

Compressive & Flexural Behaviour of Paving Blocks Reinforced with Polypropylene, Steel and Hybrid Fibers

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ABSTRACT

The majority of research on fiber-reinforced concrete only uses one kind of fibre in varying proportions and material combinations. Utilising two or more fibre types in the right proportions could potentially enhance concrete's performance in addition to its quality. Hybridisation is the process of combining multiple fibres, and the resultant mixture is termed hybrid fibre. Paving blocks are in high demand right now due to their many uses in parking lots, walkways and petrol stations, as well as their aesthetic appeal, among other reasons. Polypropylene, steel, and a mixture of the two hybrid fibres with percentages ranging from 0 to 1 percent in paving blocks were compared in this study. The compression test serves as the basis for the comparison.

Keywords: Polypropylene, Hybrid fiber, fiber reinforced Concrete, paving block, Compressive Strength.

I. INTRODUCTION

A lot of work is being done on roads, pavements and roadside areas. The best materials for walkways are concrete paving blocks since they are easier to place and have a superior appearance and finish. Precast solid goods consisting of cement concrete are known as cement concrete paving blocks. The product comes in a variety of forms and sizes, including round, square, and rectangular blocks with patterns that allow neighbouring paving blocks to interlock. The requirement for cement paving blocks has grown to be a crucial component of town and city development and expansion as nations continue to urbanise and develop at an exponential rate. Together with this, a technique has been developed that can increase the amount and performance of cement paving bricks beyond what has been possible in the past.

The majority of Europe was in ruins following World War II, and rehabilitation got underway. Because paving stones have historically shown themselves to be able to survive certain demands that concrete and asphalt could not, they were used to rebuild the roads. In concrete pavers, Fritz Von Langsdorff, a German engineer, created a variety of shapes and introduced colour. Since mass manufacture began in Germany in the 1960s, concrete interlocking pavers have become a practical and affordable option. Production technology expanded throughout Europe and other countries, including the US, throughout the 1970s. Concrete interlocking pavers have grown significantly and consistently in popularity in America since that time..

Fibres are typically added to concrete to prevent cracking caused by drying shrinkage and plastic shrinkage. Additionally, they lessen concrete's permeability, which stops water from leaking. Concrete that contains certain fibre kinds is more resistant to impact, abrasion, and shattering. Fibres often don't improve the flexural strength of concrete, therefore they can't take the role of structural steel reinforcement or moment-resisting reinforcement. The strength of concrete is actually diminished by certain fibres. A novel kind of fiber-reinforced concrete block known as "Hybrid Fibre Reinforced Concrete (HFRC)" was created in the past ten years. The term "hybridisation" describes

the blending of several fibre types. Combining the fibres is meant to enhance the concrete mixture's various qualities. The majority of research on fiber-reinforced concrete only uses one kind of fibre in varying proportions and material combinations. Utilising two or more fibre types in the right proportions could potentially enhance concrete's performance in addition to its quality.

II. LITERATURE REVIEW

Nurain Jamil et al,(2019) Presented the paper on investigates the effect of fiber percentage on compressive strength of fiber reinforced concrete and the relationship between compressive strength and time of fiber reinforced concrete immersion in seawater. FRC concrete cubes were prepared using four different percentage of fiber (0%, 1.5%, 3.0% and 4.5%). These Fiber reinforced were immersed in seawater for 7, 14 and 21 days for three consecutive weeks. Based on the experiment, it was found that there was improvement in compressive strength of Fenaf fiberwhen compared to plain cement concrete.

N Dayananda(2018) The primary objective of this study is to investigate the effect of reinforcing raw propylene fibers on the mechanical properties of cement concrete paver blocks. The mixed specimens are casted for different volume content of fibers (0.2%, 0.4%, 0.6%, 0.8%, 1%, 1.2%, 1.4%, 1.6% and 1.8%) and cured for 3, 7 and 28 days.

Dinesh W.Gawatre, et.al(2017) The concept is to make sustainable use of concrete waste in concrete which can be used in manufacturing of interlocking paver blocks, After crushing, this concrete waste can be used as a replacement of coarse and fine aggregate in one stage as half replacement in paver block by considering is specification

R.Mahadevi ,et.al{2016} 'PLASTIC IN PAVER BLOCK".The aim of this research is to reduce the unit weight, cost of block and also to reduce the environmental pollution.The plastic is used in the form of powder as partial replacement in M-Sand as fine aggregate in percentage of 0, 10 and 30 to manufacture paver blocks

Dahlke and Charkha (2016) had addressed that the impact of steel fibers on concrete strength was investigated, revealing that their addition enhanced the mechanical properties of concrete. This improvement included heightened compressive and flexural strengths, as well as decreased porosity and absorption capacity in comparison to conventional concrete.

Gherman et al. (2016) investigated the impact of fiber additions to high-strength concrete, highlighting improvements in various engineering properties. These included enhanced post-crack behavior, where fibers bridged across cracks, providing increased ductility. Significantly, the compressive strength of high-strength concrete reinforced with fibers reached its zenith at a volume fraction of 0.8% of fibers, showcasing a notable 21% enhancement compared to high-strength concrete devoid of fibers. Furthermore, fiber-reinforced concrete displayed a substantial surge in energy absorption, attaining a volumetric increase of 97.8%.

Shanmuga Priya(2015) Glass Fiber is used as an admixture in paver block for strengthening purpose. The usage of glass fiber in concrete is found from last two decades in the industry. By using glass fiber in paver block, various properties of concrete are improved like compressive strength. and tensile strength.

Marlon (2015) The utilization of undulated steel fibers for reinforcement in paving blocks was investigated. The findings revealed a lack of extensive research focused on the integration of steel fibers in concrete paving blocks, prompting the need for further analysis. Therefore, a comprehensive understanding of the material properties is essential to optimize its economic utilization in concrete.

Geethanjali C. et al. (2014) This research investigates the combination of fibres, also known as hybridization, for an M40 grade concrete with a volume proportion of 0.5 percent. Steel and polypropylene fibre proportions were varied in the control and three hybrid fibre composites. The results of the compressive strength, split tensile strength, and flexural strength tests were evaluated to determine which fibre combinations were associated with the above fibre combinations. The paper identifies fibre combinations that demonstrate maximum compressive, split tensile, and flexural strength of concrete based on experimental tests. It is discovered that compressive strength and split tensile strength, as well as compressive strength and flexural strength, have a relationship.

Rajeswari B. et al. (2011) In his research, he looked at the influence of adding mono fibre and hybrid fibre to the mechanical properties of concrete mixtures. Steel fibres of 1% and polypropylene fibres of 0.036 percent were introduced to the concrete mixture separately as mono fibres, and then combined to make hybrid fibre reinforced concrete. The compressive, tensile, and flexural strength of the material were determined. In comparison to mono fibre, the compressive strength of hybrid fibre improves somewhat. Hybridization significantly enhances split tensile strength and flexural strength.

Anacleto Turatsinze et al. (2010) The flexural properties of metallic-hybrid-fiber-reinforced concrete will be investigated. Amorphous metallic straight fibre was employed, which was classified as non-sliding due to its rough surface and large specific surface area, and carbon steel hook-ended fibre, which was classified as slipping. Normal, single-fiber-reinforced, and hybrid-fiber-reinforced concrete were all prepared. According to the results of experiments with single fibre fiber-reinforced concrete, adding high-bonding amorphous metallic fibre slows the formation of microcracks and results in a high peak load, whereas carbon steel hook-ended fibre contributes to flexural toughness by only one type of fibre. The employment of two or more types of fibres in an appropriate mix may improve not only the general characteristics of concrete, but also the ability to bridge macro-cracks in the post-peak zone. The findings of the tests on hybrid-fiber-reinforced concrete reveal that when the two metallic fibres are combined in a hybrid form, they perform better than their single-fiber-reinforced counterparts.

N. Banthia and R. Gupta (2004) Fiber reinforced concrete (FRC) contains performance synergy, which has been examined. This research investigates the merging of fibres, also known as hybridization, for a very high strength matrix with an average compressive strength of 85 MPa. Different fibre types, such as macro and microfibers of steel, polypropylene, and carbon, were used to cast control, single, two-fiber, and three-fiber hybrid composites. Flexural toughness tests were carried out, and the results were thoroughly evaluated to see if there was any synergy between different fibre combinations. The paper identifies fibre combinations that display maximum synergy in terms of flexural toughness using various analysis methodologies.

Song and Hwang (2004) The mechanical properties of high-strength steel fiber-reinforced concrete (HSFRC), including compressive strength, splitting tensile strength, and modulus of rupture, all demonstrate improvement with the addition of steel fibers at various volume fractions. These fibers, characterized by a needle-like discontinuous appearance, are utilized in steel fiber-reinforced concrete (SFRC) to enhance concrete elements. They are produced in various types such as hooked end, undulated, stranded, crimped, wave, twisted, or flat, tailored to specific construction projects. Employed in construction to augment the tensile strength of concrete materials (Chircu, 2009), steel fibers have been investigated extensively. Behbahani et al. (2011) provided an overview of the mechanical properties of steel fiber-reinforced concrete (SFRC), demonstrating significant improvements in flexural strength and overall toughness compared to conventional reinforced concrete.

Nagabhushanam et al. (1999) With three different concentrations of fibrillated polypropylene fibres, the flexural fatigue strength of fibrillated polypropylene fibre reinforced concrete was examined. The evaluation of flexural fatigue strength and endurance limit was part of the test programme. The insertion of fibres resulted in a significant increase in post-crack energy absorption capacity and ductility, according to the test results. The flexural fatigue strength and endurance limit (for 2 million cycles) were dramatically raised as compared to similar plain concrete. Despite the required increase in water/cement ratio (w/c) to meet workability standards, the results showed that raising the fibre content from 0.5 percent to 1.5 percent had a considerable favourable effect on the first crack strength.

Ozyildirim et al. (1997) The influence of different fibre kinds and quantities on Hydraulic Cement Concrete was examined (HCC). Steel fibres (hooked-end and in percentages of 0.4 and 0.6 percent by volume), fibrillated polypropylene (0.2 percent by volume), monofilament polypropylene (0.1 and 0.3 percent by volume), and polyolefin fibres (0.1 and 0.3 percent by volume) were all present in the concrete (1.3 and 1.6 percent by volume). The results showed that increasing the fibre volume and length improves the impact resistance and toughness of fibre reinforced concrete.

Bayasi and Celik (1993) The impact of silica fume on the flexural strength of synthetic fibre reinforced concrete was examined. Fibrillated Polypropylene fibres and polyester fibres were employed in the study, with fibre amounts ranging from 0 to 0.6 percent by volume. At 0, 5, 10, and 25%, silica fume was utilised to partially replace Portland cement. The findings revealed that while polyester and polypropylene fibres had a mixed effect on flexural strength, they greatly boosted flexural toughness and post-peak resistance of concrete.

III OBJECTIVES OF INVESTIGATION

1. To investigate the performance of paving blocks having various fibre percentages and to determine the best fibre percentage.
2. To compare the performance of polypropylene, steel, and a hybrid fibre made up of both steel and polypropylene fibre.

IV. MATERIALS

1. Fiber: The use of fibre in concrete is dependent on fibre features such as orientation, aspect ratio, and functional properties to improve concrete performance. Polypropylene, steel, and hybrid fibres are used in this project study.
2. Fine aggregate: As a fine aggregate, river sand is employed. The most important attribute of fine aggregate is its grading, which is one of many. Coarser sand may be desired since finer sand increases the water requirement of concrete, and extremely fine sand may not be required in fine aggregate because it typically contains more fine particles in the form of cement and mineral admixtures such fly ash and silica fume. The sand particles should also pack tightly in order to achieve a low void ratio. To develop a dense fine aggregate mix with the best cement content and the least amount of mixing water, properties including gradation, specific gravity, and water absorption must be evaluated. The fine aggregate was river sand, which conformed to zone 2.
3. Admixture and pigment: Chemical admixtures have the advantage of acting as accelerates, water reducers, extrusion aids, water reducing agents, and so on. The use of S 1014-compliant pigments was necessary. Pigmentation might be partial, such as on restricted to the upper surface, or it can cover the entire block. On the upper surface, dolomite powder is used.
4. Polypropylene fiber: Tactility is a key term in understanding the relationship between polypropylene structure and characteristics. The capacity of the polymer to form crystals is strongly influenced by the relative orientation of each methyl group (CH₃ in the figure) compared to the methyl groups in nearby monomer units.



Figure 1: Polypropylene fiber

Physical property of Polypropylene fiber

Fiber type – Monofilament

Diameter – 0.03 ± 0 mm.

Melting point -170 degree Celsius

Density - 0.91 ± 0.01 (g/cm³)

Aspect ratio - 40

Tensile strength-450 MPa. Used length – 12 mm

5. Steel Fiber: Steel fibre can be found in plenty on the market. It also has great tensile strength and melting point, as well as resistance to most chemicals, making it an excellent reinforcing material. Steel fibre is one of the most commonly used materials in many building projects due to its high ductility.



Figure 2: Steel fiber

Physical property of steel fiber

Fiber type – Crimped Metallic

Diameter – $0. \pm 6$ mm.

Aspect ratio– 60

Tensile strength- 800mpa.

Used length – 35mm.

6. Hybrid fiber: Hybrid fiber is combination of both steel and polypropylene fiber.

7. Hybridization of fibers: In the recent decade, a novel type of fibre reinforced concrete called "The Hybrid Fiber Reinforced Concrete (HFRC)" was developed, which improves both tensile strength and ductility [9-14]. The term "hybridization" refers to the blending of different fibre kinds. The goal of mixing the fibres is to improve the concrete mixture's numerous qualities. This composite material outperforms plain and mono fibre reinforced concrete in terms of behavioural efficacy.

8. Hybrids Based on Fiber Constitutive Response: The first form of fibre is stronger and stiffer, resulting in reasonable first crack strength and ultimate strength, while the second type is more flexible, resulting in better toughness and strain capacity in the post-crack zone.

9. Hybrids Based on Fiber Dimensions: One form of fibre is smaller, allowing it to bridge micro-cracks, slowing their growth and preventing coalescence. As a result, the composite's tensile strength is increased. The second fibre is larger and is designed to stop macro-cracks from propagating, resulting in a significant increase in the composite's fracture toughness. The specific surface area (SSA) of the fibre used is frequently used to differentiate hybrids based on fibre parameters. The surface area for a unit mass [5] can be defined as the SSA and mathematically,

$$SSA_m = [2(2/d) / lD_f]$$

When using fibers based on their size (micro or macro) alone, SSA can also be defined as the surface area for a unit volume, and can be written mathematically as,

$$SSA_v = [2(2/d) / d]$$

Where l is the length of a circular fibre, d is its diameter, and D_f is the density of the fibre material. Micro fibres are defined as fibres with an SSA more than 500cm²/gm while macro fibres are defined as fibres with an SSA of around 10 cm²/gm. The micro-fibers support cement paste and mortar phases, as their high SSA and tiny size imply, delaying crack coalescence and enhancing the apparent tensile strength of these phases.

V. TESTING PROGRAM

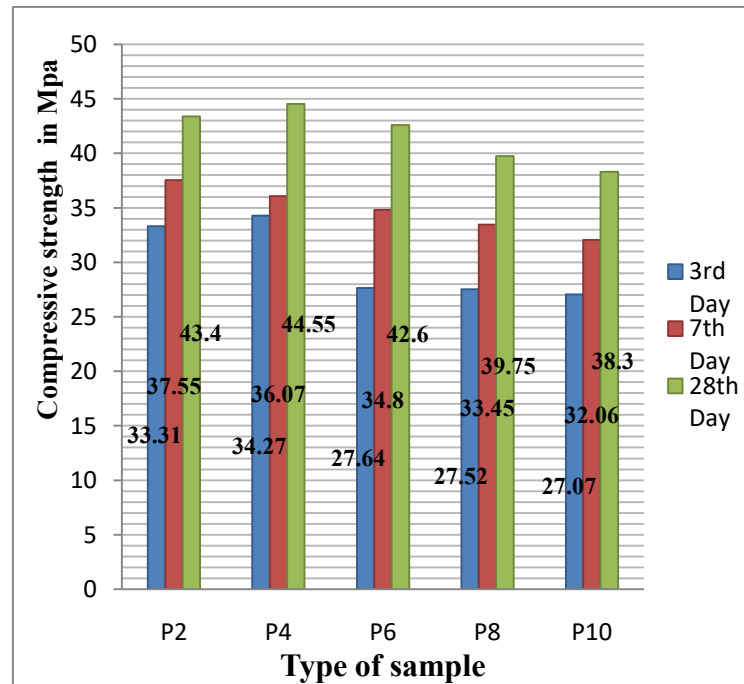
Compression test: When blocks are removed from the water and are still wet, they must be tested right away. Surface water and grit must be removed from the specimens, as well as any protruding fins. The specimen's measured compressive strength is computed by dividing the greatest force applied to it during the test by the cross-sectional area, estimated from the section's mean dimensions, and expressed to the closest N per sq mm. As a representative of the batch, the average of three values will be used. The compression test will be performed on the specimens on the 3rd, 14th, and 28th days aged. Multiply the apparent compressive strength by the appropriate correction factor from Table 5 of IS 15658: 2006, Annex D to get the corrected compressive strength.



Figure 3 - Compressive strength testing on CTM

Table 1. Compression test result for PP fiber

Nomenclature Of sample	Percentage Fiber content (%)		3 rd day compressive strength In MPa..	7 th day compressive strength In MPa..	28 th day compressive strength In MPa..
	Steel	Polypropylene			
P2	--	0.2	33.31	37.55	43.40
P4	--	0.4	34.27	36.07	44.55
P6	--	0.6	27.64	34.80	42.60
P8	--	0.8	27.52	33.45	39.75
P10	--	1	27.07	32.06	38.30

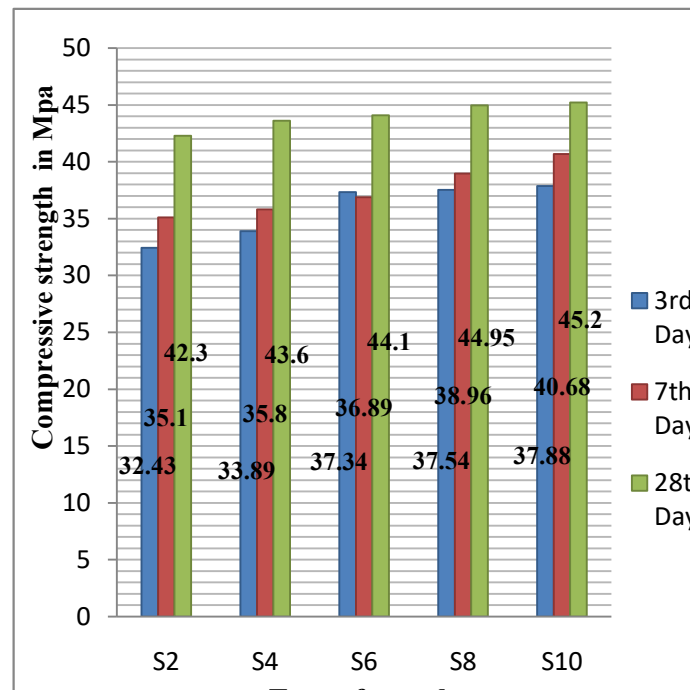


Graph 1. Compression test result for PP fiber

- As the amount of polypropylene fibre is increased, the compressive strength of polypropylene fibre reinforced concrete increases. However, as the compression strength reaches a certain limit, it begins
- For the third day test, compressive strength improved by 0.2 percent (P2) to 0.4 percent (P4), which is over 10%.
- Concrete paving block compressive strength was shown to be reduced above 0.4 percent polypropylene.
- As a result, the optimal fibre content is 0.4 percent (P4), which has a better compressive strength than conventional concrete.

Table 2. Compression test result for Steel fiber

Nomenclature Of sample	Percentage Fiber content (%)		3 rd day compressive strength	7 th day compressive strength	28 th day compressive strength
	Steel	Polypropylene			
S2	0.2	--	32.43	35.10	42.3
S4	0.4	--	33.89	35.80	43.6
S6	0.6	--	37.34	36.89	44.10
S8	0.8	--	37.54	38.96	44.95
S10	1	--	37.88	40.68	45.20

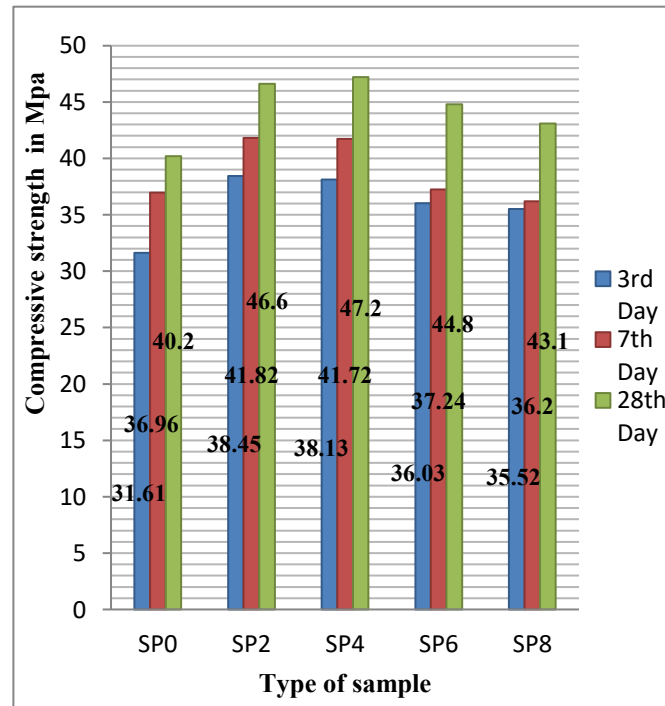


Graph 2. Compression test result for Steel fiber

- As the proportion of fibre increases, the compressive strength of steel fibre reinforced concrete increases.
- Steel fibre reinforced concrete blocks have a compressive strength of 42.3 MPa for 0.2 percent fibres in concrete paving blocks and 45.2 MPa for 1 percent steel fibre in concrete paving blocks.
- The results reveal that utilising steel fibre increased the compressive strength of conventional concrete paving blocks by 10%.

Table 3. Compression test result for hybrid fiber

Nomenclature Of sample	Percentage Fiber content (%)		3 rd day compressive strength	7 th day compressive strength	28 th day compressive strength
	Steel	Polypropylene			
SP0	--	--	31.61	36.96	40.2
SP2	0.8	0.2	38.45	41.82	46.6
SP4	0.6	0.4	38.13	41.72	47.2
SP6	0.4	0.6	36.03	37.24	44.8
SP8	0.2	0.8	35.52	36.20	43.1



Graph 3. Compression test result for hybrid fiber

- As the proportion of fibre increases, the compressive strength of hybrid fibre reinforced concrete increases. For samples SP6 and SP8, however, compression strength diminishes as the amount of polypropylene fibre increases.
- The maximum compressive strength of a steel fibre reinforced concrete block is 47.2 MPa when it contains 0.4 percent polypropylene and 0.6 percent steel fibre.
- The compressive strength of the SP4 sample is 47.2 MPa. This is over 18% more than a standard concrete paving block.

Flexural test : The flexural strength of paving blocks can be expressed in term of flexural stress or in from of breaking load. This breaking load is calculated by,

$$F_b = (3PL)/bd^2$$

F_b = Flexural strength, in N/mm², P = maximum load in N,

L = Span length in mm, b = Average width of block

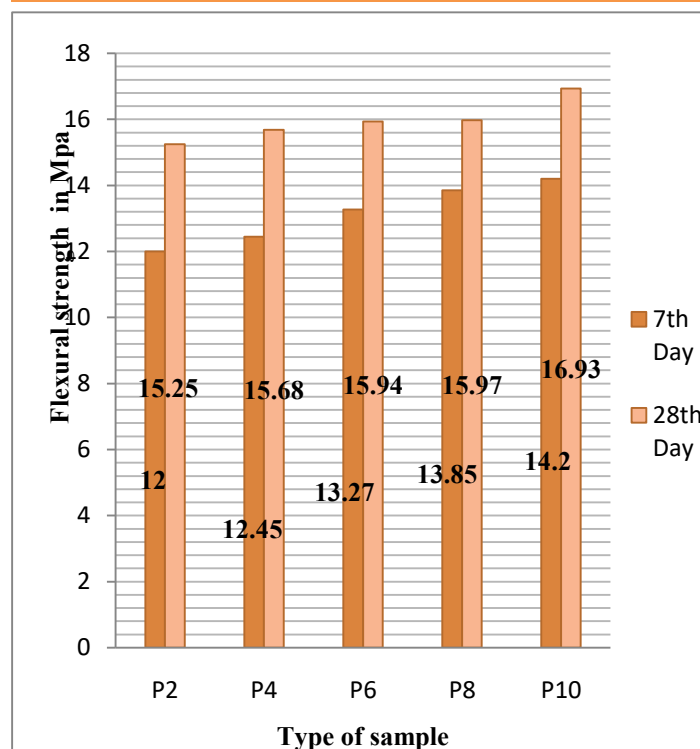
d = Thickness of block.



Figure 3 - Flexural test

Table 1. Flexural test result for PP fiber

Nomenclature Of sample	Percentage Fiber content (%)		7 th day Flexural strength In MPa.	28 th day Flexural strength In MPa.	Allowable limit as per IS 15658: 2006
	Steel	polypropylene			
P2	--	0.2	12	15.25	Minimum 7 MPa. For heavy duty load.
P4	--	0.4	12.45	15.68	
P6	--	0.6	13.27	15.94	
P8	--	0.8	13.85	15.97	
P10	--	1	14.2	16.93	



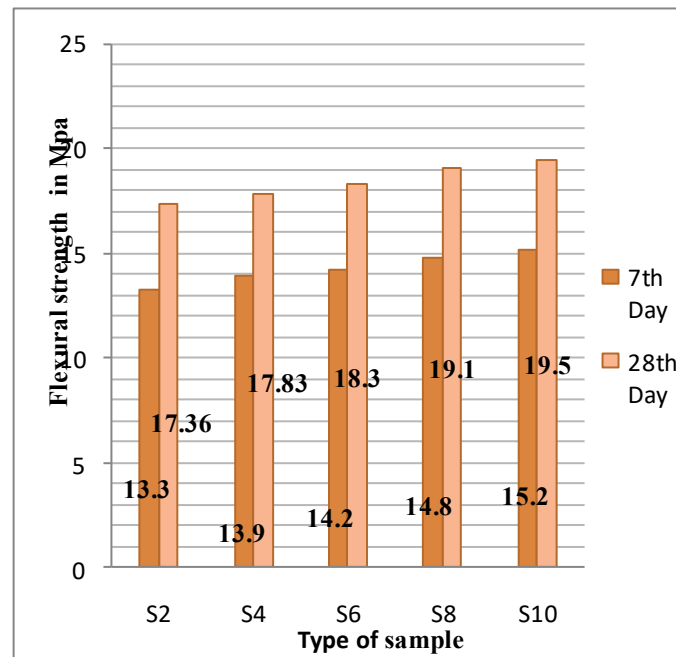
Graph 1. Flexural test result for PP fiber

- As the proportion of fibre increases, the flexural strength of polypropylene fibre reinforced concrete increases.
- Flexural strength of polypropylene fiber reinforced concrete is maximum 16.93 MPa. For P10 which is 19% higher than ordinary concrete paving block.

Table 2. Flexural test result for Steel fiber

Nomenclature Of sample	Percentage Fiber content (%)		7 th day Flexural strength In MPa..	28 th day Flexural strength In MPa..	Allowable limit as per IS 15658: 2006
	Steel	polypropylene			

S2	0.2	--	13.3	17.36	Minimum 7 MPa. For heavy duty load.
S4	0.4	--	13.9	17.83	
S6	0.6	--	14.2	18.3	
S8	0.8	--	14.8	19.1	
S10	1	--	15.2	19.5	



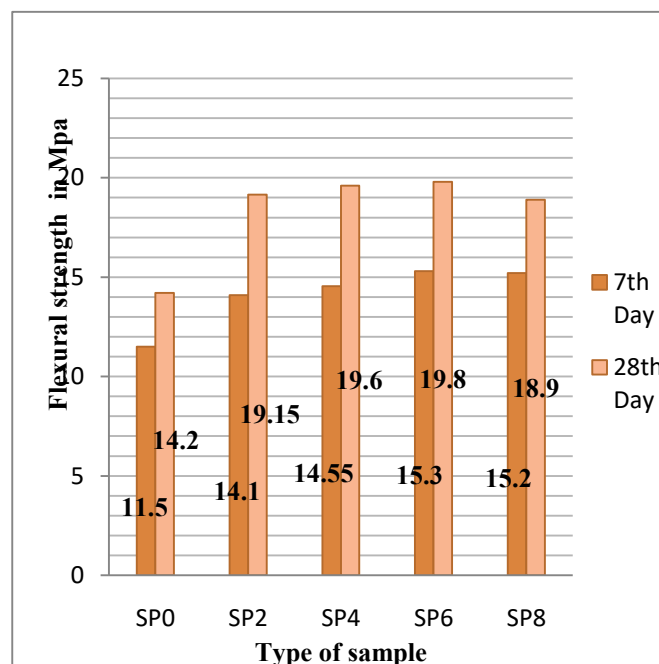
Graph 2. Flexural test result for Steel fiber

- As the proportion of fibre increases, the flexural strength of steel fibre reinforced concrete increases.
- Flexural tests on different steel fibre samples were performed on the 14th and 28th days.
- Steel fibre reinforced concrete has a maximum flexural strength of 19.5 MPa for 1 percent steel fibre in concrete paving block P10, which is 22% greater than conventional concrete paving block.

Table 3. Flexural test result for hybrid fiber

Nomenclature Of sample	Percentage Fiber content (%)		7 th day Flexural strength In MPa..	28 th day Flexural strength In MPa..	Allowable limit as per IS 15658: 2006
	Steel	polypropylene			
SP0	--	--	11.5	14.2	Minimum 7 MPa. For heavy duty
SP2	0.8	0.2	14.1	19.15	
SP4	0.6	0.4	14.55	19.6	
SP6	0.4	0.6	15.3	19.8	

SP8	0.2	0.8	15.2	18.9	load.
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Graph 1. Flexural test result for hybrid fiber

- As the proportion of fibre increases, the flexural strength of hybrid fibre reinforced concrete increases. However, as the amount of polypropylene fibre in sample SP6 and SP8 increases, the compression strength drops.
- Hybrid fibre reinforced concrete has a maximum flexural strength of 19.8 MPa for SP6 sample P10, which is 23% greater than ordinary concrete paving blocks.

VI. CONCLUSIONS

- It has been discovered that the workability of concrete decreases with the inclusion of fibre, particularly with the addition of polypropylene fibre. Steel fibre has a slight effect on workability, although not as much as polypropylene fibre.
- Paving block compressive strength rises with increasing fibre percentages up to 0.4 percent polypropylene, but steel fibre compression capacity increases with rising fibre percentages. The best combination for hybrid fibre is 0.4 percent polypropylene and 0.6 percent steel fibre, since the compressive strength for the same combination is 47.2 MPa. Ordinary concrete paving block is 18% more expensive.
- For both steel and polypropylene fibre, the flexural strength of paving blocks rises as the fibre fraction increases. Steel fibre reinforced concrete outperforms polypropylene fibre reinforced concrete.
- The result for hybrid fibre with 0.4 percent polypropylene and 0.8 percent steel fibre is the best of all the combinations, with a 23 percent higher flexural strength than standard concrete paving block.

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