A STUDY OF MICROORGANISM (BACTERIA) ON CONCRETE STRENGTH AND DURABILITY

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Abstract: the purpose of this research is to study the behavior of microorganism Bacillus Subtilis for enhancement of strength in cracked concrete specimen. In concrete, crack is very important phenomenon due to having low tensile strength and stress which cause settlement, shrinkage and expansion in concrete. Without any treatment and precaution crack is expand further more and require expensive repair. In this paper the bacillus subtilis, a gram positive bacteria was used to induced the precipitation of calcite. This procedure is incredibly applicable due to various fact like it is pollution free and natural. The comparative result is considered for evaluation of strength and durability with addition of bacteria in cracked specimen. The average percentage strength of mortar cubes improved with controlled concentration of bacteria.

Keywords: bacterial concrete, strength, durability, microorganism

I. INTRODUCTION

Some investigation has been there on the topic of microbial induced carbonate precipitation (MICP) and has been conducted in the past. Ancient time microbially induced carbonate precipitation (MICP) has shaped the earth by a natural process. In this process, calcium carbonate minerals are composed from calcium and carbonate ions. Because calcium carbonate minerals are a homogenous material and compatible with concrete and is environmentally friendly, they can use for healing the crack in concrete material. Cracks in concrete are ineluctable and one of the innate impuissance of concrete. Substances like Water and other salts seep through these cracks, corrosion initiates, and thus reduce the life of concrete. As there is some negative side-effects of the conventional techniques, bacterial induced carbonate mineralization has been proposed as a novel and environmental amicable strategy for the auspice of stone and mortar. Bacterial concrete, special, fact is a material, which can successfully remediate cracks in concrete. This technique is highly utilizable because the mineral precipitation (CACO3) induced as a result of microbial activities, which is natural and free from pollution. As the cell wall of bacteria is anionic, metal accumulation (calcite) on the surface of the wall is substantial, thus the whole cell becomes crystalline and they eventually plug the very small holes and cracks in concrete. The technique is used to improve the compressive strength and stiffness of cracked concrete specimens. In concrete, a common phenomenon i.e. cracking is due to the relatively low tensile vigor. High tensile stresses can result from external loads, imposed changes (due to temperature gradients, confined shrinkage, and differential settlement), plastic shrinkage, plastic settlement, and expansive reactions (e.g. due to reinforcement corrosion, alkali silica reaction, sulphate attack). Without immediate and congruous treatment, cracks incline to expand further and eventually require extravagant repair. The ability to withstand wear of concrete is also impaired by these cracks, since they provide an easy path for the transport of liquids and gasses that potentially contain harmful substances.

II. CLASSIFICATION OF BACTERIA

Based on shapes

They can be divided into Rod-shaped bacteria (Bacilli), Sphere-shaped bacteria (Cocci) and Spiral-shaped bacteria (Spirilla).

Based on gram strain

This classification is based on the results of Gram Staining Method, in which an agent is used to bind to the cell wall of the bacteria; they are Gram-positive and Gram-negative.

Based oxygen requirement

This classification is based on the requirement of oxygen for the survival of the bacterium. They are Anaerobic.

III. LITERATURE REVIEW

The Literature available states that bacteria can be desirable to improve the performance of the concrete. was first introduced by V.Ramakrishnan first introduced the concept of bacterial concrete, a novel technique in remediating cracks in concrete by utilizing microbiologically induced calcite ($CaCO_3$) precipitation. The pioneering work on repairing concrete with microbiologically induced calcite precipitation (MICP) is reported by the research group of Ramakrishnan V. and others at USA in an institution called the South Dakota School of Mines & Technology. V. Ramakrishnan et al. [1] purposed by the technique in remediating crack and fissure by using microbiologically induced calcite precipitation (MICP). MICP is the technique called biomineralization by which living organism form inorganic solid. They use bacillus pasteruii as a microbial sealant. MICP is highly usable because the calcite precipitation induced as a result of microbial activities, is pollution free and natural. The technique can be used to increase the compressive strength and stiffness of cracked concrete specimens. It was discoverd that all the beams with bacteria performed better than the control beams (without bacteria). The durability performance improve with improvement in the concentration of bacteria. Microbial calcite precipitation was quantified by X-ray diffraction (XRD) analysis and visualized by SEM. The unique imaging and microanalysis capabilities of SEM established the presence of calcite precipitation inside cracks, bacterial impressions and a new calcite layer on the surface of concrete. This calcite layer increases the impermeability of the substance, thus increasing its resistance to alkaline, sulfate and freeze-thaw attack. They conclude that the presence of bacteria in different medium improve the resistant towards alkali, sulfate, freeze-thaw attack and drying shrinkage. They also conclude that the durability of bacteria improve with improvement in concentration of bacteria. Bacillus pasteruii is used by authors as a microbial sealant. Day J L et al, [2] explained the results of an innovative goal in concrete crack remediation utilizing microbiologically induced calcite. A common soil bacterium, *Bacillus* pasteurii, was desired to induce calcite precipitation. The basic features for this application are that the microbial urease hydrolyzes urea to produce ammonia and CO_2 and the ammonia released in surroundings subsequently increases pH, leading to accumulation of insoluble calcite. To protect the cells from the high pH value of concrete, the microorganisms were prevent (something or someone) from moving in polyurethane polymer, lime, silica fume, and fly ash, and then applied in concrete crack remediation. Microbiologically enhanced crack remediation was evaluated by comparing the compressive strengths of the treated concrete specimens and those of the control. Scanning electron micrography (SEM) analysis evidenced the direct involvement of microorganisms in calcite precipitation and X-ray diffraction analysis quantified calcite distribution in the region of the treated cracks. By this study’s observation, they concluded that MECP has very good potential in cementing concrete as well as many other types of structural cracks. E Schlangen et al, [3] purposed in this paper that the overview of self-healing techniques in three different materials are discussed. The 1st application is using Bacteria to precipitate calcite in cracks in concrete. With this method relatively huge cracks in reinforced concrete can be filled. The method does not lead to strength improvements of the structure, but by filling the crack, the path to the reinforcement is blocked. Herewith the ingress of liquids and ions that start reinforcement corrosion is stopped and thus the ability of the structure is improved. Furthermore this method is useful for water retaining structures. Cracks can be filled in this way and leakage can be stopped. Especially in underground structures were repair is difficult or impossible Bacterial concrete has a huge future. In the 2nd application SHCC (strain hardening cementitious composites) materials are studied, which have already a high potential for self-healing because of their small crack widths. Like microfibers and SAP (Super Absorbent Polymers) i.e. new additions to seven promote this self-healing capacity further. The 3rd application is for asphalt concrete in which the self-healing capacity is increased by using encapsulated oil and micro-steel fibres. They applied this technique in a real road in the Netherlands in 2010. Leenachaurasia et al, [4] purposed that they use *Bacillus* cohniiand Bacillusmegateriumfor their urease positive activity. Effect of nickel ion concentration on the growth of bacteria and effect on carbonatogenesis activity (calcite precipitation) was investigated varying the nickel ion concentration in culture medium. Different doses of bacterial biomass were added to find the most conductive amount of bacteria (particular dose) to be used to obtain maximum compressive strength. Mortar specimens with B.cohniiand B. megateriumwere casted to study their effect on the compressive strength. The result showed a significant improvement in the compressive strength and calcite precipitation in bacteria part of a whole mortar. The qualitative and quantitative analysis of mortar cubes was highly trained by performing SEM (scanning electron micrograph) and XRD (x-ray diffraction analysis). The SEM micrograph viewed that bacteria are precipitating calcium carbonate on the cell wall of bacteria. The EDX analyses viewed improvement calcium concentration in bacteria treated mortar specimens. They use a plate of aluminum for crack development with 3mm thick and 10 to 15mm height. They get that the use of nickel ion enhance bacterial growth and being co factor for improving calcium carbonate precipitation. They conclude that the dose of 0.5gm of dry bacterial biomass can use for achieving high compressive strength for crack filling.

IV. CONCLUSION FROM LITERATURE REVIEW

- MICP is highly desirable because the calcite precipitation induced as a result of microbial activities, is pollution free and natural.
- The addition of bacillus subtilis bacteria improves the hydrated structure of cement mortar.
- The compressive strength of cement mortar is maximum with the addition of bacillus subtilis bacteria for a cell concentration of 105 cells per ml of mixing water.
- From the durability studies, the percentage weight loss and percentage strength loss with 5% H2SO4 revealed that Bacterial concrete has less weight and strength losses than the conventional concrete.
- Water absorption was less in mixtures with bacterial addition as compared to the mixtures without bacteria.
- Bacillus subtilis can be produced from lab which is proved to be a safe and cost effective.
- It is found that the use of organic matter and the bacteria the overall strength and durability of concrete structure is improved.
- With the use of bacillus subtilis in bacterial cell wall, the compressive strength is increase 15%.
- With the use of bacteria in building material the Enhancement of compressive strength, reduction in permeability, water absorption, and reinforced corrosion has been seen in various cementitious and stone materials.
- With the use of bacteria large crack can be heal especially underground structure were repair is difficult.
- From the literature review it is found that the

research work restrained for the certain depth only. Hence more detail study is required for enhanced depth.

V. OBJECTIVE AND SCOPE OF WORK

OBJECTIVE

"Parametric study on concrete and mortar cubes using bacillus subtilis"

Following parameter are under study

- Compressive strength of mortar cubes.
- Flexural strength of concrete beams.
- Durability of mortar cubes and beams

SCOPE OF STUDY

- Procurement of ingredient of concrete and bacillus subtilis.
- Testing of this materials.
- Mix design of concrete as per IS code: 10262 (2009)
- Casting of cubes and application of cracks using aluminum plates.
- To check the performance of cracked concrete beam filled with bacillus subtilis.
- To determine the compressive strength of cracked concrete beam filled with bacillus subtilis
- To determine the compressive strength of cracked mortar cubes filled with bacillus subtilis.
- To check the performance of bacillus subtilis by durability test.
- To verify the performance of bacillus subtilis with 1mm and 2mm crack width and 15mm, 20mm, 25mm, and 30mm crack depth.

To check the percentage strength loss of mortar cubes by immersing $MgSO_4$ in water.

Table 1 properties of cement

Sr no	tests		result	Requirement of IS 12269
1	Consistency		32%	---
2	Setting time	Initial min	90	Shall be more than 30 min
		Final min	170	Shall be less than 600 min
3	Le'chatlier Soundness		1.44%	Shall be less than 10 mm

Table 2 result of test on aggregate

Water absorption	Percentage %
Coarse aggregate	0.60
Fine aggregate	1.20
Free surface moisture	Percentage %
Coarse aggregate	1.00
Fine aggregate	1.5

Fineness modulus: 3.20

Zone: I Silt content: 0.1

Table 4 sieve analysis of coarse aggregate

KAPACHI 20mm			GRIT 10mm	
Material taken gms	5000		5000	
Proportion	0.65		0.35	
Sieve Size mm	Retained Material gms	% Passing	Retained Material gms	% passing
63	0	100.	0	100.0
40	0	100.0	0	100.0
20	495	90.10	0	100.0
16	1663	56.84\	0	100.0
12.5	1489	27.06	0	100.0
10	995	7.16	578	88.44
4.75	358	0.00	3595	16.54
2.36	0	0.00	756	1.42
600µ	0	0.00	71	0.00
150µ	0	0.00	0	0.00

Table 5 properties of coarse aggregate

SR No	tests	Coarse aggregate 20 mm	10 mm	Requirements as per IS : 383
1	Impact value %	17.50	20	Max 30%
2	Flakiness index	28.9%	-	Combined shall be<30%
3	Elongation index %			

Table 6 concrete mix design M20

1	Cement	Ambuja cement 53 grade OPC
2	Coarse aggregate source:	Sevalia
3	Fine aggregate source:	Sankheda
4	Characteristics strength required in 28 days	20 N/mm^2
5	Minimum Cement Content (As per IS)	300 kg/m^3
6	Maximum Size of aggregate	20 mm
7	Degree of quality control	Good
8	Exposure	moderate
9	Desired slump	70

Composition of concrete mix ordinary grade concrete (M20)

Mix proportion 1:1.425:3.1:0.5

Table 7 material required by weight

MATERIAL	WEIGHT PER m^3
Sand	546 kg.
Aggregates (grit)	475 kg.
Aggregates (kapchi)	713 kg.
Cement	383 kg.

VI. EXPERIMENTAL STUDY

PHASES OF EXPERIMENTAL PROGRAM

Phase I – Culture of bacteria

Growth of bacteria

Phase II – Strength Studies

To study the compressive strength of cement mortar cubes.
To study the flexural behavior of concrete.
Phase III – Durability Studies
To study the Strength loss of concrete
MATERIAL USED AND THEIR PROPERTIES
BACTERIA

- The bacterium Bacillus subtiliswere isolated by National Collection of Industrial Microorganism (NCIM), Pune, India.
- The culture and growth of Bacillus subtilishave been done at Biocare Research (India) Pvt. Ltd, Microbiology Laboratory, Paldi, Ahmedabad.
- The samples were suspended in a sterile saline solution (0.85% NaCl), diluted properly and plated on precipitation agar containing urea (20 g/l),NaHCO3 (2.12 g/l), NH4Cl (10 g/l), Nutrient broth (3 g/l), CaCl2_H2O(25 g/l). Incubation was done at 30Colonies were assessed every 5 days with a stereo microscope (Zeiss) and selected as positive based on visual crystal formation within 10 days. Positive isolates were purified through repetitive dilution and plating.
- The concentration of cells (105cells/ml) was obtained by centrifugation at 8000 rpm for 10 min at 4OC.

COMPRESSIVE STRENGTH STUDY
MORTAR SAMPLES
Mortar samples were casted by using ordinary Portland cement, locally available river sand and potable water. The composition of the mortar Mix is shown Cement and sand ratio was used as 1:3 (by weight). Moulds with dimensions of 70.6 mm× 70.6 mm× 70.6 mm were used. After casting, all moulds were placed in a normal room temperature for a period of 24h. After demoulding, the specimens were placed in curing tank for 28 days.
CREATION OF CRACKS
After 28 days curing, standardized cracks were created in mortar samples with dimensions of 70.6 mm×70.6 mm× 70.6 mm. the crack was developed by aluminum plate on upper surface, with a depth of 15, 20, 25 mm and 30 mm a width of 1 mm and 2mm. and 3mm There were 14 sets of cubes each containing 3 samples selected for each width and depth combination, so total 84 numbers of mortar cubes were cast for 28 days test results and for 56 days of results

Figure 1 creation of crack

REMEDIATION OF CRACKS
The cracks in specimens were filled with a mixture of sand and bacillus subtilis. The sand mixed with bacteria suspension to a final concentration of 10^5 cells/ml was forced into crack with knife edge.

APPLICATION OF FOOD
Liquid media consist of (nutrient broth + $NaHCO_3$ urea) is given for 1 month to bacteria to produce calcite during this time as a food at interval of every 6 hours.

Figure 2 culture and broth and application of it

Figure 3 application of foods

TESTING PROCEDURE FOR CUBES
The testing has been done as per IS: 516-1999. After the required period of curing the cubes are removed from the curing tank. Crack was created and food for bacteria was given for 1 month. After 1 month of food application to bacteria, the compressive strength of the mortar cubes at 28 days and 56 days is determined.

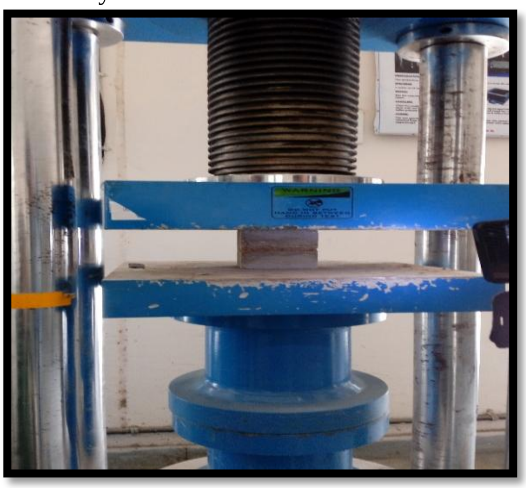

Figure 4 mortar cubes loaded in CTM

FLEXURAL STRENGTH STUDY

CONCRETE SAMPLE

The experiments have been carried out to study the flexural behaviour of repaired concrete beams. 42 simply supported beams were casted and tested. Concrete samples were made using ordinary Portland cement. The composition of concrete mix is shown in Table 3.3.1. Moulds with dimensions of 500 mm×100 mm ×100 mm. After casting, all moulds were placed in a normal room temperature for a period of 24h. After demoulding, the specimens were placed in curing tank for 28 days.

Figure 5 curing of concrete beams

CREATION OF CRACKS

Standardized cracks were created in concrete beams. The crack was developed by marble cutter on the upper surface, with a depth of 15, 20 mm or 25 mm and a width of 3 mm. There were 7 sets of beams each containing 3 samples selected for 3mm width and depth combination, so total 42 numbers of concrete beams were casted for 28 days and 56 days test results.

The procedure of Bacteria application on cracks and food application are same as mortar cubes.

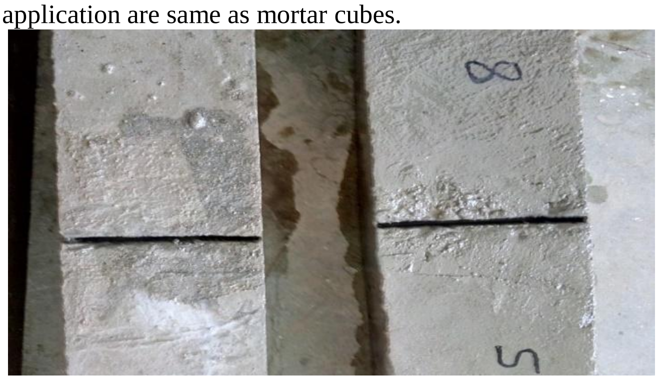

Figure 6 creation of crack

TESTING PROCEDURE

After the required period of curing the beam specimens were removed from the curing tank and cleaned. Procedure for crack creation and food application were same as for cube specimen. After required time for food application, a set of beams were tested for flexural strength at 28 days and 56 days. The beam was placed on two roller supports, resting on cast iron blocks, placed on the wing table of the concrete testing machine. The load was from the fixed cross head of the machine as two point loading, on the two rollers placed 165 mm apart, by a loading beam of sufficient stiffness.

Testing is performed under third point loading under controlled deflection the test is conducted as per IS: 516-1999.

Figure 7 flexural test on concrete beam

STRENGTH LOSS OF CONCRETE

The experiments are carried out to study the durability aspect of Bacterial concrete. For long term durability of concrete structures, it is essential that the environmental factors capable of adversely affecting their service life can be given proper consideration. Chemical attack by aggressive water is one of the factors responsible for damage to concrete. Frequently it is the presence of sulphate ions in water that accounts for its aggressive behaviour to concrete because certain constituents of cement paste can enter into deleterious soluble alkali sulphates and many industrial waters contain enough sulphate to potentially damage the Ordinary cement concrete. A total of 21 numbers of cubes of size 70.6 mm x 70.6 mm x 70.6 mm are cast and cured. After 28 days of curing and 28 days of to allow bacteria to produce calcite. cubes are immersed in 3.5% concentrated $MgSO_4$. The percentage compressive strength loss is taken for a set of cubes at 56 days.

TESTING PROCEDURE

After 28 days of casting, an accelerated experimental test program was conducted on ordinary Portland cement concrete. The procedure and time required for food application were same as stated in compressive strength study. After application of food, specimens were subjected to 3.5% solutions of $MgSO_4$. Cubes were continuously immersed in solution. The specimens were arranged in such a way that the clearance around and above the specimen is not less than 30 mm. The solution has been changed for an interval of every 15 days after taking the measurements. Before testing, each specimen was removed from the tubs, and brushed with a soft nylon brush and rinsed in tap water. This process removes loose surface material from the specimens. The percentage compressive strength loss is taken for a set of cubes at 56 days.

VII. TEST RESULTS

THE COMPRESSIVE STRENGTH OF CEMENT MORTAR CUBES

The experimental study was carried out to study the strength of cracked specimen and repaired specimen. The mortar cubes of different size and depth were cast and tested using aluminum plate for crack creation. In case of testing of mortar cubes the specimen are placed in horizontal direction. The crack size of 1mm, 2mm, and 3mm and the depth of 15mm, 20mm, 25mm, and 30mm are used. The results of compressive strengths at 28 days and 56 days at various crack depth and width were tabulated.

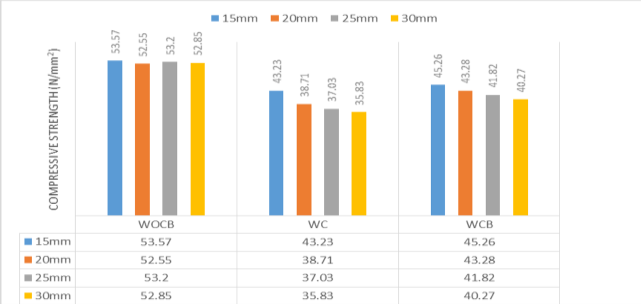

Figure 8 graph showing variation of compressive strength at 28 days crack for 1mm width

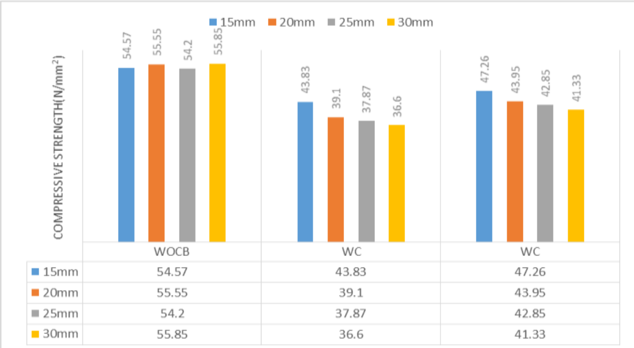

Figure 9 Graph showing Variation of Compressive Strength at 56 days for 1mm wide crack

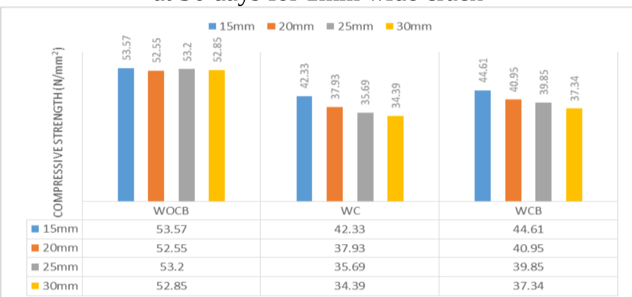

Figure 10 Graph showing Variation of Compressive Strength at 28 days for 2mm wide crack

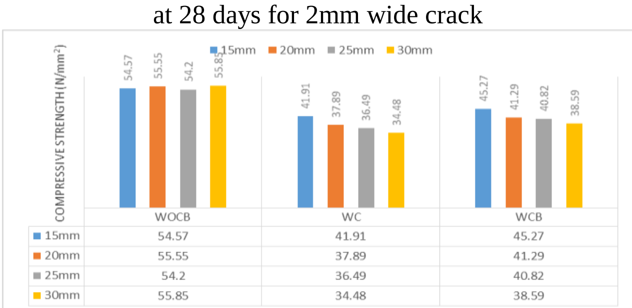

Figure 11 Graph showing Variation of Compressive Strength at 56 days for 2mm wide crack

THE FLEXURAL BEHAVIOR OF CONCRETE

The experimental study was carried out to study the flexural behavior of concrete beam with crack and repaired crack using bacteria. 42 simply supported beams consisting of cross section 100mm x 100mm x 500mm were tested for flexural strength study.

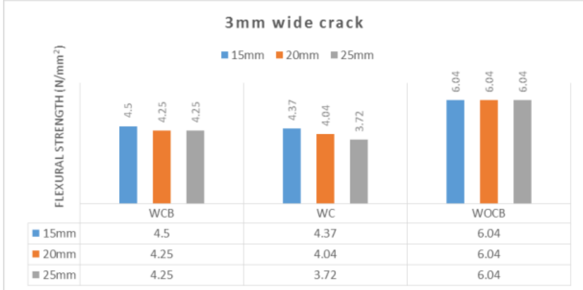

Figure 12 graph showing variation of flexural strength at 28 days

THE STRENGTH LOSS OF CONCRETE

The experimental study was carried out to study the durability aspect of bacterial concrete. 21 numbers of cubes immersed in 3.5% $MgSO_4$ after crack remediation. The results of percentage compressive strength loss of concrete is tabulated in graph.

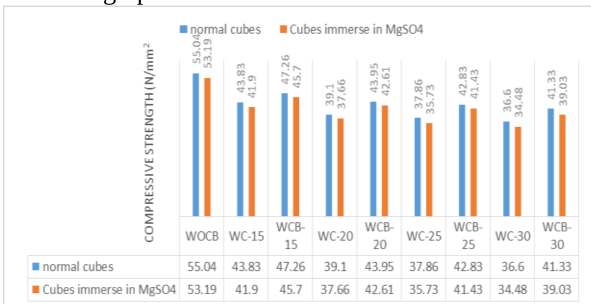

Figure 13 Graph showing strength loss at 56 days results

VIII. CRITICAL REMARKS

The following conclusions are drawn from the detailed experimental study conducted on the behaviour of ordinary grade remediated concrete.

- The addition of bacteria Bacillus subtilis in cracks improves the average compressive strength of mortar cubes around 9.28% at 28th day and 10.24% at 56th day for 1mm wide crack.
- For 2mm wide crack, the average compressive strength of mortar cubes increases up to 8.37% at 28th days and 9.19% at 56th day after remediation of crack.
- It can be concluded that the Bacteria are able to remediate cracks of smaller width at early stage.
- By comparing compressive strength results of depth remediation of repaired specimens, also it can be concluded that the bacteria remediate the crack depth up to 20mm more effectively than that of 30mm deep crack.
- From the results of flexural strength study, percentage increase in flexural strength has been obtained 4.62% and 9.97% at 28 days and 56 days respectively.
- The results of flexural study show that there is not considerable improvement in flexural strength because of proper bond not created between calcite and concrete in 56 days. It might take more than 6 month to create good bond between them.

- The percentage strength loss in WOCB, WC-15, WCB-15, WC-20, WCB-20, WC-25, WCB-25 and WC-30,WCB-30 are 3.46%, 4.40%, 3.30%, 3.68%, 3.04%, 5.62%, 3.26%, 5.79, 5.56% respectively. It shows that strength loss percentage in WCB is less compared to WC but larger than WOCB.
- The Bacillus Subtilis were isolated from soil and this bacteria are environment friendly which is proved to be safe.
- If microbiology laboratory is developed, the culture and growth of bacteria can be done at negligible cost. Hence it can be cost effective also.

SCOPE FOR FURTHER STUDY

- THE present work is concentrated on ordinary grade (M20). The same work can be extended to the higher grade concrete.
- Further the long term effects need to be studied.
- Also it is recommended to repair cracks with bacteria using different concentrations or different types.
- Directly addition of bacteria during casting of cubes and beams.

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