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AN EXPERIMENTAL INVESTIGATION ON THE PERFORMANCE OF BACTERIAL CONCRETE

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ABSTRACT
Concrete is the most used building material composed of cement, sand, stone and aggregate. Tiny micro-crack is the main reason to cause failure in concrete structure. A noble technique has been developed in recent years to remediate these cracks by incorporating special species (***bacillus***) of bacteria in concrete. These types of bacteria have the capability to secret calcite precipitation and eventually repair the cracks. This paper investigates the performances of bacterial concrete exposed to plain water. Concrete specimens of 100 mm cubical size were cast and cured for 120 days with and without using bacteria. Using spectrophotometer to determine optical density has always been a central technique in micro-biology. Concrete specimens having OD_{600} 0.107, 0.20, 0.637 and 1.221 have been studied in plain water. The specimens were taken out periodically and subjected to compressive & tensile strength tests. From the investigation, it has been revealed that microbial concrete having OD_{600} 0.637 shows better resistance against strength deterioration under all curing conditions and curing ages. Later on the concrete specimens were subjected to Ultrasonic Pulse Velocity (UPV) tests. This study proposes the UPV and strength relationship curves for different microbial ratios used in concrete. From this test, it has been observed that specimens having OD_{600} 0.637 shows better pulse velocity. The higher pulse velocity can therefore be used to assess the quality and uniformity of the concrete material.

Keywords: OPC; Microbial Concrete; ***Bacillus subtilis***; Optical Density; MICP; UPV test

INTRODUCTION
Concrete is one of the most widely used construction materials by mankind and it is the main material used for the infrastructure development of every country. It has an ultimate load bearing capacity under compression but the material is weak in tension. That is why steel bars are embedded in the concrete for the structures to carry tensile loads. The steel reinforced bars take the tensile load when the concrete cracks in tension. The elasticity of concrete is relatively constant at low stress levels but starts decreasing at higher stress levels as matrix cracking develop. That why concrete is a high maintenance material that cracks and suffers serious wear and tear over the decades of its expected term of service.
Repair of conventional concrete structures usually involves applying a concrete mortar which is bonded to the damaged surface. Sometimes, the mortar needs to be keyed into the existing structure with metal pins to ensure that it does not fall away. Repairs can be particularly time consuming and expensive because it is often very difficult to gain access to the structure to make repairs, especially if they are basements or at a great height. An advance technique has been developed in remediating cracks and fissures automatically

in concrete by utilizing Microbiologically Induced Calcite or Calcium Carbonate ($CaCO_3$) Precipitation (MICP) which will ultimately increase the durability of concrete structure. By incorporating special species (***bacillus***) of bacteria in concrete these cracks can be repaired as natural healing process. These types of microbes can secret calcite precipitations which will ultimately repair the cracks and increase the durability of structure.

Ultrasonic pulse velocity (UPV) test is a non-destructive test technique to monitor the post construction performance of concrete. This technique was first introduced by Long, Kurtz and Sandenaw (1945) for evaluating the non destructive method of testing for quality of concrete by transmitting an irrational pulse to travel a known distance through a concrete. In this study, cylindrical specimens of dia 100 mm and height 200 mm were used. Curing period for test was taken as 28 days. 5 different microbial groups having OD_{600} 0, 0.107, 0.20, 0.637 and 1.221 had been studied.

EXPERIMENTAL DETAILS

The experimental work was carried out to study the different aspects of strength development of microbial concrete in plain water over a period of 28 days. The variable parameters studied and the materials involved were as follows:

Materials

(i) Bacteria :

Bacillus subtilis strain 121 has been used in the following study. It was obtained from Micro-biology Department, Chittagong University. Media used was nutrient broth for ***B. subtilis*** growth. Four different OD_{600} (0.107, 0.20, 0.637 and 1.221) has been used to investigate the performances of bacteria. Absorbance of the cell suspension is also being measured by using 'Spectrophotometer'. The cell concentration varies with optical density and could be roughly determined by following formula:

$$\mathbf{Y = 8.59 \times 10^{7} X^{1.362}}$$

where,

X = reading at OD 600 nm

Y= concentration of bacterial cells per ml

(ii) Cement :

Ordinary Portland Cement (OPC) ASTM Type-1, conforming to ASTM C-150 was used as binding material. Its physical properties and chemical compositions are given in Table 1.

Fig. 1: Microbial Concrete

(iii) Aggregate :

Locally available natural sand passing through 4.75 mm sieve and retained on 0.075 mm sieve was used as fine aggregate. The coarse aggregate was crushed stone with nominal size of 12.5 mm. The properties of aggregates are given in Table 2.

(iv) Water :

Water confirming to the requirements of IS456-2000 was taken with pH value 7 and at zero turbidity.

Table 1: Physical properties and chemical composition of OPC

SL. No	Characteristics	Value
1	Blaine's Specific surface (cm^2/gm)	2900
2	Normal Consistency	26%
3	Soundness by Le Chatelier's Test (mm)	4.5 mm
4	Specific gravity	3.15
5	Setting Time (a) Initial (min) (b) Final (min)	 70 175
6	Compressive Strength (a) 3 Days (MPa) (b) 7 Days (MPa) (c) 28 Days (MPa)	 16.2 21.2 31.4
7	Calcium Oxide (CaO)	64%
8	Silicon Dioxide (SiO_2)	21%
9	Aluminum Oxide (Al_2O_3)	6%
10	Ferric Oxide (Fe_2O_3)	3.5%
11	Magnesium Oxide (MgO)	1.2%
12	Sulfur Trioxide (SO_3)	2.5%
13	Loss on ignition	1.2%
14	Insoluble matter	0.6%

Table 2: Physical properties of aggregate

Properties	Coarse Aggregate	Fine Aggregate
Specific Gravity	2.59	2.55
Unit Weight	1560 Kg/m^3	1580 Kg/m^3
Fineness Modulus	6.77	2.57
Absorption Capacity	0.6%	1.45%
Moisture Content	0.57%	1.12%

Table 3: Properties of microbial water (Absorbance reading: T60 UV-VIS Spectrophotometer @ RT & Absorbance at 600 nm wave length)

Group	Control	Bacterial Treatment	Optical Density
A	0.089	0.196	0.107
B		0.289	0.20
C		0.762	0.637
D		1.31	1.221

Variables

(i) Concrete Quality :

Three different grades of microbial concrete having OD600 0.107, 0.20, 0.637, 1.221 were used. OPC plain concrete was cast for comparing its properties with that of microbial concrete.

(ii) Exposure Period :

Specimens were tested periodically after the specified curing period of 28 days in plain water.

(iii) Size of Specimens :

Cylindrical specimens of 100 mm dia and 200 mm high were used following ASTM standard procedure.

(iv) Curing Environment :

A total of 45 cylindrical concrete specimens were cast in the laboratory. After casting, the specimens were kept at 27°C temperature and 90% relative humidity for 24 hours. After demoulding, all the specimens were cured in plain water for curing at room temperature.

(v) Mix Proportion :

Concrete was designed on the basis of material properties. For a mix design of 20 MPa concrete, the ratio of cement, fine aggregate, coarse aggregate was obtained as 1.0: 2.57: 2.71 with water cement ratio of 0.592 by mass. For 30 MPa concrete the mix ratio was 1.0: 1.68: 2.04 with water cement ratio of 0.45 and for 40 MPa concrete it was 1.0: 1.28: 1.73 with water cement ratio of 0.38 by mass. 100% water by mass was used for conventional concrete and a water cement ratio of 50% and microbial culture of 50% by mass was used for microbial concrete.

RESULT & DISCUSSION

The ultrasonic pulse velocity of a material can be determined by placing a pulse transmitter on one face of a sample of the material and a receiver on the opposite face. A timing device measures the transit time of the ultrasonic pulse through the material. If the path length is known, then the UPV can be calculated from the path length divided by the transit time. In UPV test, an appropriate coupling agent of petroleum jelly is applied to the transducer diaphragms and over the test surface to avoid air entrap between the contact surfaces of the transducers diaphragms and the surface of concrete. Then the transducers are pressed against the surfaces of the concrete for reasonably good contact between two surfaces and then the transit time is measured. Measurements are repeated at same location to minimize erroneous readings due to poor contact (Ref. Figure: 2).

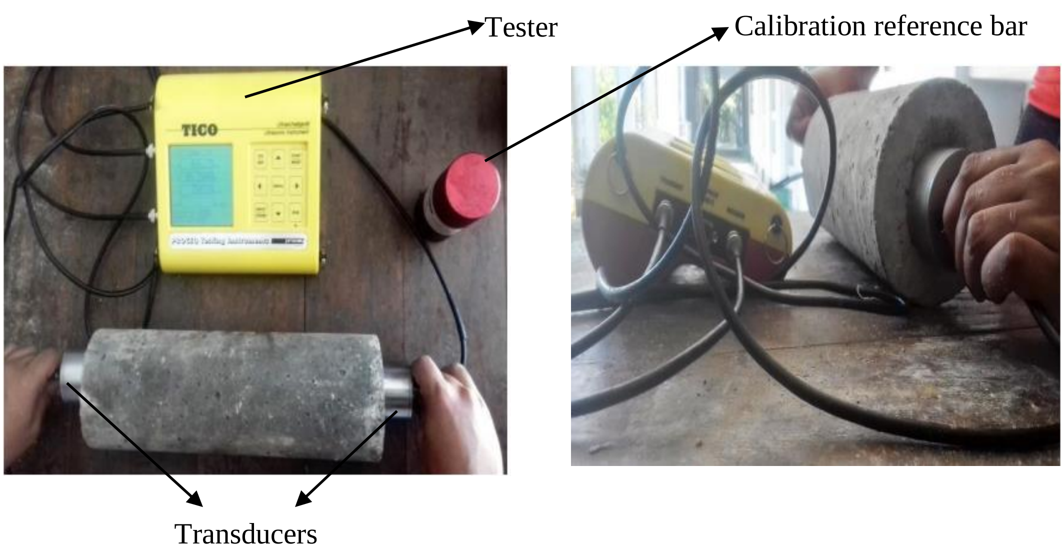

Fig. 2: Ultrasonic Pulse Velocity Measurement Process

It can be seen that concrete specimens having OD_{600} 0.637 have the higher velocity. That means that specimens having OD_{600} 0.637 are denser and more compact than other microbial groups. UPV values for different grades of concrete have been presented in Figure 3.

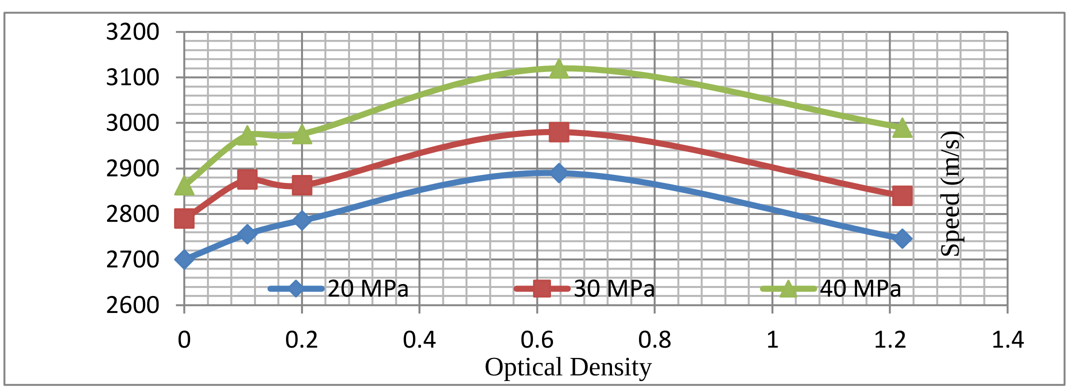

Fig. 3: UPV Values for different grades of concrete specimens with various optical density

Many scientists have studied and mentioned how UPV can be correlated with concrete strength. According to previous research by **Tharmaratnam**, the compressive strength and ultrasonic pulse velocity UPV values are related by the following equation (Non-linear model is suggested):

$$F_c = ae^{bV}$$

Here,

F_c= Compressive strength
V = Pulse velocity (km/s)
a and b are empirical constants

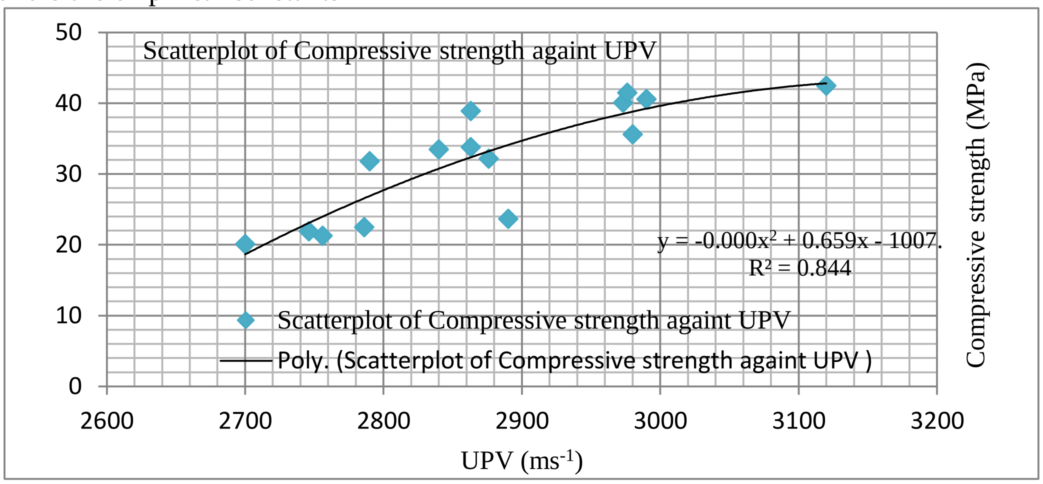

Fig. 4: Correlation between compressive strength against UPV

Considering the test result, the following expression relating compressive strength (F_C in MPa) to UPV (V in m/s) was established:

$$y = -0.000x^2 + 0.659x - 1007$$
$$R^2 = 0.844$$

It was an acceptable polynomial relationship between UPV and compressive strength. Because of R^2= 0.844, it can be said that 84.4% of the variation in the values of compressive strength is accounted for by polynomial relationship with UPV.

CONCLUSION

Based on the limited number of test variables including different concrete grades, the following conclusions can be drawn.

(i) Bacterial concrete technology has been proved to be better than many conventional technologies because of its eco-friendly nature, self-healing abilities and increase in durability of structural concrete as building materials.

(ii) Cementation by this method is very easy and convenient for usage. This will soon provide the basis for high quality structures that will be cost effective and environmentally safe but, more work is required to improve the feasibility of this technology from both an economical and practical viewpoints

(iii) Mix proportion of microbial water with plain water has a significant effect on strength development of microbial concrete. Among the microbial concretes, concrete with OD_{600} 0.637 is found to be most effective in increasing the strength and pulse velocity.

(iv) It can be seen from the above Figure 4 that 84.4% of the variation in the values of compressive strength is accounted for by polynomial relationship with UPV.

(v) If the spectrophotometer technique is adequately controlled and the sample is properly calibrated, the estimation of microbial numbers by optical density can be considered sufficiently accurate for use in preparing inoculate for QC testing.

(vi) The study may provide some necessary information related to the use of microbial concretes for the construction of marine onshore / offshore reinforced concrete structures.

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