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Effectiveness of Bacillus Pasteurii on Properties of Self-Healing Concrete

Gehad A. M. Metwally [a],Mohamed G. E. Mahdy[b],Ahmed H. A. EL-Raheem [c]
[a]Researcher at structural Engineering department, Faculty of Engineering-Mansoura University ,Egypt
[b]professor and Vice dean for students and education affairs, Faculty of Engineering-Mansoura University, Egypt
[c] professor of structural Engineering department, Faculty of Engineering-Mansoura University, Egypt

Abstract: *Concrete that contains self-healing supplementary materials is a feature of many sustainable structuresbecause it decreases maintenance costs and extends service life. Conventional concretes exposed to cracking during tension that is problem. The cracks on the concrete surfaceallow the liquids to pierce inside causing collapse of the structures of concrete. Because of the cost, the challenges and time consumingof concrete structures'renovation and restoration, self-healing concrete solves the problem by healing this cracks on the surface. This concrete is characterized asfriend -environment and controlling the inner part of cracks by releasing the calcium carbonate. This paper aims to reveal the healing ratio of crack by using biological factors to improve the concrete nature. The mechanical and durability tests are used to calculate the ratioof concretes' self-healing. The study showsthat bio concrete blends after curing it for twenty eight days achieved improvement in compressive strength, permeability resistance and flexural strength compared to conventional concrete. The precipitations effectiveness formed at the crack surface of the cement paste specimens were studied by Scanning Electron Microscope (SEM), and with Energy Dispersive X-ray Spectrometer (EDS), attached to it. In this study the self- healing concrete abled to fill crack with widths lead to 0.80 mm. The study above showed that specific conditions were needed to obtain self-healing agent.*

Keywords: *Bioconcrete, Self-Healing Compound, Cracks in Concrete, Corrosion of Steel, Repairs, Maintenance.*

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I. Introduction

Concrete is the most commonly used single synthetic material in the world. Moreover, cracks frequently happen during its life period due to mechanical processing, environmental consequences (e.g. freezing and thawing, chloride intrusion and rebar corrosion) and volumetric changes (e.g. shrinkage in fresh or hardened concrete, thermal contraction).

Cracks lead to water leakage, and reduction of the stability of civil systems such as reservoirs, retaining walls, Residential buildings and tunnels. Cracks often encourage the ingress of hostile agents by supplying gas and water delivery pathways, often harmful to the stability of cement.Moreover; degradation of cracks is one of the most major sources of risk that has a significant impact on the stability and longevity of reinforced concrete.

While manual maintenance extends the life period of reinforced concrete buildings, they involve large resources of maintenance activity, their costs and resources loss, the conclusion may not be positive. According to information supplied by ConRepNet research [1], Twenty per cent of these corrections have crashed within 5 years, growing to 55 per cent throughout ten years and ninety per cent in twenty five years of service. In terms of this, it is important to consider automated way to reduce the maintenance / repair rate in the long term and to enhance the life period of concrete structures.

Recently, influenced by the biological self-healing, scientists have come up with a revolutionary term of this concrete [2–6] .Because of an intensive research, several self-healing systems are suggested and their implementation extends thelife of its structures. In this research,Self-healing in cracks in cemented tools that usebacillus pasteurii as a healing agent, among others, seems to be the most preferred and promising method.

The mortar and epoxy gel application can fill the crack but demands constant maintenance. Use of the biological factors to heal the cracks on the surfaces is beneficial since they are natural and free from pollution [7]

Self-healing materials produced by continuous hydration of unhydrated cementis very complicated to heal the wide of crack on the surface by autogenously healing the concrete [8]. This process is capable of healing up to 150 µm [9]. The use of external factors such as biological factors (Bacillus pasteurii),the materials with high pozzolanic and chemical factors to seal cracks is classified as separate healing [10]. The strain of bacteria that is used in concrete depends on the degree of pH in the water, because some bacteria cannot withstand the acidic condition and other cannot thrive in the simple condition. They go through the concrete as sporesconnecting with the water and become alive bycalcium carbonateSediment [11]. This paper assesses the mechanical parameters viz: the test of compressive strength and flexural strength and durability properties viz: permeability test of normal concrete and bacterial one. The ratio of self-healing can be estimated by area repair rate method which measures the area before and after immersion of samples in distilled water for 28 d and 90d.

1.1 Bacteria as a Solution (Healing- agent)

Self-healing of bacterialconcrete (Bacillus pasteurii) in this study was improved by adding microbial factor that able to enhance the self-healing by activating bacteria mineralsedimentation. By Scanning Electron Microscope (SEM), sedimentations were examined at the surface and measure the impact of its width with curing methods. The results show that the microbial self-healing factor is used for achieving the aim of the concrete.

II. Methods And Materials

The grade of cement was OPC 42.5N in the present study and all the characteristics of cement were ES4756-1/2013. The cement gravity is 3.15, cement fineness is 3290cm2/g, the first settingtime is 180 min, and the last setting time is 230 min. The siliceous sand as p00er ES 1109:2008 was used as fine aggregates. Its modules of fineness are2.95.Local crushed dolomite from ataka in Suez city with nominal maximum size 9.5 mm are taken for coarse aggregate and the characteristics are in the ES guideline 1109:2008. Its specific gravity is 2.60.Potable water that satisfies the characteristics of ES 1109:2008is used in the present study. The chemical structure of OPC is illustrated in [table 1].

Table 1: Chemical composition of Portland CementCEM I 42.5 N (Aramean, et al., 2016)

Constituent	PC	
	Proportion %	ESS 4756-1/2013
SiO_2	20.36	-
Al_2O_3	5.12	-
Fe_2O_3	3.64	-
CaO	63.39	-
Na_2O	0.29	≤ 5%
K_2O	0.62	-
MgO	1.03	-
SO_3	2.21	≤ 3.5% for 32.5 N&R and 42.5 N
L.O.I	1.39	≤ 4% for 42.5R and 52.5 N&R
CL	0.055	≤ 0.1%

2.1 Preparation of Microbial self-healing agent

A. Collection samples

Bacillus pasteurii is spore-forming alkali-resistant bacteria.Many samples were collected from alkaline lake soil (Wadi Natrun, Egypt). This site is specially chosen because of its relatively high alkalinity and temperature which is close to the conditions of concrete.

B. Culture Bacteria - Final Sample Preparation

The bacteria were collected in liquid that includes 5.0 g peptone and 3.0 g yeast elicit per liter of purified water (PH = 7.0) which was autoclaved at 121°C for 25 min. Aftervaccination on laminar flow, the medium was incubated at 30°C on a shaker at 170 rpm for 24 h. Themicrobial factor comprised from substrate and bacteria. The cells of bacteria wereestimated by centrifuging the 24 h old grown culture and were re-pendent in filtered water. The condensation of bacteria was 10^9cells/ml with Optical density (OD600) and its service life is shown in [fig 1].

2.2 Mix Design

The formulations of the concrete mixtures are illustrated in [Table 2] and [Table 3], presented study mixture proportion of traditional concrete (TC), and study mixture components of High strength (HC) concrete by weight (kg/m3).

III. Cement Paste Specimens Preparation

A totalof thirty five (35) batches of 7 mixtures with varied (w/c) ratio were designed. Each five batches were identical in composition and proportions, except for the inclusion of bacteria. The first batch of each mixture without bacteria is regarded as the control mix. All mixtures were designed by using absolute volume method. The study mixtures binder content was 250 kg/m3, 450 kg/m3 and 475 kg/m3.Cubic specimens with dimension of (15×15×15) cm were cast for permeability test, and Cubic specimens with dimension of (10×10×10) cm were cast for compressive strength test. Prismatic specimens with dimension of (10×10×50) cm were cast, first division of them were for flexural strength test, and the others were reloaded using one-point bending tests to simulate the cracks insitue, then cured in order to utilize it for mineralogical composition test: scanning Electronic Microscope (SEM). All specimens were cured in clean tap water at room temperature for 28 days for cube specimens and for 28, 90 days for prismatic specimens.

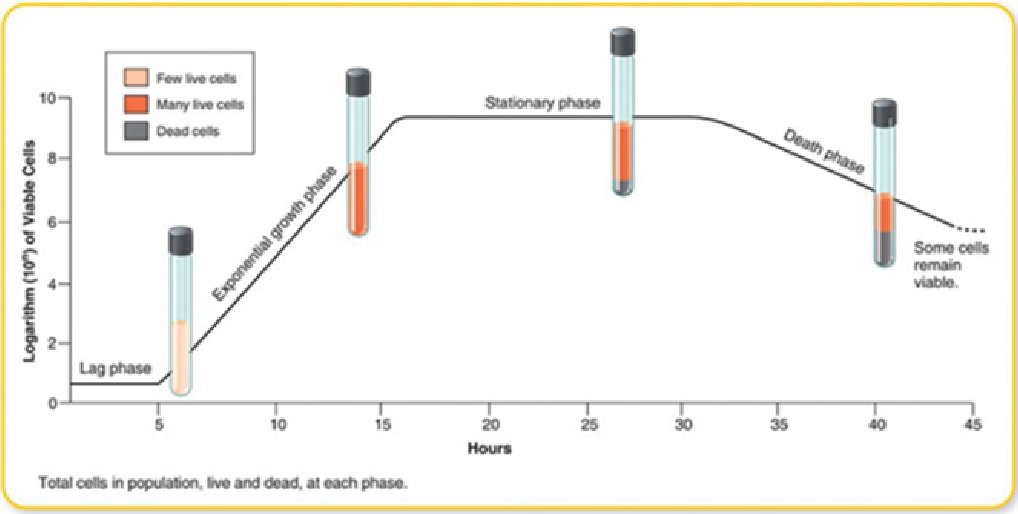

Fig 1: Schematic for Bacterial Growth life

Table 2: Mixing proportion of 1 m^3 cement paste of TC

Fcu (kg/cm2)	w/c (%)	Cement (kg)	Water (L)	Dolomite (kg)	Sand (kg)
250	35	350	122.5	1218.56	812.4
250	40	350	140	1190.73	793.82
250	50	350	175	1135.08	756.72
400	35	500	175	1059.37	706.25
400	40	500	200	1019.62	679.74
400	50	500	250	940.12	626.75

Table 3: Mixing proportion of 1 m^3 cement paste of HC

Fcu (kg/cm2)	w/c (%)	Cement (kg)	Water (L)	Dolomite (kg)	Sand (kg)	S.F (kg)	S.P (kg)
800	28.5	475	148.91	940.12	704.45	47.50	15.675

IV. Mechanical Tests On Concrete

A. Compressive Strength

Its test was achieved at 28 days in compliance with BS EN 12390-2:2009 standard. 105 cubes of 100x100x100 mm were prepared to be tested at 28 days. All specimens were checked by using compression hydraulic testing machine with capacity 200 tons and accuracy 0.5 tons. The specimen must be aligned in the center of the machine. The test schedule for compressive strength

Wasperformed. The compression strength (Fc) (ton/cm2) was calculated according to equation (1):

$$\boldsymbol{Fcu} = \frac{\boldsymbol{Pc}}{\boldsymbol{A}} \quad (1)$$

Where:

F_c**:** Compression strength.
P_c**:** The average strength of 3 compressionsamples result (machine reading (ton)).
A: Cube sample area (cm2).

Using aerobic microorganisms (Bacillus pasteurii), as self-healing factors causes an advanced in the compressive strength of cement mortar containing bacteria compared with control one.

B. Flexural Strength

Its test was the mostsignificant. Flexure test are generally used to define the flexural modulus or flexural strength of a material. It was aimed to study the effect of utilizing SCMs and BC on The flexural strength test. Studying the effect of flexural strength was important to maintain the concrete durability by preventing the crack and corrosion. It must be taken into design consideration. The test was performed and complied with BS EN 12390-6:2009 standard after 28days of curing. The test was performed on prismatic samples because of its better accuracy than another sample. Results showed 50% improvement in flexural strength compared with control one. The machine capacity is 100 KN and samples are estimated by the rate of loading 140 kg/cm2/min. The process of self-healing is applied on almost specimens in normal water.The flexural strength (Fb) (ton/cm2) was calculated according to following equations:

$$\mathbf{Fb} = \frac{\boldsymbol{Mmax}\times\boldsymbol{Y}}{\boldsymbol{I}} (2)$$

$$\boldsymbol{Y} = \frac{\boldsymbol{Pmax}\times\boldsymbol{L}}{\boldsymbol{4}} (3)$$

$$\boldsymbol{I} = \mathbf{b} \times \boldsymbol{h^3} \ (4)$$

Where:

- ***Fb:***direct strength machine
- ***Mmax***: Maximum Bending Moment (kg.cm).
- ***Pmax:*** Maximum Fracture load (machine reading (KN)).
- ***h:*** prismatic specimen height.
- ***I:*** Moment of inertia.

C. Permeability test

It was performed to estimate the transport characteristics, the coefficient ofpermeability, material either virgin (uncracked), preloaded (cracked), or rehealed specimen. It was performed at 28 days according to ASTM

C 1012 standard. 30 cubes of 150x150x150 mm were prepared to be tested at 28 days, this cubes were chosen due to their highercompressive strength achived. The outside of the cubic perimetersof the specimens were pictured with epoxy resin. The sides of the faces were covered with sand to clean surfaces. The specimens were putten in the permeability cells of the testing apparatus, shown in fig 2. The water flow from one to other at 30 bar pressure for 24 hours. The permeated water is gathered in a 100 ml graduated flask. The test was performed in Housing and Building National Research Center in Doki, cairo. The formula for estimating the permeability coefficient (Darcy coefficient) is:

- $k = \frac{cc \times h}{Ax\ T\ x\ p}$ (cm^2/P_a .s) (5)

Where:

- ***cc:*** permeated water (cm3).
- ***h. :*** specimen height (cm).
- ***A:*** specimen surface area (cm2).
- ***T:*** permeation time (sec).
- ***P:*** hydrostatic pressure (bar).

Fig.2 Permeability apparatus

V. Evaluation of Healing Agent Effect on Self-Healing Process.

To assess the healing of anycrack under several widths, the cracked specimens were extracted after twenty eight days and ninety days curing in distilled water in ceramic tub that unfolded to the weather during the healing time and oxygen go through the water. The sediments that are formed at the surface were examined by using (SEM) with Energy Dispersive Spectrometer (EDS) as shown in fig (3).Using two ways help to determine the efficiency of the healing. The method of characterization and the prismatic specimens were used toeliminate from for few days to record any variation of the cracks wide by using the camera and microscope. The processing of cracks were performed pre and post healing. The rate of healing was estimated by measuring the surface area of the cracks before and after healing according to Eq (6).

$$\text{The area repair rate} = \frac{\mathbf{Ao-At}}{\mathbf{Ao}} \times 100\% (6)$$

Where:
A_o:crack surface area of the original specimen
A_T: crack surface area of repaired specimen at time t

a. Effect on Concrete microstructure

The observed phenomenon in the structure is forming the crack. The formation of micro crack influences the characteristics of construction but it reducesthe strength of concrete and it may be a threat because of the risk of aggressive substances in a wet environment.

Factors in the concrete matrix help in increasing the healing of crack. The use of Bacillus pasteurii helps in designing biological self-healing concrete. According to the findings of Tittelboom et al. (2010), pure bacterial group are not able to make a bridge of the cracks but in silica gel, the cracks heal. Increasing in permeability after treating with **Bacilluspasteurii** leads to the filling of unavoidable of air bubbles.

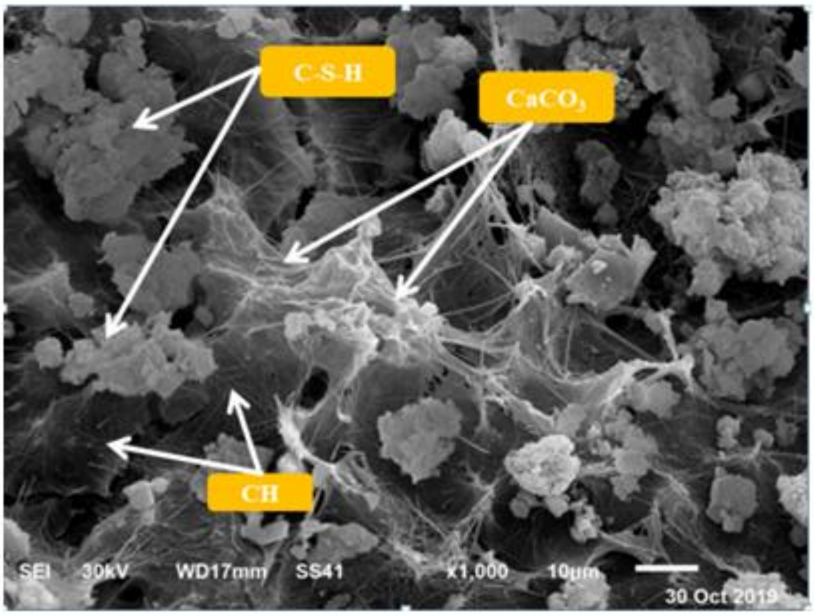

Figure 3: SEM images of participation at crack surface (F_{cu} = 250 kg/cm^2, w/c = 0.50, MII)

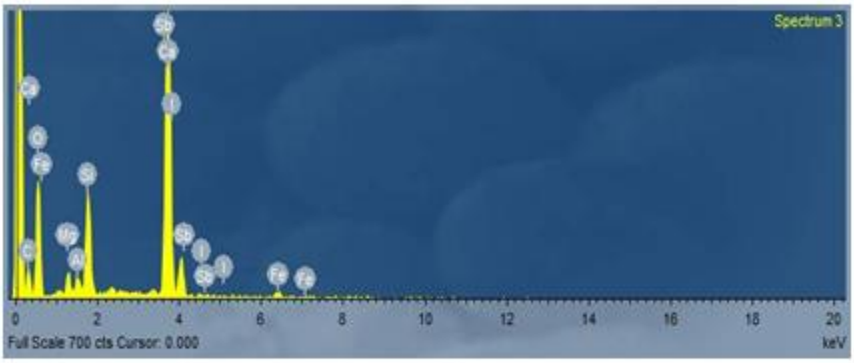

Figure 5:EDS spectrum of precipitations at crack surface

VI. Results and discussion

6.1 crack- healing estimation under different crack width

Figure (4) illustrates that the wide of crack was 0.40mmwith self-healing factor after many healing phases. The cracks were handledby white precipitations. The rate ofhealing was various. Thiswashealed fullyafter immersion in water for twenty eight days, but the wide of crack was 0.8 mm was partially healed.

Microscopic study of such precipitation at cracking surfaces of cement samples was performed. The SEM representations of precipitation at thesurface are illustrated in Fig [3]. The crystal appears to be lamellar in the region of the morphology of packing.

The analysis of composition by using EDS discovered thatsedimentation on the layer of crack composed from carbon, oxygen and calcium atoms as shown in Fig [5]. The area repair rate of samples of specific crack width after varying repair period was determined on the basis of calculation of the surface area of the crack before and after healing using the Vernier calliper as shown in Fig n[6] and Table [4].

6.2 Restoration of permeability after healing

It was observed that for mixtures with Fcu= 250kg/cm2, permeability gradually decreased until MIV with replacement 20% of water by bacteria to reach 51.14%, of MI in 28 days and with increasing the ratio of replacement it was observed that there was gradually increase in permeability as shown in Fig (7).While with Fcu= 400kg/cm2,permeability gradually decreased until MII with replacement 10% of water by bacteria to reach 60.10%, of MI in 28 daysand with increasing the ratio of replacement it was observed that there was gradually increase in permeability as shown in Fig (8).This can be attributed to the bacterial growth cycle, where after 15h, the bacterial cells starts to Decompose.

6.3 Efficiency of sealing cracks

From figure [6] it can be shown that the crack was more difficult to be sealedbecause of an increase in the average crack width and a reduction in the repair capacity of the microbial healing. The healing impact of the widthof 0.1–0.3 mm was complex, and the ratio of crack healing was 85 % after twenty days.

The repair effect was also great for width that reached to 0.3–0.5 mm and the healing level was 50–70% after twenty days of repair.

Although the performance of the microbial healing was decreased to 0.8 mm width and the rate of repair reached to less than 30%.

This experiment is illustrated from two sides depending on microbial mineralization theory. Adding Bacteria and substratesto the concrete is important. If cracks happen, microorganisms are stimulated and cracks are healed by mineralization. Calcium carbonate precipitation is formed by the metabolic transformation of the respiration substrate.

Calcium carbonate precipitation occurs first in the location of the bacteria, then increases and eventually completely heals the crack. More mineral precipitation is required for large cracks to heal the crack completely.

It is complicated to heal large cracks with amount of repair factor. On the other side, the size of the crack is widelarge. The repair agent and the production of mineral precipitation spread water layer out, leads to loss of the healing agent, and a weak repair effect.

VII. Conclusion And Future Scope

The microorganisms are called alkali-resistant that mean their expanding in the definite environment by a high pH (10-11).These strains can generate germs that rest on the wall. It protects them from mechanical and chemical stresses.

As a result, these bacteria are able to resist high pH values inside the concrete and continue to survive for a long period as well as the survival of the spore for more than two hundred years is known.

It is speculated that spores freeze in the concrete of such bacteria has the ability to fill cracks through bio-mineral composition after they have been resurrected by water and nutrients that penetrate to the cracks.

The integration of a factor in concrete may be inexpensive as well as easy when the agent is freeze in lightweight assemble before adding the concrete blends. Applying the assumed constant biochemical healing factormay lead to reducing the repair cost.

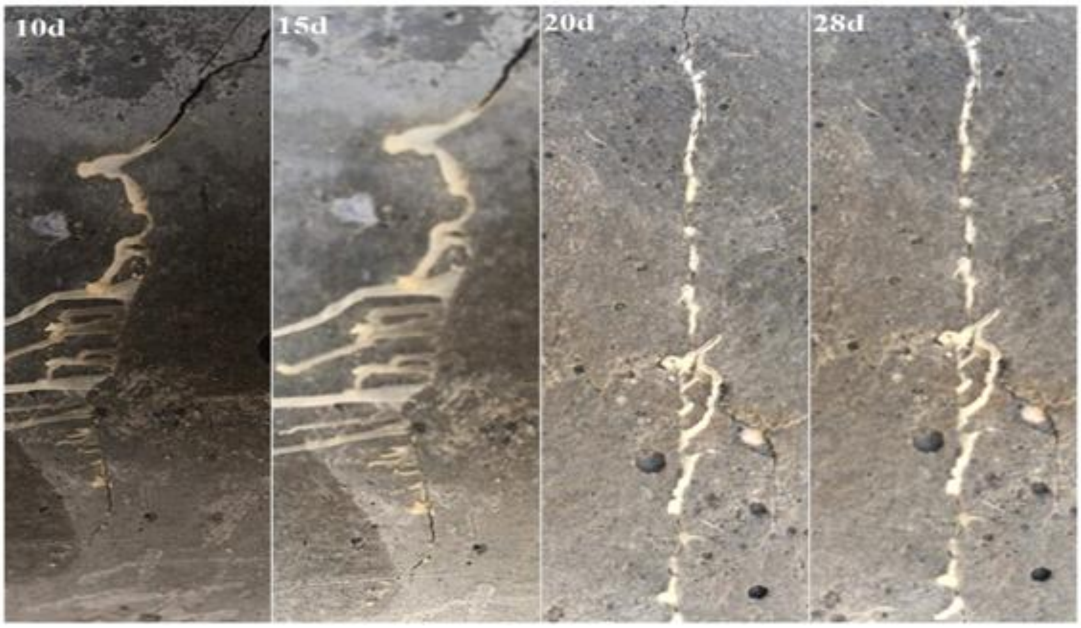

Figure 4: surface image of a specimen with average crack width of 0.40mm

Table 4:area repair rate statistics of specimens withdifferent crack width after different repair time

crack width	Ao (mm2)	At (mm2)				area repair rate %			
		0d	10d	20d	28d	0d	10d	20d	28d
0.1	10	10	0	0	0	0	100%	100%	100%
0.2	20	20	3	2	0	0	85%	90%	100%
0.3	30	30	12	6	4.8	0	60%	80%	84%
0.4	40	40	24	16	14	0	40%	60%	65%
0.5	50	50	29.5	21.5	19.5	0	41%	57%	61%
0.6	60	60	37.8	34.8	32.4	0	37%	42%	46%
0.7	70	70	51.1	48.3	42	0	27%	31%	40%
0.8	80	80	64	57.6	50.4	0	20%	28%	37%
0.9	90	90	81	81	81	0	10%	10%	10%
1	100	100	100	100	100	0	0%	0%	0%

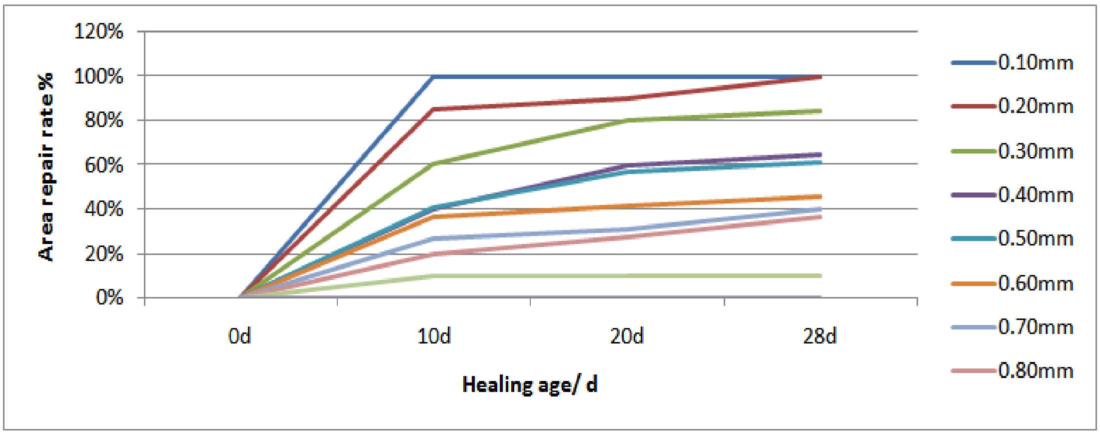

Figure 6: The repair rate of specimens with different crack width after different repair time

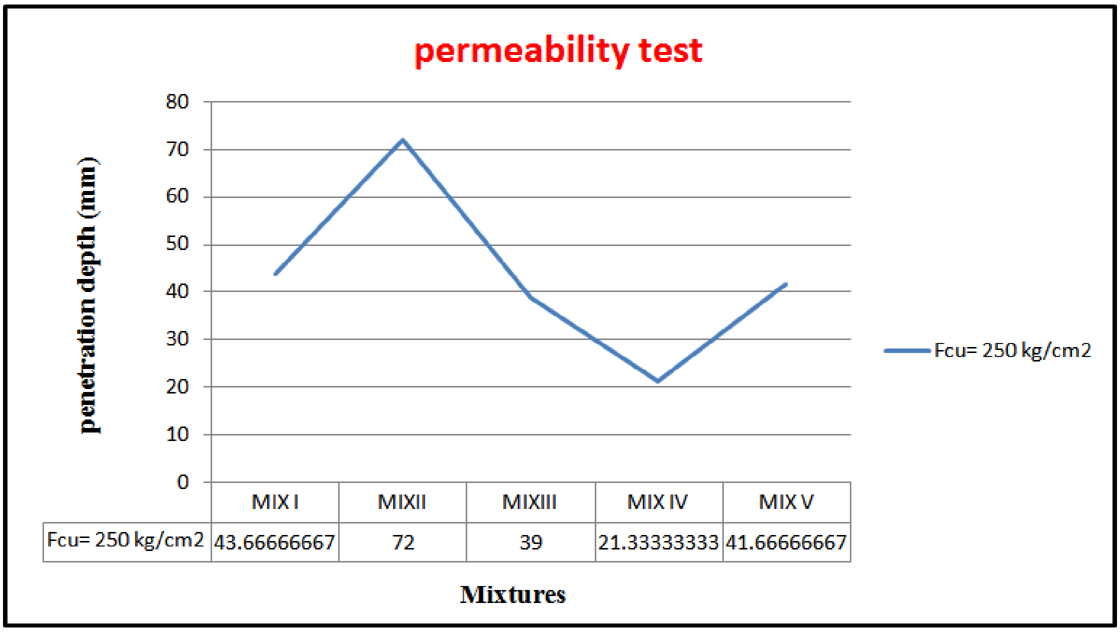

Figure 7: Permeability test for fcu= 250kg/cm^2, w/c = 0.50

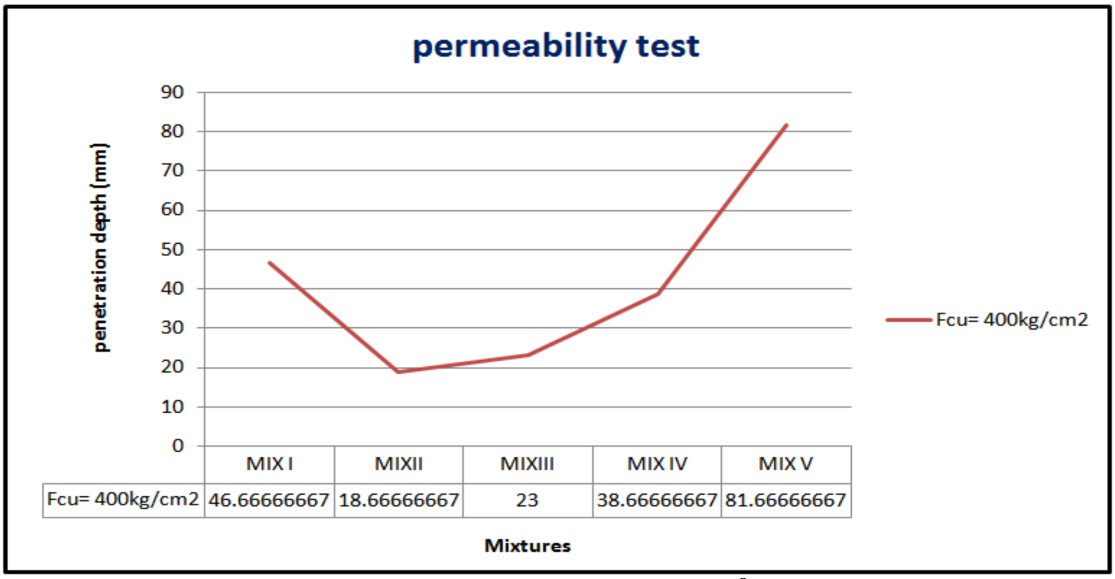

Figure 8: Permeability test for fcu= 400kg/cm^2, w/c = 0.50

The addition of Bacillus Subtilis bacteria increases the compressive strength of concrete. The compressive strength is increased nearly 11-79% at 28 days for ordinary, standard and high grades of concrete when compared to controlled concrete.

The Durabilitystudies carried out in the paper through permeability test showed that bacterial one is sturdier in the time of "penetration depth" than traditional concrete.

Permeable is more than conventional concrete till 20% replacement of bacillus pasteurii. Based on the previous, Bacillus Subtilisis used inhandlingthe crack of concrete.Although the nature of the minerals requires to be illustrated, they appear morphologically related to calcite precipitates.

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