08	153.17	37.71	3.77	70.70	23.57	0.71
D1	371.41	541.92	751.25	1252.08	153.17	0.00	5.66	70.70	23.57	0.71
D2	352.56	541.92	751.25	1252.08	153.17	18.85	5.66	70.70	23.57	0.71
D3	333.71	541.92	751.25	1252.08	153.17	37.71	5.66	70.70	23.57	0.71

4. Experimental Methodology

The test examination carried out on HSC by replacement of cement with metakaolin, fly ash, silica fume at different extents by weight of cement. For all mixes, w/c ratio is 0.33. HSC contains cement, fine aggregate, coarse aggregate 10mm and 20mm, superplasticizer, fly ash, metakaolin, and silica fume. Determination of compression test and Water absorption test both three cube tests were cast on mould size 150X150X150 mm for each concrete mix with partial replacement of cement by metakaolin and/or fly ash, silica fume for compression test and Water absorption test.

4.1 Compressive strength test

When a specimen of material is stacked in such a way that within the event that the material compresses and shortens it is said to be in compression. Compressive strength is frequently measured on a universal testing machine. Compressive strengths are usually reported concerning a particular specialized standard. Compressive strength is one of the foremost critical engineering properties of concrete. It is a standard mechanical practice that the concrete is classified based on grades. Fig. 2 shows the universal testing machine which is conducted compressive strength test at BVM Engineering College, V.V.Nagar, Gujarat. For the compression test, a specimen of the size of 150mm X 150mm X 150 mm was cast and tested in a compression testing machine concerning the test procedure given in IS: 516-1959. The equation for finding out compression test is given underneath,

Compressive Strength (N/mm^2) = P / Δ ……… (1)

Where, P =Failure load of specimen (N)

Δ = Area of specimen (mm^2)

Figure 2 Compressive strength test

4.2 Water absorption test

Standard measure concrete blocks ought to be completely submerged in clean water at room temperature for 24 hours. All concrete blocks should be dried in a ventilated oven at 100 to 1150°C for not less than 24 hours, and measuring the saturated weight. After that the tests were kept in oven by keeping up 100 ± 5° C for one day. Oven dry weight of the samples is recorded and the water absorption is assessed.Fig.3 shows cube curing in curing ponds.

Water absorption = $(W_1-W_2) / W_2$ X 100…… (2)

Where, W_1=Wet mass unit (kg)

W_2=Dry mass of unit in (kg)

Figure 3 Water absorption test

5. Experimental results and discussion

The following table 12 and Figure 2 appears Compressive strength force against deformation at 7, 28, and 56 days and following table 13 and Figure 3 shows water absorption in percentage at 28 days which are as follows.

5.1 Compressive strength test

The following table 12 and Figure 2 and appears Compressive strength force against deformation at 7, 28, and 56 days and following table 13 and Figure 4 shows water absorption in percentage at 28 days which are as follows.

Table 12 Compressive strength at 7, 28, and 56 days

Concrete Mixes	Compressive strength (N/mm^2)		
	7 Days	28 Days	56 Days
A0	56.22	63.33	65.55
B1	66.96	78.07	83.54
B2	63.85	76.44	81.03
B3	60.37	65.93	69.55
C1	61.63	70.52	74.75
C2	63.19	77.70	82.75
C3	61.11	63.11	64.37
D1	64.44	70.22	72.33
D2	60.22	73.04	79.89
D3	52.59	59.93	60.53

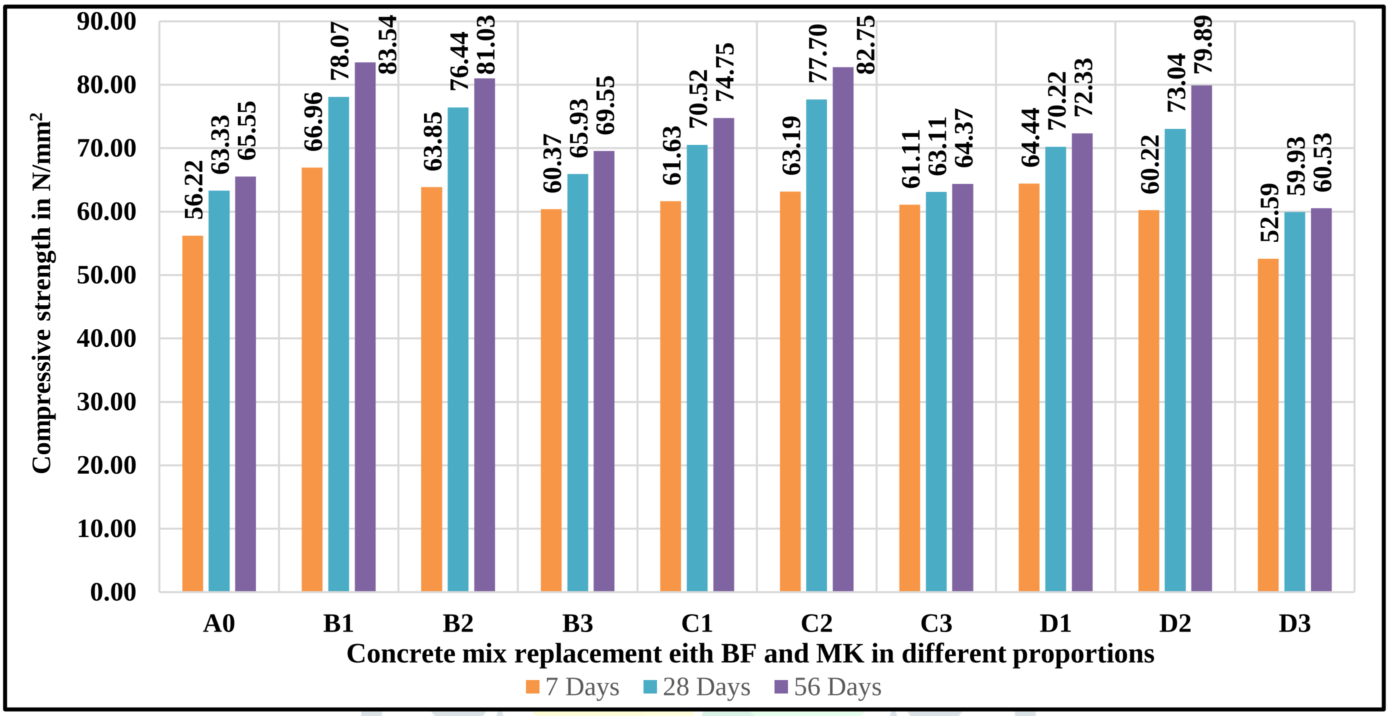

Figure 4 Compressive Strength Results for M60 Concrete Mixes: Control mix Concrete and Concrete with replacement of Cement with BF and MK in Different Proportions at 7, 28 and 56 days

Table 12 appears Compressive strength at 7, 28, and 56 days for different HSC mixes.A0 represent 65.55 N/mm^2 at 56 days.B1 is made with 0.5% BF and 0% MK shows 83.54 N/mm^2 at 56 days. C2 is made with 1% BF and 5% MK shows 82.75 N/mm^2 at 56 days. D2 is made with 1.5% BF and 5% MK shows 79.89 N/mm^2 at 56 days. It shows the rate of fiber is to increase the compressive strength of a decrease in HSC. The higher proportion of metakaolin results in moderate strength.

5.2 Water absorption test results

Following table 13 appears the results of percentage water content submerged in cubes for the water absorption test done on concrete cubes at 28 days for M60 grade concrete control mix concrete and concrete with replacement with BF & MK in several proportions.

Table 13 Water absorption test results for M60 concrete mixes with inclusion of BF and MK in different proportions at 28 days.

Concrete Mixes	24 Hour Saturation Weight (W_1) in Kg	Oven Dry Weight (W_2) in Kg	Water absorption (%)
A0	8.45	8.66	2.48
B1	8.68	8.45	2.72
B2	8.64	8.45	2.24
B3	8.56	8.32	2.88
C1	8.53	8.32	2.52
C2	8.54	8.35	2.27
C3	2.68	2.44	2.84
D1	8.55	8.36	2.27
D2	8.51	8.33	2.16
D3	8.49	8.36	1.55

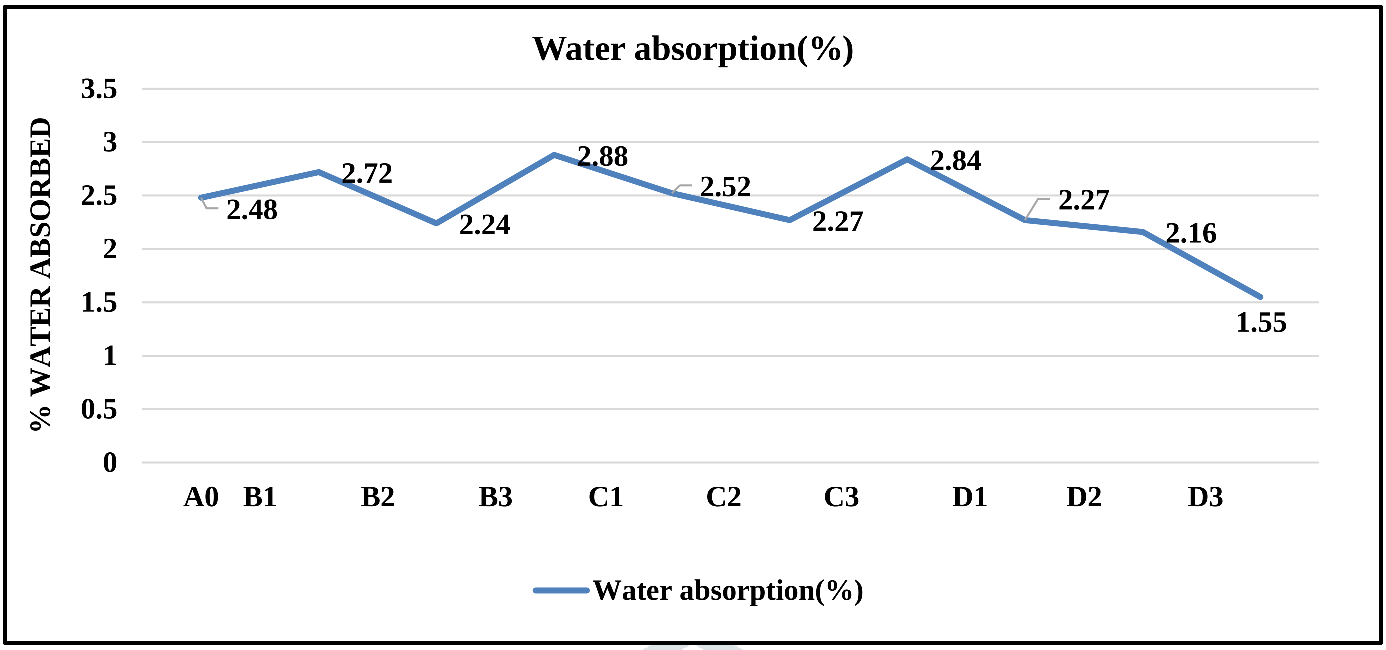

Figure 5. Percentage Water Absorbed for M60 Concrete Mixes: Conventional Concrete and Concrete with Substitution of BF and MK in several Proportions

From above Figure 5, it is observed that for HSC mix percentage water absorbed was decreases with an increase in BF and MK in concrete. The most elevated water absorption ratio is observed at B3 which is 2.88% and the least water absorption ratio is observed at D3 which is 1.33%.which states that increment of BF and MK content reduces the water absorption ratio without changing its property.

6. Cost Comparison

Following table 14 shows the rate analysis as per distinctive amount of items as per current market rates for different concrete mixes.

Table 14 Material cost per kg

Materials	Rupees (₹) per kg
Cement (Kg)	6 ₹
Fine Aggregate (Kg)	0.45 ₹
Coarse Aggregate - 10mm (Kg)	0.48 ₹
Coarse Aggregate - 20mm (Kg)	0.8 ₹
Fly ash (Kg)	1.9 ₹
Silica fume (Kg)	15 ₹
Superplasticizer (ltr)	35 ₹
Basalt fiber (Kg)	600 ₹
Metakaolin (Kg)	10 ₹

Following Table 15 shows total Cost of Concrete Mixes for 1 m^3 with Replacement of BF and MK in Different Proportions.

Table 15 Total Cost of Concrete Mixes for 1 m^3 with Replacement of cement with BF and MK in Different Proportions

Concrete Mixes	Cost of Material of Concrete/ m^3
A0	4381.10 ₹
B1	5995.55 ₹
B2	6508.47 ₹
B3	7021.39 ₹
C1	7610.00 ₹
C2	7133.82 ₹
C3	7646.74 ₹
D1	9224.45 ₹
D2	8253.72 ₹
D3	8766.63 ₹

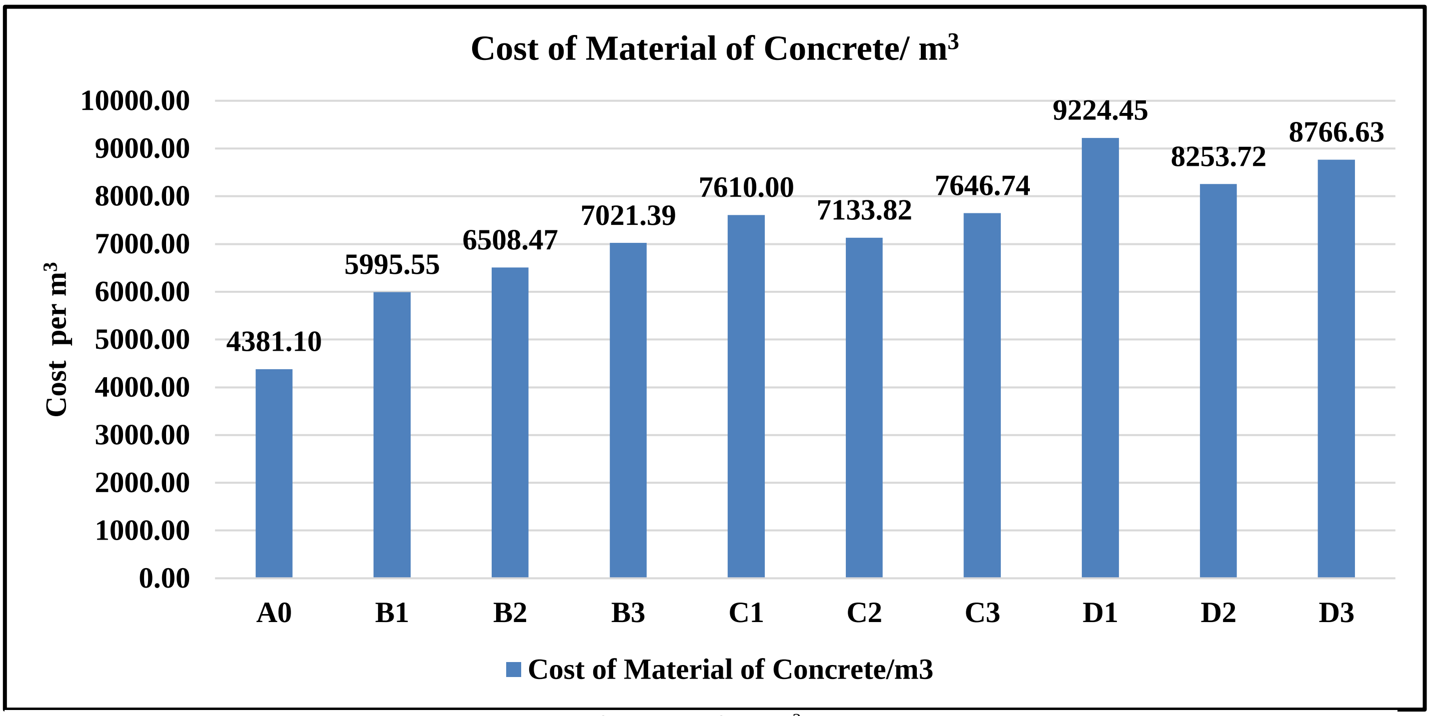

Figure 6 Total Cost of Concrete for 1 m^3 M60 Concrete Mixes

From above Figure 6, it is observed that HSC mix with Inclusion of BF and MK with different proportions have higher rates for 1 m^3 concrete compared to Control Mix Concrete A0. Rates of HSC increase with an increment in BF and MK proportion.

7. Conclusion

The conclusions based on experimental work are as follows

1. The compressive strength increments with the inclusion of BF and MK. It is observed that the percentage of fiber is less, the strength to begin with increases, and with increasing the content of fiber at that point encompasses a downward trend implies the strength is decreasing.
2. The strength has been appearing the most extreme at B1. When the proportion of BF and MK is the same, the compressive strength is decreased and after that increases somewhat with the BF and MK proportion increasing.
3. The inclusion of BF and MK increases the compressive strength of HSC. The results indicate that the B1 concrete mixes exhibit the compressive strength of 83.54 N/mm^2 (at 56 days), which is higher than that of the A0 control mix concrete 65 N/mm^2 (at 56 days).
4. The inclusion of BF and MK significantly influences the water absorption properties of concrete. The highest water absorption ratio is 2.88 observed at the B3 concrete mix and the lowest water absorption ratio is 1.55 observed at the D3 concrete mix.
5. It is observed that the inclusion of fiber proportion gives less compressive strength we gain and on another side, the moderate fiber proportion is there we gain more compressive strength. The compressive strength of HSC has increased with reference to conventional concrete due to the inclusion of fibers in the concrete mix.
6. In B batch of concrete mixes with BF and MK, B1 mix made with 0% replacement of MK and 0.5% BF shows 7021.39 ₹ and control mix concrete A0 mix shows 4381.10 ₹ Which is 60.27% higher than control mix concrete 4381.10 ₹.
7. In C batch of concrete mixes with BF and MK C3 mix made with 10% replacement of MK and 1% BF, C3 mix shows 7646.74 ₹ and control mix concrete A1 mix shows 4381.10 ₹. Which is 74.54% higher than control mix concrete 4381.10 ₹.
8. In D batch of concrete mixes with BF and MK D1 mix made with 0% replacement of MK and 1.5% BF, D1 mix shows 9224.45₹ and control mix concrete A1 mix shows 4381.10 ₹. Which is 110.55% higher than control mix concrete 4381.10 ₹.
9. BF and metakaolin have no poisonous impact on air & water even water absorption without changing its property is observed which is satisfying special needs of special application for a specific site condition.
10. As a result of its characteristics, BF and MK are truly considered as a material of our future for a green and sustainable development.

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