HIGH PERFORMANCE CONCRETE EXPERIMENTAL ANALYSIS USING POLYOLEFIN MICROFILAMENT FIBER

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Abstract

In many parts of the world, concrete is a widely used construction material, and as technology develops, so do concrete's properties. High performance concrete is a new improvement in concrete technology that is aimed to allow for the use of materials, exposure situations, and cost requirements while also offering greater service life and durability. Concrete's strength and durability are increased when chemical admixtures and mineral admixtures are used in place of cement. To increase the strength and ductility of high-performance concrete, fibres are added. Polyolefin fibres are synthetic fibres manufactured by humans. The two most popular polyolefin fibres are polypropylene and polyethylene. Fibers made of polyolefin can be used for both structural and non-structural purposes. A polyolefin fibre is wear and corrosion resistant. For testing, M50 grade concrete will be utilised. With varied amounts of polyolefin fibre addition, materials were mixed using M50 grade of concrete and a water cement percentage of 0.34 for fibre reinforced concrete. Super plasticizer is utilised as a chemical admixture, whereas silica fume and metakaolin are employed as mineral admixtures.

Keywords: Cement, metakaolin, silica fume, coarse aggregate, and polypropylene fibre

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1. Introduction

Many constructions employ concrete significantly in their construction. The most commonly used material on the earth is concrete, second only to water. Concrete has a very low tensile strength and is fragile. Yet, due to a number of reasons like autogenous shrinkage, freeze-thaw reactions, and mechanical compressive and tensile stresses, it is a fragile material that breaks easily. The strength of concrete is unaffected by microcracks, but they do enable additional fluids to penetrate, including water and other chemical solutions (chlorides, sulphates, and acids), which weakens the cement matrix and, as a result, accelerates the corrosion of embedded steel reinforcing bars.(Alberti et al., 2017) Cracks impair the structural safety in addition to reducing the material's mechanical strength and longevity. In more extensive applications, it is increasingly popular to reinforce concrete with tiny and randomly dispersed synthetic or natural fibres in order to lessen shrinkage cracks and increase strength, fracture toughness, and ductility.(Alberti et al., 2014) To improve the performance of concrete, mineral and chemical admixtures have been utilised to partially replace cement in recent years. Concrete gains density from mineral admixtures including fly ash, GGBS, metakaolin, and silica fume, which makes it stronger, safer, and longer-lasting. Water and other acids won't be able to enter the structure because to the low permeability, enhancing its strength and usefulness.(Noushini et al., 2018)

1.1 Concrete with High Performance

High performance concrete is described as having great durability, strength, and workability by the American Concrete Institute. High performance concrete is defined as concrete that has specialised qualities created for a certain purpose and environment exposure.(AlKhatib et al., 2020) The development of high performance concrete has been influenced by various factors, including the type of cement, partial replacement of cement with mineral admixtures (such as fly ash, GGBS, silica fume, metakaolin, and other industrial wastes), type of super plasticizer, and mine omposition of fine and coarse aggregate. Regular concrete is weaker than high-performance concrete, which is also simpler to maintain. In high-performance concrete, the use of pozzolans and a low water content provide a dense microstructure with high strength and low permeability.(de Sá et al., 2020; Deng et al., 2016) Improved durability has been attained by the use of concrete with high strength and low water to cement ratio. The capillary pore system can be reduced and chemically active binding materials can be produced as two ways to stop the transit of harmful ions like chlorides. HPC is often more brittle than standard strength concrete. A confining pressure can increase the ductility of high-performance concrete. Also, it may be enhanced by modifying the content of the design by using fibres. Fibers occur in a number of sizes and forms and are created from a variety of materials, including steel, glass, polyester, aramid, polyolefin, and natural fibres. Most fibres are used in structural as well as non-structural applications. Fibers offer the benefit of minimising shrinkage cracks, conserving cement, and boosting the tensile and compressive strength of concrete. High ductility and high strength fibre reinforcement are combined to produce the best flexural strength and toughness performance. A high-potential contemporary structural material that is gaining favour is fibre reinforced concrete.(Kim et al., 2007)

1.2 Polyester Fibers

In order to create polyolefin fibres, synthetic linear polymers are used to polymerize unsaturated hydrocarbons into saturated linear hydrocarbons. In order to make synthetic fibres, polyolefin polymers in the forms of polypropylene (CH2 = CH - CH3) and polyethylene (CH2-CH2) are utilised. The two most popular polyolefin fibres are polypropylene and polyethylene. The most popular polyolefins are the next in line. Polyolefin fibres are produced by melting and spinning.(Xiao & Falkner, 2006; Yang et al., 2012) The extruder melts the material after receiving the polymer grains. The filaments are then collected in cans after being cooled in an air stream.

Chain polymerization is used to create polyolefin fibres, which are manufactured from olefin polymers that include 85% ethylene, propylene, or other olefins. At room temperature, polyolefin fibres have a specific gravity of less than one, are solvent-unaffected, and only swell at high temperatures when exposed to aromatic and chlorinated compounds.(Ostrowski et al., 2020) A fibre has a high level of abrasion resistance. The benefits of polyolefin fibres are numerous, including their high strain capacity and resistance to corrosion. Because of its corrosion resistance, it may be used in hostile environments to shield buildings against rust. Long-term fracture control and strong bonding in the cement matrix are made possible by polyolefin fibres.(Maruthachalam et al., 2013; Sasipriya et al., 2017) The usage of polyolefin in commonplace applications has improved because to polymer research and engineering developments. Polypropylene and polyethylene are the fastest-growing polymeric families because to their low manufacturing costs as compared to other fibres and materials. Because of the low cost, excellent chemical resistance, high strength, and toughness, they promoted use. The tensile strength, abrasion resistance, and chemical resistance of polyolefin fibres are generally good. The use of polyolefin fibres in place of corrosive steel solutions is growing in favour. The two types of polyolefin fibres that are now on the market, micro and macro polyolefin fibres, each have a specific use. Cementitious composites utilise polypropylene, one of the polyolefin fibres, to increase the strength, longevity, and fracture resistance of the construction. By incorporating fibre into concrete and developing synthetic macrofibers based on polyolefins, mechanical properties were improved and shrinkage cracking was decreased. In fibre reinforced concrete, the use of macro synthetic fibres as an alternative to steel fibre has gained popularity. According to reports, the crystalline structure of polypropylene falls between between low density polyethylene (LDPE) and high density polyethylene (HDPE). The operating temperature and tensile strength of polypropylene are higher than those of polyethylene.

1.3 Polyester Fibers

Polypropylene was the first stereo regular polymer to achieve industrial relevance. In the 1970s, polypropylene fibres were initially introduced to the textile industry, and they immediately became recognised as a significant member of the rapidly expanding synthetic fibre family. Nowadays, polypropylene is placed fourth among the "big three" categories of fibre, which also include acrylic, nylon, and polyester. Although its usage in clothing and home textiles has been limited compared to other commodity fibres, the bulk of the fibre produced is used in industrial applications. The monomer CnH2n binds the linear structure together. It is made with the help of a catalyst like titanium chloride and propylene gas. In addition, polypropylene could be a waste product from an oil refinery. The majority of polypropylene is crystalline and geometrically regular, in contrast to amorphous thermoplastics like polystyrene, PVC, polyamide, and others, which have radical placement that is random.

2. Considered materials

2.1 Cement

Cement is a binding agent or chemical that may bond various building materials together. The main argument in favour of choosing OPC 53 grade is that the hydration process will be facilitated by its appropriate strength, surface area, and fineness. The initial material testing of cement was successful.

Table 1: Cement's properties

Properties	**Results**
Specific gravity	3.13
Initial Setting Time	28 minutes
Final Setting Time	532 minutes
Consistency	33%
Fineness modulus	2.6

2.2 Fine Aggregate

Fine aggregate is any substance that is inert or chemically inactive that can pass through a 4.75mm screen. The fine aggregate in concrete reinforces the concrete paste and reduces its porosity by filling the spaces between the coarse particles. The initial materials testing for both fine and coarse aggregate has been completed.

Table 2: Fine aggregate characteristics

Properties	**Results**
Grading of sand	Zone II
Specific gravity	2.63
Fineness modulus	2.47
Water absorption	1.5%

2.3 Granular Aggregate

Sand, gravel, crushed stone, slag, and recycled concrete made up the large group of coarse particle materials known as "construction aggregate" that are used in building. We used gritty pebbles that had been sieved through a 20mm sieve and kept in a 12.5mm filter. Strong concrete is required for high performance concrete. Shrinkage will be reduced if coarse aggregates are used. The fundamental material testing has been completed for both fine and coarse aggregate.

Table 3: lists the qualities of coarse aggregate

Properties	**Results**
Specific gravity	2.70
Water absorption	2%
Fineness modulus	6.2

2.4 Fiber made of olefins

Synthetic linear polymers are used to polymerize unsaturated hydrocarbons into saturated linear hydrocarbons, resulting in polyolefin fibres. The fibres of polyolefin fibres are created by whirling and melting olefin polymers, which include 85% ethylene, propylene, or other olefins. The two varieties of polyolefin available on the market are macro and micro. Each has a distinct purpose. A polyolefin microfilament fibre that also has strong tensile strength, abrasion resistance, and chemical resistance increases the ultimate load.

Figure 1: Fibrous Polyolefins

Table 4: Micro polyolefin fiber characteristics

Fiber	Micro polyolefin
Length (mm)	12
Appearance	White
Specific gravity	0.91
Melting Point (°c)	160
Acid and alkali proof	High

2.5 Silicic acid

According to the American Concrete Institute, silica fume is very fine noncrystallizing silica produced in an electric arc furnace as a by-product of the production of elemental silicon or silicon alloys (ACI). Micro silica, condensed silica fume, volatized silica, and silica dust are other names for silica fume. Generally, it looks like fly ashes or Portland cement and is a grey powder. It has cementitious and pozzolanic qualities. By adding silica fume, which also protects the embedded steel from corrosion, concrete's endurance is strengthened. There are several nucleation sites where the hydration products can precipitate thanks to the pozzolana particles in the paste's finely distributed form. The paste thickens and gains greater homogeneity in the dispersion of its tiny pores as a result of this process. This is caused by a contact between the calcium hydroxide produced during the cement hydration processes and the amorphous silica present in pozzolanic materials. Due to its chemical and physical properties, silica fume byproducts are used in concrete for a variety of purposes; it is a pozzalana that is particularly reactive. Concrete may become extraordinarily resistant and durable because to silica fume

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Table-5: Silica fume's characteristics

Properties	**Results**
Physical form	Powder
Color	White
Specific gravity	2.20
Size of particles	0.1 □
Chloride Content	Nill

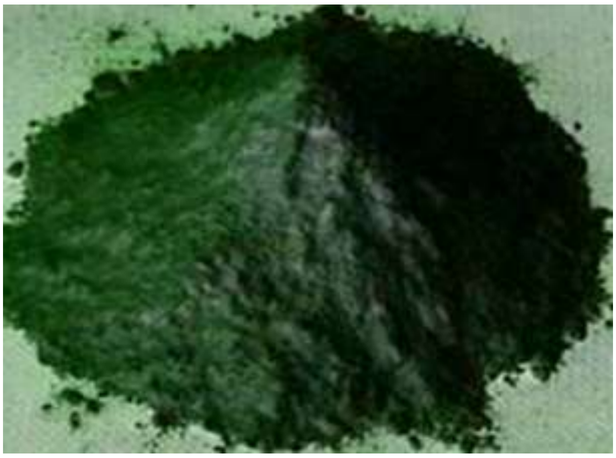

Figure 2: Silica Fume

2.6 Metakaolin

Natural pozzolans have been the subject of several investigations, especially kaolin clay and thermally activated common caly. The term "metakolin" is used to describe these impure compounds. Although they exhibit certain pozzolanic traits, they are not particularly reactive. When non-reactive elements are removed during water processing, pure reactive pozzolan is created. When water processing removes nan-reactive impurities from metakolin, pure reactive pozzolan is created. White or cream-colored, highly reactivated metakolin (HRM). Significant pozzolanic reactivity and a drop in Ca(OH)2 may be seen in high reactive metakolin as early as one day. Highly reactive metakolin can compete with silica fume. Like other pozzolanic compounds, metakolin is a purposefully produced material with specific qualities as opposed to being a byproduct.

Table 6: Metakolin's characteristics

Properties	**Results**
Physical form	Powder
Color	White
Specific gravity	2.50
Fineness modulus	800 m^2/kg
Specific surface	11 m^2/g

Figure 3: Metakolin

2.7 Pink Sikacim

A liquid solution for waterproofing concrete, masonry, and plaster. An innovative, pink-colored liquid integrated water proofing compound has been created using Sika's technology of specialised selective polymers, surface active agents, and additives for use in concrete, mortar, and plaster.

Table-7: characteristics of pink sikacim

Appearance	Pink colour hazy liquid
Density	1.21 at 25°C

pH value	≥6

3. Experimental Results and Discussion

3.1 Cone-slump test

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specimens with dimensions of 0.3 m in height, 0.2 m in base diameter, and 0.1 m in top diameter were measured. The dampening rod is 0.6 metres long with a diameter of 0.0016 metres

Table 8: Slump Cone Test Result

Replacement of polyolefin fiber (%)	Trial No	Slump Value (mm)	Average Slump value (mm)	Type of slump
0	1	105	100	True or High Slump
	2	95		
0.1	1	110	108	
	2	105		
0.3	1	105	110	
	2	115		
0.5	1	110	115	
	2	120		

3.2 Test of compressive strength

A cube with the usual dimensions of 0.15m X 0.15m X 0.15m is tested for compressive strength on a compressive testing equipment with a capacity of 2000kN while being loaded at a rate of 4kN/s. The test was carried out when the animal was 7 and 28 days old. Compressive strength of concrete with and without fibres, as well as with and without replacements for metakaolin (10%) and flyash (15%). The concrete's compressive strength values are shown in the table below.

Table 9: Test of Compressive Strength Results

Replacement of polyolefin fiber (%)	Average Compressive Strength of concrete at 7 Days (N/mm2)	Average Compressive Strength of concrete at 28 Days (N/mm2)
0	34.44	51.33
0.1	34.75	53.51
0.3	36.43	56.21
0.5	35.69	55.67

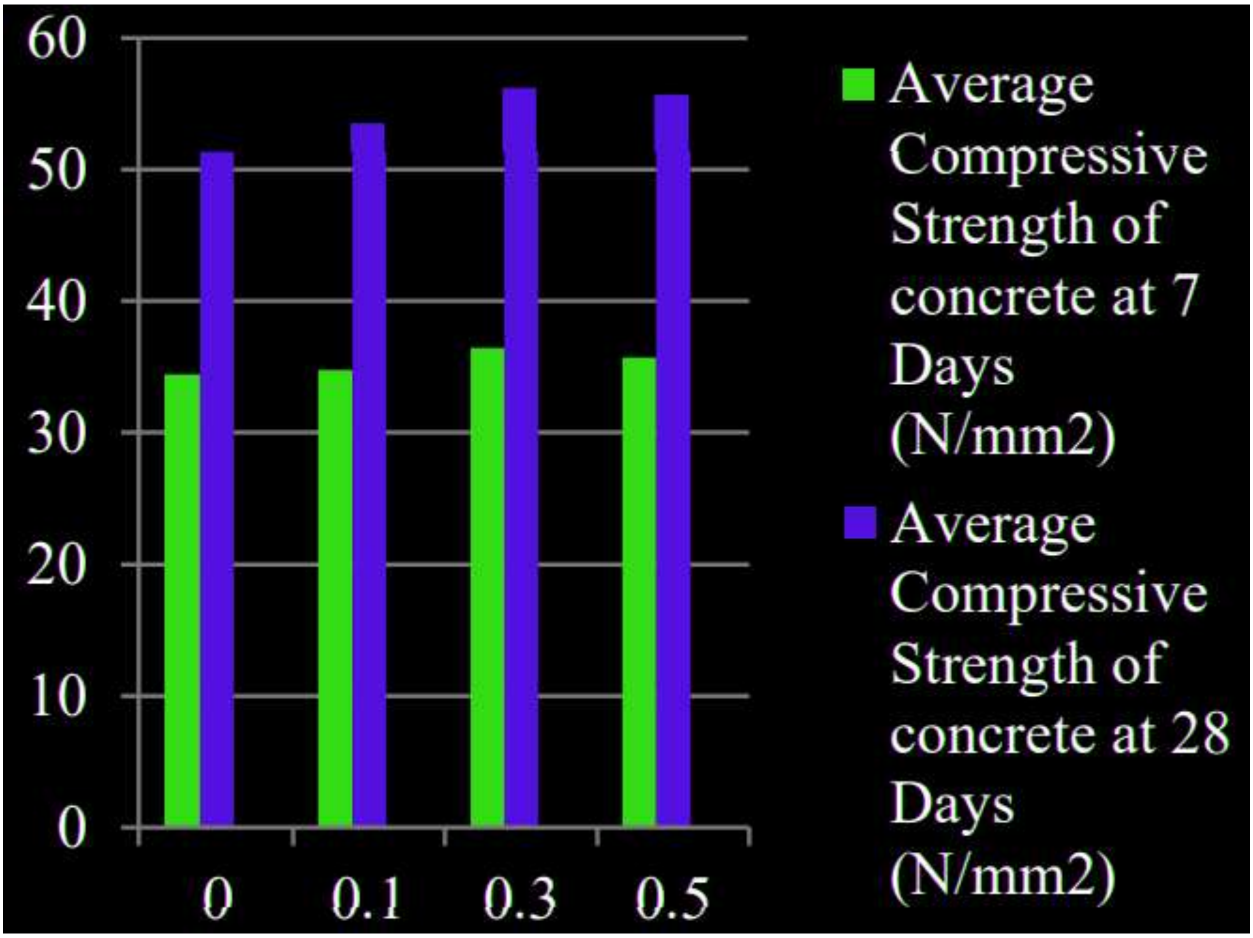

Chart-1: Results of the compression test

The HPC's 28-day compressive strength (56.21 N/mm2) at 0.3% polyolefin fibre content is higher than that of regular concrete.

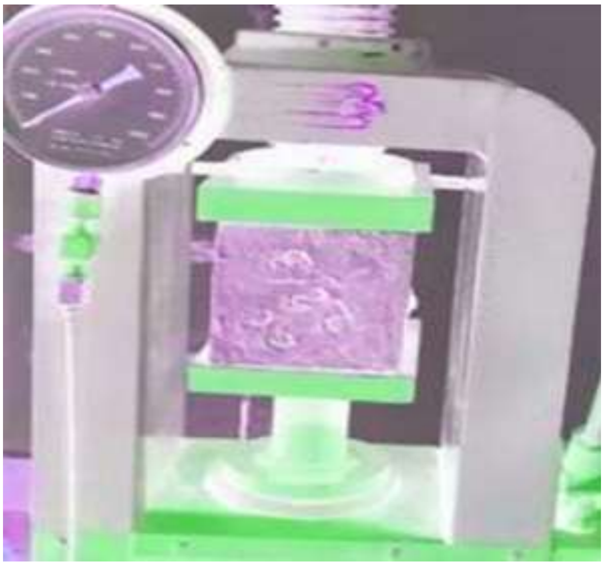
Figure 4: Compressive Strength Test

3.3 Test of split tensile strength

The split tensile strength test was conducted on a cylindrical construction with a standard diameter of 0.15 m and a height of 0.3 m. To achieve split tensile stress in accordance with IS 5816:1998, the load was progressively increased. The animals were collected when they were 28 and 7 days old for the test specimens. The split tensile strength results for concrete with and without fibres are shown in the table along with replacements of 10% metakaolin and 15% fly ash.

Table 10: Test Results for Split Tensile Strength

Replacement of polyolefin fiber (%)	Average Split Tensile Strength of concrete at 7 Days (N/mm2)	Average Split Tensile Strength of concrete at 28 Days (N/mm2)
0	3.28	5.5
0.1	3.32	5.28
0.3	3.74	5.9
0.5	3.43	5.47

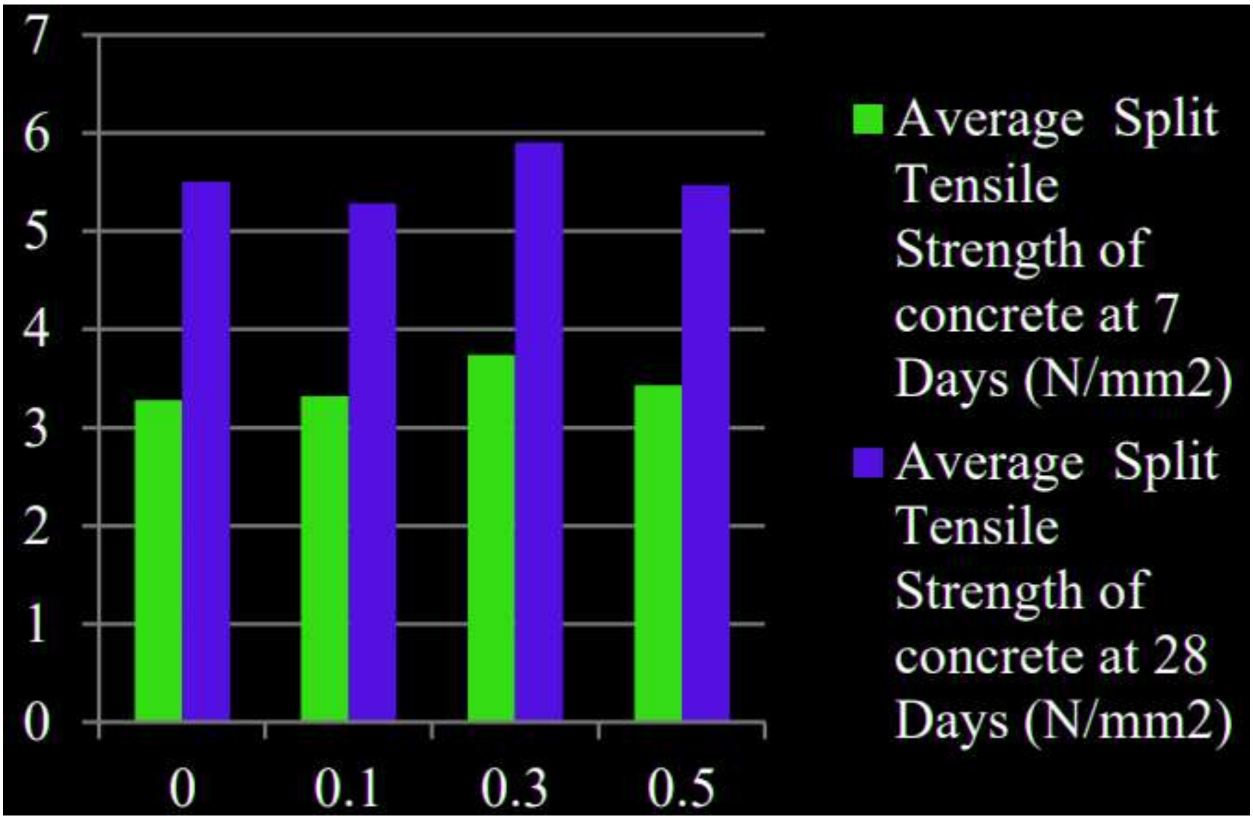

Chart-2: Test Results for Split Tensile Strength

As comparison to regular concrete, HPC's Split Tensile Strength at 28 Days (5.90 N/mm2) with 0.3% Polyolefin Fibers is higher.

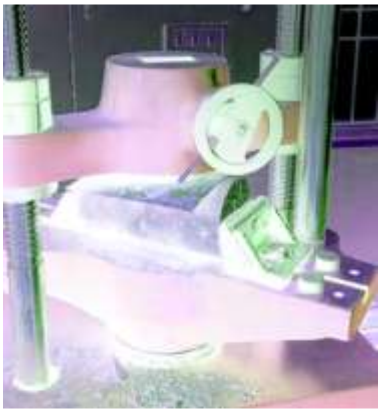

Figure 5: Split Tensile Strength Test

3.4 Test of flexural strength

The specimens have a 0.75 m long beam. Flexural tests on concrete may be guided by one of the three point load tests. Data on the flexural strength of concrete are shown in a table
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Table 11: Results of the Flexural Strength Test

Replacement of polyolefin fiber (%)	Flexural Strength of concrete at 7 Days(N/mm2)	Flexural Strength of concrete at 28 Days (N/mm2)
0	4.4	6.23
0.3	4.98	7.35

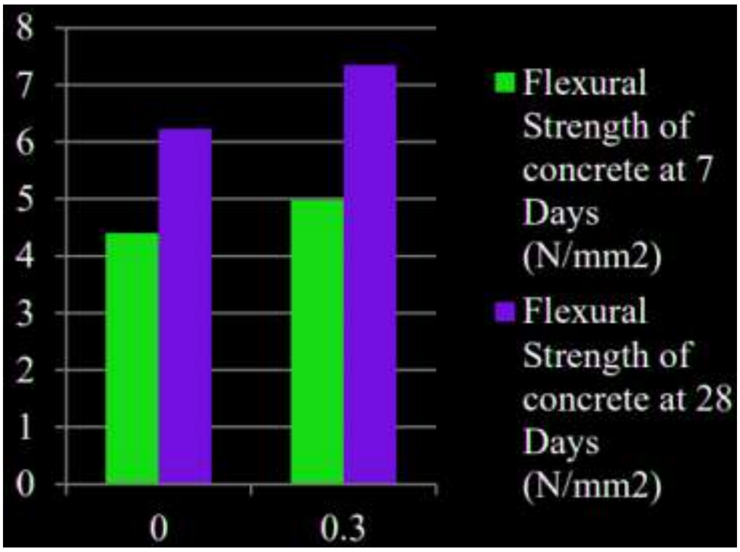

Chart-3: Test of Flexural Strength Results

In comparison to regular concrete, HPC has a higher flexural strength at 28 days (7.35 N/mm2) when polyolefin fibres are 0.3% of the material.

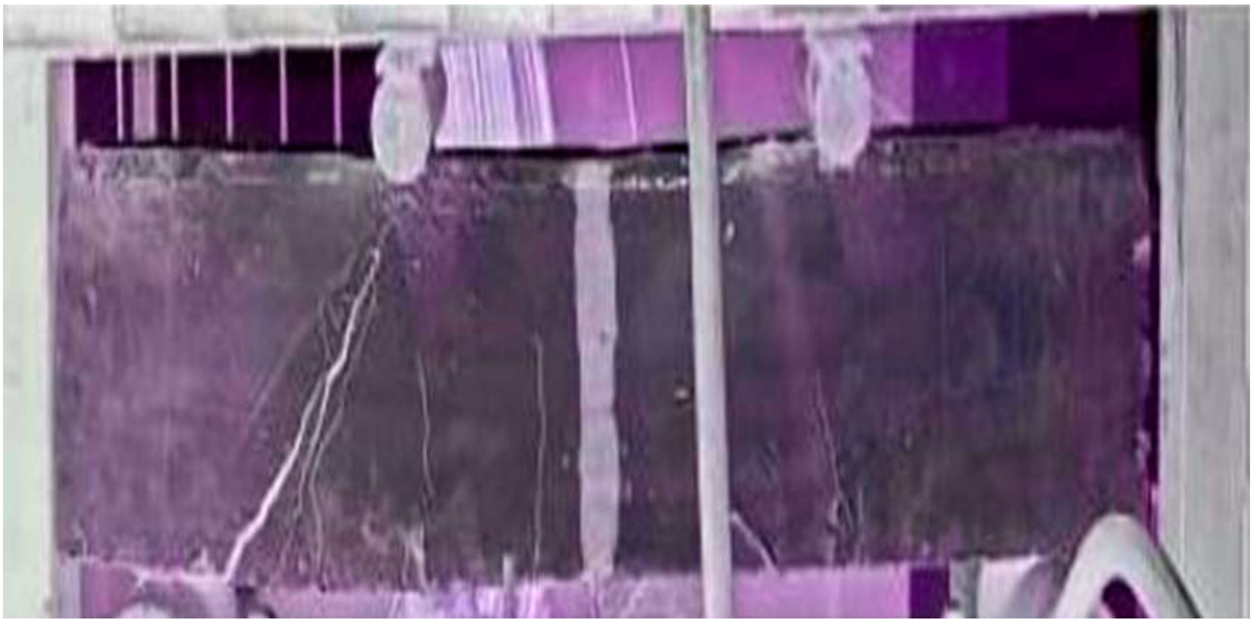

Figure 6: Flexural Strength Test

4. Conclusion

High performance concrete produced the greatest results when 0.3% polyolefin fibre was combined with 10% silica fume and 10% metakaolin as a fractional exchange for the fine aggregate. The strength of HPC is a comparatively high substitute for silica fume and metakaolin as fine aggregate when compared to regular concrete. Comparable to that of conventional concrete, the greatest compressive strength recorded in HPC at 28 days (56.21 N/mm2) at 0.3% polyolefin fibres. As comparison to normal concrete, the peak split tensile strength observed in HPC at 28 days (5.90 N/mm2) with 0.3% polyolefin fibres is greater. As comparison to normal concrete, the maximal flexural strength recorded in HPC at 28 days (7.35 N/mm2) with 0.3% polyolefin fibres is greater. The compressive strength, split tensile strength, and flexural strength all increase when fibre content is added to conventional concrete. The problem of concrete's poor tensile strength can be resolved by adding polyolefin fibres. This study demonstrates that reinforced concrete beams constructed using silica fume and metakolin as a cement replacement material may exhibit better structural performance. Because of the admixtures' ductile behaviour, beams have seen an increase in deflection value. Fibers can help reduce water permeability by preventing macro fractures from forming out of micro cracks.

5. Reference

Alberti, M. G., Enfedaque, A., & Gálvez, J. C. (2014). On the mechanical properties and fracture behavior of polyolefin fiber-reinforced self-compacting concrete. *Construction and Building Materials*, *55*, 274–288.

Alberti, M. G., Enfedaque, A., & Gálvez, J. C. (2017). Fibre reinforced concrete with a combination of polyolefin and steel-hooked fibres. *Composite Structures*, *171*, 317–325.

AlKhatib, A., Maslehuddin, M., & Al-Dulaijan, S. U. (2020). Development of high performance concrete using industrial waste materials and nano-silica. *Journal of Materials Research and Technology*, *9*(3), 6696–6711.

de Sá, F. R. G., Silva, F. de A., & Cardoso, D. C. T. (2020). Tensile and flexural performance of concrete members reinforced with polypropylene fibers and GFRP bars. *Composite Structures*, *253*, 112784.

Deng, Z., Shi, F., Yin, S., & Tuladhar, R. (2016). Characterisation of macro polyolefin fibre reinforcement in concrete through round determinate panel test. *Construction and Building Materials*, *121*, 229–235.

Kim, H.-S., Lee, S.-H., & Moon, H.-Y. (2007). Strength properties and durability aspects of high strength concrete using Korean metakaolin. *Construction and Building Materials*, *21*(6), 1229–1237.

Maruthachalam, D., Padmanaban, I., & Vishnuram, B. G. (2013). Influence of polyolefin macro-monofilament fibre on mechanical properties of high performance concrete. *KSCE Journal of Civil Engineering*, *17*(7), 1682–1689.

Noushini, A., Hastings, M., Castel, A., & Aslani, F. (2018). Mechanical and flexural performance of synthetic fibre reinforced geopolymer concrete. *Construction and Building Materials*, *186*, 454–475.

Ostrowski, K., Dudek, M., & Sadowski, Ł. (2020). Compressive behaviour of concrete-filled carbon fiber-reinforced polymer steel composite tube columns made of high performance concrete. *Composite Structures*, *234*, 111668.

Sasipriya, R., Ezhilarasi, E., Thangadurai, A., & Magudeaswaran, P. (2017). An Experimental Study on Flexural Behaviour of Damaged Reinforced HPC Beams Strengthened with CFRP Wrapping. *International Journal of Civil Engineering and Technology*, *8*(3), 617–627.

Xiao, J., & Falkner, H. (2006). On residual strength of high-performance concrete with and without polypropylene fibres at elevated temperatures. *Fire Safety Journal*, *41*(2), 115–121.

Yang, J.-M., Min, K.-H., Shin, H.-O., & Yoon, Y.-S. (2012). Effect of steel and synthetic fibers on flexural behavior of high-strength concrete beams reinforced with FRP bars. *Composites Part B: Engineering*, *43*(3), 1077–1086.