Effect of bacteria on strength and porosity of M-sand based pumpable concrete

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Abstract: This paper presents the results of experimental investigation which was carried out to evaluate the effect of bacteria on the compressive strength, porosity of M-sand concrete. The river sand was replaced by M-sand and M20 and M30 grade pumpable concretes were designed for investigation purpose. The w/c ratio of the concrete was selected as 0.45 and 0.4 respectively. Bacillus subtilis bacteria was included at a concentration of $30 \times 10^5$ cells/mL of water. The compressive strength, water absorption and porosity of concrete were determined after the curing period of 3, 7, 28 and 90 days. Results were indicated that the substitution of M-sand instead of river sand was reduced the compressive strength up to 20% when compared with river sand based control concrete. The porosity and water absorption behaviour of M-sand concrete were observed in higher order than that of control concrete. On the addition of bacteria, 37% - 45% reduction in water absorption and porosity level of bacterial M-sand concrete was achieved due to the self-healing of micro crack in the concrete.

1. Introduction

The concept of bacterial concrete is considered as one step ahead towards the smart concrete. The smart concrete has the ability to adopt itself to the environment but the bacterial concrete has the ability to repair itself. Bacillus pasteruii is a common soil bacterium. It has the ability to produce calcite. When this bacterium is used in concrete, it produces a highly impermeable layer of calcite over the surface of existing concrete. The bacteria can be able to suspend in water when mixed in concrete [1]. Along with the supplementary cementitious materials, which are enhancing the properties of concrete, the introduction of bacteria in concrete can further improved the durability properties [2-5]. The bacteria when introduced in concrete which continuously precipitated a layer of calcite over the existing concrete. The precipitated calcite layer is an impermeable and insoluble in water presence in concrete. It is able to adhere in the existing concrete surface of hardened concrete. When the bacteria was introduced during the manufacturing of concrete, the precipitated calcite fill the pores developed during the hydration of cement particles. It lowers the permeability and reduce the sorptivity [6]. Manufacturing sand (M-sand) is an alternative man-made sand which can be carefully manufactured from the granite crushed stone quarry. The restriction in sand mines imposed by the local body authorities took the construction people to look
for an alternate to the natural sand. Researchers are engaged to evaluate the suitability of M-sand in concrete as a fine aggregate instead of natural sand. The research finding are evidence that the M-sand can be used in the form of partial replacement of sand and considering 100% M-sand was promising in some applications [7].

It has more advantages than the natural sand including the availability in the proximity of the construction site. It can be purchased depends up on the demand and relatively lower cost than the river sand. It has some technical drawbacks which can be considered while designing in a concrete mix proportions. Relatively, it has more water absorption nature and angular surface structure which affects the workability of concrete in its fresh state and subsequently compressive strength in hardened state.

Ready mixed concrete (RMC) industry is one of the supporting type of industry which provide suitable concrete at site as per the demand. It was observed that most of the RMC units are used M-sand fully or partially while making pumpable concrete [8]. In this background, the resent study was intended to evaluate the impact of bacteria on the properties of M-sand based pumpable concrete and compared the results with pumpable concrete specimens prepared using river sand.

2. Experimental Investigation

2.1 Materials used

In the present investigation, 53 grade Ordinary Portland cement (OPC) in accordance with IS 269: 2015 was used [9]. As per specifications provided, the cement contains 5% fly ash (FA) as performance improver. The chemical compositions of cement are mentioned in Table.1. The physical properties are given in Table.2.

| Chemical compositions | Composition (%) |
|-----------------------|-----------------|
| SiO₂                  | 21.92           |
| Al₂O₃                 | 5.71            |
| Fe₂O₃                 | 3.23            |
| CaO                   | 60.37           |
| MgO                   | 1.65            |

The river sand was employed for developing the control pumpable concrete and the investigation was further carried out by replacing the river sand with M-sand as fine aggregate. The grading limit of both river sand and M-sand confirmed to Zone – II as per IS 383:1970 [10]. The fine particles in M-sand were within the limit of code provisions. Two different sizes of coarse aggregate obtained from crushed granite stones of maximum sizes 20 mm and 12 mm were considered. The physical properties of fine aggregates and coarse aggregates are given in Table. 3. Polycarboxylic ether based retarding superplastizer (RSP) was selected. It is light brown in colour with pH ≥ 6. The specific gravity of the RSP was 2.2 at 30°C.

| Properties                         | Results | Limitations as per IS 4031:1988 [11] |
|------------------------------------|---------|-------------------------------------|
| Specific gravity                   | 3.15    | ≤ 3.15                              |
| Initial setting time (min.)        | 55      | > 30                                |
| Final setting time (min.)          | 160     | < 600                               |
| Specific surface area (m²/kg)      | 335     | 300 -350                            |
Table 3. Properties of fine aggregate and coarse aggregate

| Properties            | Fine aggregate | Coarse aggregate |
|-----------------------|----------------|------------------|
|                       | River sand     | M-sand           | 20 mm   | 12 mm   |
| Specific gravity      | 2.65           | 2.76             | 2.71    | 2.74    |
| Absorption capacity   | 0.65%          | 1.5%             | 0.55%   | 0.45%   |
| Fineness modulus      | 2.79           | 2.57             | 7.65    | 7.93    |
| Grading limit         | Zone – II      | Zone - II        | Single sized | Single sized |

2.2 Bacterial culture

The bacterial culture was initiated at the rate of 1.25 g of nutrient source (calcium nutrient) added to a 50 ml of distilled water in a flask. Then the flask was closed using cotton pad and covered with silver foil. Solution was sterilized about 20 minutes at 120°C in an autoclave and the solution was in clear orange colour after sterilization. Then the flasks were opened and add 1mL of the bacteria to the sterilized solution and was incubated in an orbital shaker with a speed of 125 rpm at 37°C [12,13]. After 24 hours, it can be seen that the growth of the bacteria by changing solution from orange colour to whitish yellow colour. The bacterial culture in laboratory environment for using the research work is shown in Figure 1.

2.3 Sample preparation and testing methods

The fresh concrete samples were collected at a construction site accordingly the concrete was prepared at the RMC unit for investigation purpose. The slump value of the pumpable concrete was conducted in two occasions. The fresh concrete was collected when it was discharged and immediately the initial slump test was carried out and after 30 minutes the slump test was conducted in order to check the slump retention. The cubes of 150 mm size was prepared for finding the compressive strength, water absorption and porosity tests. The oven dried cube specimens were immersed in water for 24 hours and the percentage of water absorption was determined with the weight of fully saturated weight specimens. The porosity of
concrete was determined based on the weight measurement while converting wet condition to dry condition [14]. The collection sample at discharge point for preparing samples is shown in Figure 2.

![Figure 2. Fresh concrete sample collection point](image)

2.4 Mix proportioning
According to ASTM C494, the dosage of RSP was selected to the range between 525mL /100 kg of cement [15]. M20 grade and M30 grade concretes were considered. The initial mix proportioning was prepared as per the guidelines of IS: 10262-1999[16] and the final mix proportioning of the proposed concrete was developed after three different trails and shown in Table 4.

| Mix ID | Cement kg/m³ | R-sand kg/m³ | M-sand kg/m³ | 20mm kg/m³ | 12mm kg/m³ | RSP kg/m³ | w/c ratio | water kg/m³ | Bacteria cells/mL |
|--------|---------------|--------------|--------------|-------------|-------------|------------|-----------|-------------|-----------------|
| CC20   | 356           | 790          | -            | 680         | 370         | 3.92       | 0.47      | 167.3       | -               |
| MC20   | 356           | 790          | -            | 680         | 370         | 3.92       | 0.47      | 167.3       | -               |
| BC20   | 356           | 790          | -            | 680         | 370         | 3.92       | 0.47      | 167.3       | 30x10⁵          |
| CC30   | 377           | 770          | -            | 662         | 358         | 4.15       | 0.43      | 162.1       | -               |
| MC30   | 377           | -            | 770          | 662         | 358         | 4.15       | 0.43      | 162.1       | -               |
| BC30   | 377           | -            | 770          | 662         | 358         | 4.15       | 0.43      | 162.1       | 30x10⁵          |

3. Results and discussion
3.1 Workability
The slump value of the pumpable concrete was conducted to evaluate the workability. The slump retention was also examined after 30 minutes of mixture preparation in accordance with IS 9103:1999 [17, 18]. It was observed that the slight reduction slump value while using M-sand as fine aggregate due to the angular surface and higher degree of water absorption nature [19]. The slump value required for a pumpable concrete is normally more than 120mm [20]. Though reduction of slump value results noticed in M-sand based pumpable concrete, the results were satisfactory for pumping the concrete. In addition, an
insignificant improvement in slump value was observed due to the addition of nutrient source (calcium nutrient) in concrete for bacterial culture. The comparison of slump value at initial period and after 30 minutes of elapsed time is shown in Fig. 1 and found 8% reduction in control concrete and 6.5% reduction in M-sand concrete. The reduction of slump was noticed up to 3.5% in bacterial concrete but the results are more than the M-sand based pumpable concrete.

![Slump value of pumpable bacterial concrete](image)

**Figure 3.** Slump value of pumpable bacterial concrete

### 3.2 Compressive strength

The compressive strength of control concrete, pumpable concrete and bacterial pumpable concrete for M20 and M30 grade concrete are shown in Figure 3 and 4 respectively. In both grade of concrete considered in this investigation, the pumping concrete prepared with M-sand and bacterial concrete had shown almost similar compressive strength during the early periods of curing. After seven days curing, the compressive strength of M-sand based pumpable concrete was found as lower than that of control concrete. The reduction of compressive strength was noticed up to 28% during the 28 curing period. However, the bacterial pumpable concrete made with M-sand had shown higher compressive strength than the control concrete due to the deposition of calcite on the bacterial cell surface and within the pores of cement sand matrix which fill the pores. The compressive strength of bacterial pumpable concrete after 7 days curing was found 20% higher in M20 concrete and 22% higher in M30 grade concrete. Ghosh (2009) also reported that the improvement in compressive strength may be due to the deposition of some minute filler material produced by the bacteria that reduce the pore size and modify the microstructure of concrete [21]. Therefore, the bacteria helps to fill the micro pores in concrete and the compressive strength increases.

### 3.3 Water absorption

The water absorption characteristics of 28 days cured control concrete, M-sand based pumpable concrete and bacterial pumpable concrete for M20 and M30 grade concrete are shown in Figure 5. In both grade of concrete considered in this investigation, the pumping concrete prepared with M-sand had shown higher water absorption level than the control concrete. The M-sand based pumpable quality M20 grade concrete was 30% higher and in M30 grade concrete was 20% higher than the control concrete due to the formation of shrinkage cracks during the curing period. However, the bacterial pumpable concrete made with M-sand had shown lower water absorption than the control concrete. The water absorption of bacterial pumpable concrete prepared with M-sand was reduced up to 42% and 40% in M20 and M30 grade concrete.
concrete respectively. This reduction of water absorption was due to the pore filling action of the calcite developed by the bacterial cells. The bacteria can develop the self-healing behaviour of concrete and helps to fill the micro pores in concrete to reduce the water absorption [19]. The relationship between the water absorption and compressive strength of concrete is shown in Figure 6. A perfect non-linear correlation was found with higher co-efficient which proved that the bacterial concrete had very low water absorption.

Figure 4. Compressive strength development of M20 grade pumpable bacterial concrete

Figure 5. Compressive strength development of M30 grade pumpable bacterial concrete
3.4 Porosity

The porosity of 28 days cured concrete specimens prepared with control concrete, M-sand based pumpable concrete and bacterial pumpable concrete for M20 and M30 grade concrete are shown in Figure 7. The dense concrete is generally lower porosity and lower water absorption in nature. The formation of shrinkage cracks during hydration process is a common unavoidable occurrence in concrete and the self-healing nature of the bacterial concrete can help to arrest the cracks subsequently which leads to reduce the porosity of concrete. In both grade of concrete considered in this investigation, the pumpable concrete prepared with M-sand had shown higher porosity than the control concrete due to the higher absorption nature of M-sand. This causes to reduce the hydration process and retain the un-hydrated cementitious particles which reflect in the compressive strength development. The M-sand based pumpable quality M20 grade concrete was 22% higher and in M30 grade concrete was 20% higher than the control concrete due to the formation of shrinkage cracks during the curing period. However, the bacterial pumpable concrete made with M-sand had shown lower porosity than the control concrete. The porosity of bacterial pumpable concrete prepared with M-sand was reduced up to 50% and 57% in M20 and M30 grade concrete respectively. This reduction of porosity was due to the self-healing behaviour of concrete and helps to fill the micro pores in concrete to reduce the porosity [19]. The relationship between the porosity and compressive strength of concrete is shown in Figure 8. A perfect non-linear correlation was found with higher co-efficient which proved that the bacterial concrete had very low porosity. Lower the porosity allowed the concrete to improve the compressive strength was clearly observed from the Figure 8.

4. Conclusions

- Addition of bacteria in pumpable concrete reduces the workability insignificantly due to the presence of M-sand when compared to control concrete and found 8% reduction in control concrete and 6.5% reduction in M-sand concrete after 30 minutes. The reduction of slump was noticed up to 3.5% in bacterial concrete after the retention period of 30 minutes but the results are more than the M-sand based pumpable concrete.

- The bacterial pumpable concrete made with M-sand had shown higher compressive strength than the control concrete due to the deposition of calcite which fill the pores in cement sand matrix. The compressive strength of bacterial pumpable concrete after 7 days curing was found 20% higher in M20 concrete and 22% higher in M30 grade concrete.
The water absorption of M-sand based pumpable quality M20 grade concrete was 30% higher and in M30 grade concrete was 20% higher than the control concrete. The water absorption of bacterial pumpable concrete prepared with M-sand was reduced up to 42% and 40% in M20 and M30 grade concrete respectively. A perfect non-linear correlation was found between the water absorption and compressive strength of concrete with higher co-efficient.

The porosity of M-sand based pumpable quality M20 grade concrete was 22% higher and in M30 grade concrete was 20% higher than the control concrete. The porosity of bacterial pumpable concrete prepared with M-sand was reduced up to 50% and 57% in M20 and M30 grade concrete respectively. A perfect non-linear correlation was found between the porosity and compressive strength of concrete with higher co-efficient.
strength of concrete with higher co-efficient which proved that the bacterial concrete had very low porosity.

![Figure 9. Compressive strength vs. porosity of bacterial pumpable concrete](image)

5. References

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\[ y = 640.25x^{-1.609} \quad R^2 = 0.9783 \]
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