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Research paper

Study on Strength and Durability Characteristics of Hybrid Fibre Reinforced Self-Healing Concrete

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Abstract

The main disadvantage of using concrete, which is accepted to be irreplaceable building material, is the formation of micro cracks. This is due to the fact that concrete is weak in tension. To arrest the microcracks developed in the concrete and to eliminate the drawbacks due to microcracks, the recent trend in the innovation of the concrete is the usage of self-healing concrete or bacterial concrete. It is based on the principle that; the bacteria present in the moisture of the concrete repairs or heals the cracks on the concrete. Another recent advancement in the field of concrete technology is the usage of the fibres in the concrete. It not only arrests the cracks in the concrete but also increases the strength and durability characteristics and also it reduces the quantity of cement to some extent. This paper tries to attempt the usage of hybrid fibres along with the self-healing concrete to enhance the desirable characteristics of hybrid fibres as well as bacterial concrete. This experimental programme investigates the concrete on its strength and durability characteristics.

Keywords: *Compressive strength, Hybrid fibres, Micro cracks, Self-healing, split tensile strength.*

1. Introduction

After the construction of a building or any other structure with the help of concrete, there is a possibility of the development of cracks in the wall or the reinforced concrete materials. If the type of crack is passive, it does not affect the structural behavior, but it affects the aesthetic view. Whereas, if the crack is active, i.e., it develops with respect to time, there may be serious problem in structural behavior of the material which may even leads to failure of the structure. The reasons for active cracks in the building may be due to differential settlement, growth of roots near the foundation area etc. Psychologically, it seems as if the building is going to fail. Thus, it is mandatory for a civil engineer to repair the cracks immediately.

The passive cracks can be repaired easily with the help of cement mortars or grouting methods which are simple and easy. Whereas, if the cracks are active, it needs more advanced methods like, stitching, epoxy resin treatment etc. The recent technology adopted for repair the cracks is 'bacterial concrete' which is also called as self-healing concrete. Due to presence of bacteria it heels the cracks automatically.

Another major drawback in the field of concrete technology is the development of micro cracks in the concrete due to shrinkage. In order to counter balance this, fibres are used in the concrete. Several natural and synthetic fibres are used in concrete to arrest the microcracks in the concrete and also to increase the strength characteristics of the concrete.

Earlier times, steel fibres are found to be excellent in arresting the micro cracks and it gives great strength, but when exposed to atmosphere or moisture it corrodes, leads to the loss of strength and durability. Later, several researches have been carried out with different kinds of natural and synthetic fibres. The next stage of development in the field of fibre reinforced concrete is the usage of hybrid fibres i.e., it involves the desirable characteristics of two or more dfifferent fibres in concrete. Generally steel fibres are used as one of the fibres and the other one includes natural or synthetic fibres.

In this research paper it uses the technique of bacterial concrete as well as hybrid fibre reinforced concrete. The main objective behind this research proposal is that, the presence of bacteria in the concrete heels the cracks developed in the concrete but as far as the strength characteristics are concerned, it lags. In order to improve the strength characteristics of the bacterial concrete, hybrid fibres are attempted to include in the bacterial concrete and finally results with the optimum content of bacteria in proportion with the optimum content of hybrid fibres.

The objectives towards the proposal of this research paper is

i. to enhance the mechanical properties as well as durability properties of the bacterial concrete,
ii. to reduce the cement content in the concrete,
iii. to arrest the micro cracks in the concrete due to shrinkage and
iv. to heel the cracks automatically.

2. Literature Survey

Mohan Ganesh et al., conducted experiments on the performance of the self-healing concrete with replacement of fine aggregate with rice husk [1]. Here the type of bacteria used is bacillus cohnii. It reveals that, 5% replacement of rice husk and addition of bacteria increases the compressive strength,

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split tensile strength and flexural strength by 26%, 14% and 7% after 28 days of curing. Ashok varma and Chandrasekhar conducted studies on strength and durability properties of bio concrete[2]. The type of bacteria used in this research is bacillus subtilis. This project concludes with the fact that addition of 10 ml of bacillus subtilis enhances the overall performance in terms of strength and sulphuric attack exposure. Sagar Sarangi and Anand Kumar Sinha conducted experiments to evaluate the mechanical properties of hybrid fibre reinforced concrete [3]. Coconut coir fibres and polypropylene fibres have been used to investigate the mechanical properties of the concrete. The ratio of polypropylene to coir fibres at 0.75:0.25 gives the better results. Ghosha et al., attempted to use the microorganisms for the strength improvement of the cement mortar. It reveals that, when a quantity of microorganism is added in concrete, it grows rapidly in the matrix of the concrete and increase the strength up to 25% overall. Thus, the above literature confirms that the addition of bacteria increases the performance of the concrete and also hybrid fibres improves the overall performances of the concrete. This paper attempts to include all the desirable properties of these techniques.

3. Bacteria

3.1 Selection of Bacteria

This present study tries to improve the concrete based on strength and durability characteristics as well as self-healing property. There are several types of bacteria have been used in the concrete for the overall performance improvement but the bacteria, named as bacillus subtilis' is most commonly used because of its easy availability and cheap cost and easy to work as well. Thus, in this present study, 'Bacillus subtilis' is used.

3.2 Preparation of Bacteria

The growth of bacteria is enhanced with the help of a culture medium. The medium chosen is nutrient agar slants. It should be maintained at a temperature of 37°C and it is shaken continuously at a speed of 125 rpm in a orbital shaker. The elements required for the survival of the bacteria are peptone, an extract from beef and sodium chloride etc.

In order to use the bacteria in concrete, this culture is then added in the distilled water. About 12.5 g of nutrient are primarily added in 1000 ml of distilled water. Then the Conical flask is made air tight by closing it with a piece of cotton cloth and sealed with a rubber band. At this stage, the colour of the bacterial water looks yellowish. The conical flask is sterilized with the help of a oven at normal boiling temperature for the period of 10 – 20 minutes. The process of sterilization removes all the types of contaminants and it is indicated by a colour change from yellow to orange. Now 1 ml of bacteria is added to this solution and it should be agitated well with the help of shaker at 150-200 rpm for 24 hours. Now the colour of the solution is whitish, and this solution is to be used in the concrete.

4. Experimental Program

4.1 Materials Used

4.1.1 Coarse Aggregate

The size range of the aggregates which are used as coarse aggregate is 80mm to 4.75mm sieve size. The maximum size of aggregate to be chosen is based on the size of cube specimen. It is planned to prepare 15 cm size cubes and the maximum size of aggregate is 20mm. The physical properties were tested as per IS2386 (part 1) – 1963 and the results are shown in table 1.

Table 1: Test Results of Coarse Aggregates

Properties	Test results
Fineness modulus	7.22
Specific gravity	2.80
Sieve analysis	Zone II

Figure 1 Sieve Analysis Curve for Coarse Aggregate Confirming to IS383:1970.

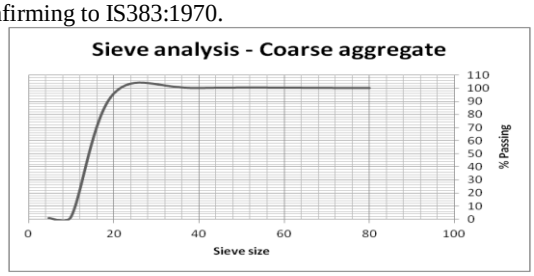

Fig 1 Sieve analysis curve – Coarse aggregate

4.1.2 Fine Aggregate

The size range of the aggregates which are used as coarse aggregate is 4.75mm to 75µ sieve size. Natural river sand is used as a fine aggregate in concrete. Now-a-days manufactured sand are used as fine aggregate which is giving better results but uneconomical. The physical properties were tested as per IS2386 (part 1) – 1963 and the results are shown in table 2.

Table 2: Test Results of Fine Aggregates

Properties	Test results
Fineness modulus	3.38
Specific gravity	2.65

Figure 2 Sieve Analysis Curve for fine Aggregate Confirming to IS383:1970.

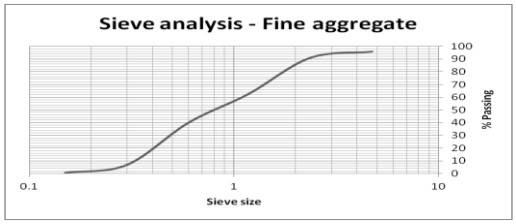

Fig 2 Sieve Analysis Curve – Fine Aggregate

4.1.3 Water*:*

The water used for the preparation and curing of concrete is as per IS 456-2000 guidelines. Potable tap water is used.

4.1.4 Fibres

The type of fibres chosen for this experimental purpose is steel fibres and polypropylene fibres. The steel fibres are of hooked ended type. These are particularly chosen for their excellent strength intensification. The properties of the fibres are shown in the table 3.

Table 3: Properties of Fibres

S. no	Properties	Steel fibre	Polypropylene fibre
1	Diameter (mm)	0.75	0.20
2	Length (mm)	50	12
3	Aspect ratio	67	60
4	Bulk density (g/cc)	7.8	0.9

4.1.5 Bacteria

The bacteria prepared from the above-mentioned methods is added during the preparation of the concrete. Initially it is mixed with water based on the desired proportion and the water is used for the preparation of concrete.

4.2 Testing Procedure

The grade of the concrete chosen is M25. According to IS10262 the mix design for M25 grade of concrete has been made and the requirements of various materials has been found out. The concrete specimens are prepared in the form of cubes, cylinders and beams for carrying out various tests such as compressive strength test, split tensile test, flexural test, young's modulus test and durability tests. As per the literature survey an optimum percentage or quantity of bacteria has been chosen and various proportions of fibres are added and tested. According to literature survey, 10 ml addition of bacteria in 500 ml of water gives better results when compared to other proportions. Thus, it is considered as optimum quantity of bacteria. Table 4 gives the various mix proportions of fibres. The fibres having the constant aspect ratio. The percentages given in the table indicated the percentage of weight of the fibre with respect to the weight of the cement. The cubes, cylinders and beams are of standard sizes.

i. Cube – 15 x 15 x 15 cm
ii. Cylinder – 15 cm (dia) x 30 cm height
iii. Beam – 15 cm x 15 cm x 75 cm

Table 4 Mix Proportions

S.No	Mix proportions	Quantity of bacteria (500 ml of water)	Percentage of steel fibres (%)	Percentage of polypropylene fibres (%)
1	MPC 0	0	0	0
2	MPC 1	10	0	0
3	MPC 2	10	0.75	0.25
4	MPC 3	10	0.5	0.5
5	MPC 4	10	0.25	0.75

5. Experimental Tests

5.1 Mechanical Properties

5.1.1 Compressive Strength Test

Concrete cubes of size 15cm*15cm*15cm have been casted with different mix proportions of fibres by weight of cement added and has been cured in the water for three different ages (7,14,28 days) and the tests has been conducted. Average of 3 specimens has been casted per design mix of fibre per curing day. The test has been conducted with the help of universal testing machine as per codal provision IS516:1959[10]. The experimental setup for the compression test has been shown in figure 3. The ultimate load at which the concrete specimen fails is noted and the compressive strength is calculated using the formula compressive strength = $\frac{P}{A}$.

4.2 Split Tensile Strength Test

Concrete cylinders of size 15cm * 30cm have been casted with different mix proportions of fibres by weight of binder added and has been air cured for three different ages (7,14,28 days) and the tests has been conducted. Average of 3 specimens has been casted per design mix of fibre per curing day The test has been conducted with the help of universal testing machine as per codal provision IS5816:1999[11]. The experimental setup for the split tensile test has been shown in figure 2. The ultimate load at which the concrete specimen fails is noted and the split tensile strength is calculated using the formula split tensile strength = $\frac{2P}{\pi DL}$.

4.3 Flexural Strength Test

Concrete beams of size 15cm*15cm*75cm have been casted for various mix proportions of fibres by weight of cement added and has been cured for 14, 28 days in water and the tests has been conducted. Average of 3 specimens has been casted per percentage of fibre per curing day. The test has been conducted with the help of universal testing machine as per codal provision IS516:1959[13]. The experimental setup for the flexural strength test has been shown in figure 3. Two-point loading method has been adopted and the ultimate load at failure is noted. The flexural strength or modulus of rupture of the concrete beam specimen is then calculated by using the formula flexural strength = $\frac{Pl}{bd^2}$



Fig 3 Experimental Setup for Cube, Cylinder and Beam Specimens

5.2 Durability properties

5.2.1 Chloride Attack Test

Concrete cube specimens of standard size 0.15m x 0.15m x 0.15m have been casted for the examination of chloride attack of the concrete. Concrete cubes of all mix proportions have been casted and cured in water for 28 days. After 28 days of water curing the specimens are dried and weighed and again exposed to chloride attack by immersing the concrete specimens in 5% chloride solution i.e., 500 mg of the sodium chloride salt s added in 10 liters of water. This exposure continues for the period of 28 days. After 28 days of chloride exposure, the concrete is again dried, weighed and the compressive strength is determined. Percentage reduction in loss of weight or strength is evaluated and the results are concluded.

5.2.2 Sulphate Attack Test

Concrete cube specimens of standard size 0.15m x 0.15m x 0.15m have been casted for the examination of sulphate attack of the concrete as well. Concrete cubes of all mix proportions have been casted and cured in water for 28 days. After 28 days of water curing the specimens are dried and weighed similar to chloride attack test and again exposed to sulphate attack by immersing the concrete specimens in sulphate solution i.e., 500 mg of 5% Na_2SO_4 and 5% $MgSO_4$ salts added in 10 liters of water. This exposure continues for the period of 28 days. After 28 days of sulphate exposure, the concrete is again dried,

weighed and the compressive strength is determined. Percentage reduction in loss of weight or strength is evaluated and the results are concluded.

6. Results and Discussions

6.1 Compressive Strength Test

Compressive strength test for various mix proportions for varying ages of water curing has been conducted and the results are summarized below in the table 5. It is observed that addition of 10 ml bacteria without the addition of fibres increases the compressive strength up to 30% to that of conventional concrete. If the quantity of steel fibres dominates the polypropylene fibres, it increases the strength of the bio concrete by 12% after 28 days of water curing and 30% increase is observed when compared to conventional concrete. If the polypropylene fibre dominates, there is no significant increase in the strength of concrete. However, to reduce the quantity of concrete MPC 4 proportion can be used. Figure 4 gives the variation of strength with respect to mix proportion and curing days.

Table 5 Compressive Strength Test Results

S.No	Mix proportion	Average compressive strength – 7 days of curing (N/mm^2)	Average compressive strength – 14 days of curing (N/mm^2)	Average compressive strength – 28 days of curing (N/mm^2)
1.	MPC 0	15.4	22.4	25.1
2.	MPC 1	20.1	28.4	29.3
3.	MPC 2	22.5	30.6	32.8
4.	MPC 3	21.3	28.7	30.9
5.	MPC 4	16.2	21.9	24.6

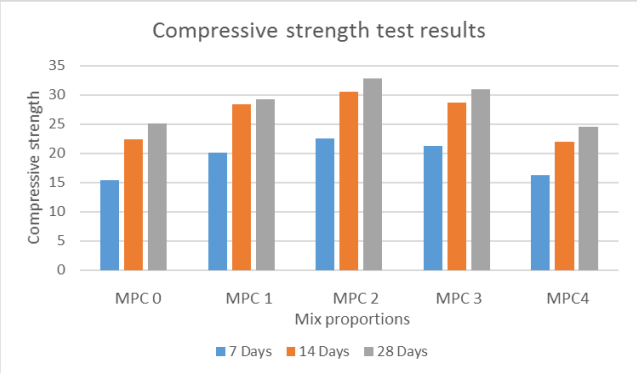

Fig 4 Compressive Strength Comparison for Various Mix Proportions

6.2 Split Tensile Strength Test

For various mix proportions of concrete and for various curing days, the split tensile strength of the concrete has been examined and it is shown in table 6. The split tensile strength of the concrete has been increased up to 15% by the addition of 10 ml bacteria. Both mix proportions MPC 3 and MPC 4 shows similar results i.e., strength increases up to 13% to that of bio concrete and 31% with respect to conventional concrete for 28 days of water curing. If the polypropylene fibre dominates, there is no significant increase in the split tensile strength of concrete. However, to reduce the quantity of concrete MPC 4 proportion can be used as in the previous case.

Table 6 Split Tensile Strength Test Results

S:NO	Mix proportions	Average split tensile strength – 7 days of curing (N/mm^2)	Average split tensile strength – 14 days of curing (N/mm^2)	Average split tensile strength – 28 days of curing (N/mm^2)
1.	MPC 0	1.916	2.126	2.306
2.	MPC 1	2.234	2.449	2.677
3.	MPC 2	2.475	2.821	3.028
4.	MPC 3	2.329	2.745	3.079
5.	MPC 4	2.191	2.326	2.531

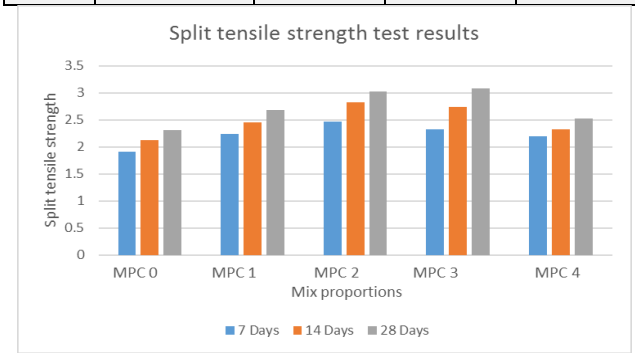

Fig 5 Split Tensile Strength Comparison for Various Mix Proportions

6.3 Flexural Strength Test

Table 7 gives the results of flexural strength of beam concrete specimens for various mix proportions and various curing days. Optimum addition of bacteria in concrete increases the flexural strength up to 20% than the conventional concrete. As far as the proportions of fibres are concerned, equal amount of fibres or domination of steel fibres gives better results. It increases up to 22% and 37.5% with bacterial concrete and conventional concrete respectively. Here the mix proportion MPC 4 gives improvement in the flexural strength. Both mix proportions MPC 3 and MPC 4 shows similar results i.e., strength increases up to 13% to that of bio concrete and 31% with respect to conventional concrete for 28 days of water curing. If the polypropylene fibre dominates, there is no significant increase in the split tensile strength of concrete. However, to reduce the quantity of concrete MPC 4 proportion can be used as in the previous case.

Table 7 Flexural Strength Test Results

S:NO	Percentage of fibre by volume	Average flexural strength – 14 days of curing (N/mm^2)	Average flexural strength – 28 days of curing (N/mm^2)
1.	MPC 0	3.50	4.00
2.	MPC 1	4.50	5.00
3.	MPC 2	5.00	5.50
4.	MPC 3	5.00	5.50
5.	MPC 4	4.50	5.00

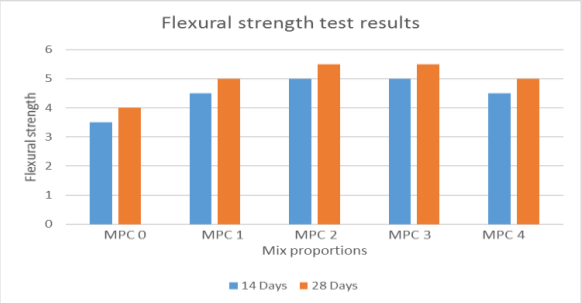

Fig 6 Flexural Strength Comparison for Various Mix Proportions

6.4 Chloride Attack Test

The weight and compressive strength of the concrete after 28 days of water curing and 28 days of exposure to chloride has been examined and summarized in table 8. The percentage reduction in weight and strength implies the loss in weight of concrete before and after exposure to 28 days of chloride. It is observed that the mix proportion MPC 3 shows better results in terms of weight. i.e., equal quantities of steel and polypropylene fibres with 10 ml addition of bacteria shows better resistance to chloride in terms of weight reduction. If the polypropylene fibres dominate it shows better result in the reduction of strength.

Table 7 Chloride Attack Test Results

S.No	Mix Proportion	% Reduction in weight	% Reduction in Compressive strength
1	MPC 1	2.51	2.38
2	MPC 2	1.95	2.14
3	MPC 3	1.74	2.52
4	MPC 4	1.96	1.98

6.5 Sulphate Attack Test

The weight and compressive strength of the concrete after 28 days of water curing and 28 days of exposure to sulphate has been examined and summarized in table 9. The percentage reduction in weight and strength implies the loss in weight of concrete before and after exposure to 28 days of sulphate. The mix proportions MPC 2 and MPC 3 shows similar results when compared to the weight reduction whereas the mix proportion MPC 4 shows better resistance towards strength reduction.

Table 8 Sulphate Attack Test Results

S.No	Mix Proportion	% Reduction in weight	% Reduction in Compressive strength
1	MPC 1	2.36	2.51
2	MPC 2	1.92	2.65
3	MPC 3	1.89	2.34
4	MPC 4	2.65	2.12

7. Conclusion

The main objective of this research attempt is to improve the strength characteristics of the self-healing concrete with the hybrid fibre technology. Several experimental tests have been conducted and the following conclusions are made.

The compressive strength test reveals that when the quantity of steel fibres dominates the polypropylene fibres, it gives better result with bacterial concrete and it increases strength up to 30% to that of conventional concrete.

When there is equal quantity of steel and polypropylene fibres in concrete, it gives better results in bacterial concrete which increases the strength up to 31% to that of conventional concrete.

The proportions of fibres do not affect the change in flexural strength since it gave similar results. However, in order to reduce the quantity of concrete or cement, these proportions can be used.

The mix proportion MPC 4 shows better results in terms of its resistance to chloride and sulphate attack. This may be due to the involvement of natural fibre i.e., polypropylene fibre. Thus in case of coastal areas, or where sulphate attacks are suspected, the mix proportion MPC 4 can be used, which will be eco friendly and economical as well.

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