

Investigation on the Effect of Coconut Shell and Polypropylene Fibers on Engineering Properties of Concrete

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Abstract: Concrete is a very important building material in the construction industry, because of its good mechanical properties, durability and its economical use. But there are some limitations in its strength properties. The tensile strength of concrete is much lower than its compressive strength which is responsible for the development of cracks that can easily propagate and significantly reduce its durability and serviceability, this is a limitation for its applications in several important constructions. However, the addition of several types of fibres in the concrete mix produces Fiber Reinforced Concrete (FRC) which increases its crack-resisting properties in hardened concrete and improvement in some properties of the concrete mix. The demand for concrete is increasing globally for infrastructure development. Since, coarse aggregate is a component in the production of concrete, its demand and usage are also increasing. Natural coarse aggregate which is used in the production of concrete is a non-renewable limited resource and much research is going on for a material suitable for the replacement of coarse aggregate. Coconut shell is a waste material that is produced in large quantities and can partially replace coarse aggregate. By using coconut shells, the disposal problem of coconut shell waste is reduced and

also reduce the usage of natural coarse aggregate in concrete. So, in this research work, experiments were conducted to study the effect of the addition of Coconut shell (CS) as a partial replacement of coarse aggregate and the addition of Polypropylene fibre (PF) on properties of the concrete mix such as workability, compressive strength and flexural strength on concrete in the fresh and hardened state. In the present study, 5% waste CS was used as partial replacement in place of natural coarse aggregate, and PF was mixed in four different proportions of 0.5%, 1%, 1.5% and 2% by volume of cement in the concrete mix. Concrete cubes and beams using crushed coconut shell and polypropylene fibre were casted and tested for variation in workability and effect on compressive and flexural strength values were noted and results were compared with the control set cube and beam. It was observed that the slump value of the concrete mix kept on decreasing with an increase in the percentage of polypropylene fibre in concrete. The test results show that the compressive strength and flexural strength of concrete cubes and beams kept on increasing up to an extent and then kept on decreasing with an increase in the percentage of polypropylene fibre in concrete.

Keywords: Fiber Reinforced Concrete, Polypropylene fibre, Coconut shell, workability, Compressive strength, Flexural strength

1. Introduction

Concrete is an important construction material used in the construction industry, which is strong in compression but weak in tension [1]. The tensile strength of concrete is around ten times smaller than compressive strength [2]. Since the tensile strength of concrete is much lower than its compressive strength, therefore crack propagation can be developed easily and cracks in members of structures significantly reduces its durability and serviceability [3]. Due to this development of cracks, there are some limitations to the use of concrete in its

application in the construction of important buildings [4]. Using different types of fibres like steel, glass, carbon, and polypropylene fibres with a different aspect ratio as a reinforcing material in concrete, commonly known as Fiber Reinforced Concrete (FRC), is a possible solution to alter the behaviour of concrete which restricts cracks produced in concrete [5], [6]. Using FRC with fibres like steel covers the majority of concrete applications but can get corrosion due to moisture in the air. However, using fibre like polypropylene fibre is a great solution to resist corrosion in concrete [7]. Concrete

which is resistant to corrosion has a long life and is more durable. With high strength, excellent durability, low price, excellent ductility, and low modulus of elasticity, polypropylene fibre is often used in concrete to improve the crack-resisting property of concrete matrix [8].

Fiber Reinforced Concrete (FRC) is a type of concrete produced by mixing concrete materials with discrete fibres. Polypropylene fibre is a by-product obtained from the textile industry, it consists of 85 % propylene which can be used in different range of applications [9]. Polypropylene fibre is a new-generation commodity fibre which is produced in large volumes reaching production of around 4 million tons a year globally. Since, it has low density, excellent chemical resistance, and high stiffness, therefore it has many applications in industries, packaging materials, carpets, textiles etc. [10]–[12]. FRC is useful in several applications consisting of important and large projects. These fibres are already in use in various projects like the construction of pavements, highway overlays, industrial floors etc. in India [4]. The addition of polypropylene fibres in concrete leads to improvement in the properties of concrete. In research work, the effects of adding polypropylene fibres on various properties of concrete samples such

as compressive strength, permeability and electrical resistivity of the concrete sample were checked [13], [14]. It was observed that the addition of these polypropylene fibres to concrete affects many of its properties such as workability, compressive strength and flexural strength.

Cracks produced in concrete influence its durability and strength properties. If the width of cracks produced is large, it will cause a reduction in the durability and serviceability of the structure. Thereby, it is important to restrict the width of cracks produced in conventional concrete, this can be achieved by the addition of polypropylene fibres to concrete. The addition of fibres in concrete can create a “bridge” across these cracks, after the application of load and restrict it from further opening [15].

Sustainable development is a type of principle in which the conservation of Earth resources is made in such a way that productive utilization of resources is done so that meeting current requirements for various human needs as well as conserving resources for future generations. Sustainable construction also follows the same principle in infrastructure development. Non-renewable natural resources are limited on our planet, and over-utilization of it can

deplete these resources drastically. In the field of construction, concrete consists of natural aggregates which are limited on our planet [16]. So, we need to find alternative sources of coarse aggregates. Much research is going on around the world for a suitable material that can replace coarse aggregate. Lightweight aggregate concrete (LWAC) is a new material used in construction and has gained immense popularity because of its low weight or density, economical, has thermal insulation properties, and there are many Lightweight concrete structures (LWC) formed around the world using these materials[17]. The advantage of lightweight aggregate concrete is that it has an overall cost saving of around 10-20% as compared to equivalent normal wt. concrete and a smaller cross-section of structural elements are formed [18]. One such alternative to lightweight aggregate is a coconut shell, which is agricultural waste produced in large volumes [19]–[21]. India is the third largest producer of coconut having an annual production of about 7562 million nuts with an average of 5295 nuts per hectare. Also, demand for coconut is increasing globally, which in turn will also generate a lot of coconut shell waste, as it generates solid waste in the form of shells with an annual production of approximately 3.18 million

tonnes. So, it also creates a waste disposal problem as there are not many options for the application of these coconut shells [22]–[25]. So, using this waste coconut shells as a partial replacement of coarse aggregate helps in the reduction of the problem of waste disposal, reduces the use of coarse aggregate in construction which leads to the conservation of natural coarse aggregate, lowers the cost of concrete mix, effective utilization of agricultural waste of coconut shell and produces Lightweight concrete structures.

In research, it was found that coconut shell mixing in concrete decreases its workability, and an increase in the percentage of coconut shells decreases the densities of concrete. Using coconut shell as partial replacement of coarse aggregate, of around 10% and 20% replacement decreases slightly strength properties of concrete. But, the partial replacement of coarse aggregate by coconut shell, and partial replacement of cement by fly ash, increase compressive strength properties [26].

There is much research going on globally for other waste materials that can be added to concrete, for reducing the cost of construction, causing less environmental pollution and improving some of the properties of concrete. Some of the waste

materials added to the concrete are recycled aggregate, carbon nanotubes, recycled glass, coconut fibres and crushed clay bricks [27].

In a study, it was found that using recycled aggregate in concrete affects its properties depending on the quality of recycled aggregate and the site from which it is recovered. However, there are some limitations due to variations in aggregate strength, gradation requirements etc., and can be resolved during the mix proportioning stage. Using different combinations of coarse and fine aggregates without changing particle size would give comparable flexural, splitting and compressive strength of concrete, produced by mixing recycled aggregates [28]–[30].

Mixing Carbon nanotubes (CNT) in cement paste would increase the electrical conductivity of concrete and concrete attains self-sensing properties. Composites made by mixing CNT and cement improve their mechanical strength and the sensitivity of concrete to electrical conductivity increases, which helps in monitoring stress, strain, pressure, displacement and temperature to make it suitable for structural health monitoring applications [31]. Adding CNT to concrete, test results show it leads to an increase in the tensile, compressive and bond

strength of specimens compared to control set specimens [10].

Mixing waste glass powder (WGP) as partial replacement of cement for three concentrations of 10%, 20% and 30%, increases compressive strength and flexural tensile strength at 20% partial replacement of cement in concrete and increase in workability of concrete with the increase in partial replacement of cement by waste glass powder in concrete mix [32].

Natural fibres have emerged as one of the better materials that can be used as reinforcing material in concrete for sustainability. A study conducted on mixing coconut fibre with concrete shows that, it helps in resisting the development of cracks in concrete [27].

In a study conducted by using recycled brick aggregate (RBA), test results showed that Asphalt concrete made with RBA has better properties of specimens than made with granite aggregates, because of the roughness and high porosity of the surface of crushed clay brick aggregates [33].

In this project, partial replacement of coarse aggregate by 5% weight of crushed coconut shell is used. Also, the addition of polypropylene fibre of 18mm length in 4 proportions of 0.5%, 1.0%, 1.5% and 2% was

added to the concrete. This project deals with the effect of adding partial replacement of coconut shell and addition of polypropylene fibre on properties of concrete such as workability, compressive strength and flexural strength. All the experiments were carried out in the Civil Engineering Department of Madan Mohan Malaviya University of Technology, Gorakhpur, UP, India.

2. Materials and methods

2.1. Materials

Different materials used in our project work are:

Cement: The OPC-43 grade cement was used in all experiments conforming to Indian Standard IS: 8112-2013 was used as a binder.

Fine aggregate (Sand): The analysis of fine aggregates was done according to IS:383-1970, it was found to be natural sand of Zone-II having a specific gravity of 2.69. Sand passing through a 4.75 mm sieve was used. The sand was brought from a nearby local shop.

Coarse aggregate: Natural crushed stones were used in all experiments. A coarse aggregate sample passing through a 20mm sieve and retained on a 4.75 mm sieve was used. Coarse aggregate was brought from a nearby local shop.

Water: Water used here in all types of the mix was tap water, free from all types of chemicals as per IS 456: 2000 code.

Polypropylene fibre: Polypropylene fibre (PPF) is a type of synthetic fibre obtained from the propylene polymerisation of linear polymer synthetic fibres (Bhat and Vikram,2023). In this study, polypropylene fibres of 18 mm in length and an average diameter of 0.035 mm were used. The Polypropylene fibres were purchased from Pashupati Polytex Pvt. Ltd., Kashipur, Uttarakhand, India. Figure 1 shown below is polypropylene fibre used in this study.

A coconut shell is an agricultural waste material obtained from the outer shell of the coconut. Coconut shell was collected from a nearby temple, it was washed with water and dried in sunlight. The crushed coconut shell was obtained by manually crushing it in an iron okhli, as shown below in **Figure 2**. The crushed coconut shell sample used in the experiment was passed through a 12.5 mm sieve and retained on a 4.75 mm sieve was used as a partial replacement of coarse aggregate. The properties of crushed coconut shells as found are shown below in Table-1.



Figure 1 Sample of Polypropylene fibre used

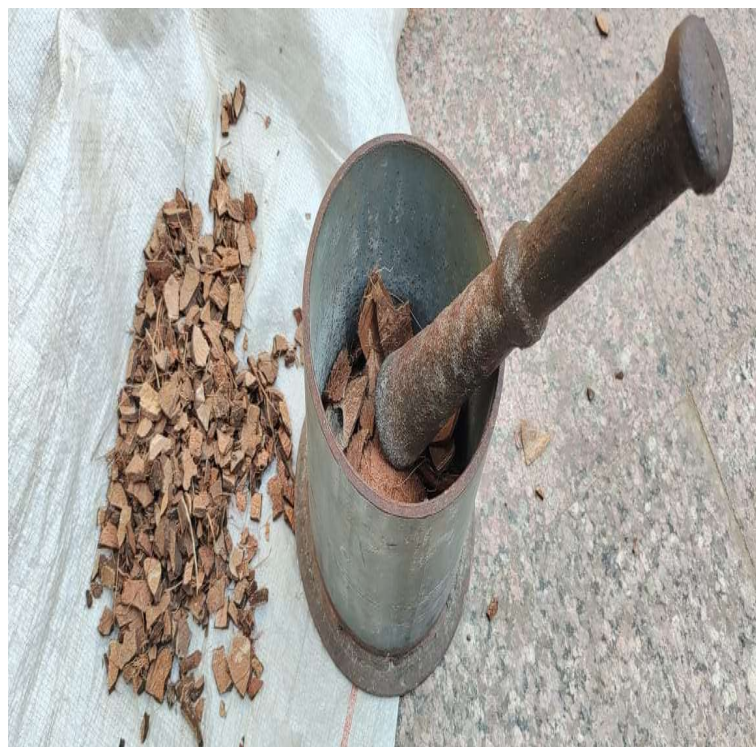


Figure 2 Crushed coconut shell in an iron okhli

Table 1 Properties of crushed coconut shell

S. No.	Properties	Crushed coconut shell values
1	Maximum size (mm)	12.5
2	Minimum size (mm)	4.75
3	Water absorption (%)	24
4	Fineness modulus	6.26
5	Specific gravity	1.10
6	Shell thickness (mm)	3-8
8	Bulk density(g/cc)	0.64
9	Moisture content (%)	4.2

2.2. Methodology

The methodology of work consists of:

- 1) Identify the particulars of materials to be used in the experiment.
- 2) Required materials were collected.
- 3) M 25 grade of concrete mix design is prepared.
- 4) Cubes and beams were cast for different types of mix.
- 5) Different types of mix are prepared such as for the control set and mixes made by adding 0.5%, 1%, 1.5% and 2% of polypropylene fibres in concrete.
- 6) A slump test was performed on freshly prepared concrete and got information about its workability.
- 7) Compressive strength test was performed at 7 & 28 days of curing of cube specimen.
- 8) Ultrasonic pulse velocity test performed at 28 days of curing of cube specimen.
- 9) Flexural strength test performed at 28 days of curing of beam specimen.
- 10) Test results were analyzed and the optimum percentage of addition of polypropylene fibre and coconut shell is found.

2.3. Mix proportioning

Five types of mixes were prepared in this experiment with the partial replacement of coarse aggregate by 5% coconut shell. The first mix of concrete M1 was a control set prepared with 0% polypropylene fibre by volume of cement. Control set cube and beam were cast by replacing 5% of coarse aggregate with crushed coconut shell and without using polypropylene fibre. The second, third, fourth and fifth mix was prepared by using variations of polypropylene fibres of 0.5%, 1%, 1.5% and 2% respectively by volume of cement, denoted as M2, M3, M4 & M5 respectively. OPC 43 grade cement, natural sand, coarse aggregate, coconut shell, polypropylene fibre and tap water was used. The water-cement ratio was kept constant for all mixes. All ingredients were mixed by hand until a uniform mix was made. All moulds of cube of size (150x150x150 mm) and beam of size (100x100x500 mm) were properly cleaned and oiling was done on the inside faces of moulds. The freshly prepared concrete mix was filled in moulds and then placed on a spring vibrator table for full compaction of concrete. Cube and Beam's moulds were then opened the next day and kept in a curing tank filled with tap water, until the day of testing at 7 and 28 days. The mix proportions of all mixes are listed below in **Table 2**. For each

type of mix, three samples were made. All these five types of the mix were prepared for M 25 grade of concrete as per IS 10262.2009. **Figure 3a & 3b** shown below shows dry mixing & wet mixing of concrete. **Figure 3c**

shows the cube specimen cast. All experiments were performed in the Civil engineering department of Madan Mohan Malaviya University of Technology, Gorakhpur, UP, India.

Table 2 Mix proportions

Mix	Cement (kg/m ³)	Sand (kg/m ³)	Coconut shell aggregates (kg/m ³)	Coarse aggregates (kg/m ³)	Water content (kg/m ³)	Polypropylene fibre (%)	w/c
M1	372	711.45	58.903	1119.15	186	0	0.5
M2	372	711.45	58.903	1119.15	186	0.5	0.5
M3	372	711.45	58.903	1119.15	186	1	0.5
M4	372	711.45	58.903	1119.15	186	1.5	0.5
M5	372	711.45	58.903	1119.15	186	2	0.5



Figure 3 a) Dry mixing of concrete; b) Wet mixing of concrete; c) Cube specimen casted

2.4. Test Setups

A slump test was performed on all types of a mix of concrete prepared, such as a control set without coconut shell and polypropylene fibres and concrete with the addition of coconut shell and polypropylene fibres. Fresh concrete was filled in a slump cone in 4 layers by tamping each layer 25 times. **Figure 4** which is given below, shows a slump formed for M3 mix concrete. Dimensions of the

slump cone are 100 mm, 200 mm and 300 mm for the top internal dia., bottom internal dia. and height of the cone respectively. It was observed from test results that as proportions of polypropylene fibre were increased from 0.5% to up to 2%, the workability of concrete mix reduces as slump value reduces.



Figure 4 Slump cone test performed and reading of slump value measured

A compressive strength test was performed on a concrete cube specimen to find its compressive strength properties. Cube specimens were taken out after 7 days and 28 days of curing to test them for compressive strength. After weighing each cube specimen,

it was placed in a compressive strength testing machine (CTM) and the load was applied to it until cube failure takes place. After the failure of the cube specimen, readings were taken of the load and noted down [34]–[38]. Here, the effect of adding different proportions of polypropylene fibre on the crack formation of cube specimens and the effect on compressive strength value was observed. **Figure 5** shows the cube specimen after failure, which shows the cube specimen is intact even after failure, due to the crack bridging effect of polypropylene fibre.



Figure 5 Cube specimen after fail

On beam specimens cast for all mix types, M1 to M5, a flexural strength test was carried out. The experiment's beam moulds had dimensions of 100x100x500 mm. For a 28-day curing period, three beam examples of each kind of mix were cast. The weight of the beam specimen was measured on a weighing machine after taking it out from the water tank. After that, applied four-point loading on the beam specimen in the flexural testing machine until the beam fails and the reading is noted down, as shown in **Figure 6**. When the beam fails, it is taken out, and the mean length of the crack from nearer support is found.

$$\begin{aligned} \text{Modulus of rupture}(f_b) &= PL/BD^2, \\ \text{if } a \text{ is greater than } 133\text{mm} \\ &= 3Pa/BD^2, \\ \text{if } a \text{ is less than } 133\text{mm but greater} \\ &\text{than } 110\text{mm} \end{aligned}$$

Where P= maximum load applied in (KN),
L= length between support (mm), B= width
of the specimen in mm, D= measured depth
of the specimen in mm, a= length of fracture
from nearest support in mm



Figure 6 Load applied on beam in two-point loading arrangement

3. Results and discussion

Cube and beam concrete specimens were cast and water cured. The different properties of the cube (150mm x150mm x150mm) and beam (100mm x 100mm x500mm) were measured according to the Indian standard code of testing.

3.1. Fresh properties of concrete

The workability of fresh concrete was measured using a slump cone test. The slump values of all mixes are shown below in

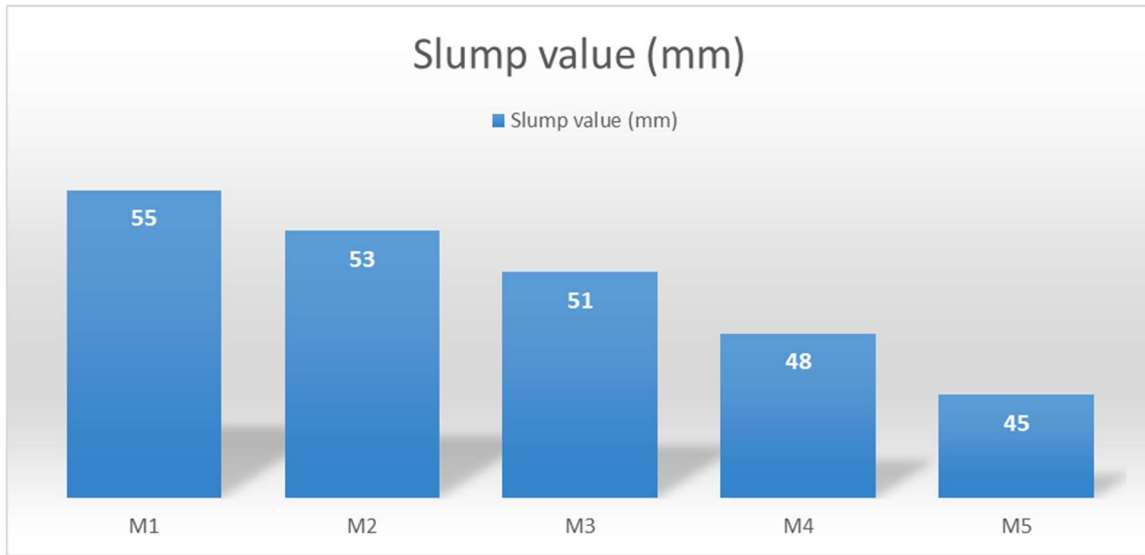


Figure 7 Slump value for all types of mixes

3.2. Hardened properties of concrete

3.2.1. Compressive strength of concrete

Cube specimen is taken out from the water tank after 7 and 28 days of curing and applied crushing load in a compressive strength Test machine (CTM). Before testing it in CTM, the moisture of the cube specimen surface is

allowed to dry out. Load is applied to the cube specimen until it fails. After the cube fails, load readings are noted and analysis is done. In **Figure 8**, compressive strength test results are shown at 7 and 28 days for all types of mixes.

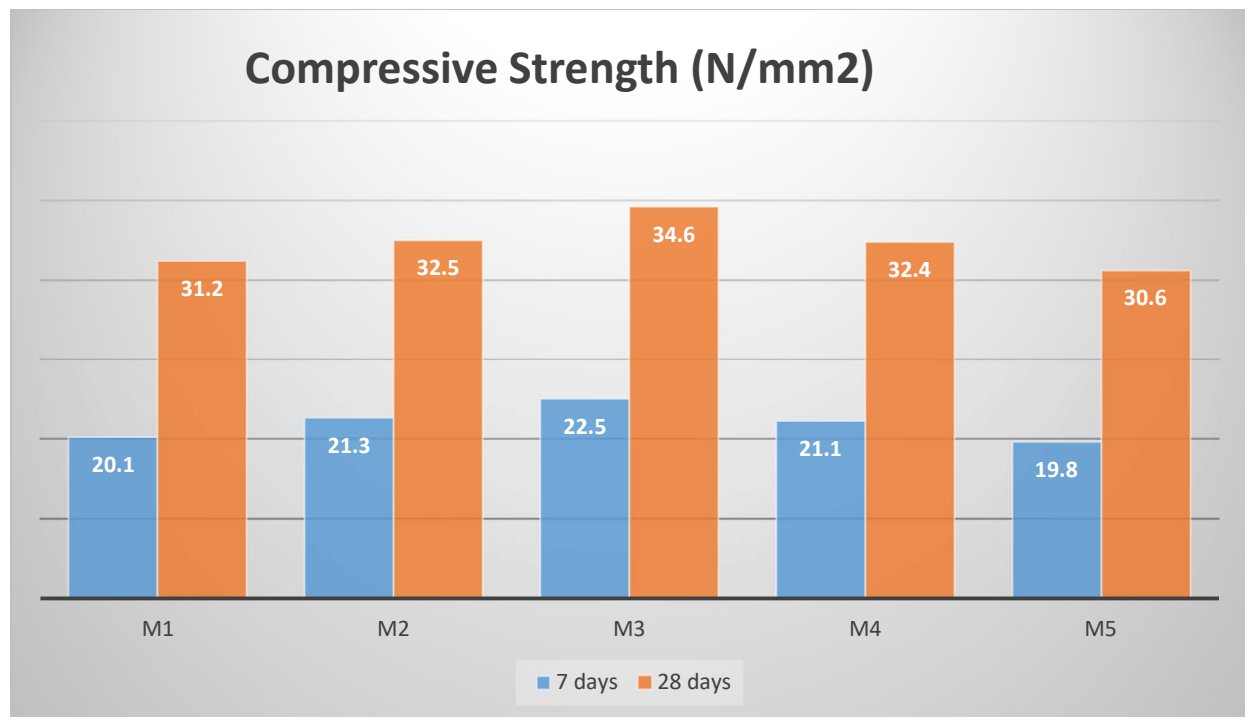


Figure 8 Compressive strength test results

3.2.2. Flexural strength test

Flexural strength value increases as polypropylene fibre increases. and decreases as 5% coconut shell is used as

a partial replacement of natural aggregates after 7 days and 28 days of curing. Test results are shown graphically in **Figure 9**.

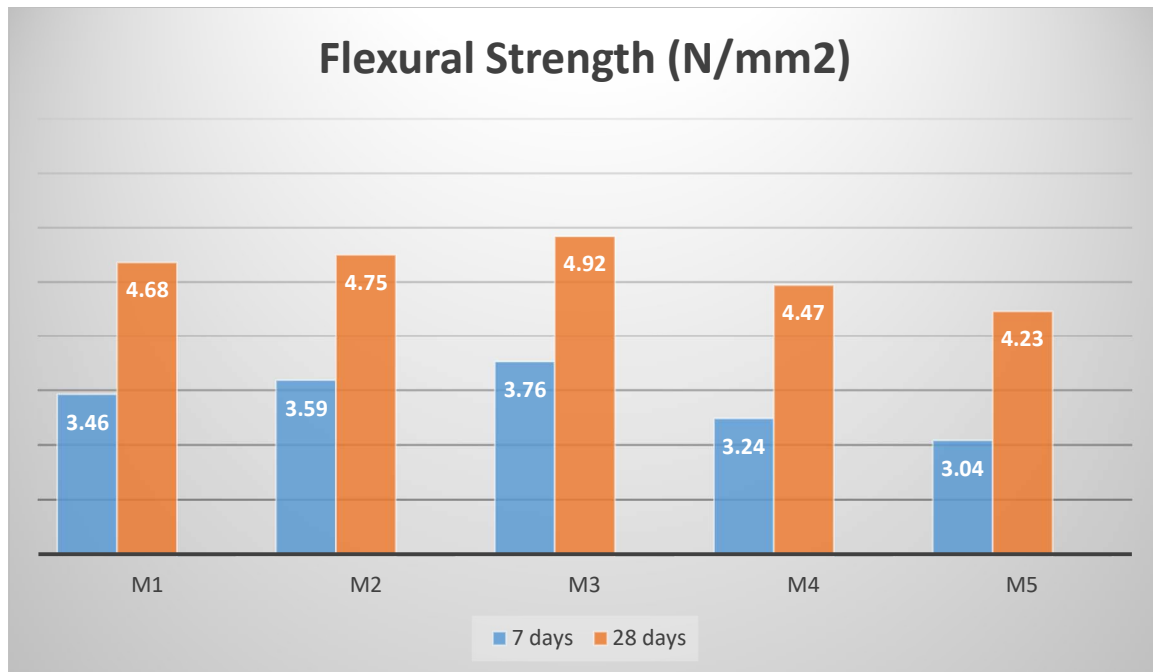


Figure 9 Flexural strength Test results

4. Conclusions

In this study, the partial replacement of coarse aggregate by 5% weight of coconut shell and the addition of polypropylene fibre with proportions of 0.5%, 1%, 1.5% and 2% by volume of cement. The conclusions drawn from test results are given below:

- A compressive strength test performed on five mixes shows that the compressive strength of concrete keeps on increasing until the proportions of polypropylene fibre increase from 0% to 1%, but compressive strength decreases with increasing proportions of polypropylene fibre from 1% to 2%.
- A slump test performed on five mixes shows that the workability of concrete mix keeps on decreasing as proportions of polypropylene fibre are increased from 0% to up to 2%.
- The flexural strength test performed on five mixes shows that the flexural strength of concrete keeps on increasing until the proportions of polypropylene fibre increase from 0% to 1%, but flexural strength decreases with increasing proportions of polypropylene fibre from 1% to 2%.
- From experiments conducted, it was observed that the optimum dosage of the proportion of polypropylene fibre is 1% by volume of cement, for

improvement in the compressive and flexural strength of concrete.

- For further studies, partial replacement of coarse aggregate by coconut shell can be increased beyond 5%, and its effect on the properties of concrete mix can be observed, as compared to mix prepared by using only natural coarse aggregate.

Also, from this study, it was concluded that partial replacement of coarse aggregate by coconut shell helps in, reducing the problem of disposal of coconut shell waste and helps in sustainable construction, while the addition of polypropylene fibre helps in increasing the serviceability of structure by resisting increase of crack width of concrete.

Future scope:

Coconut production and demand are increasing globally, and due to this coconut shell waste generation is increasing. There is immense scope for further studies to develop methods to decrease the problem of coconut shell waste disposal, and to find the optimum usage of this waste material for construction

purposes, so that goal of sustainable construction can be achieved. Also, further studies can be done on the mixing of polypropylene fibre in concrete to check for different applications of this fibre for construction purposes.

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