Experimental Study on Basalt Fibre Reinforced Concrete with Partial Replacement of Cement with Quarry Dust and Metakaolin

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***Abstract* - Concrete being the mostly used building material in the world out of its inherent strength and durability properties, yet it leads to the depletion of many natural resources like raw materials of cement limestone and other constituents like aggregates. Apart from this, it is very weak in tension because of its brittle nature. To enable the concrete with tensile nature the concept of fibre reinforced concrete has been develop my adding a variety of natural or synthetic fibers to the concrete. Also the production of lot by-products from the industries like quarry dust, metakaolin, fly ash putting a lot of thrust on environment as the quarry dust is directly released into the environment and there were no proper disposal methods. Metakaolin a mineral admixture used in the concrete to get a highly compacted concrete. In the present study the mechanical properties of M25 grade of concrete with partial replacement of cement with quarry dust at 10%, 15%, 20%,25%, 30% and metakaolin at 2.5%, 5%, 7.5%,10% and 12.5%. After getting the optimum, basalt fibres added to the concrete at 0.5%, 1%, 1.5%, 2%, 2.5% and 3%. From the experimental results it is found that the replacement of quarry dust and the metakaolin improved the strength properties of concrete with an optimum of 25% and 10% respectively. Addition of basalt fibers has increased the split tensile and flexural strength considerably at 2% optimum. Durability studies using 5% HCl has also resulted in better performance compared with conventional concrete.**

***Index Terms* - Fiber reinforced concrete, quarry dust, metakaolin, basalt fibers, durability.**

1.INTRODUCTION

Construction industry has undergone a rapid change in the last century especially with the advancement of different types of concrete. Concrete with the development of technology has undergone several changes not in its composition, but also in its performance and applications. Concrete is the most widely used construction material. Apart from its excellent properties concrete is very poor in tensile strength.

To improve its tensile strength, fibers are added to concrete which is known as fiber reinforced concrete. Cement industry is one of the major contributors to pollution by releasing carbon dioxide. The principle constituent in the traditional cement is Portland concrete. The measures of bond production discharge roughly break even with measure of carbon dioxide into the air. Bond creation is expending critical measure of normal assets. That has conveyed weights to diminish bond utilization by the utilization of supplementary materials. The fuse of supplementary cementitious material is fly ash is another mineral admixture, which enhance primarily the mechanical properties of cement furthermore lessen the bond utilization by supplanting a portion of concrete with these pozzolanic materials.

Cement is likely the most broadly utilized development material as a part of the world. The principle constituent in the traditional concrete is Portland cement. The amount of cement manufacture release approximately equal amount of carbon dioxide into the atmosphere. Cement production is consuming significant amount of natural resources. That has brought pressures to reduce cement consumption by the use of supplementary materials. The incorporation of supplementary cementitious materials like Quarry Dust (QD) and Metakaolin (MK) improves mainly the mechanical properties of concrete and reduce the cement consumption.

It is one of the strategies to enhance the fragile conduct of the solid is the expansion of little fibers in cement with randomly circulated. Such strengthened cement is called Fiber Reinforced Concrete (FRC).

There are diverse sorts of fibers that can be utilized as a part of FRC they are Basalt fibers, Steel fibers, Glass fibers, Synthetic fibers, Carbon fibers, Nylon fiber. In this study the option of Basalt fibers are added to solid, prompts change in breaking and rigidity.

Plain concrete possesses a very less tensile strength, limited ductility, and little resistance to cracking. Internal micro cracks are present in the concrete and its poor tensile strength is due to the propagation of such micro cracks. In plain concrete structural cracks develop even before loading, due to drying shrinkage or other causes of volume change. The width of these initial cracks is few microns, but their other dimensions may be of higher magnitude.

When loaded, the micro cracks propagate and open up, and additional cracks form in places of minor defects. The development of such micro cracks is the main cause of inelastic deformations in concrete. It has been recognized that the addition of small, closely spaced and uniformly dispersed fibers to concrete would act as crack arrester and uniformly dispersed fibers to concrete would act as crack stop and would substantially improve its properties.

1.1 BASALT FIBER

The process of producing fibers from basalt is based on selecting the richest chemical proprieties basalt rocks with the use of quality tests, crushing the rocks, and melting to high temperatures. The melted basalt falls from a specific calculated hole where its temperature gradually decreased and forms a yarn which thickness reduces over the cooling process where it gets rolled in a roving. The Continuous Basalt Fiber is short for CBF, which is make use of the natural volcanic rock as the raw material and put them in the furnace after being crushed into power and then which are produced by the platinum rhodium drawing filament laminate. Compared to the carbon fiber, Aramid fiber which has many unique advantages. Such as the physical property, the high temperature resistance, good acid & alkali-resistance, the good UV resistance, the low hygroscopic property, the environmental resistance and sound insulation, high temperature filter-ability, radiation resistance and the excellent wave-adsorption and wave-penetration and soon.Many sorts of composites which are use of the basalt fiber as the reinforced material can be used many fields such as fire, environmental protection, aerospace, armament, automotive & vessels' manufacture, infrastructural material and so on. Crushed basalt rock is the only raw material required for manufacturing the fiber. It is a continuous fiber produced through igneous basalt rock melt drawing at about 2,700°F (1,500°C).Though the temperature required to produce fibers from basalt is higher than glass, it is reported by some researchers that production of fibers made from basalt requires less energy by due to the uniformity of its heating.

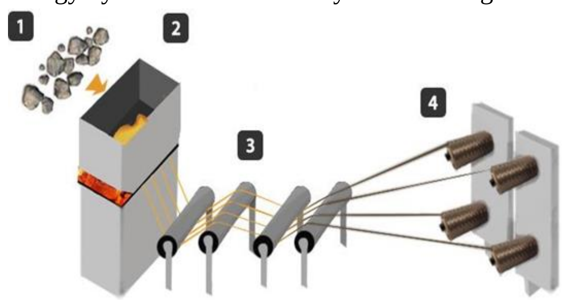


Fig: Process of manufacturing Fibers from rocks

The CBF - Continuous Basalt Filament formed in the melting process of basalt results in our Primary Products product line. The filament can be winded in three types of roving’s: Assembled Roving, Direct Roving and Gun Roving. From the chopped filament we produce the Chopped Strands and from twisted filaments ours Twisted Yarns.

1.2 QUARRY DUST

Quarry dust is a by-product from the crushing process during quarrying activities. Quarry dust has been used for different activities in the construction industry. The dust produced by quarrying has already been used in the construction industry for projects such as road building and making materials such as bricks and tiles. The dust has been found to be suitable for these practices, and this makes its transformation into a useful cement mix replacement more likely.

Environmental Benefits of Using Quarry Dust:

- The use of Quarry dust as partial cement replacements with lower environmental load provides chance for significant reductions in energy use and carbon dioxide emissions.
- The use of Quarry Dust in concrete results in following environmental benefits in reducing the emission of carbon dioxide

1.3 METAKAOLIN

Metakaolin is a manufactured pozzolanic mineral admixture, which significantly enhances many performance characteristics of cement-based mortars, concretes and related products. Metakaolin derived from purified kaolin clay, is a white, amorphous, alumino-silicate, which reacts aggressively with calcium hydroxide, a normal cement hydration by-product, to form compounds with cementitious value.
In the case of Metakaolin, the change that is taking place is dehydroxylization, brought on by the application of heat over a defined period of time. At about 100- 2000C, clay minerals lose most of their adsorbed water. The temperature at which kaolinite loses water by dehydroxilization is in the range of 5000C -8000C. This thermal activation of a mineral is also referred to as calcining. Beyond the temperature of dehydroxylization, kaolinite retains two-dimensional order in the crystal structure and the product is termed Metakaolin .The key in producing Metakaolin for use as a supplementary cementing material, or pozzolana is to achieve as near to complete dehydroxilization as possible without overheating. Successful processing results in a disordered, amorphous state, which is highly pozzolanic. Thermal exposure beyond a defined point will result in sintering and the formation of mullet, which is dead burnt and not reactive. In other words, kaolinite, to be optimally altered to a Metakaolin state, requires that it is thoroughly roasted but never burnt.

Environmental benefits of using metakaolin:

- The use of Metakaolin as partial cement replacements with lower environmental load provides chance for significant reductions in energy use and carbon dioxide emissions.
- The use of Metakaolin in concrete results in following environmental benefits in reducing the emission of carbon dioxide

1.4 FIBER REINFORCED CONCRETE

Fiber Reinforced Concrete can be characterized as a composite material comprising of blends of bond, mortar or concrete and broken, discrete, consistently scattered reasonable filaments. Ceaseless lattices, woven fabrics and long wires or poles are not thought to be discrete strands.
Fiber Reinforced Concrete (FRC) is concrete comprising fibrous material which expands its basic trustworthiness. It contains short discrete fibers that are consistently conveyed and randomly situated. Fibers incorporate steel fibers, glass fibers, synthetic fibers and natural fibers. Inside these distinctive fibers that character of fiber strengthened solid changes with reinforced concrete, fiber materials, geometries, distribution, orientation, and densities.
Fiber-reinforcement is predominantly utilized as a part of concrete yet can likewise be utilized as a part of ordinary cement. Fiber-reinforced ordinary cement is for the most part utilized for on-ground floors and pavements yet can be considered for an extensive variety of development parts either alone or with hand-tied rebars.

Advantages of using FRC:

- It increases the tensile strength of the concrete.
- It reduces the air voids and water voids the inherent porosity of gel.
- It increases the durability of the concrete.
- It has been recognized that the addition of small, closely spaced and uniformly dispersed fibers to concrete would act as crack arrester and would substantially improve its static and dynamic properties.

2. OBJECTIVES OF THE STUDY

In this research work, an experimental investigation is carried out to obtain the optimum replacements Quarry dust, Metakaolin and the Basalt fibers by testing the mechanical properties of the concrete as per the Indian standards. Also, it is proposed to carry out the durability studies of the concrete with the obtained optimum percentages of Quarry dust, metakaolin and the Basalt fibers by means of curing them in 5% H2SO4 for 28 days.

3. PROPERTIES OF THE MATERIALS USED

Table: Physical Properties of Materials

Physical Properties of Materials	Results
Normal Consistency of Cement	28 %
Initial Setting Time Final Setting Time	47 min 406 min
Specific Gravity of cement	3.15
Fineness of cement	3%
Specific Gravity of aggregates of Coarse aggregates Fine aggregates	 2.822 2.65

Fineness Modulus of Fine Aggregate	2.78
Fineness Modulus of Coarse Aggregate	6.88

Table: Physical properties of QD

Physical Properties	Value
Specific Gravity	2.56
Bulk density (Kg/m^3)	1760
Moisture content	Nil

Table: Chemical Composition of QD

Material	Quantity%	Material	Quantity%
SiO_2	62.48	Na_2O	NIL
Al_2O_3	18.72	K_2O	0.18
Fe_2O_3	6.54	TiO_2	1.21
CaO	4.83	Loss of ignition	0.48
MgO	2.56		

Figure: Quarry Dust

Table: Physical Properties of MK

Physical Properties	Value
Specific gravity	2.6
Colour	White
Particle shape	Spherical

Table: Chemical Composition of MK

Material	Quantity%	Material	Quantity%
SiO_2	62.62	Na_2O	1.57
Al_2O_3	28.63	K_2O	3.46
Fe_2O_3	1.07	TiO_2	0.36
CaO	0.15	Loss of ignition	2.0
MgO	0.06		

Figure: Metakaolin

4. MIXDESIGN

Concrete mix proportion is created for specific and desirable properties. mixing various amounts of Portland cement, water, sand, and coarse aggregate and admixtures produces different samples with altered characteristics of homogeneous mix.

The method adopted for identifying mix proportion was in reference to the amount of the material in an unit of fully compacted concrete. The method resulted in specifying mix constituents in terms of weights in kilograms necessary to get the required volume of concretes.

Therefore, mix proportions for concrete mix of M 30 Grade as per IS: 10262-2009 and IS: 456 -2000 is Cement: FA: CA: Water = 1:1.22:3.19:0.45

5. RESULTS AND DISCUSSIONS

Table: Compressive strength for different Quarry dust percentages

S.NO	% of Quarry dust	7 days strength	28 days strength
1	0	25.95	39.76
2	10	26.63	40.97
3	15	27.12	41.35
4	20	27.63	42.41
5	25	28.56	43.36
6	30	25.12	39.52

Table: Flexural Strength for different Quarry dust percentages

S.NO	% of Quarry dust	7 days (N/mm^2)	28 days (N/mm^2)
1	0	4.45	5.66
2	10	4.58	5.89
3	15	4.61	5.92
4	20	4.85	6.07
5	25	4.98	6.25
6	30	4.52	5.68

Table: Split Tensile strength for different Quarry dust percentages

S.NO	% of Quarry dust	7 days (N/mm^2)	28 days (N/mm^2)
1	0	3.59	4.7
2	10	3.67	4.86
3	15	3.75	4.91
4	20	3.97	5.06
5	25	4.18	5.12
6	30	3.61	4.96

From the above, the optimum percentage of quarry dust is obtained as 25% for all strengths.

Table: Compressive strength for 25% Quarry dust and % Metakaolin

S.NO	%Metakaolin	7 days (N/mm^2)	28days (N/mm^2)
1	0	28.56	41.85
2	2.5	29.41	41.96
3	5	30.25	42.35
4	7.5	31.47	43.06
5	10	32.58	43.96
6	12.5	30.18	41.92

Table: Flexural Strength for 25% Quarry dust and % Metakaolin

S.NO	%Metakaolin	7 days (N/mm2)	28 days (N/mm2)
1	0	4.98	6.25
2	2.5	5.26	6.38
3	5	5.28	6.44
4	7.5	5.31	6.51
5	10	5.41	6.55
6	12.5	5.24	6.49

Table: Split Tensile strength for 25% Quarry dust and % Metakaolin

S.NO	%Metakaolin	7 days (N/mm^2)	28 days (N/mm^2)
1	0	4.18	5.12
2	2.5	4.29	5.18
3	5	4.3	5.26
4	7.5	4.32	5.29
5	10	4.36	5.38
6	12.5	4.28	5.3

From the above experimental results, it was found that the concrete is giving enhanced strength properties at an optimum of 25% Quarry dust along with 10% of Metakaolin as partial replacement to cement.

Now, these optimums are considered for identifying the optimum percentage of Basalt fibers to be mixed to produce a good quality concrete.

Table: Compressive strength for 25% Quarry dust + 10% Metakaolin and % Basalt Fibers

S.NO	% Basalt Fibers	7 days (N/mm^2)	28days (N/mm^2)
1	0	32.58	43.96
2	0.5	32.61	44.23
3	1.0	32.85	44.85
4	1.5	32.93	44.92
5	2.0	33.86	45.85
6	2.5	33.58	44.56
7	3.0	32.95	44.63

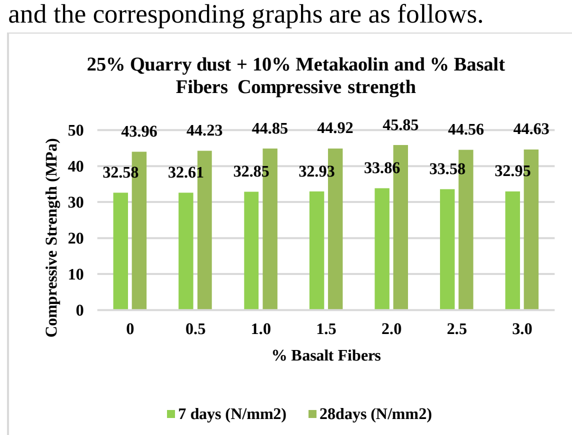
Table: Flexural Strength for 25% Quarry dust + 10% Metakaolin and % Basalt Fibers

S.NO	% Basalt Fibers	7days (N/mm^2)	28days (N/mm^2)
1	0	5.41	6.55
2	0.5	5.68	6.67
3	1.0	5.85	6.69
4	1.5	6.01	6.78
5	2.0	6.21	6.85
6	2.5	6.05	6.7
7	3.0	5.8	6.65

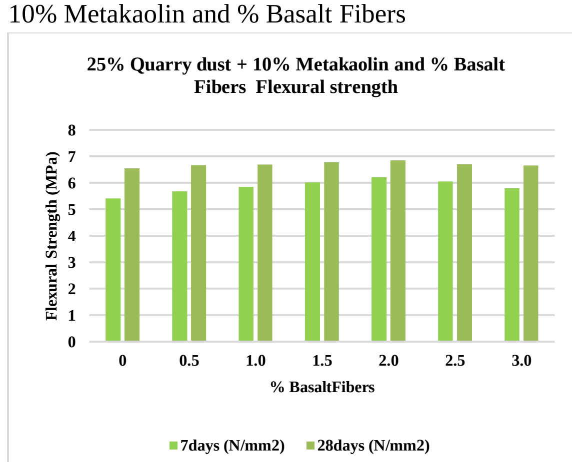
Table: Split Tensile strength for 25% Quarry dust + 10% Metakaolin and % Basalt Fibers

S.NO	% Basalt Fibers	7days (N/mm^2)	28days (N/mm^2)
1	0	4.36	5.38
2	0.5	4.61	5.41
3	1.0	4.65	5.42
4	1.5	4.66	5.47
5	2.0	4.68	5.56
6	2.5	4.56	5.48
7	3.0	4.44	5.41

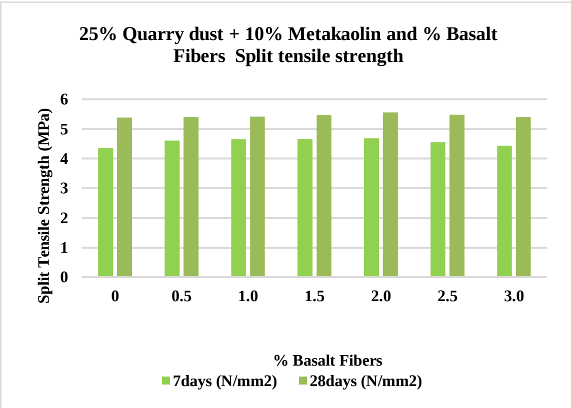
From the above graph, it is observed that the compressive strength, flexural strength and the split tensile strength are having higher values for concrete with 25% QD with 10% MK and 2% of Basalt fibers and the corresponding graphs are as follows.



Graph: Compressive strength for 25% Quarry dust + 10% Metakaolin and % Basalt Fibers



Graph: Flexural Strength for 25% Quarry dust + 10% Metakaolin and % Basalt Fibers



Graph: Split Tensile strength for 25% Quarry dust + 10% Metakaolin and % Basalt Fibers

DURABILITY STUDIES:

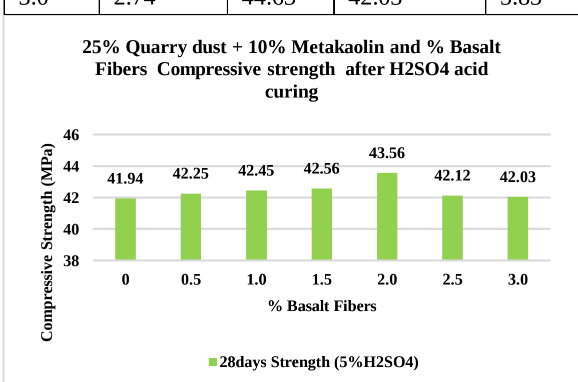
To check the Acid resistance of concrete Sulphuric Acid (H2SO4) is selected. The concentrations of acids in water are taken as 5%. The standard specifications for this study are IS 516-1959 and ASTM C666-1997.

Table: Details Acid for durability study

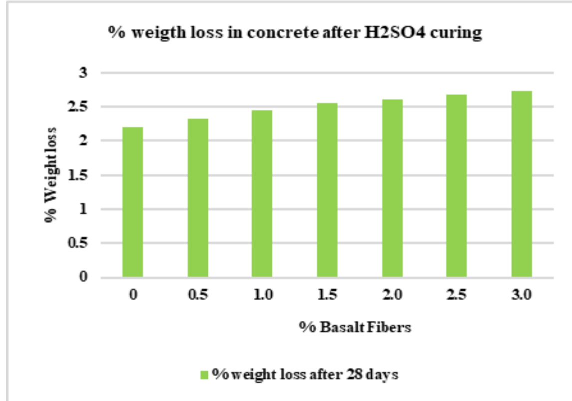
Acids used	H_2SO_4
Concentrations for trails	0.5% in water
Number of days of testing	28 days

Table: 25% Quarry dust + 10% Metakaolin and % Basalt Fibers Compressive strength after 28 days H2SO4 acid curing

% Basalt fibers	% weight loss at 28 days	28 days strength	28days Strength (5%H_2SO_4)	% Strength loss
0	2.21	43.96	41.94	4.60
0.5	2.32	44.23	42.25	4.48
1.0	2.45	44.85	42.45	5.35
1.5	2.56	44.92	42.56	5.25
2.0	2.61	45.85	43.56	4.99
2.5	2.68	44.56	42.12	5.48
3.0	2.74	44.63	42.03	5.83



Graph: 25% Quarry dust + 10% Metakaolin and % Basalt Fibers Compressive strength after 28 days H2SO4 acid curing



Graph: 25% Quarry dust + 10% Metakaolin and % Basalt Fibers % weight loss after 28 days H2SO4 acid curing

6 CONCLUSIONS

- Replacement of cement with quarry dust and metakaolin have resulted in a considerable increase of the mechanical properties of the concrete.
- Quarry dust at 25% and metakaolin at 10% replacement to cement in the concrete were identified as optimum percentages for M30 grade of concrete, and at that optimum replacements, there is good improvement in compressive strength.
- Addition of 2% of basalt fibers to the concrete with Quarry dust at 25% and metakaolin at 10% replacement to cement have a great influence in the entire properties of the concrete.
- On overall there is enhancement of 15.31% in compressive strength, 18.29% split tensile strength and 21.02% flexural strength compared to conventional concrete.
- Addition of 2% basalt fibers has resulted in decreased strength loss under 5% H2SO4 curing for 28 days.

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