COMPARATIVE EXPERIMENTAL STUDY ON STRENGTH PROPERTIES OF STEEL AND POLYPROPYLENE FIBRE REINFORCED CONCRETE

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ABSTRACT: *This paper has presented the findings of an experimental study that was carried out on the strength of properties of M30 grade of concrete reinforced with hooked steel fibre and monofilament polypropylene fibre at the dosage of 0.25, 0.5, 0.75 and 1.0 percent by the volume of concrete. The research involves the comparison of the strength of concrete to assess the compressive strength, split tensile strength, and flexural strength, in order to establish the best fibre content. It was discovered that the compressive strength greatly increased when there was 0.75% of steel fibres and 0.5% of polypropylene fibres. The highest tensile strength split is obtained at 0.5% dosage of fibre in both types and highest flexural strength is obtained at 0.75% dosage of steel fibre and 0.5% dosage of polypropylene fibre. This demonstrates that addition of fibres to concrete increases the impact resistance of fibre-strengthened concrete, as the optimum fibre dosages of 0.5% polypropylene fibre and 0.75% hooked steel fibre by volume of concrete significantly increases impact strength on drop weight. The polypropylene fibres also were found to be better than the steel fibres in flexural strength and resisting crack propagation. In addition, polypropylene fibres emerged to be cheaper than steel fibres in an economic viewpoint. Findings confirm that the mechanical behaviour of concrete may be significantly enhanced by the fibre reinforcement with optimum proportions and result in the enhanced structural behaviour.*

Keywords: ***Steel fibres, Polypropylene fibres, Reinforced concrete, Compressive Strength, Split tensile strength, Flexural Strength.***

INTRODUCTION

Concrete is a construction material which is highly utilized in the world. It is very versatile and can be shaped in any form, and the material is made using cost-effective materials. But concrete is brittle substance that has low tensile strength, flexural strength and it forms cracks when it is under services loads. Fibre-reinforced concrete (FRC) is designed in order to eliminate these shortcomings. FRC is a composite material that is constituted of hydraulic cement, water, aggregates, and discontinuous discrete fibre. Fibre gives concrete superior toughness, ductility, crack resistance and post crack behaviour, and over the last few years, there has been intense research leading to significant success and innovations in fibre technology [1]. Some of the materials studied include steel, glass, polypropylene and carbon fibre which has enhanced understanding of mechanical behaviour of concrete with the fibres.

The use of fibres in experimental studies is owed to other fibres including the steel fibres due to their high tensile strength and strain to increase impact resistance [6]. The polypropylene fibres are of choice as they are light in weight and non-reactive. They both improve compressive, tensile and flexural strength, but the comparative effectiveness is dependent on the kind of fibre utilized, dosage and dispersal of the fibre in the mix [2]. Although many studies have claimed to improve mechanical properties as a result of adding fibre, the comparative study under controlled conditions is required to identify a specific dosage and performance efficiency of different types of fibres.

The given study will fill this research gap by providing an experimental study of M30 grade concrete reinforced with different ratio of hooked steel fibre and polypropylene fibre and to determine the optimum dose of fibres to be applied to provide the concrete with maximum strength properties (compressive strength, split tensile strength, and flexural strength).

LITERATURE REVIEW

The mechanical performance improvements of fibre-reinforced concrete have been studied widely. Gupta *et al.* [1] evaluated the M40 grade concrete with steel and polypropylene fibres (0.3 cent) and found that polypropylene fibres with a 60-aspect ratio had a greater flexural strength than steel fibres. In a similar study, Fathima and Varghese [2] compared steel and polypropylene fibres in M30 grade concrete and emphasized that the flexural behaviour was greatly enhanced by the presence of 0.5% polypropylene fibres but not by the crimped and hooked-end steel fibres.

Bharath *et al.* [3] experimentally obtained optimum dosage of polypropylene (0.05%) and steel (0.75%) fibres in M30 concrete, which showed better compressive and flexural strengths than regular mixes. Indra Kumari and Ravi [4] established that incorporation of 0.4-1.2% polypropylene and crimped steel fibres into M30 concrete improved compressive, tensile and flexural strengths by 61% at optimum contents.

Kiran Kumar [5] evaluated hybrid fibre reinforced concrete (HFRC) and showed that the addition of an equal quantity of steel and polypropylene fibre (up to 1.5%) enhanced all mechanical properties. In a study of hooked-end steel fibres reinforced concrete and conventional concrete, Reddy and Rafi [6] concluded that hooked-end steel fibres considerably increased the overall performance of the concrete structure.

Concrete mixes containing steel and glass fibre were studied by George *et al.* [7] and demonstrated enhanced flexural behaviour; polypropylene fibres, instead, were shown to have a positive impact on the fibre reinforced concrete performance by Antarvedi [8]. On the same note, Uniyal and Rawat [9] established that cement reinforced with steel fibres increased the resistance and strength of reinforced concrete.

As noted by Bhat and Khan [10], the addition of fibre steel accelerated the early strength gain of concrete. Moreover, Ali *et al.* [11] verified that steel fibres had a positive effect on mechanical properties such as compressive and tensile. Concrete mix design and material behaviour continue to rely on standard textbooks like Shetty [12] and Neville [13], and IS codes [14, 24].

OBJECTIVES

- To study the influence of the addition of hooked steel fibres and polypropylene fibres on compressive, split tensile and flexural strength of M30 grade concrete.
- To determine the optimum dose of fibres to be used to attain maximum strength properties of fibre-reinforced concrete.
- To evaluate and compare the strength characteristics of concrete reinforced with hooked steel fibres and polypropylene fibres.

MATERIALS AND METHODOLOGY

CEMENT:

In the present experimental investigation, 53 Grade Ordinary Portland cement (OPC) was used. The physical properties of cement are shown in Table 1.

Table 1 Physical Properties of Cement

S. No	Properties	Values	IS Specification
1	Fineness	4	IS:4031(part1)-1996
2	Specific Gravity	3.11	IS:4031(part11)
3	Normal Consistency	30%	IS:4031(part4) & IS269
4	Initial Setting Time	50 min	> 30 Min. IS:4031(part5) & IS269
5	Final Setting Time	335 min	< 600 Min. IS:4031(part5) & IS269

FINE AGGREGATE

Aggregate is also an important constituent of concrete, in the present experimental investigation, locally available sand confirming to Zone II of IS 383-2016 [19]. The Physical Properties of fine aggregate as shown in Table 2.

Table 2 Physical Properties of Fine Aggregate

S. No	Properties	Values
1	Specific Gravity	2.48
2	Water absorption	2.5%
3	Fineness Modulus	2.69
4	Zone	II

COARSE AGGREGATE

The coarse aggregates are irregular broken stones or naturally available gravels that are used in making concrete. Aggregates that have a size more than 4.75 mm are considered as coarse aggregates. They are usually found in stone quarries and stone crushers with sizes of 4.75mm to 80 mm. The graded mixture of 20 mm and 12 mm coarse aggregates was adopted in the current experimental study to attain higher compaction and improve the mechanical properties of the concrete. As indicated in Table 3, the Physical Properties of coarse aggregate are as follows.

Table 3 Physical Properties of Coarse Aggregate

S. No	Properties	Values
1	Specific Gravity	2.8
2	Water absorption	0.4
3	Fineness Modulus	7.32

WATER

Casting and curing of the specimens were carried out using potable water. The quality of water plays a crucial role in determining the strength and durability of concrete. Therefore, it must be free from substances that are harmful to both concrete and reinforcement. Parameters such as pH, chloride content, sulphate content, alkalinity, acidity, and hardness are typically evaluated to assess the suitability of water for construction purposes. In this experimental study, water samples were analyzed, and the results are compared with the permissible limits specified in IS: 456–2000 [21] to verify compliance with standard requirements. The laboratory test results of the water quality are presented in Table 4.

Table 4 Analysis of Water Used for Casting and Curing of Concrete

S. No	Water Parameters	Test Results	Permissible Limits
1	pH	6.52	Not less than 6
2	Chlorides	140 mg/L	500 mg/L
3	Sulphates	98 mg/L	400 mg/L
4	Alkalinity	540 mg/L	250 mg/L
5	Acidity	24 mg/L	50 mg/L
6	Hardness	740 mg/L	>600-700 mg/L
7	TDS	1400 mg/L	2000 mg/L
8	Organic matter	200 mg/L	200 mg/L
9	Inorganic matter	1200 mg/L	3000 mg/L

Although the water sample exhibited higher alkalinity and hardness beyond desirable limits, the concrete achieved satisfactory strength. This outcome may be attributed to the fact that a slight increase in alkalinity and hardness does not affect the hydration of concrete. Moreover, other critical parameters, including pH, chlorides, and sulphates, were within safe limits.

HOOKED STEEL FIBRE

Steel Fibre Reinforced Concrete (SFRC) is a composite material which is a mixture of hydraulic cement, aggregates and dispersion of discontinuous steel fibres. These fibres are randomly distributed in the concrete mix to promote the mechanical properties of the concrete. High toughness, ductility, crack resistance and energy absorption are some of the applications of SFRC. This investigation involves round and hooked-type steel fibres. Aspect ratio Steel fibres (Length 60 mm and diameter 0.75 mm) with tensile strength of 1120 N/mm2. Fig. 1 demonstrates steel fibres used in the current experimental study.

Fig 1 Hooked Steel Fibres

POLYPROPYLENE FIBRE

Polypropylene fibre reinforced concrete (PPFRC) refers to a category of fibre-reinforced concrete in which polypropylene fibres are incorporated in the concrete mix to improve concrete performance, in particular its crack resistance, impact strength and durability. Polypropylene is a synthetic thermoplastic polymer, and the fibres are chemically inert, thus highly resistant to alkaline concrete conditions.

Mono-filament Polypropylene Fibres used in the experimental investigation are shown in Fig. 2. The Polypropylene Fibres of diameter 0.024 mm, length 12 mm (Aspect ratio 500 approximately) and tensile Strength of 750N/mm^2 were utilized. Monofilament fibres are fine individual strands, which are specifically effective in curbing plastic shrinkage cracks in the early development phases of concrete setting.

Fig 2 Polypropylene Fibres

CONCRETE MIX

In compliance with IS 10262:2019 [20] and IS 456:2000 [21], concrete mix design is a procedure of determining the proportions of the constituents of concrete in order to achieve the required strength and workability. The proportions of design mix of grade of M30 concrete are 1:1.9:3.68 water-cement ratio = 0.5, and cement content = 340kg/m^3.

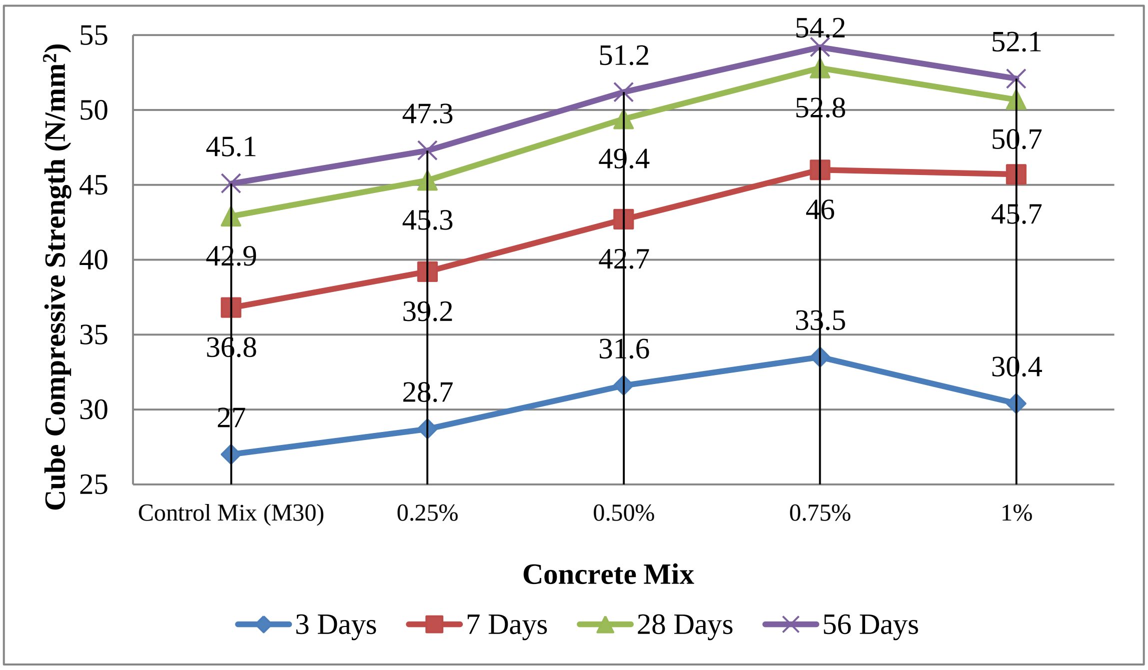
TESTING PROCEDURE

Test specimens of concrete are in the shape of cubes (150 mm × 150 mm × 150 mm), cylinders (150mm × 300mm) and prisms (100mm × 100mm × 500mm). Concrete cubes were casted to test 3,7,28, and 56 days compressive strength though cylindrical and prism specimens were dried to test 28 days. Hardened concrete was cast after which tests were carried out on hardened concrete to establish the cube compressive strength of concrete, split tensile strength (on cylinders), flexural strength (on prisms) and drop weight impact strength. The outcomes of the test were compared with the control mix concrete (devoid of fibre) to identify the impact of fibre reinforcement on different strength characteristics, and the conclusions were made.

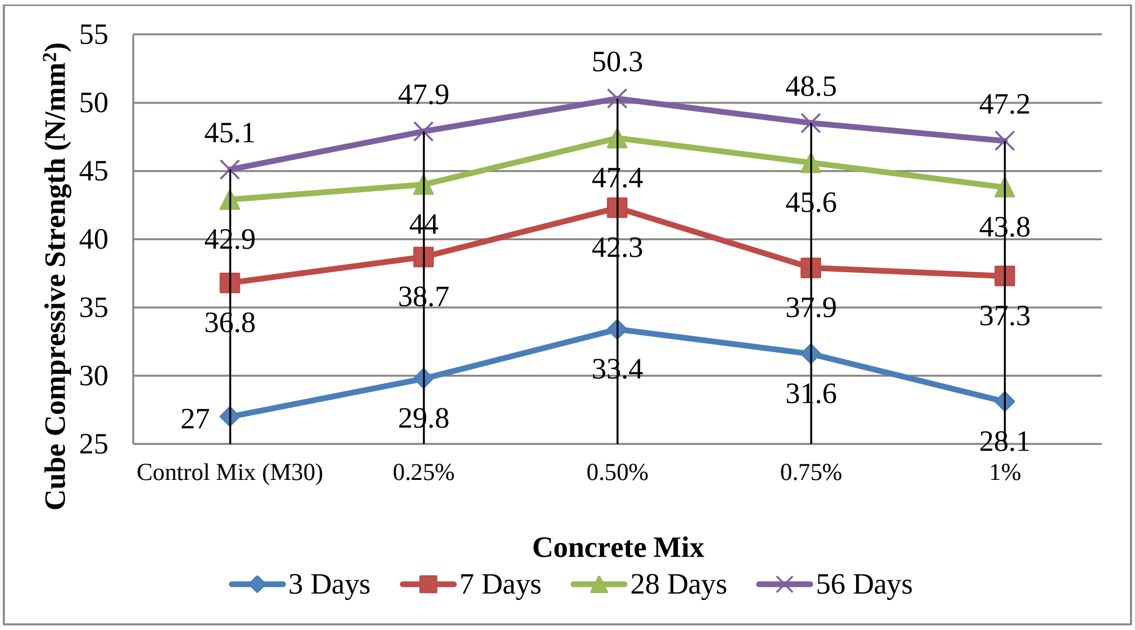
EXPERIMENTAL RESULTS

Compressive Strength:

Initially, a Compression strength test was conducted on cured conventional M30 grade concrete cubes, in accordance with IS 516:2021 [23]. The cubes were tested at the ages of 3, 7, 28, and 56 days to determine the compressive strength. The results of the compressive strength test of concrete are shown in Fig.3.



(a)



(b)

Fig 3 Variation of Cube Compressive Strength Concrete with different types of Fibres and Varying Percentages of Fibres (a) Hooked steel fibres, (b) Polypropylene fibres

Fig.3 indicates that compressive strength of the hooked steel fibre concrete and polypropylene fibre concrete have a similar variation. The Strength of hooked steel fibre concrete increases steadily with the addition of fibres content and the optimum content is 0.75% and compressive strength is lowered at 1.0%. This means that a 0.75 percent optimum of steel fibre is reached and above that the fibre forms a weaker matrix. On the other hand, polypropylene fibre concrete exhibits a linear relationship with the increase in fibre percentage and maximum fibre is 0.5% and the compressive strength has reduced slightly above 0.5%. This is due to the reduction in workability of concrete quantity of fibre exceeds 0.5%. The compressive strength of both fibre concretes constantly rises with curing period. It is therefore possible to observe that addition of fibres enhances compressive strength over that of the control mix but the best percentage is dependent on the type of fibre used.

Split Tensile Strength:

The split tensile strength test in the current experimental study was conducted on cylindrical specimens that were cast in conventional M30 grade concrete of 150 mm and 300 mm diameter and height respectively. It was the test conducted in IS 5816:1999 [22]. The specimens were also cured in water after casting and allowed to cure in a period of 28 days. The specimens were put in the machine lying horizontally, and compressive load was applied upon its vertical diametric plane until failure.

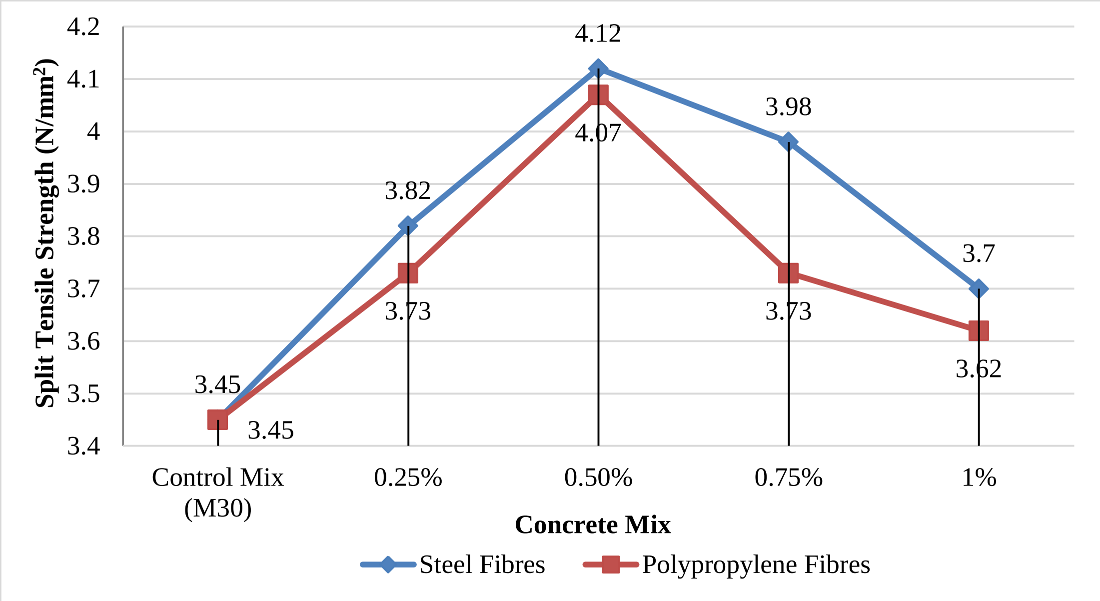


Fig 4 Variation of Split Tensile strength of concrete with Different Percentages of Steel and Polypropylene Fibres

Fig. 4 represents the variation of split tensile strength after 28 days of curing of cylinders of M30 grade concrete, with hooked steel fibres and polypropylene fibres of varying quantities, 0.25%, 0.50%, 0.75% and 1.0%. The addition of fibres has a great impact on improving the split tensile strength. The concrete with 0.25% of hooked steel fibre and polypropylene fibre possesses an increase in strength, which shows that the addition of fibres has a positive effect on tensile resistance. The optimum split tensile strength is obtained for 0.50% of fibre content, where the fibres are well dispersed and securely bridge the cracks, thus enhancing the tension of concrete. The reason for the decrease in split tensile strength can be attributed to the clustering of fibres and the insufficient dispersion of fibres at larger volumes. The hooked steel fibres always exhibited more strength than the polypropylene fibres at all percentages because they are more rigid and have a high crack-arresting capacity.

Flexural Strength:

The flexural strength test is conducted to evaluate the ability of concrete to resist bending or flexural stresses. In this study, the test was carried out on M30-grade conventional concrete prisms of size 100 mm × 100 mm × 500 mm, in accordance with IS 516:2021 [23]. After casting, the specimens were cured in water for 28 days.

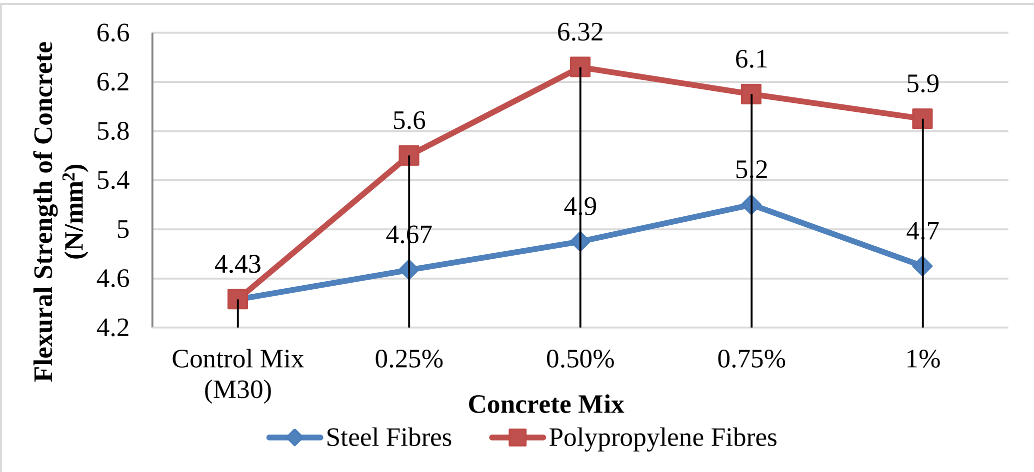


Fig 5 Variation of Flexural Strength of M30 Concrete with Different Percentages of Hooked Steel and Polypropylene Fibres

Fig.5 illustrates the flexural strength variation of M30 grade concrete to different number of hooked steel and polypropylene fibres as opposed to the control mix. Flexural strength of Polypropylene fibre concrete is higher than the hooked steel fibre concrete of same percentage of fibre contents. In the case of hooked steel fibre reinforced concrete the strength rose at a slow rate to 0.75% and slightly dropped at 1%. On the other hand, the polypropylene fibre reinforced concrete showed a higher level of improvement, the strength rose by 0.5%. This is explained by the high aspect and well dispersion of the polypropylene fibres as compared to the hooked steel fibres in the concrete. More than optimum content of fibres, the flexural strength of concrete reduction could be explained by the decline in workability of concrete. Judging by the results of the conducted test, one can conclude that flexural strength properties of concrete are increased when polypropylene fibres are used.

Impact Strength of Fibre Reinforced Concrete:

A drop weight impact strength test is conducted to determine the strength of concrete. The impact strength test determines the number of blows that are required to cause particular magnitudes of distress to concrete specimens. The casting is done in cylindrically shaped moulds (diameter 150 mm and thickness 64 mm). It will be tested based on ACI 544.2R-89[24]. Fig. 6, indicates the comparison of impact strength of the control concrete and the fibre reinforced concrete. According to the test findings the impact strength of fibre reinforced concrete is higher than the controlled concrete..

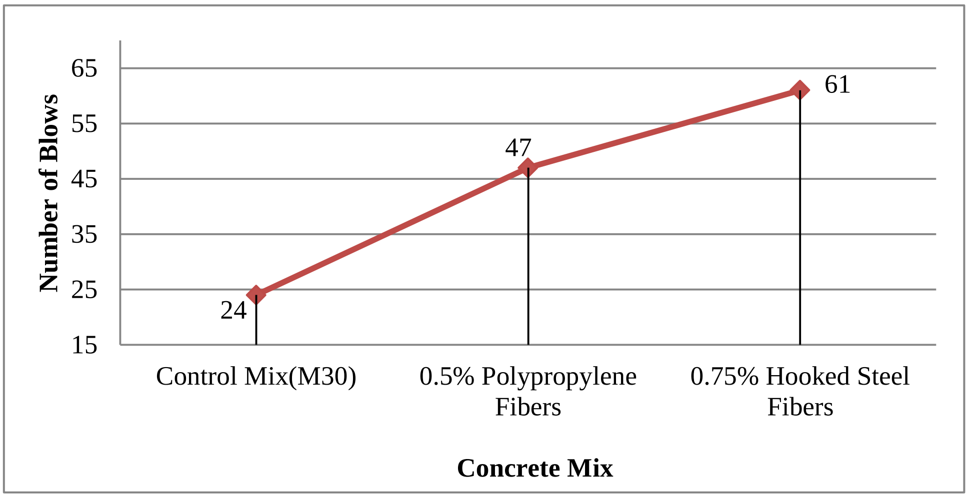


Fig. 6. Variation of Impact Strength of M30 Concrete with and without Fibres.

CONCLUSIONS:

1. The compressive strength of 0.75% hooked steel fibre reinforced concrete exhibits 20% to 25% and Polypropylene fibre reinforced concrete exhibits 10 % to 23% more strength than the control concrete at 3, 7, 28, and 56 days of curing.
2. The maximum split tensile strength of concrete is obtained at 0.5% for steel and Polypropylene fibre reinforced concretes. The split tensile strength of fibre reinforced concrete (steel and Polypropylene fibres) is approximately 18 % more than the control concrete.
3. Based on the test results, improved flexural strength of fibre reinforced concrete at the optimum content of fibres can be observed. The increase in flexural strength of concrete is 21.5 % in case of Steel fibres and 42% for Polypropylene fibres. The improved flexural strength properties can be attributed to the delayed crack formation due to the presence of fibres.

Finally, based on the results of the experimental investigation, it can be concluded that the presence of steel fibres or Polypropylene fibres improves the strength properties of concrete. The optimum percentage of fibres depends on the type of fibres used. Hence, the use of fibre reinforced concrete is recommended for various structural applications and the durability of concrete can be enhanced.

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