Journal Homepage: -www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

Article DOI: 10.21474/IJAR01/13758
DOI URL: http://dx.doi.org/10.21474/IJAR01/13758

RESEARCH ARTICLE

DEVELOPMENT OF COMPRESSIVE STRENGTH AND ULTRASONIC PULSE VELOCITY RELATIONSHIP OF MICROBIAL CONCRETE USING BACILLUS SUBTILIS BACTERIA

Mohammad Saiful Islam[1] and Dr. Md. Saiful Islam[2]

1. Lecturer, Department of Civil Engineering, Chittagong University of Engineering & Technology, Bangladesh.
2. Professor, Department of Civil Engineering, Chittagong University of Engineering & Technology, Bangladesh.

Manuscript Info

Manuscript History
Received: 19 September 2021
Final Accepted: 24 October 2021
Published: November 2021

Key words:-
Bacterial Concrete, Bacillus subtilis, Bacterial Culture Concentration, MICP, Ultrasonic Pulse Velocity (UPV)

Abstract

Concrete,a multiscale composite in its natural state, is an absolutely essential element of infrastructure throughout the world. Concrete is able to carry high compressive load but very weak in case of tensile forces, for which steel bars are embedded in the concrete.Again, cracks in concrete are unavoidable. Corrosive elements can go into cracks once they've formed and consequently deterioration of the structural concrete starts with the corrosion of embedded steel. This leads to the strength reductionand durability curtailment of concrete. So, crack minimization in reinforced concrete is a must for both strength and durability aspect as well as for economic reasons as crack repair is a costly process. The goal of this study is to compare the performance of traditional and bacterial concrete and to find a link between compressive strength and bacterial culture concentration, as well as to determine the optimal bacterial concentration in concrete. 100 mm cubical sizeconcrete specimens were cast and cured for different ages in plain water to study the strength aspect and ultrasonic pulse velocity (UPV) analysis of concrete using ***Bacillus subtilis*** bacteria.With different bacterial concentrations of 2.12×10^8 cells/ml, 2.12×10^7 cells/ml, 3.25×10^8 cells/ml, 3.25×10^7 cells/ml, 6.39×10^8 cells/ml, 6.39×10^7 cells/ml, 7.91×10^8 cells/ml and 7.91×10^7 cells/mlconcrete specimens have been studied. From the investigation it is found that concrete specimens containing bacterial species shows better performance than conventional concrete due to calcite precipitation. Among them, concrete specimens of bacterial concentration 6.39×10^8 cells/ml of bacterial water shows better result against strength deterioration and UPV analysis.

Introduction:-

Concrete is the most important ingredient, as it is a necessary component of public infrastructure and most structures. Concrete is a multiscale composite in its natural state. The proportions ofingredients include cement, water, aggregate, additivesetc.can be adjusted over a wide range. Because concrete is an open composite structure, it can easily incorporate a variety ofmodification materials. As a result, smart and versatile structural elements made of concrete may be achievable.

Corresponding Author:-Mohammad Saiful Islam
Address**:**-Lecturer, Department of Civil Engineering, Chittagong University of Engineering & Technology, Bangladesh.

Smart and multifunctional concrete has not just a basic structural purpose like conventional concrete, but also one or more intelligent functional actions.An intelligent concrete system is one that is both smart and versatile.Different smart characteristics, as well as the capacity to react to external stimuli like stress and temperature, set it apart from regular concrete. Smart and versatile concrete is typically designed to satisfy specific needs by adjusting its qualities to increase the safety and function of infrastructure while loweringenvironmental pollution, life cycle costs, and resource consumption.Special processing in design compositionbasedonbiomimetic design, and the incorporation of extra functional components or change of the microstructure of standard concreteare all used to make concrete smart.

The properties of concrete's pore structure are known to influence its durability. Concrete degradation mechanisms are frequently dependent on the ability of potentially hostile substances to penetrate the concrete and cause harm. Concrete's permeability is determined by its porosity, as well as the connectivity and/or structure of its pores. The more open the pore structure of concrete is, the more susceptible it is to penetrating substance-induced breakdown mechanisms.The ingress of hostile gases and/or liquids into concrete structures is frequently followed by physical and/or chemical reactions inside the concrete's internal structure, which can cause permanent damage (Achal et al., 2011). Despite the fact that numerous chemical and physical treatments have been used to reduce susceptibility to damage, these treatments are ineffective due to their non-reversible nature and limited long-term performance.

Many researchers are looking for alternative elements including fly ash, silica fume, and ground granulated blast furnace slag (GGBS) that can be put into concrete to reduce the use of cement and improve its qualities(Srinivasan & Saravanan, 2020). Such admixtures have been shown to improve the characteristics of concrete to some extent. However, these materials are highly expensive, demand a large volume, and are limited in supply. Bio calcification, a new eco-friendly technology that improves the strength and longevity of concrete, was recently presented.This Microbiologically Induced Calcite Precipitation (MICP) is a method of calcium carbonate precipitation in concrete that requires the use of microorganisms.Calcite precipitation fills the spaces between the cement matrixes, resulting in denser concrete. Because the microorganisms utilized can be easily reproduced through the cultivation process, this method does not degrade natural resources. Furthermore, the calcite precipitation caused by microbial activity is both pollution-free and natural (Wang et al., 2010).

The structural concrete's strength has been enhanced based on calcite precipitation. Because the cement mortar was permeable, microbial cells received adequate nutrition throughout the initial curing period. However, these cells were adjusting to a new environment. Because of the high p^H of cement, bacterial cells may develop slowly in the beginning and then adapt to highp^Hcircumstances over the curing phase. Calcite precipitates on the cell surface and in the cement mortar matrix during cell growth, which could be owing to the presence of different ions in the medium. As a result, the cement mortar has decreased porosity and permeability.If many of the pores in the matrix are closed at the same time, the supply of nutrients and oxygen to the bacterial cells is halted. The cell either dies or transforms into endospores throughout time. As a result, the behavior of microbial cells with higher compressive strength may be explained. When ***Bacillus megaterium*** bacteria were added to concrete at a concentration of $30x10^5$ cells/ml, higher grade concrete exhibited more calcite precipitation than lower grade concrete, implying that higher grade concrete was stronger.For the highest grade of 50 MPa concrete, the maximum strength development rate was as high as 24% (Andalib et al., 2016).The cement was substituted with 10% fly ash, and 10^5 cells/ml ***Sparciouspasteurii*** bacteria were added to the mix. The deposition of calcium carbonate on the cell surfaces of microorganisms resulted in a 20% increase in compressive strength of structural fly ash concrete(Chahal et al., 2012).

The presence of calcium carbonate in the concrete was confirmed by microstructure investigation using XRD and SEM(Chahal et al., 2012).Concrete with ***Sparcinapasteurii*** and ***Bacillus subtilis*** bacteria ($2x10^9$ cells/ml) has a compressive strength that is 20% higher than concrete without bacteria after 28 days. When cement was replaced with varying concentrations of fly ash (e.g. 10%, 20%, and 40%) in mortar, bacterial cells enhanced mortar compressive strength by 19%, 14%, and 10%, respectively, when compared to control specimens (Achal et al., 2011). After the addition of ***Bacillus subtilis*** bacteria together with GNP, the compressive strength of concrete increased in all ages due to microbial precipitation of calcium carbonate(Khaliq& Ehsan, 2016).The 28-day compressive strength of the reactive spore powder in cement mortar was increased as compared to the control cement mortar (Luo & Qian, 2016). By depositing calcium carbonate on cell surfaces and in the pores of the cement-sand matrix, Bacillus sp. CT-5 enhances the compressive strength of the mortar (Achal et al., 2011; Reddy et al., 2012).

Ultrasonic Pulse Velocity (UPV) is a well-known non-destructive test method for determining the velocity of longitudinal waves in concrete. It is the measurement of the time it takes for a pulse to reach a specified distance. This apparatus consists of concrete-contact transducers, a 10 Hz to 15 Hz pulse generator, an amplifier, a time measuring circuit, and a digital display unit for the time taken by pulses of longitudinal waves to travel between transducers.

A material's UPV can be calculated by placing a pulse transmitter on one face and a receiver on the opposite face of a sample of the material. The ultrasonic pulse's transit time through the material is measured by a timing device. The UPV can be computed by dividing the path length by the transit time if the path length is known.The accuracy of this method will be determined by the test geometry and the width of the transducers' contact faces. Flat faced transducers introduce a degree of uncertainty since the precise point of contact for maximum pulse transmission and reception is unknown—it could be anywhere within the contact face's width.

Ultrasonic pulse velocity was determined for the concrete specimen by using equation given below:

$$UPV = \frac{L}{T} \quad \ldots \ldots \ldots (1)$$

Here, L = Distance between transducers
T = Transit time

The major goal of this study was to evaluate the strength variation of multiple concrete groups using varying concentrations of self-healing chemicals, followed by a UPV analysis to build a link between UPV and compressive strength and to determine the denser concrete group. The laboratory investigation attempted was to find a link between compressive strength and bacterial culture concentration, as well as to determine the optimal bacterial concentration in concrete.

Materals and Methods:-

Bacteria used for the investigation: ***Bacillus subtilis*****ATCC-6633** was utilized as an experimental bacterium in this investigation. This bacterium**(Figure 1)** was supplied from the Department of Microbiology, University of Chittagong. ***Bacillus subtilis*** is a Gram-positive bacteria that also produces catalase. It is typically found in soil. The cells are rod-shaped and range in size from 4 to 10 micrometers(μm)in length and 0.25 to 1.0μmin diameter. It may develop an endospore, like other Bacillus species, to endure harsh environmental conditions such as temperature and desiccation.It is considered as an obligate aerobe and ***B. subtilis***is found to be alive at -3^0C low temperature to 70^0C hightemperature.

Figure 1:- Cultered Bacterial Sample.

Cement:
As a binding medium, ASTM Type-1 Ordinary Portland Cement (OPC) complying to ASTM C150 was employed. **Table 1** lists its physical characteristics.

Table 1:- Physical properties of OPC.

Blaine's Specific surface (cm^2/gm)	2900
Normal Consistency	26%
Soundness by Le Chatelier's Test (mm)	4.5 mm
Specific gravity	3.15
Setting Time (a) Initial (min) (b) Final (min)	 70 175

Coarse Aggregate:
The "crushed stones" were utilized as coarse aggregate according to ASTM C33 specifications, with a maximum size of 19 mm and a nominal size of 12.5 mm, as well as other attributes shown in **Table 2**.

Table 2:- Physical properties of coarse aggregate.

Specific Gravity	2.59
Absorption Capacity	0.6%
Moisture Content	0.57%
Unit Weight	1560 Kg/m^3

Fine Aggregate:
Based on the ASTM C778 standard, locally available "Sylhet sand" that passed through a 4.75 mm screen and was kept on a 0.075 mm sieve was utilized as fine aggregate, and some of its physical attributes are listed in **Table 3**.

Table 3:- Physical properties of fine aggregate.

Specific Gravity	2.55
Absorption Capacity	1.45%
Moisture Content	1.12%
Fineness Modulus	2.57

Water:
The concrete was mixed with portable water, and the specimens were cured according to ASTM C1602 criteria, with a pH value of no less than 6.

Variables:
Concrete quality:
Two different grades of microbial concrete having eight bacterial cultures of 2.12×10^8 cells/ml, 2.12×10^7 cells/ml, 3.25×10^8 cells/ml, 3.25×10^7 cells/ml, 6.39×10^8 cells/ml,6.39×10^7 cells/ml, 7.91×10^8 cells/ml and 7.91×10^7 cells/ml were used. Control concretes of similargrades were cast for comparing its properties with that of microbial concrete.The summary of the bacterialconcentrations is presented in **Table 4**, where M0 represents the control specimens.

Table 4:- Bacterial Concentrations/ml of bacterial waterof different concrete mixes.

M0	0
M1	2.12×10^8 cells/ml
M2	2.12×10^7 cells/ml
M3	3.25×10^8 cells/ml
M4	3.25×10^7 cells/ml
M5	6.39×10^8 cells/ml
M6	6.39×10^7 cells/ml
M7	7.91×10^8 cells/ml
M8	7.91×10^7 cells/ml

The bacterial concrete's performance was assessed using two arbitrary design strengths of 20 MPa and 40 MPa, as well as five curing times of 7, 14, 28, 60, and 120 days. The compressive strength and UPV analysis of the concrete were evaluated using concrete specimens prepared according to ASTM C92 guidelines using a 100 mm cube. All of

the specimens were cast at Engineering Materials Laboratory of CUET and kept at room temperature for 24 hours before being taken from the mold and treated to various curing times in plain water.

The ACI standard approach was followed when producing the concrete mix design. Furthermore, for a water-cement ratio of 0.592 by mass, the ratio for 20 MPa design strength on the 28th day was calculated to be 1.0:2.56:2.71.For 20 MPa concrete, three different scenarios were formulated. One was conventional concrete with 100% plain water and two bacterial concrete with varying the ratio of plain water and bacterial water by adding 40% and 60% bacterial water respectively. To monitor the compressive strengths of bacterial concrete, 40 MPa concrete was also prepared in the same way. **Table 5** shows a summary of the mix design selections.

Table 5:- Summary of Mix Design.

Design Strength	Cement	Fine Aggregate	Coarse Aggregate	w/c Ratio	Plain Water (%)	Bacterial Water (%)
20 MPa	1.0	2.56	2.71	0.592	100	-
					60	40
					40	60
40 MPa	1.0	1.28	1.73	0.38	100	-
					60	40
					40	60

Results & Discussions:-

The compressive strength was measured according to ASTM C39 standards, and the findings are shown in **Figures 2-6** in graphical form.

The test results for both control and microbial concrete specimens were analysed critically to observethe variation of concrete strengths between normal and bacterial concrete.**Figures 2-6**clearly demonstrate the variation incompressive strengths with bacterial concentration for different curing periods. For early curing period, some bacterial concrete show slightly lower strength than control concrete. However, this issue was seen to be diminished with the increment of curing ages.The increment in the values was probably due to the addition of ***Bacillus subtilis***bacteria. The (%) increase in compressive strength of microbial concrete after 28 days exposure period are shown in **Table 6**. For compressive strength test, **Table 6** represents the variation of compressive strength as compared to control concrete at 28 days curing period. From table, it is clear that the compressive strength for all bacterial concrete is higher than control concrete and for the bacterial concentration 6.39 x 10^8 cells/ml, the maximum increase in strength was observed. This is most likely linked to the development of more noticeable mineral depositions in concrete's internal structures (Ehrlich, 1999). Researchers such as (Nivedhitha M, 2016)and (Reddy et al., 2012)made similar observations.

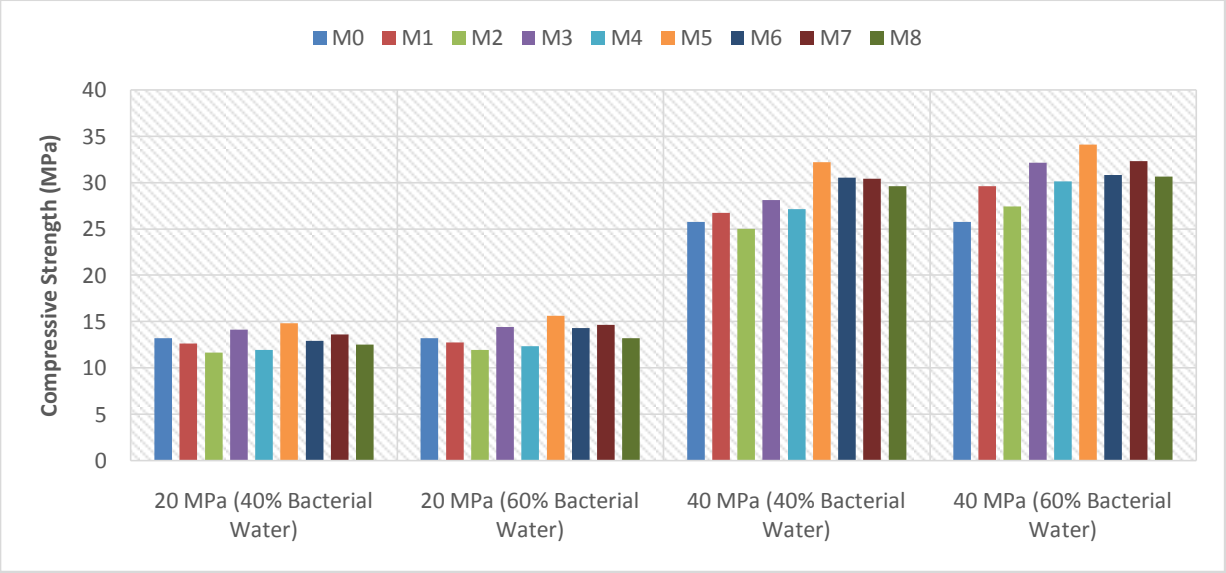

Figure 2:- Compressive strength variation with Bacterial Concentration (7 days).

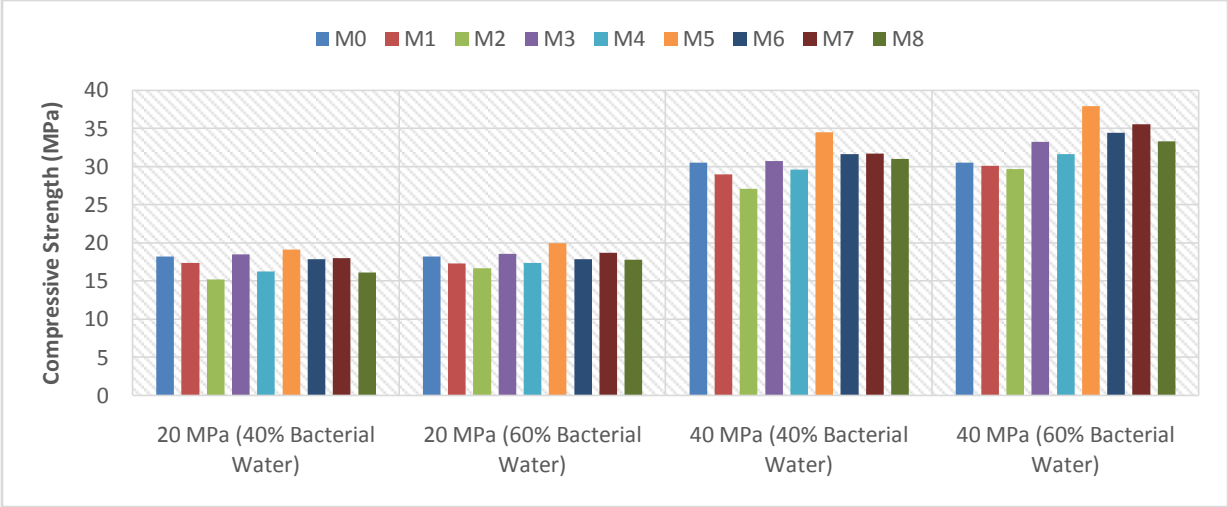

Figure 3:- Compressive strength variation with Bacterial Concentration (14 days).

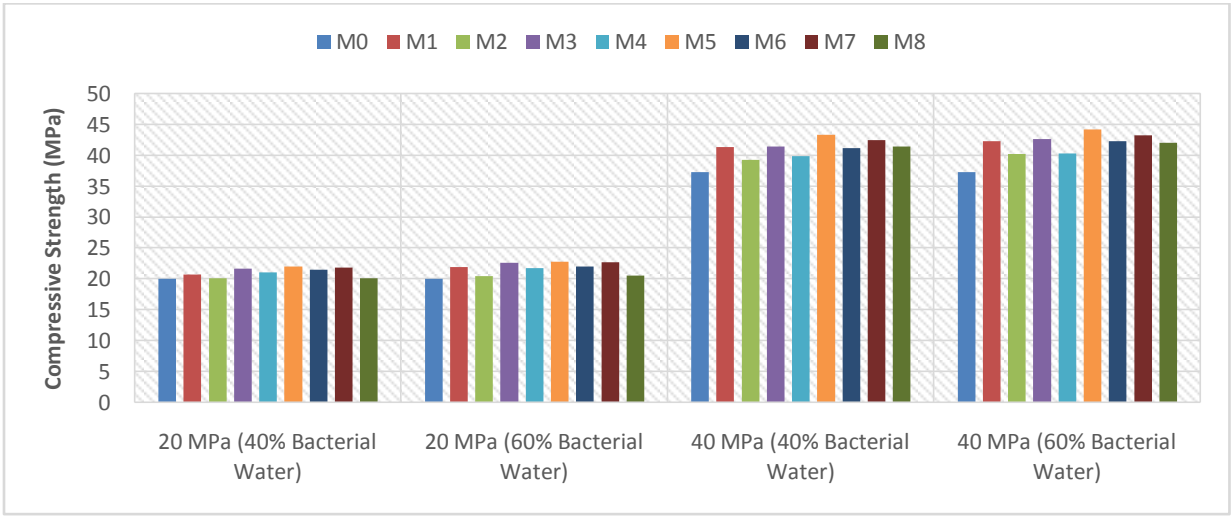

Figure 4:- Compressive strength variation with Bacterial Concentration (28 days).

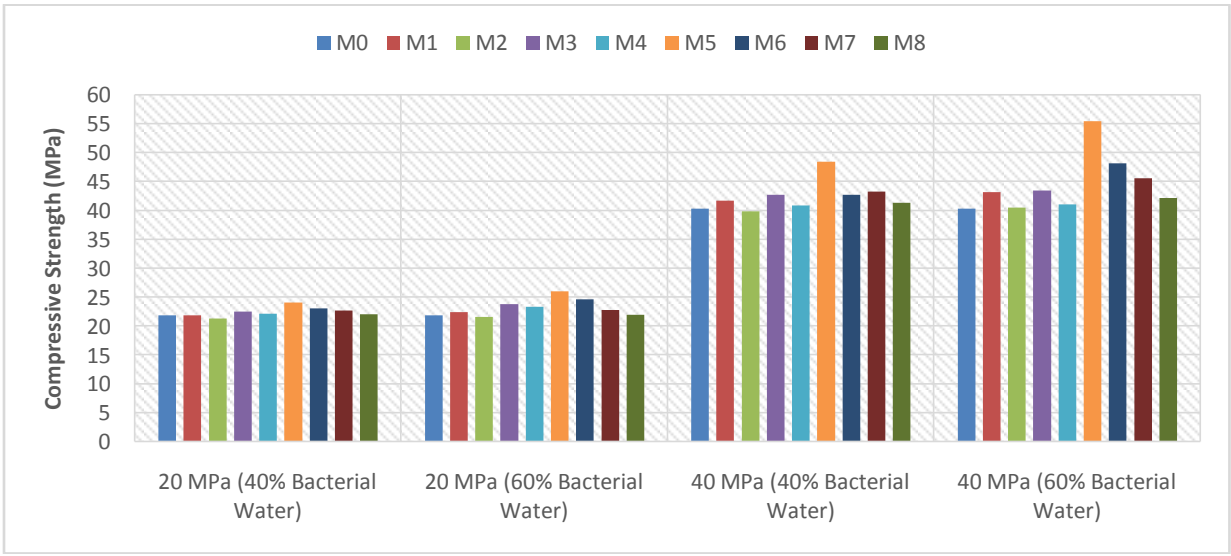

Figure 5:- Compressive strength variation with Bacterial Concentration (60 days).

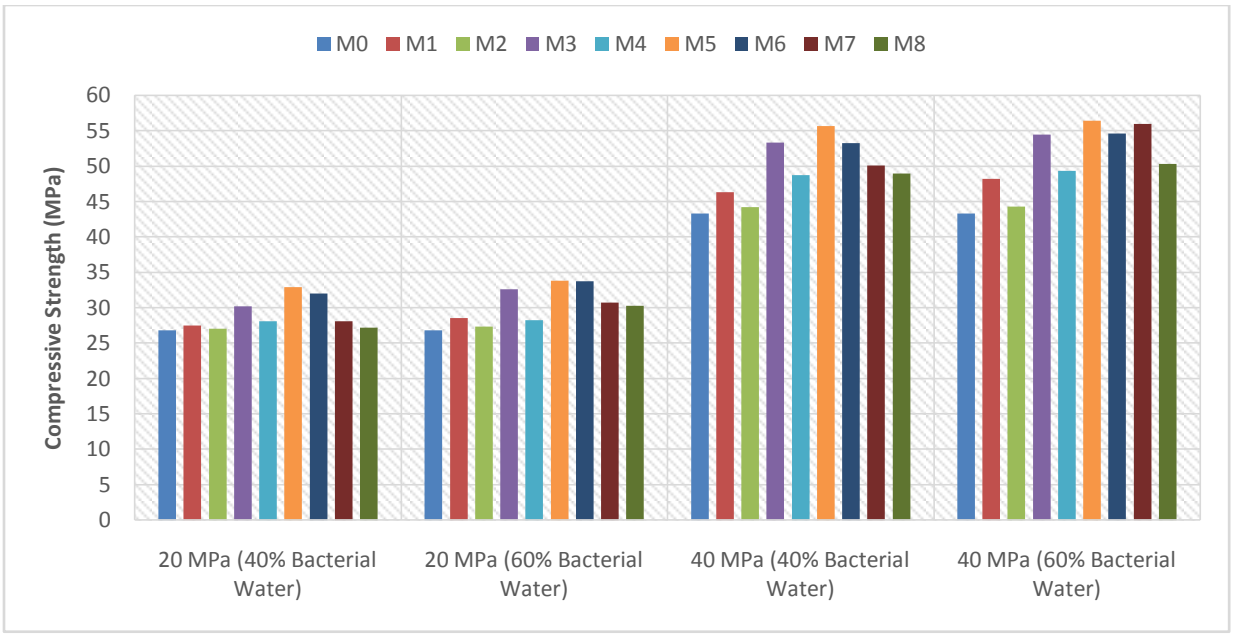

Figure 6:- Compressive strength variation with Bacterial Concentration (120 days).

The density of prepared specimens is directly represented by the UPV results. The voids will be less as the value increases. This means that concrete specimens having a higher pulse velocity will be denser. From **Figure 7**, it is clear that the UPV for all bacterial concrete is higher than control concrete and concrete specimens having bacterial concentration of 6.39 x 10^8 cells/mlhave the higher velocity. The specimens made with this concentration are denser than other microbial groups. The findings of the compressive strength tests also show that specimens with a bacterial concentration of 6.39 x 10^8 cells/ml have higher strength values than the other microbial groups. The (%) increase in UPV of microbial concrete after 28 days exposure period are shown in **Table 6**.

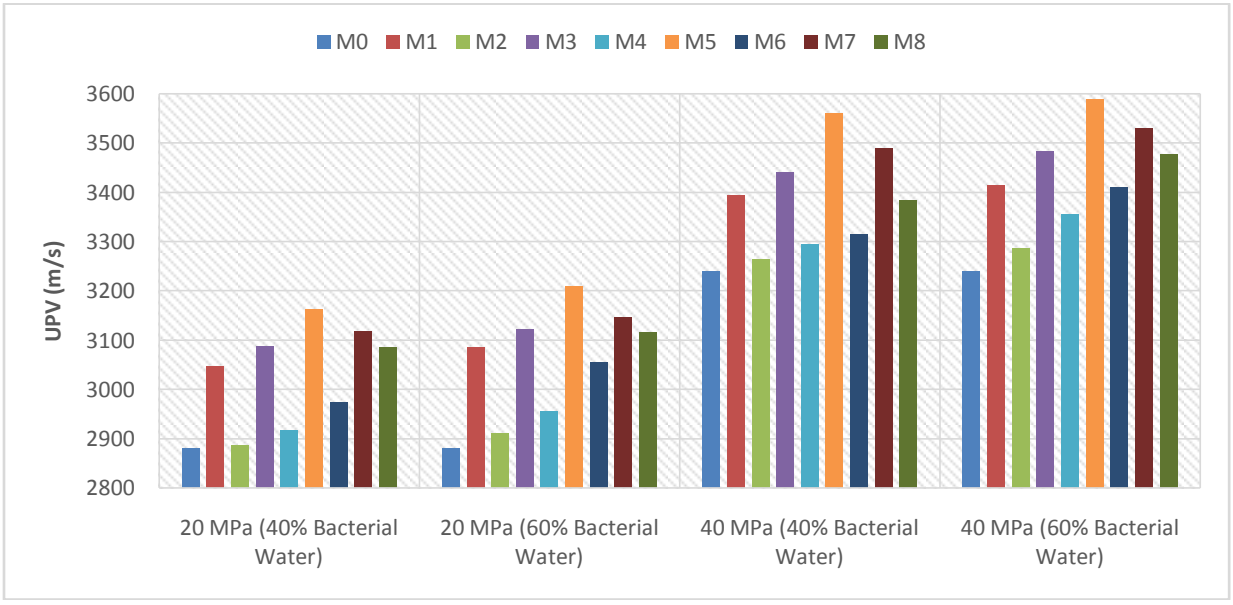

Figure 7:- UPV variation with Bacterial Concentration (28 days).

Table 6:- % Increase in Compressive Strength & UPV as compared to control concrete (28 days).

Bacterial Concrete	20 MPa (40% Bacterial Water)	20 MPa (60% Bacterial Water)	40 MPa (40% Bacterial Water)	40 MPa (60% Bacterial Water)

	Increase in Compressive Strength (%)	Increase in UPV (%)	Increase in Compressive Strength (%)	Increase in UPV (%)	Increase in Compressive Strength (%)	Increase in UPV (%)	Increase in Compressive Strength (%)	Increase in UPV (%)
M1	3.5	5.8	9.5	7.1	11.0	4.8	13.4	5.4
M2	0.5	0.2	2	1.1	5.4	0.8	8.1	1.5
M3	8	7.2	13	8.4	11.3	6.2	14.5	7.5
M4	5	1.3	8.5	2.6	7.0	1.7	8.3	3.6
M5	10	9.8	14	11.5	16.4	9.9	18.5	10.8
M6	7.5	3.2	10	6.1	10.5	2.3	13.4	5.2
M7	9	8.3	13.5	9.2	14.0	7.7	16.1	9.0
M8	0.5	7.2	2.5	8.2	11.3	4.5	12.9	7.3

For establishing relation between UPV and compressive strength, the exponential regression was applied for 20 MPa and 40 MPa concrete individually**(Figure 8& Figure 9).**From the data, it has been observed that for 20 MPa concrete, the pulse velocity ranges from 2880 to 3210 m/secfor which the values of compressive strength ranges from 20.0 to 22.8 MPa, and for 40 MPa concrete the pulse velocity ranges from 3240 to 3590 m/sec for which the values of compressive strength ranges from 37.2 to 44.1MPa. The coefficients of determination (R^2), respectively, are 0.4578 and 0.8495. This means that in 20 MPa concrete, the exponential relationship with UPV responded to 45.8% of the assortment, whereas in 40 MPa concrete, the exponential relationship with UPV responded to 85% of the assortment; i.e., data points and regression curves are more relevant for higher strength concrete.

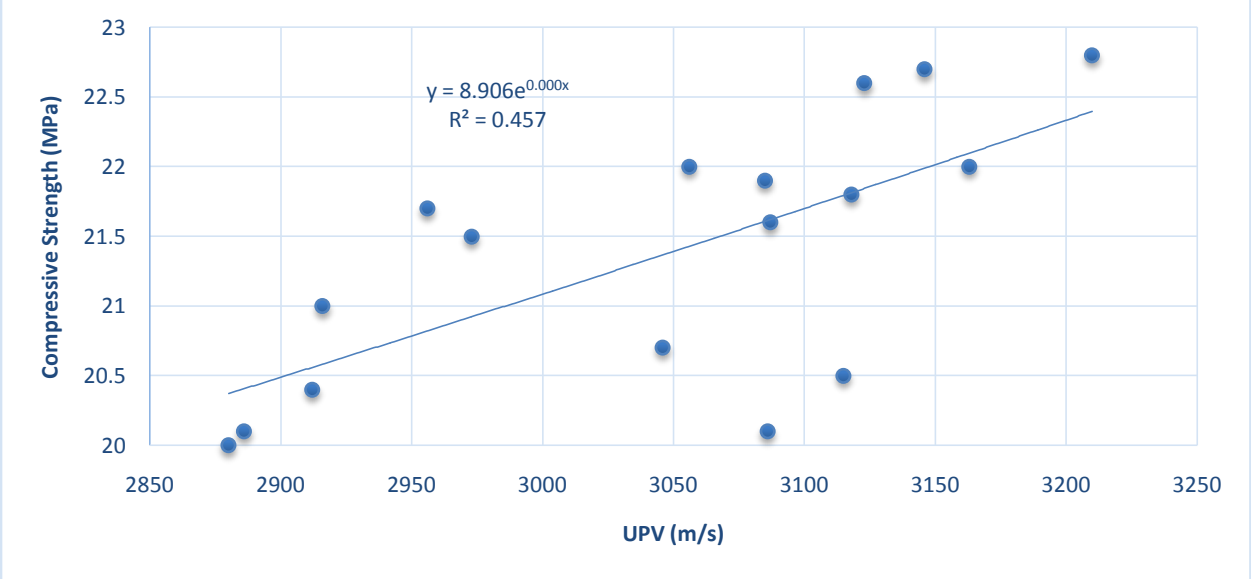

Figure 8:- Correlation between compressive strength and UPV for 20 MPa concrete (28 days).

The correlation factors/equations for the simulation curvesfor 20 MPaand 40 MPaconcrete are given below as eq.2 and eq.3 respectively:

$y = 8.9065e^{0.0003x}$ … … … (2)

$y = 11.951e^{0.0004x}$ … … … (3)

Where,the compressive strength (MPa) and ultrasonic pulse velocity (m/s) are represented by y and x, respectively.

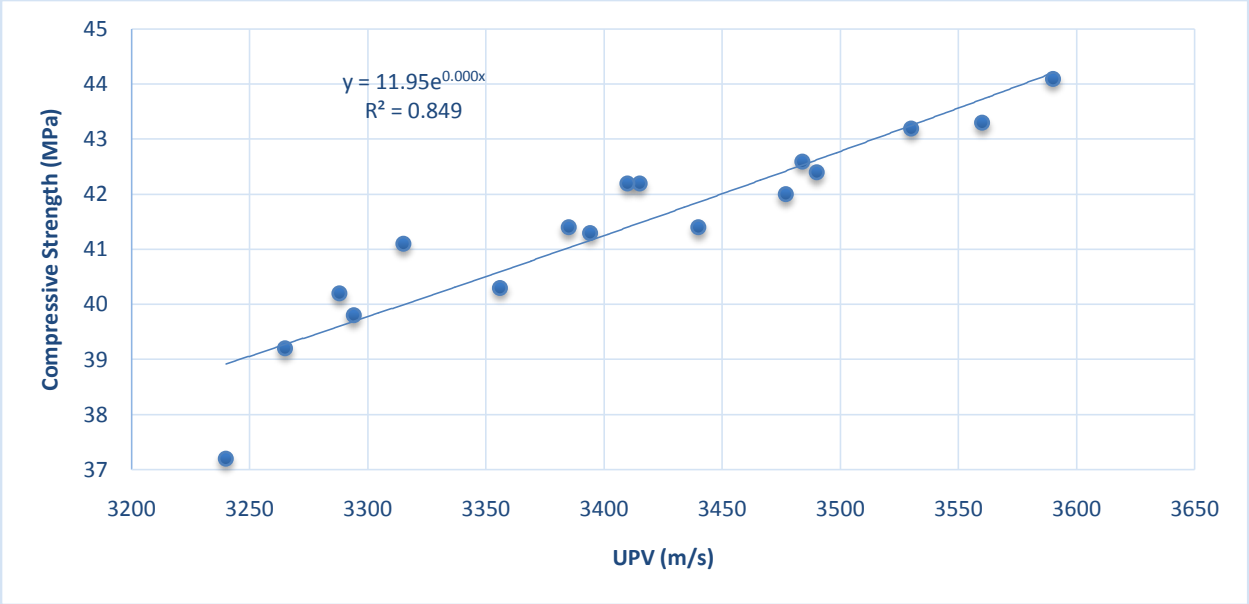

Figure 9:- Correlation between compressive strength and UPV for 40 MPa concrete (28 days).

Conclusion:-

The application of ***Bacillus subtilis*** bacteria in concrete and the establishment of the optimum bacterial culture concentration in concrete were the focus of this experimental study. Based on the predetermined limited number of factors, the following is a summary of the findings.

1. In comparison to the control specimen or M0, adding ***Bacillus subtilis*** bacteria to concrete significantly boosted the compressive strength of the concrete.
2. The best bacterial culture concentration was found to be M5 (6.39 x 10^8 cells/ml)which increased compressive strength by around 10-14% in 20 MPa concrete after 28 days of curing, and 16.4-18.5% in 40 MPa concrete.
3. With the usage of M5 bacterial concentration, ultrasonic pulse velocities were also enhanced by 9.8-11.5%.
4. The exponential connection of compressive strength with UPV was 45.8% in 20 MPa concrete, which is 85% in 40 MPa concrete. The specimen with a bacterial concentration of 6.39 x 10^8 cells/ml was shown to be the most effective in increasing the compressive strength and UPV of the concrete among all bacterial cultures.
5. Concrete specimens with 60% bacterial water shows more increase in strength and UPV as compared to that of 40% bacterial water in cases of both lower grade (20 MPa) and higher grade (40 MPa)of concrete.

References:-

1. Achal, V., Pan, X., &Özyurt, N. (2011). Improved strength and durability of fly ash-amended concrete by microbial calcite precipitation. Ecological Engineering, 37(4), 554–559. https://doi.org/10.1016/j.ecoleng.2010.11.009
2. Andalib, R., Abd Majid, M. Z., Hussin, M. W., Ponraj, M., Keyvanfar, A., Mirza, J., & Lee, H. S. (2016). Optimum concentration of Bacillus megaterium for strengthening structural concrete. Construction and Building Materials, 118, 180–193. https://doi.org/10.1016/j.conbuildmat.2016.04.142
3. Chahal, N., Siddique, R., &Rajor, A. (2012). Influence of bacteria on the compressive strength, water absorption and rapid chloride permeability of fly ash concrete. Construction and Building Materials, 28(1), 351–356. https://doi.org/10.1016/j.conbuildmat.2011.07.042
4. Ehrlich, H. L. (1999). Microbes as geologic agents: Their role in mineral formation. Geomicrobiology Journal, 16(2), 135–153. https://doi.org/10.1080/014904599270659
5. Khaliq, W., &Ehsan, M. B. (2016). Crack healing in concrete using various bio influenced self-healing techniques. Construction and Building Materials, 102, 349–357. https://doi.org/10.1016/j.conbuildmat.2015.11.006
6. Luo, M., &Qian, C. (2016). Influences of bacteria-based self-healing agents on cementitious materials hydration kinetics and compressive strength. Construction and Building Materials, 121, 659–663. https://doi.org/10.1016/j.conbuildmat.2016.06.075

7. Nivedhitha M. (2016). Evaluation of Biocalcification and Strength Aspects in Bacterial Concrete with Bacillus Subtillis. International Journal of Engineering Research And, V5(11), 35–38. https://doi.org/10.17577/ijertv5is110018
8. Reddy, S., Satya K, A., & Rao, S. (2012). a Biological Approach To Enhance Strength and Durability in Concrete Structures. International Journal of Advances in Engineering & Technology, 392(2), 392–399.
9. Srinivasan, G., &Saravanan, J. (2020). A study on strength characters of bacterial concrete. IOP Conference Series: Materials Science and Engineering, 993(1), 121–127. https://doi.org/10.1088/1757-899X/993/1/012043
10. Wang, J. Y., Van Tittelboom, K., De Belie, N., &Verstraete, W. (2010). Potential of applying bacteria to heal cracks in concrete. 2nd International Conference on Sustainable Construction Materials and Technologies, 1807–1818.