An Experimental Study on Microbial Bio-cementation in Enhancing the Performance of Rice Husk Ash Concrete

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Abstract - *The technique of Microbiologically Induced Calcite or Calcium Carbonate ($CaCO_3$) Precipitation (MICP) can be used to improve the strength and durability of concrete. The incorporation of pozzolans improves the properties of concrete. Rice Husk Ash (RHA), an agro waste, has been proved to exhibit good pozzolanic characteristics. The effectiveness of MICP using the bacteria Bacillus subtilis in enhancing compressive strength, split tensile strength and reducing water permeability, water absorption and susceptibility to chloride attack of RHA concrete (M25 grade) was investigated in this thesis work. The optimum dosage of RHA in concrete was determined by conducting the compressive strength and split tensile strength tests at 7 and 28 days of curing of concrete specimens prepared with varying dosages of RHA (3%, 4%, 5%, 6% and 7% of cement partially replaced by weight). An optimum of 5% dosage was obtained. Optimum bacterial concentration was obtained as 10^5cells/ml from compressive strength test after 28 days' curing. The comparison of normal concrete, RHA concrete and bacterial concrete with RHA were done. Bacterial concrete with RHA showed better performance, followed by RHA concrete, than normal concrete without RHA and bacterial cells.*

Key Words: Rice husk ash, *Bacillus subtilis*, Microbiologically Induced Calcite or Calcium Carbonate ($CaCO_3$) Precipitation (MICP), bacterial concrete, bio-cementation.

1. INTRODUCTION

Concrete has a unique place among the construction materials owing to the inexpensive easy availability and convenience in usage. But development of cracks under sustained loading is a drawback which is remediated by using synthetic materials. But their cost, blotch on aesthetics and need for constant maintenance urges the necessity for an alternative. Here lies the significance of Microbiologically Induced Calcite or calcium carbonate ($CaCO_3$) Precipitation (MICP) which can be used to remediate cracks and also to improve the strength and durability of concrete.

Rice Husk Ash (RHA), an agro waste, exhibits good pozzolanic characteristics owing to its high silica content.

1.1 Chemistry behind MICP

Various ureolytic bacteria produce urease (as part of metabolism), which catalyzes the hydrolysis of urea to carbamate and ammonia leading to further hydrolysis producing ammonia and carbonic acid and finally forming bicarbonate.

1.2 Pozzolanic Reaction & Rice Husk Ash

A pozzolanic reaction occurs when a siliceous or aluminous material comes in contact with calcium hydroxide in the presence of humidity to form compounds exhibiting cementitious properties. It is acknowledged that under suitable burning conditions (600 to 850°C), reactive RHA has a high content of amorphous silica that imparts pozzolanic activity.

2. LITERATURE REVIEW

Bacterial concrete (10^5cells/ml concentration) with fly ash and Ground Granulated Blast furnace Slag (GGBS) have shown better strength properties than conventional M40 concrete [1]. Fibre reinforced concrete with 5% replacement level of RHA gave mechanical and toughness properties [2]. At 6% replacement of OPC with RHA, concrete exhibits good compressive strength, because of its high pozzolanic activity [3]. An alkalophilic aerobic *Sporosarcina pasteurii* at different cell concentrations (10^3, 10^5, 10^7 cells/ml) with the mixing water led to 33% increase in 28 days compressive strength of cement mortar [4]. The compressive strength and durability were enhanced in bacterial concrete specimens (M20, M40, M60 and M80 grades) by the addition of *Bacillus subtilis* bacteria at a cell concentration of 10^5 cells/ml of mixing water [5]. "Microbial concrete" by *Bacillus sp*. had improved compressive strength and decreased water-absorption [6]. The untreated *Bacillus Subtilis* and Chemically Modified *Bacillus Subtilis* (CMBS) formed the C-S-H gel filled the cement microstructures producing low permeability concrete [7].

The review of literature urges the need for investigating the microbial influence in concrete containing rice husk ash.

3. MATERIALS

The materials used in the preparation of concrete mix in the present investigation are cement (OPC 53 grade), fine aggregate (Zone II), coarse aggregate (of max. nominal size 20mm), RHA, *Bacillus subtilis* bacteria and water as per IS specifications [8-11]. The chemical composition and specifications of RHA are presented in Table 1.

Table -1: Chemical Composition and Specifications of RHA (as per manufacturer's data)

Compound	Chemical content (%)
Silicon dioxide (SiO_2)	93.80
Calcium oxide (CaO)	0.89
Ferric oxide (Fe_2O_3)	0.30
Aluminium oxide (Al_2O_3)	0.74
Magnesium oxide (MgO)	0.32
Potassium oxide (K_2O)	0.12
Sodium oxide (Na_2O)	0.28
Titanium dioxide (TiO_2)	0.10
Loss on ignition (LOI)	3.45
Specific gravity	2.11
Incinerating temperature	600°C – 700°C

4. EXPERIMENTAL PROGRAMME

M25 grade concrete was designed as per the relevant IS specifications [12-13]. The proportions are tabulated in Table 2.

Table -2: Mix Proportions for 1m^3 of concrete

Ingredient	Quantity
W/C ratio	0.45
Water	166.5 litres
Cement	370 kg
Fine Aggregate	703.801 kg
Coarse Aggregate	1247.92 kg

Standard cubes and cylinders were cast for each mix [14].

The study was carried out in three stages. In the first stage, which dealt with the determination of optimum dosage of RHA from 7th and 28th day compressive and split tensile strength test results, specimens of M25 grade concrete mixes were prepared partially replacing 3, 4, 5, 6 and 7% by weight of cement by RHA.

The second stage which was aimed at the determination of the optimum bacterial cell concentration in RHA concrete from the 28th day compressive strength test results, was conducted by preparing specimens of M25 grade concrete with varying concentrations of *Bacillus subtilis* and the optimum dosage of RHA. Bacterial cell concentrations of 10^3, 10^5, 10^7 cells/ml were mixed in the mixing water.

The comparison of properties of conventional concrete, concrete with optimum RHA and concrete with optimum dosages of both RHA and bacterial cells were done as the third stage of the investigation. The strength properties compared were compressive and split tensile strengths whereas, the durability properties studied were water permeability, water absorption and susceptibility to chloride attack.

5. RESULTS AND DISCUSSIONS

The results obtained for the tests in the different stages and the discussions are summarised.

5.1 Stage I - Determination of Optimum Dosage of RHA

Slump test, compressive and split tensile strength tests at 7th and 28th day were conducted for different percentages of RHA and the results are depicted in Charts 1, 2, 3, 4 and 5.

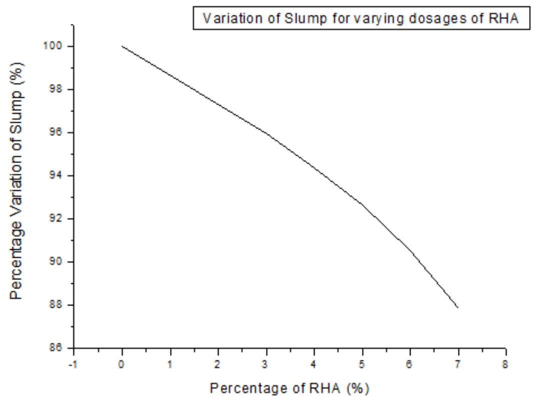

Chart -1: Variation of Slump for Concrete with varying Percentages of RHA

The Y-axis in the Charts represents the percentage variation of slump. Control mix is considered to have a percentage variation of 100% so that a positive quadrant graph is obtained.

From Chart 1, it can be observed that the slump decreases with the increase in replacement percentage of cement with RHA. This can be due to the increase in the volume of concrete after adding RHA by weight owing to the lower specific gravity of RHA than that of cement.

From Chart 2, it is apparent that the 7th day compressive strength for concrete with all percentages of RHA is lower than that of normal concrete. But from Chart 3, RHA content helps to increase the strength at 28th day which indicates that the pozzolanic reaction of RHA is slow.

From Chart 4 and 5, the variation of split tensile strength is clear.

The increase in strength can be attributed to the development of more C-S-H gel in RHA concrete due to the reaction between RHA and calcium hydroxide in hydrating cement. It can also be justified by the filler (physical) effect.

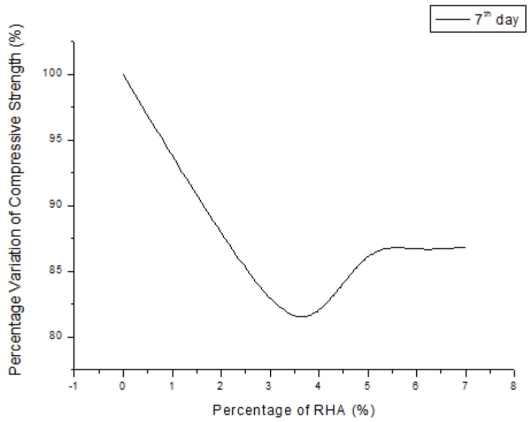

Chart -2: Variation of 7th day Compressive Strength of Specimens with varying RHA Dosage

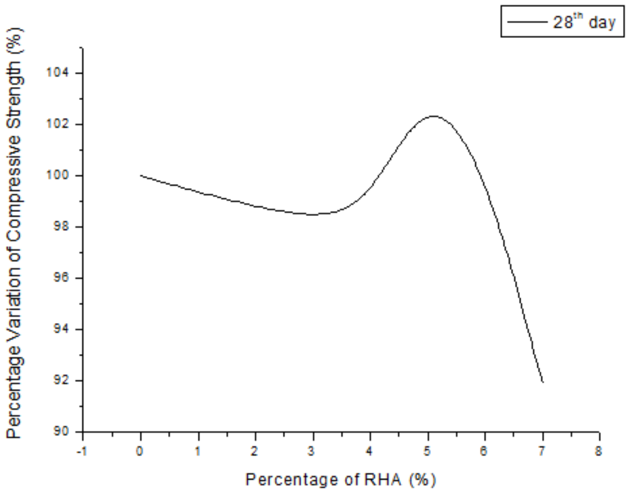

Chart -3: Variation of 28th day Compressive Strength of Specimens with varying RHA Dosage

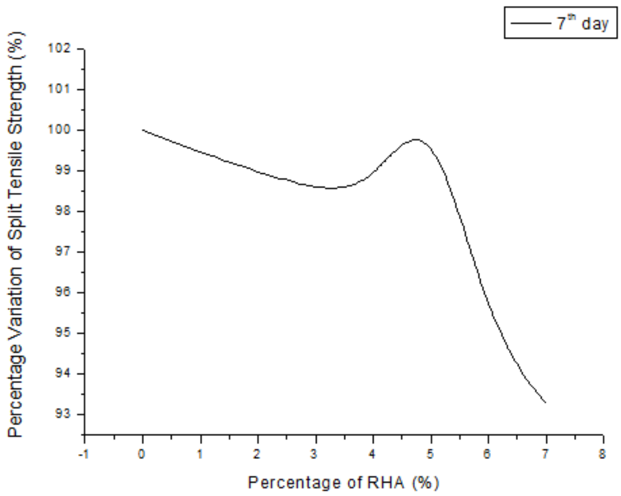

Chart -4: Variation of 7th day Split Tensile Strength of Specimens with varying RHA Dosage

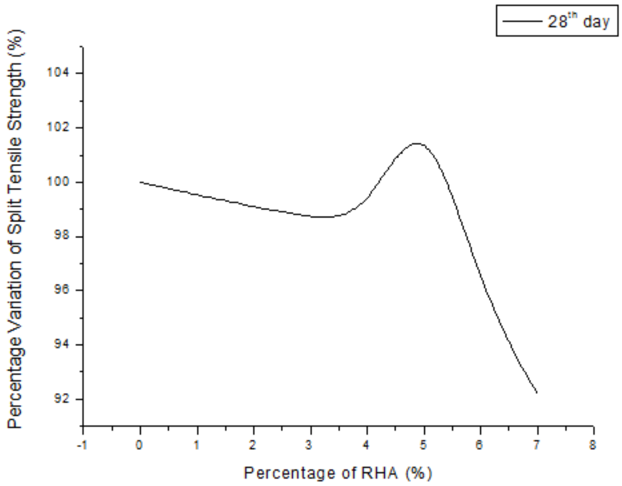

Chart -5: Variation of 28th day Split Tensile Strength of Specimens with varying RHA Dosage

Both compressive and split tensile strengths reach the maximum for concrete with 5% RHA and decrease is observed for partial replacement percentages larger than 5%. Hence, the optimum dosage of RHA is 5%.

5.2 Stage II - Determination of Optimum Dosage of Bacterial Cell Concentration

Compressive and split tensile strength tests at 28th day were conducted for concrete with 5% RHA but varying concentrations of bacterial cells in the mixing water and the results are depicted in Chart 6. The mixes were designated as R5B3, R5B5, and R5B7 (10^3, 10^5, 10^7 cells/ml).

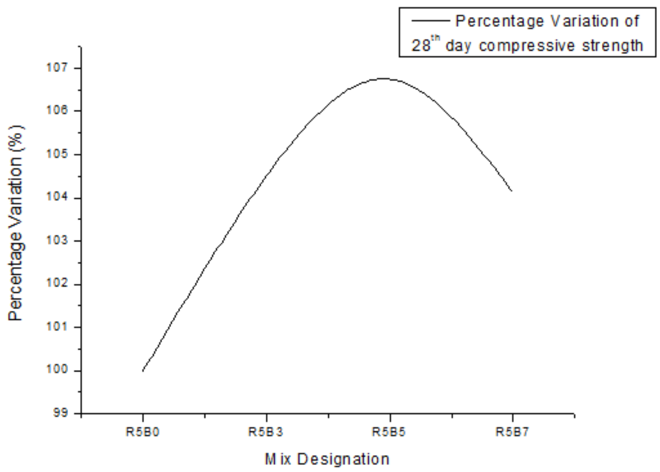

Chart -6: Variation of 28th day Compressive Strength of RHA (5%) Concrete with varying Bacterial Cell Concentrations.

From Chart 6, it is apparent that the maximum compressive strength is obtained for R5B5. Also, the compressive strength of RHA concrete increased with increase in bacteria cell concentration up to 10^5cell/ml, and then there was a reduction in the strength at 10^7cells/ml. The increase in strength was due to the known microbial action. An optimum dead cells act as filler material. At higher concentrations of bacterial cells, there will be excessive number of cells in the mixing water which leads to more dead cells and hence effective deposition of calcite is hindered. The optimum bacterial cell concentration is determined as 10^5cells/ml.

5.3 Stage III - Comparison of Properties of the Three Concretes

The third stage was carried out by preparing three mixes designated as R0B0, R5B0 and R5B5 i.e., normal concrete, concrete with 5% RHA (but without bacterial cells) and, concrete with 5% RHA and 10^5 cells/ml concentration of bacterial cells, respectively. The tests conducted are compressive and split tensile strengths water permeability, water absorption and susceptibility to chloride attack at 28th day.

5.3.1 Compressive Strength Test

The results are represented in Chart 7.

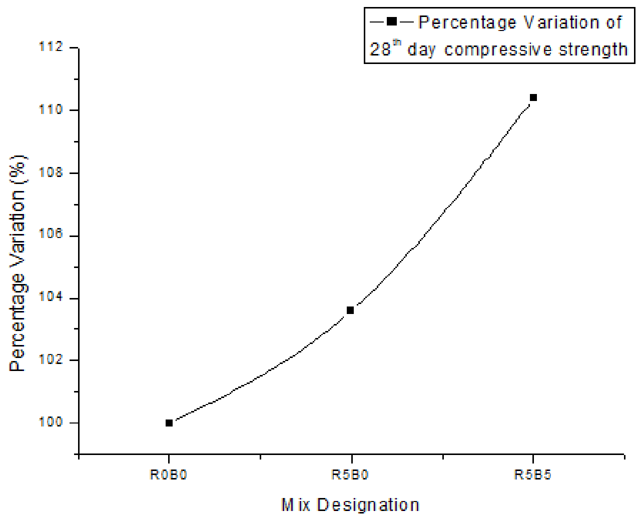

Chart -7: Variation of 28th day Compressive Strengths

From Chart 7, it is clear that there is an increase in compressive strength of concrete with RHA and concrete with both RHA and bacteria, as compared to control concrete.

5.3.2 Split Tensile Strength Test

The results are represented in Chart 8.

A clear understanding of the variation in split tensile strengths is obtained from Chart 8. Rice husk ash is responsible for an increase of 3.39% in the split tensile strength whereas combined action of RHA and bacteria has brought about an increase of 11.53%, as compared to control concrete.

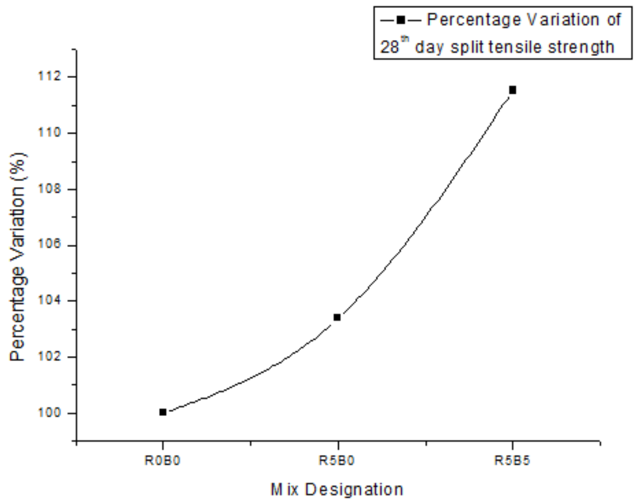

Chart -8: Variation of 28th day Split Tensile Strengths

5.3.3 Water Permeability Test

The results are represented in Chart 9.

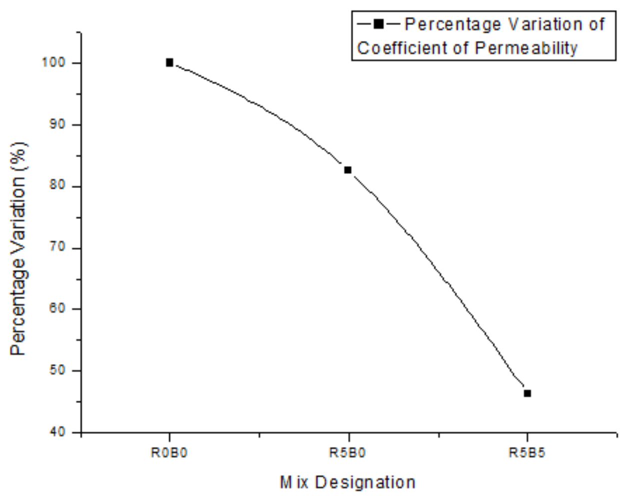

Chart -9: Variation of Coefficient of Permeability after 28 days' curing

From Chart 9, it is observed that the incorporation of RHA in the concrete decreased permeability and presence of bacteria reduced the permeability further. This may be due to an extensive pore refinement in the matrix owing to pozzolanic property of RHA and microbial calcite precipitation.

5.3.4 Water Absorption Test

The results are represented in Chart 10.

It can be seen from Chart 10 that the percentage of water absorbed by RHA concrete is lower than that by normal concrete specimens. The water absorption reduced further for bacterial concrete with RHA.

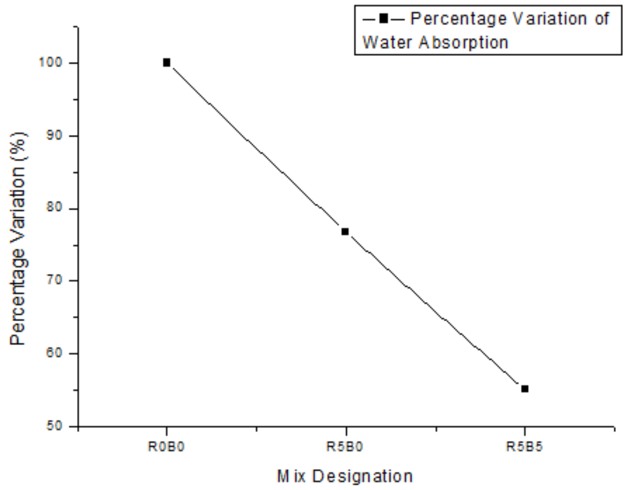

Chart -10: Variation of Water Absorption Percentage after 28 days' curing

5.3.5 Chloride Attack Test

The results are represented in Chart 11.

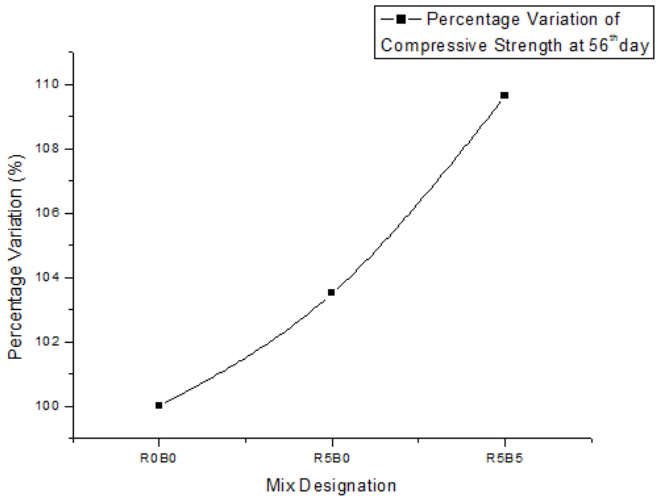

Chart -11: Variation of Compressive Strengths after 56 days' immersion in NaCl

The compressive strength after immersion in NaCl solution is the least for normal concrete and better performance is shown by RHA concrete and bacterial concrete with RHA as represented inChart 11. Incorporation of RHA had a positive effect on strength and bacterial presence further improves the strength. From the results, it can be inferred that RHA incorporation and addition of bacterial cells are advisable to increase the durability of concrete in cases of chloride exposure conditions.

6. CONCLUSIONS

An extensive literature survey was conducted on the topics related to microbially induced calcite precipitation and the partial cement replacement by RHA. The objectives and scope of this study were fixed in order to find the influence of Bacillus subtilis bacteria on strength and durability of RHA incorporated concrete. The conclusions drawn are:-

- The optimum dosage of RHA to be incorporated in concrete by partially replacing cement (by weight) is 5% for obtaining the maximum strength.
- The optimum bacterial cell concentration in concrete for achieving maximum strength is 10^5cells/ml in the mixing water.
- The workability of RHA concrete decreases with the increase in percentage of RHA due to production of larger volume of concrete owing to lower specific gravity of RHA (than cement).
- The compressive strength and split tensile strength are the maximum for bacterial concrete (with RHA), showing better performance than RHA concrete and normal concrete. RHA concrete achieved better strength than normal concrete.
- Water permeability and water absorption were decreased considerably for bacterial concrete (with RHA) and RHA concrete. Bacterial presence showed more positive results.
- In the case of susceptibility to chloride attack, RHA incorporated concrete and bacterial concrete with RHA exhibited good resistance.

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