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Experimental Investigation of High-Performance Concrete Using Metakaolin and Steel Fibers in Conventional Concrete

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Abstract
Possibly the most extensively utilized building material worldwide is concrete. To address concerns about cost, energy, environmental protection, and resource conservation, the amount of mineral admixture added to cement has significantly increased as the concrete industry has grown. However, pressure has been applied to limit cement use through the use of supplemental materials due to environmental concerns about the harm caused by raw material extraction and carbon dioxide emissions during cement manufacturing. With the increase in demand for construction materials, there is a strong need to utilize alternative materials for sustainable development. The main objective of this investigation is to study the properties, such as compressive strength Metakaolin is used for the project is available in chemical factories. The proportion of cement substitutes by metakaolin and steel fibers has been substituted at 10%+5%, 20%+10%, 30%+15% and 40%+20% respectively. After testing, the cast specimens for 28days curing. The Mechanical and resilience characteristics of the specimens at various ages have been found out.
Keywords: *Concrete, Metakaolin, Steel fibers, Durability and mechanical characteristics*

1. Introduction
Based on its compressive strength, concrete is classified as either regular concrete or high strength concrete for use in building. Normal concrete's compressive strength is in the range of 20 to 40 MPa. The influence of the high-strength concrete will surpass 40 MPa. Concrete with compressive strengths ranging from 40 to 140 MPa is an example of concrete with high strength. The characteristics that set normal concrete apart from concrete with high strength have evolved over time and with historical shifts. For example, a concrete with a 28 MPa compressive strength was regarded as strong strength a century ago. However, concrete can now reach strengths of over 800 MPa. High-performance concrete is another name for these. Compared to high strength concrete, concrete with normal strength is the most widely utilised variety regarding application. Reducing weight, creep, or permeability problems, increasing the structure's endurance, and taking into account unique design concerns that call for components that support lighter weights are the in primary goals of adopting high strength concrete. Regardless of the concrete type—normal or high strength, for example—the freshly mixed concrete needs to be semifluid or flexible in order to be moulded by hand or with the aid of any machinery. In a concrete in fresh mixture state, all of the coarse aggregates and sand particles are enclosed in an outer layer and remain suspended. It is imperative that during handling or transit, the mixture not experience bleeding or segregation. Controlling segregation in concrete is aided by the uniform distribution of particles. In recent years, the term high performance concrete (HPC) meant that the concrete of high strength with better performance. Also, the primary objectives in developing these were to have adequate resistance to aggressive environment. High performance concrete is usually having high initial cost but however, it proves to be more economical with high performance concrete that considered to be durability and reliability for all type of structures, were rapid research and developments in various

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types of admixtures including pozzolanic admixtures by the application of which the performance characteristics of high-performance concrete can be increased. As we know, brittle failure is the inherent property of the plain concrete, i.e. Its tensile strength and strain capacity at cracks are extremely poor. Reinforcement bars or prestressing steel are used to address these drawbacks of plain concrete. Corrosion from chloride ions entering the concrete is the primary disadvantage of the reinforcing steel. In coastal places, this issue gets more serious. Over time, rust is created as steel bars corrode. Because this rust has a larger capacity than iron, it expands. Concrete experiences significant tensile strains as a result of this expansion, which causes fractures to form and spread, eventually resulting in concrete spalling. Fibers are added to cement concrete to get over this drawback. Although there are many various kinds of fibers, steel fibers are utilised in this case due to their high tensile strength, ductility, enhanced bond strength, and capacity to stop cracks from spreading. The manufactured product, metakaolin, is made by calcining kaolin at a temperature between 7000 and 8000 degrees Celsius. As a result, its well regulated engineering qualities produce favourable outcomes for concrete's workability and durability. When mixed with cement, fly ash or silica fume darkens the colour of the concrete, whereas metakaolin, which is white, doesn't change the colour of the concrete, improving its appearance. [1-3]

2. Methodology

A homogenous blend of cement, sand, coarse aggregate, and water, along with evenly distributed steel fibers and metakaolin, is known as high performance concrete. All of the experimental work uses concrete mix grade M-70. In the lab, the control mix is produced using the proportions specified by the IS technique. Throughout the experimental investigation, M-70 grade concrete with mix proportions of 1: 0.81: 1.12, or cement: fine aggregate: coarse aggregate with a w/c ratio of 0.3, was utilised. The design of the concrete mix was completed in compliance with I.S. 10262. When the concrete was still wet, fibers and powdered metakaolin were added, and everything was thoroughly mixed one more. 150 mm cubes for compressive strength, 150 mm diameter x 300 mm length cylinders for split tensile strength, 100 x 100 x 500 mm beams for flexural strength, and 450 x 150 x 150 mm push-off specimens for shear strength were all cast using 0–10% crimped fibers spaced 2.5 percent apart and 0–20% Metakaolin spaced 5 percent apart by cement weight. Three specimens were cast for every test. To prevent balling, all of the specimens were compacted using a table vibrator fibers. To prevent fiber balling, a table vibrator was used to compact all of the specimens. Every specimen was tested in surface dry condition using a 1000 kN Universal Testing Machine (UTM) and a Compression Testing Machine (CTM) with a 2000 kN capacity after being water cured for 28 days at ambient temperature. To assess the strength performance, a total of 60 specimens were cast and put through testing. Three test samples were averaged to produce each value of the data shown in this study. Table 1 shows Properties of Steel Fibers, Table 2 shows Properties of Binding Agents

Table 1 Properties of Steel Fibers

S.No	Property	Value
1.	Diameter (*d*)	0.65 mm
2.	Length of fiber (*l*)	55 mm
3.	Aspect ratio of fiber (*l*/*d*)	85
4.	Appearance and form	Bright, clear
5.	Modulus of Elasticity	200 GPa
6.	Tensile strength	1000 MPa

Table 2 Properties of Binding Agents

S.No	Chemical composition	Metakaolin	Cement OPC 53 G
1.	SiO_2	52.8	23.74
2.	Al_2O_3	36.3	5.0
3.	Fe_2O_3	4.21	3.17
4.	MgO	0.81	2.97
5.	CaO	< 0.10	61.79
6.	K_2O	1.41	1.36
7.	LOI	3.53	1.19

2.1. Materials

Steel Fiber: Steel fiber's physicochemical parameters should be in compliance with

IS14871:2000; its length should be between 20 and 60 mm, and its diameter, or equivalent diameter, should be between 0.3 and 1.2 mm. The ratio of length to diameter should be between 30 and 65.

Cement: HPC employed 53-grade regular Portland cement, and the cement's performance index and strength after three and twenty-eight days were examined using the "Hydraulic Cement" performance index (IS4031:1988).

Fine Aggregate: Fine aggregate performance was examined in accordance with IS 383:2016, and high-quality graded sand was chosen. The fineness modulus should be maintained between 2.3 and 3.0.

Coarse Aggregate: With a particle size of 20 mm, tests were conducted to identify aggregate shapes with a more uniform edge polyhedron, hard texture, and graded continuous gravel.

2.2. Sample Composition

Cement, Metakaolin, and fiber were added after fine and coarse aggregate had been combined to guarantee even dispersion of fibers in the mixture. The water and additions were added while stirring the mixes after they had been combined for 30 seconds. Steel fiber-reinforced concrete was stirred for three minutes, and the mixing procedure was completed. After the prepared mixture vibrated in the test mould, it was flattened. Specimens were cured in a typical curing room at 27°C and 97% relative humidity after the mould was removed during a 24-hour maintenance period. By causing cement powder and fine material to scatter rapidly, the strengthening mechanism of vibration accelerated the water and cement hydration reaction speed uniformly, improving the cement concrete's microscopic structure and successfully lowering the cement dosage. In addition to comparing the microstructure of vibratory and traditional mixing, the effect of each method is compared.

3. Experimental Investigation

3.1. Cube Compression of Steel Fiber Metakaolin Concrete

The cube compressive strength test used a standard 150 mm cube specimen, and the test was conducted using the procedures and methods of "Methods of tests for concrete strength IS 516. This test employed constant-speed stress control, with a loading speed of 0.6 MPa/s. The machine would automatically unload the specimen and record the degree of damage. Figure 1 below depicts the cube compressive strength testing apparatus. [4-6]

Figure 1 Cube Compressive Strength Testing Machine

3.2. Split Tensile Test of Steel Fiber Metakaolin Concrete Cylinder

The splitting tensile strength test was conducted using cylinder specimens of standard length (300 mm × 150 mm), with three specimens per group. This test was conducted using a 2000 kN pressure testing equipment, and as Figure 2. illustrates, the splitting position should be depicted prior to the splitting test.

Figure 2 Cylinder Splitting Tensile Strength Testing Equipment

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3.3. Acid attack test

As seen in Figure 3, cured SFMC cube specimens of 150 mm x 150 mm x 150 mm were passed undergo an acid attack test. by submerging them in a 3.5% sulphuric acid (H_2SO_4) solution.

Figure 3 Cube Specimen Subjected to H_2SO_4 Acid Attack

In this study, acid attack on SFMC was observed for 28 days. The pH value of the sulfuric acid was maintained at 1.0 as long as 28 days. In this test, loss in compressive strength and loss in weight were calculated as long as 28 days of immersion in order to determine the intensity of an acid assault on SFMC cube specimens. Visual observation test was also made as long as 28 days of immersion show in Figure 4

Figure 4 Visual Inspection of Cube Specimen Subjected to H_2SO_4 Acid Attack After 28 Days

4. Results and Discussion

4.1. Compressive strength

Table 3 displays the compressive strength results. When compared to regular concrete, the 28-day compressive strength is highest at 10% steel fiber and 20% Metakaolin. Therefore, it is better to use 20% metakaolin and 10% steel fibre are added to structural concrete to boost its compressive strength. Table 3 shows Compressive Strength of SFMC

Table 3 Compressive Strength of SFMC

Mix	Metakaolin (%)	Steel Fiber (%)	Avg compressive strength (N/mm^2)
SFMC0	0	0	85.58
SFMC1	10	5	92.84
SFMC2	20	10	100.84
SFMC3	30	15	99.56
SFMC4	40	20	98.72

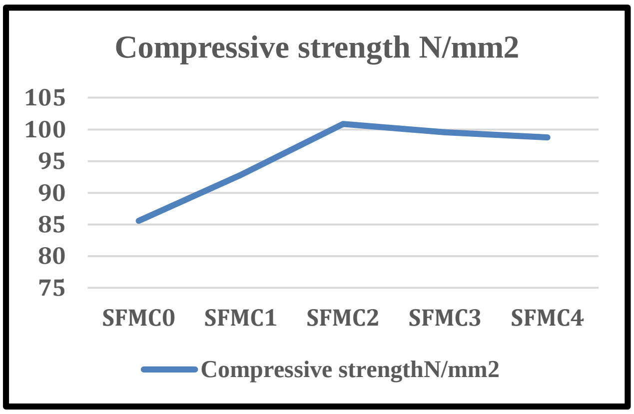

Figure 5 Compressive Strength Testing Results

According to figure 6, the data represents the compressive strength rises with the amount of steel and metakaolin fiber, with minor variances occurring after SFMC3. Since it has been shown that adding more filler materials stabilises the concrete's compressive strength, it is also discovered that the variance in the readings obtained decreases.

4.2. Split Tensile Strength

Table 4 displays the variance in split tensile strength as a function of fiber content and Metakaolin. It was found that when the proportion of steel fiber and metakaolin increased, the 28-day split tensile strength improved steadily. 20% Metakaolin and 10% steel

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fiber yield the highest split tensile strength. The enhanced qualities of the matrix and the robust interphase link between the fiber and the matrix, which results from the synergistic interaction of fibers with metakaolin, may be responsible for this strength gain. Table 4 shows Split Tensile Strength of SFMC [7-8]

Table 4 Split Tensile Strength of SFMC

Mix	Metakaolin(%)	Steel Fiber (%)	Avg Split Tensile strength (MPa)
SFMC0	0	0	8.21
SFMC1	10	5	9.36
SFMC2	20	10	9.85
SFMC3	30	15	9.52
SFMC4	40	20	9.34

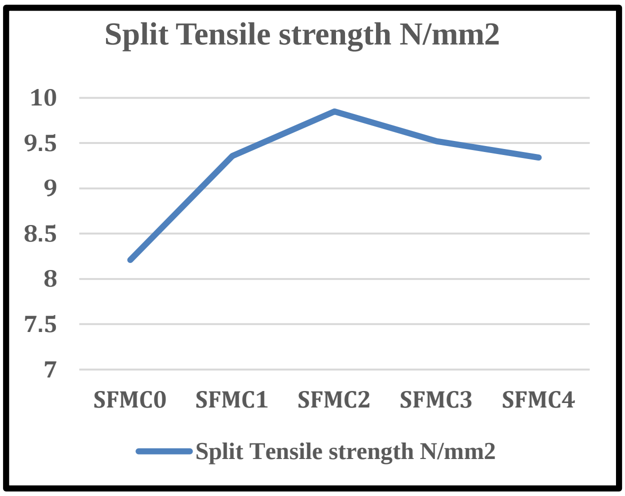

Figure 7 Split Tensile Strength Testing Results

Tensile strength measurements are shown in Figure 7. The difference between SFMC3 and SFMC4 is discovered to be quite small, while the difference between all readings of the same composition is more than usual. since it has been discovered that the stability of filler materials has been moderate.

4.3. Acid Attack

Table 5 represents strength results before acid attack and after acid assault for 28 days. Conventional concrete which inhibits more loss in compression strength after acid attack. SFMC 2 inhibits less loss inn strength compare to conventional SFMC0. Figure 8 showcases the comparison of strength before and after acid assault of cube specimens.

Table 5 Acid Attack of SFMC

Mix	Compressive Strength before Acid Attack (MPa)	Compressive Strength after Acid Attack (MPa)	Loss in Compression Strength (%)
SFMC0	85.58	82.36	3.76
SFMC1	92.84	89.90	3.16
SFMC2	100.84	98.24	2.57
SFMC3	99.56	95.86	3.71
SFMC4	98.72	95.12	3.64

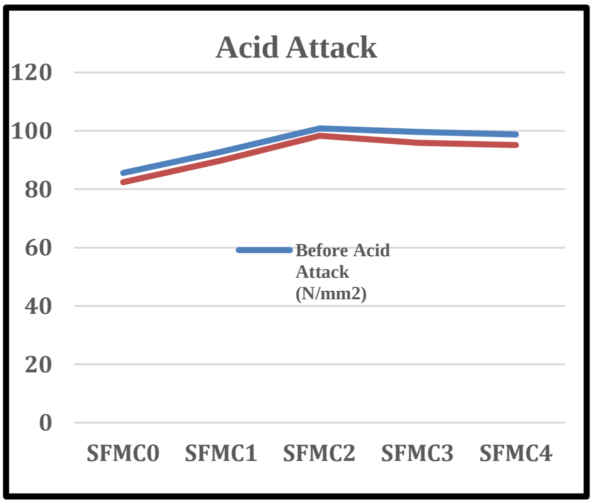

Figure 8 Acid Attack Before and After Strength Testing Results

Conclusions

Based on the findings of the experimental inquiry, the following conclusions have been drawn:

- As the proportion of fiber content in concrete increases, its density somewhat increases as well. Metakaolin-reinforced steel fiber concrete has a density that is somewhat more than regular concrete.
- The rise in the percentage of fiber content causes concrete's workability to decrease.
- As the proportion of fiber content in concrete increases, so does its compressive strength.

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The strength of SFMC2 is greater than that of SFMC conventional. At 1% fiber volume fraction, the strength-effectiveness ratio is shown to be greater than that of the control concrete.

- As the proportion of fiber content in concrete increases, so does its split tensile strength. While SFMC3,4 is comparable to and superior than conventional SFMC, SFMC2 has a higher tensile strength than conventional SFMC. At 1% fiber volume fraction, strength-effectiveness is shown to be at its highest contrasted to the control concrete.
- The weight loss of SFMC specimens in 3.5% sulphuric acid solutions during the first periods of immersion is comparatively reduced than that of the traditional sample. Over a 28-day exposure period, SFMC specimens submerged in H_2SO_4 solution lose weight by approximately 3.76% in conventional specimens where as SFMC2 lose weight by 2.57% which is lower than conventional SFMC.

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