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Behaviour of Bacterial Concrete

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Abstract: ***Concrete is the most commonly used building material, but the cracks in concrete create problem. Cracks in concrete occur due to various mechanisms such as shrinkage, mechanical compressive and tensile forces. Cracking of the concrete surface may enhance the deterioration of embedded steel bars as ingression rate of corrosive chemicals such as water and chloride ions in to the concrete structure increased. Therefore a novel technique has been developed by using a selective microbial plugging process, in which microbial metabolic activities promote calcium carbonate (calcite) precipitation; this technique is referred as Microbiologically Enhanced Crack Remediation. In this technique urolytic bacteria are used hence the concrete is called Bacterial concrete. The percentages of bacteria selected for the study are 3.5% and 5% by weight of cement. In addition, calcium lactate was used at 5% and 10% replacement of cement by weight. Various tests such as compressive strength, elastic modulus and fracture properties of concrete were analyzed in this study.***

Keywords: Bacteria, Cracks, Calcium lactate, alkaline environment, Bacillus pasteurii

1. Introduction

Concrete is the predominate material used in the structural engineering stream. Concrete is widely adopted in huge structures (commonly used buildings). It is known for its durability, ductility, and resistance towards the external loads. If water droplets enter into the concrete structure due to lack of permeability then it can damage the steel reinforcement present in the concrete member. When this phenomenon occurs, the strength of the concrete decreases and which results in the decay of structure. To prevent these phenomenon bacteria was introduced in concrete. Now a day's calcium lactate powder has been used along with bacteria in concrete which results in the formations of calcium carbonate crystals. This crystal looks like precipitate chain which locks the minute cracks and also the pores in the concrete. Cracks are the major reason for the reduction of strength and permeability in the concrete. Bacteria used in concrete totally based on the pH value of water that which bacteria used in the concrete. Many kinds of bacteria cannot sustain higher alkalinity and some cannot sustain higher pH value of more than 10.These bacteria is added in the form of spores into concrete. When contacted with water this bacterium gets active and it starts making lime stone in the sense calcium carbonate crystals out of calcium lactate powder .Many kinds of bacteria are adopted by many researchers. But for this study Bacillus pasteurii was used. The bacteria that which used as self healing agent must be able to survive for the longer time periods, and it should be the effective crack healing agent. The main mechanism of self healing concrete is , the bacteria that which we added into the concrete should perform as a catalyst for the whole reaction for the longer periods, and also it should convert the precursor compound into the best filling material. This filled up material that originated newly is from the calcium lactate powder that we added to the concrete. This newly filled up material performs as a kind of bio cement which clearly fills up the newly originated cracks. These spores can survive in dry state for 45 to 50 years.

2. Materials Used

The materials used in the present study are
2.1. Cement.
2.2. Fine Aggregates and Coarse Aggregates.
2.3. Calcium Lactate.
2.4. Bacillus Pasteurii (Bacteria).
2.5. Water

2.1. Cement

In the study should be conducted by Ordinary Portland cement of 53 grade. The properties of cement were shown in Table 1 (As per IS: 12269-1987).

Table 1: Properties of cement

S.No	Property of Cement	Values
1	Specific gravity	3.10
2	Fineness modulus	7.4
3	Initial setting time	34 min
4	Final setting time	448 min
5	Consistency	28%

2.2. Fine Aggregates and Coarse Aggregates

Aggregates of size less than 4.75mm is termed as fine aggregates. In this study, river sand with fineness modulus of 2.46 was used. The specific gravity of fine aggregates is 2.74.Coarse aggregates of size more than 4.75mm are termed as coarse aggregates. The fineness modulus and specific gravity of coarse aggregates are 6.89 and 2.8.

2.3. Calcium Lactate

Calcium lactate is also known as calcium salt pentahydrate and the chemical formula is $C_6H_{10}CaO_6$. It looks like white powder and it possesses efflorescent odor. This calcium lactate powder is produced by reacting lactic acid with calcium hydroxide or calcium carbonate. Calcium lactate can be easily dissolved in ethanol and the melting point of calcium lactate is 239^0c. In this research we use different percentages of calcium lactate and the percentages are

0%,5% and 10% by the weight of cement. The physical properties of calcium lactate are tabulated in Table 2.

Table 2: Physical properties of calcium lactate

Physical properties	
Chemical formula	$C_6H_{10}CaO_6$
Appearance	White powder
Density	1494 kg/m^3
Solubility in water	7.8 g/100 ml
Odor	Efflorescent
Solubility	Very soluble in ethanol
Molar mass	218.22 g/mol

2.4. Bacteria

Bacillus pasteurii is also known as sporosarcina pasteurrii. It has an ability to form into precipitate when calcium lactate comes into contact with it in the presence of water droplets. The pH were this bacteria can sustain is from 7 to 9. Some kinds of bacteria cannot sustain alkalinity and the selection of bacteria is totally based upon the pH value of water that we used in the entire research. The percentages of bacteria selected for the study are 0%, 3.2% and 5% by the weight of cement.

2.5. Water

Ordinary tap water has been used as per IS: 3025-1904 and IS: 456-2000.

3. Objectives and Methodology

The main objectives of the current study are to study the following properties.

- Evaluation of compressive strength of controlled concrete and bacterial concrete mixes of grade M40.
- Evaluation of Young's modulus of elasticity of controlled concrete and bacterial concrete mixes.
- Evaluation of fracture energy using three point loading.

3.1. Methodology

Methodology for producing bacterial concrete involves

- Selection and growth of bacteria.
- Preparation of test specimens.
- Strength testing.
- Evaluation of fracture energy.

3.2. Preparation of concrete samples with bacteria

Bacterial concrete is prepared by using ordinary Portland cement mixed with bacterial concentration of 10^9 cell/ml of water. The percentages of bacteria selected were 0%, 3.2%, 5% and calcium lactate of 0%, 5% and 10% by weight of cement. Table 3 shows the mix proportions of concrete.

Table 3.1: Bacterial concrete mix proportions

Mix Id	Bacteria (%)	Calcium lactate (%)	Cement Kg/m^3	Fine Aggregates Kg/m^3	Coarse Aggregates Kg/m^3	Water Lit/m^3
Control mix	-	-	492.5	673.6	1099.12	197
5%Calcium lactate	-	5	467.87	673.6	1099.12	197
10% calcium lactate	-	10	443.23	673.6	1099.12	197
15% Calcium lactate	-	15	418.63	673.6	1099.12	197
3.2% Bacteria	3.2	-	492.5	673.6	1099.12	198.77
5% Bacteria	5	-	492.5	673.6	1099.12	199.53
10% Calcium lactate + 3.5% Bacteria	3.2	10	443.23	673.6	1099.12	198.77
10% Calcium lactate + 3.5% Bacteria	5	10	443.23	673.6	1099.12	199.53

4. Experimental Program

4.1. Compressive Strength

As per IS: 516-1959 (reaffirmed 2004), the compressive strength was tested on the concrete specimens which are hardened due to curing phenomenon. The compressive strength of various proportionate mixes were determined by using digital compression machine. The capacity of the compression machine is 2000kN and the specimens are tested at a loading rate of 2.5 kN/s. The dimensions of the cube are maintained as 100x100x100 mm. The compressive strength set up is shown in Fig.1.

Figure 1: Concrete specimen subjected to compression

4.2 Elastic modulus

In this research, the cylindrical specimens of dimensions 150x300 mm were tested for elastic modulus under uniaxial load. The set up consists of a dial gauge which records the deformations. The values from the dial gauge are then divided by the length of gauge that results in the strain and then the stress will be calculated by divided internal resisting load by the cross sectional area. Then the stress-strain relationship is derived from the series of values and then it results in elastic modulus. As per IS:516-1959, the elastic modulus were obtained. The elastic modulus set up is shown in Fig.2.

Figure 2: Elastic modulus test

4.3 Fracture energy test

The fracture energy of the concrete specimen were determined by using a prism of dimensions 840x100x100 mm. The prism of 840 mm is assumed to be length of 2L and then the distance from center of prism to the either sides of the supports is L/2. The load on the prism is made to act upon L (centre of the prism). Now the fracture energy is calculated by dividing the total energy consumed by the prism to the cross sectional area of the ligament. The area of ligament were calculated as b*(d-a) were b is the thickness of the prism, d is the depth of the prism and a is the length of the notch. The fracture energy test set up is shown in Fig.3.

G_{F}=w/b(d-a) N/m

Figure 3: Fracture energy test

5. Results and Discussions

5.1. Compressive Strength

5.1.1. Effect of calcium lactate on compressive strength of concrete

The compressive strength of concrete using calcium lactate were shown in Fig.4. From the Fig.4, it can be observed that compressive strength for controlled concrete at 7 days and 28 days were found to be 19.8 MPa and 40.53 MPa respectively. With the addition of calcium lactate, there is considerable decrease in compressive strength.

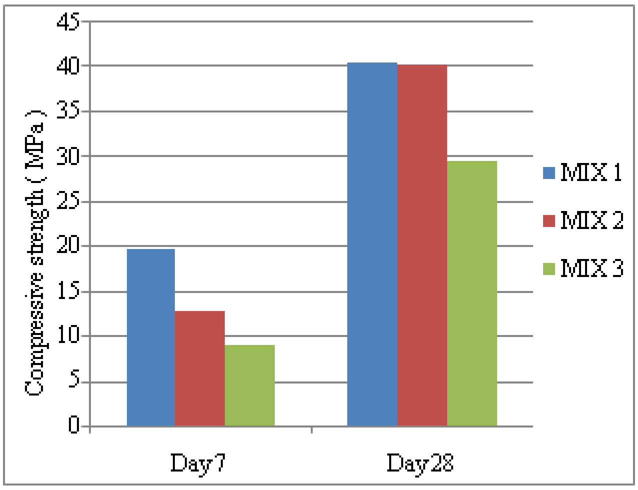

Figure 4: Comparison of compressive strength of concrete with different percentages of calcium lactate

Table 3: Effect of calcium lactate on compressive strength of concrete

S. No	Mix Id	Compressive strength (MPa)	
		7 days	28 days
1	MIX 1	19.8	40.53
2	MIX 2	12.83	40.36
3	MIX 3	9.06	29.66

5.1.2. Effect of bacteria on compressive strength of concrete

The compressive strength values of concrete using bacteria were shown in Table 4. From Table 4, it can be observed that there is slight increase in compressive strength of concrete with 5% of bacteria. It was also observed that pores in concrete are partially filled up by material growth with the addition of bacteria. Reduction in pores will obviously increase the density of the material and strength. As the pores in concrete are filled by bacteria, a chance of development of cracks reduces considerably. Hence bacteria can be used as self healing agent. Compressive strength of concrete with 5% bacteria was found to be 49.5 Mpa at 28 days, which is more than controlled concrete. The increase in strength may be due to reduction in pores of concrete with the incorporation of bacteria.

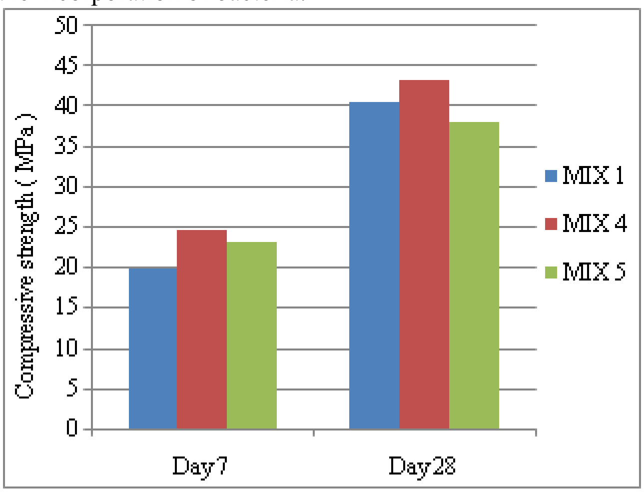

Figure 5: Comparison of compressive strength of concrete with different percentages of bacteria

Table 4: Effect of bacteria on the compressive strength of concrete

S. No	Mix Id	Compressive strength (MPa)	
		7 days	28 days
1	MIX 1	19.8	40.53
2	MIX 4	24.73	43.33
3	MIX 5	23.06	38.1

5.1.3. Effect of calcium lactate and bacteria on strength of concrete

The compressive strength of concrete using calcium lactate and bacteria were shown in Table 5. From the Table.6, it can be observed that there is considerable increase in compressive strength of concrete with bacteria and calcium lactate mix. With the addition of calcium lactate at 10% (optimum percentage) and bacteria to concrete, there is considerable increase in compressive strength. Hence calcium lactate along with 3.2% and 5% bacteria can be used as an effective self healing agent.

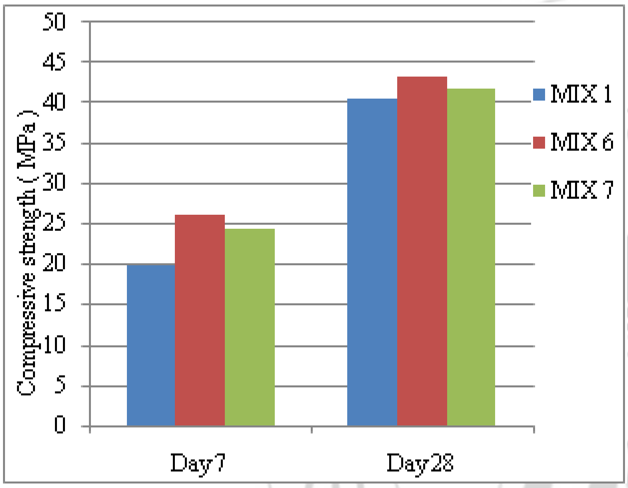

Figure 6: Comparison of compressive strength of concrete with different percentages of calcium lactate and bacteria

Table 5: Effect of calcium lactate and bacteria on the compressive strength of concrete

S. No	*Mix Id*	*Compressive strength (MPa)*	
		7 days	*28 days*
1	MIX 1	19.8	40.53
2	MIX 6	26	43.4
3	MIX 7	24.3	41.9

5.2 Elastic Modulus

To determine the elastic modulus, compressometer is attached to the cylinder of dimensions 150mm in diameter and 300mm in height. It was made sure that the reading in dial gauge should be zero before the cylinder is subjected to the uniaxial compression. For an interval of every 5kN load values on the cylinder has to be noted down. Then the stress strain graph was plotted for the load and deflection values. Then the elastic modulus is determined by the slope of the line that drawn to 40 percent of stress value at the ultimate load. The elastic modulus of 28th day is tabulated in Table 7.

Table 7: Results of elastic modulus

Mix Id	*Ultimate Stress (MPa)*	*Elastic Modulus (GPa)*
MIX 1	33.72	13.74
MIX 2	36.10	13.46
MIX 4	39.95	14.92
MIX 6	31.51	12.11
MIX 7	28.80	9.94

5.3 Fracture Energy

A dial gauge of least count 0.01 is attached to the prism of dimensions 840x100x100 mm and the prism is subjected to point load. To determine the fracture energy, the values for every 1kN of point load were recorded. Then the fracture energy was obtained by dividing the total amount of energy consumed by the prism to the cross sectional area of the ligament. The fracture energy obtained on 28th day is tabulated in Table 8 and shown in Fig.7. MIX 4 has obtained higher fracture energy when compared with all other proportions and it obtained higher energy of 1070 N.

Table 8: Results of Fracture energy (G_F)

Mix Id	*Total energy consumed by prism (N)*	*Cross sectional area of the ligament (m)*	*Fracture energy (N/m)*
MIX 1	1030	0.005	206000
MIX 2	355	0.005	71000
MIX 4	1070	0.005	214000
MIX 6	720	0.005	144000
MIX 7	555	0.005	111000

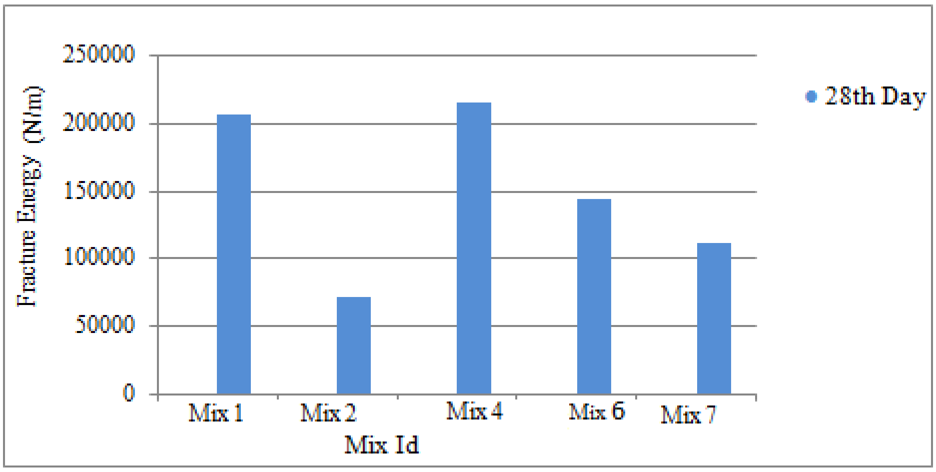

Figure 7: Fracture energy of different percentages of calcium lactate and bacteria specimens

6. Conclusions

The followings conclusions are made from the present study

1) Compressive strength of 5% Bacterial mix considerably increases to 2.63% when compared with Control mix.
2) Compressive strength of 10% Calcium lactate increases to 2.63% when compared with Control mix. Beyond 10% of Calcium lactate there is 20.80% decrease in compressive strength of concrete.
3) Compressive strength of 10% Calcium lactate + 3.2% Bacterial mix decreases to 9.95% when compared with control mix and 10% Calcium lactate + 5% Bacterial mix strength increase to 4.35% when compared with Control mix.
4) The maximum compressive strength obtained was 50.3 MPa for 10% Calcium lactate + 5% Bacterial mix .
5) Elastic modulus of 10% Calcium lactate + 5% Bacterial mix considerably increases to 8.75% when compared with Control mix.
6) The maximum elastic modulus obtained was 21.73 GPa for 10% Calcium lactate + 5% Bacterial mix.
7) Among all the fracture energy mixes,10%c Calcium lactate+5% Bacteria mix attains maximum fracture energy of 214000N/m

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