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USE OF SEAWATER IN CONCRETE

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***Abstract*:** Engineering construction in this era is facing challenge of shortage of fresh water for mixing and curing. Since potable water has become a scarce in the planet, replacing seawater for fresh water in the construction of both Reinforced Cement Concrete (RCC) and Plain Cement Concrete (PCC) structure should be welcomed. But the major consequences faced by the concrete structure due to the use of seawater was corrosion and variation of strength characteristic. This project deals with the addition of a bacteria named Bacillus subtilis JC3 in the concrete mix, which is made up of seawater. This can reduce the adverse effects of seawater in the concrete structure. The Bacillus subtilis JC3 bacteria is usually used in waste management. The bacterial culture is added to the concrete with seawater. It shows self-healing mechanism when cracks are formed. It is due to the calcite precipitation by the bacteria. The bacterial concrete is shows better strength and durability than ordinary concrete mix. These bacteria can survive in adverse situations also.

Index Terms – Bacillus Subtilis JC3, Concrete

I. INTRODUCTION

1.1 General Background

Concrete is one of the major building material in modern day construction. But the availability of freshwater for the manufacturing purpose of concrete is declining on earth. Consumption of tremendous amount of fresh water led to many serious environmental issues. So it becomes necessary to search for an alternative solution. About 70.90 % of earth is covered with sea water. So in future, sea water need to be used in construction purpose but the contents of sea water cause deterioration in steel. Desalting of sea water leads to extra construction cost. In this project, the usage of sea water without desalting was adopted and its effect on compressive strength of concrete was studied. In this research work, the comparative study of effect of sea water and fresh water on the strength characteristics of concrete was investigated. This paper presents the results of an experimental research on the effect of sea water and fresh water on compressive strength, flexural strength, split tensile strength of concrete.

IS 456:2000 recommends the use of at least M20 grade concrete in case of plain cement concrete in seawater exposed directly along the sea-coast and M30 in case of reinforced cement concrete. For reinforced cement concrete minimum M20 grade concrete is used. In our project M15 grade concrete made up of slag cement is used for the analysis. M15 grade concrete is generally used for plain cement concrete works. The previous studies on the use of seawater in concrete determined that, the use of slag cement for making concrete can reduce the sulphate attack and chloride attack on the concrete structure. In their studies rich mixes where used like M30, M40, M50 etc. So we want to know the effect of seawater in the poor mix like M15.

The finding of alternate materials for construction purpose, which is as suitable as that of such material from economic and durability of view is very difficult. The primary chemicals consist in seawater are the ions of chloride, magnesium, sodium, calcium and potassium. The researchers recently found that the deterioration of steel can be inhibited by the use of bacteria. Very recently, a specie of Bacillus subtilis JC3 has been used in concrete structure to inhibit corrosion by absorbing the oxygen in RCC. Surprisingly, the bacteria can survive with in the concrete structure and resist oxidative corrosion for a long time. Bacteria are sometimes blamed for attacking building materials such as corrosion of steel. However, bacteria could play a protective role, depending up on the type of its metabolism, resulting in the formation of protective compounds. The presence of Bacillus subtilis JC3 enhanced steel's resistance to corrosion in sea water environment. The corrosion of steel is prevented by the formation of a bio-mineralized film induced by Bacillus subtilis JC3. The film is consist of extra cellular polymeric substances (EPS) and calcium carbonate with a calcite structure. It is exhibiting a stable and self-healing anti-corrosion activity.

1.2 Objectives

The objectives of this study is as follows:

- To study the effect of using sea water in concrete instead of fresh water.
- To study the effect of compressive strength, split tensile strength and flexural strength of concrete manufactured by sea water.
- To study the effect of Bacillus subtilis JC3 for the protection of steel from corrosion.
- To provide an alternative method which result into saving fresh water.

1.3 Scope

In the near future, fresh water will be very difficult to get and scarce. It is found that in 2025 there will not be enough fresh water for living beings. Also, United Nations and World Metrological Organization are predicting 5 billion people will be live in short of drinking water. Also, in the present, there are some areas where sea water is used as mixing water with or without intension. Due to the increasing requirements, the possibilities of using sea water as mixing water in concrete should be investigated seriously. The need for using sea water in concrete manufacturing will bring demand for this research project. The bacteria used in this study are not harmful to animals and humans. Bacillus subtilis JC3 can be produced in laboratory and it is proven to be safe.

II. LITERATURE REVIEW

Tina Jose et al (2019) investigated the possibility of using sea water and sea sand in the manufacturing of concrete. This paper deals with the study of using sea sand and sea water in concrete manufacturing in replacement of river sand and fresh water. To determine the effect of corrosion in the epoxy coated reinforcement bars accelerated corrosion test were conducted. They concluded that in all combinations the corrosion rate is minimum and was safe in construction mainly in marine areas.

Lagazo et al (2019) was conducted research on the behaviour of Bacillus subtilis JC3 bacteria in corrosion and self-healing of cracks. It was basis of strength infrastructure in the Philippine city. The study demonstrates the use of micro-organisms. Bacillus subtilis JC3 is developed for tough framework and put forth a concentrated effort in mending concrete as a strategy for break control. This study analyse that the Bacillus subtilis JC3 bacteria is very effective in heal cracks in concrete.

Arunya A, Rajesh s (2018), conducted a study and reported the results of using seawater as mixing component with OPC. The compressive strength test, flexural strength test and split tensile strength test were carried out with respect of seawater which was used as curing and mixing in the concrete. The effect of seawater on concrete may conveniently been examined. From the study we can analyse that increase in strength of specimen about (4 – 7 %), later it decreases in tensile strength.

B Sathishkumar et al (2018) have conducted a study on effect of seawater in the strength of concrete. The study suggested the possibility of sea water as a mixing water. The reference plain cement concrete was prepared by freshwater and salt water both for mixing and curing. After conducting the study there concluded that the use of seawater in concrete mix will not reduce its strength.

K.Kaja, S.Sidharthan (2009), by this study crack formation is very common phenomenon in concrete construction due to the use of different waters and effects of various chemical cracks in concrete have been developed which effects the strength of concrete is a material which resist the compressive load to a limit but due to various loads cracks has been developed. In order to solve this problem bacteria has been used. They produce crystals of calcium carbonate which resist micro-cracks and pores in the concrete. When the rack appears water enters through the crack, bacteria become active and produce calcium carbonate. The result of the study shows that compressive strength is increased.

III. MATERIALS AND METHODS

3.1 Details of materials

Various materials are used in this project work for casting, curing and testing of concrete specimens. They are slag cement, aggregates, normal water, sea water, bacteria, reinforcement bars.

3.1.1 Slag cement

Slag cement is a hydraulic cement. Blast furnace slag is an industrial by-product of an iron blast furnace. The molten slag from the iron manufacturing plant is rapidly chilled, producing glassy granules that yield desired reactive cementations characteristics when ground into cement fineness and replace a portion of Portland cement to make slag cement. Portland slag cement (PSC) is comprising of more than 90% glass with silicates and alumino silicates of lime as shown in table 3.1. *JSW* Portland slag cement was used in our work which is blended with 45-50% slag, 3-5% gypsum and 45-50% clinker. It has good resistance to corrosion, attack of chloride ion, improves drying shrinkage and water absorption thus improves durability of concrete.

Table 3.1: Properties of Slag cement

Properties	Result
Specific gravity	2.86
Standard consistency	38
Initial setting time	120 minute
Fineness	90%

3.1.2 Coarse aggregate

Coarse aggregate (CA) is of particle size 25 mm and the properties are shown in table 3.2.

Table 3.2: Properties of Coarse aggregate

Properties	Result
Specific gravity	2.75
Percentage of water absorption	0.518 %
Fineness modulus	6.027
Bulk density of fully compacted CA	1618.88 kg/m^3
Bulk density of partially compacted CA	1539.43 kg/m^3
Percentage of voids	72.18 %

3.1.3 Fine aggregate

In this project M-sand is used as fine aggregate (FA). The table 3.3 contains the different properties of fine aggregate.

Table3.3: Properties of Fine aggregate

Properties	Result
Specific gravity	2.62
Water absorption	2.23 %
Fineness modulus	2.89
Bulk density of fully compacted FA	1673.3 kg/m^3
Bulk density of partially compacted FA	1486.67 kg/m^3
Percentage of voids	51.47 %
Particle size	< 4.75 mm
Zone	2

3.1.4 Seawater

Seawater was collected from Vypin, Kerala. The sea water used in the project work have such properties shown in table 3.4.

Table 3.4: Properties of Seawater

Properties	Result
pH	8.2
Chloride content	1300 mg/L
Turbidity	85 NTU
Total solids	6000 mg/L

3.1.5 Bacteria

The bacteria used in our project is Bacillus subtilis JC3 which we made available in liquid form. It is a gram positive bacteria mainly found in soil. It is aerobic in nature. It is a laboratory cultivated microorganism collected from Kerala Agricultural University, Mannuthy. The figure 3.1 shows the microscopic view of the bacteria and the table 3.5 given below shows their properties. This can produce calcium carbonate in the presence of oxygen, which is entered into the concrete matrix through the cracks. The formation of calcium carbonate will fill the cracks. Thus, the bacteria is termed as self -healing bacteria.

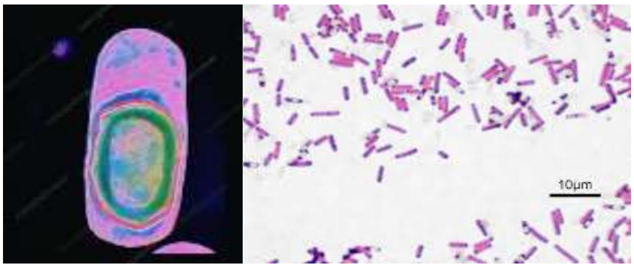

Fig 3.1: Microscopic view of Bacillus subtilis JC3

Table 3.5: Properties of Bacteria

Properties	Result
Shape	Long rod
Size	Length - 2 to 3 µm Width - 0.6 to 0.8 µm
Gram strain	Positive
Colony morphology	Irregular, dry, white colour colonies
Commonly found	Soil
Toxicity / Harmfulness	Not pathogenic or toxic

3.2 Experimental methods

3.2.1 Mix design

Mix is designed based on the guidelines given in IS10262:2004 and IS 456:2000.

Table 3.6: Materials required for 1m^3 of concrete

Combination of mix	**Concrete consist of normal water**	**Concrete consist of seawater without bacteria**	**Concrete consist of seawater with bacteria**
Grade	M15	M15	M15
Weight of Cement	336.14 kg	336.14 kg	336.14 kg
Weight of Fine Aggregate	686.964 kg	686.964 kg	686.964 kg
Weight of Coarse Aggregate	1176.45 kg	1176.45 kg	1176.45 kg
Weight of Water	191.6 kg	191.6 kg	191.6 kg
Weight of Bacteria	0	0	18.641 kg

3.2.2 Casting

The process of mixing the required amount of materials according to the mix design and placing it on specific moulds is termed as casting. In our project work we have 3 different combinations of concrete mix. The grade of concrete mix is M15. The 3 combinations are:

i. Concrete consist of normal water
ii. Concrete consist of seawater without bacteria
iii. Concrete consist of seawater with bacteria

30 specimens are totally needed to cast with 10 specimens from each combination of mix. The specimens consist of cylinders, cubes, beams, columns.12 cylinders of 150 mm diameter, 300 mm height were casted. 6 columns of 100 x 100 x 300 mm size, 6 cubes of 150 x 150 x 150 mm size, 6 beams of 100 x 100 x 500 mm size were casted in which 6 cylinders and 6 columns are casted with reinforcement bars of 10 mm ø and 250 mm length. The casted specimens are shown in figure 3.2.

Fig 3.2: Casted specimens

In the case of concrete consist of seawater with bacteria, the Bacillus subtilis JC3 bacteria is added to the concrete in the time of mixing. The reinforcement bars are dipped in the bacterial culture 2 days before the casting. The treatment of bacteria with steel bars helps to create a bio-mineralised film in the surface of steel bars which prevent corrosion.

3.2.3 Curing

Curing of concrete is a method to protect the concrete against loss of moisture content required for hydration and kept within the recommended temperature range. Curing will decrease the permeability and increase the strength of hardened concrete. The concrete specimens are unmoulded after 24 hours and immersed in a curing tank as shown in figure 3.3.

Fig 3.3 : Curing of specimens

3.3 Workability test

Workability of concrete is the property of fresh concrete that determines it's easiness with which it can be mixed, transported, placed, compacted and finished. Water cement ratio is directly proportional to workability of concrete. Workability of concrete increases with increase in water-cement ratio. Workability of concrete can be determined by slump test and compaction factor test. It is carried out with the freshly prepared concrete.

Table 3.6: Results of workability test

Combination of specimen	Slump test	Compaction factor
Concrete consist of normal water	17.5	0.95
Concrete consist of seawater without bacteria	16.50	0.92
Concrete consist of seawater with bacteria	15.50	0.84

As per the previous studies on the relation of workability and strength of concrete, the strength of concrete decreases with increase in water-cement ratio. The water-cement ratio indicates increase in workability of concrete. Thus, the workability of concrete inversely proportional to the strength of concrete. It tells that the concrete having lesser workability have high strength. As per the slump test and compaction factor test conducted on the freshly prepared concrete mixes of different 3 combinations, it is found that from the table 3.6, the results of the concrete consist of seawater with bacteria shows lesser workability. So this combination of concrete can have high strength than other two mixes.

IV. RESULTS AND DISCUSSION

4.1 Compressive strength test

Compressive strength test is the maximum stress which can withstand by a material under crushing and pushing forces. Compressive strength was determined by using compressive testing machine. The grade of concrete used for construction was ensured by compression test on concrete cube at 28 days. Cubes of size 150 x 150 x 150 mm are tested for compressive strength.
Compressive strength is calculated by the equation,

$$\text{Compressive strength} = \text{load / area} \tag{4.1}$$

Table 4.1: Result of Compressive strength test

Combination of specimen	Average 14 day's Compressive strength (N/mm^2)	Average 28 day's Compressive strength (N/mm^2)
Concrete consist of normal water	14.22	19.11
Concrete consist of seawater without bacteria	19.56	20.44
Concrete consist of seawater with bacteria	17.78	23.11

From the obtained data in the table 4.1 and graph shown in figure 4.1, it was observed that the concrete consist of seawater with bacteria shows greater value of compressive strength than other mix. The 14^{th} day compressive strength of concrete mix consist of seawater without bacteria shows greater compressive strength.

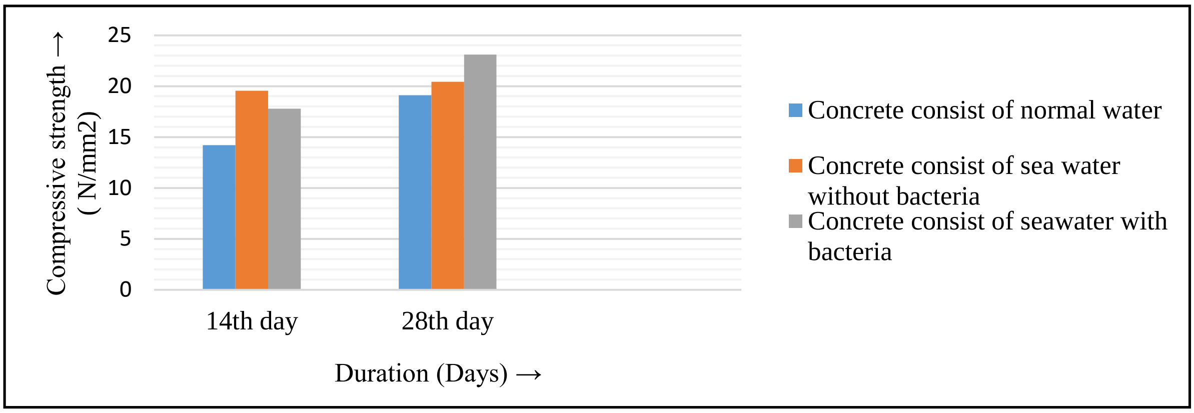

Fig 4.1: Graph of Compressive strength test

4.2 Split tensile strength test

Tensile strength was determined usually using Universal Testing Machine (UTM) and also by compressive testing machine. The split tensile strength of concrete was carried out by placing a cylindrical specimen between the loading surfaces of the machine and the load was applied until the failure of the specimen. Cylinder specimens of 300mm length and 150mm diameter were prepared. It was calculated using equation,

$$\text{Split Tensile Strength} = 2P/\pi LD \qquad (4.2)$$

Where, P = applied load
D = diameter of the specimen = 150mm
L = length of the specimen = 300 mm

Table 4.2: Result of Split tensile strength test

Combination of specimen	**Average 14 day's Split tensile strength (N/mm^2)**	**Average 28 day's Split tensile strength (N/mm^2)**
Concrete consist of normal water	1.56	1.63
Concrete consist of seawater without bacteria	1.41	1.49
Concrete consist of seawater with bacteria	1.56	1.70

The values obtained by split tensile strength is tabulated in table 4.2. From the above observations of split tensile strength of 3 concrete mix combinations at 14 days and 28 days, the concrete consist of seawater with bacteria shows a split tensile strength greater than or equal to the standard specimen made of normal water. In two stages the concrete consist of seawater without bacteria have less value of split tensile strength than other mixes. A graph is plotted by the use of tabulated results shown as figure 4.2.

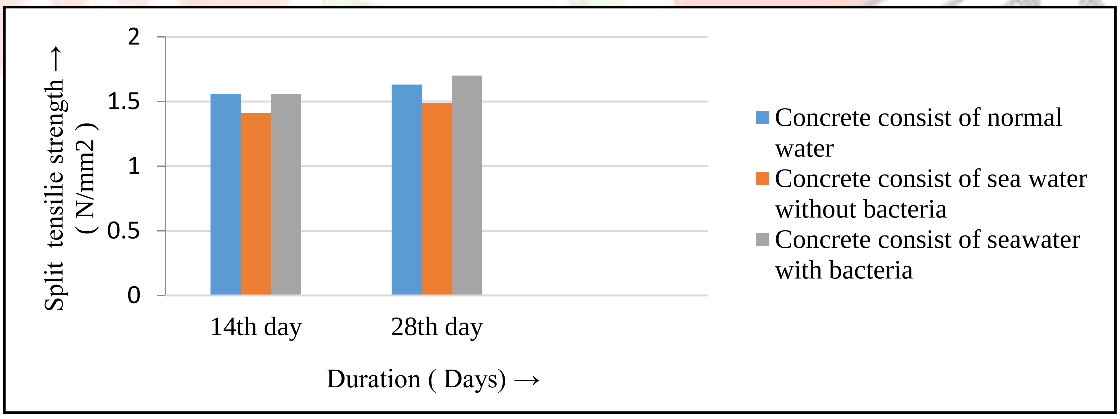

Fig 4.2: Graph of Split tensile strength test

4.3 Flexural strength

Flexural strength is also known as modulus of rupture. The flexural strength is measured in terms of stress. Beam specimens having dimensions 100 x 100 x 500 mm were prepared for the test. Two point loading was adopted on an effective span of 400 mm during loading. It is determined by flexural strength testing machine

Flexural strength is calculated using equation,

$$\text{The Flexural strength} = PL \div bd^2 \qquad (4.3)$$

Where,
P = maximum load in N
L, b, d are length, breadth and depth of the beam respectively, all in mm.

Table 4.3: Result of Flexural strength test

Combination of specimen	Average 14 day's Flexural strength (N/mm²)	Average 28 day's Flexural strength (N/mm²)
Concrete consist of normal water	3.5	5
Concrete consist of Seawater without bacteria	4.5	6
Concrete consist of Seawater with bacteria	5.5	7

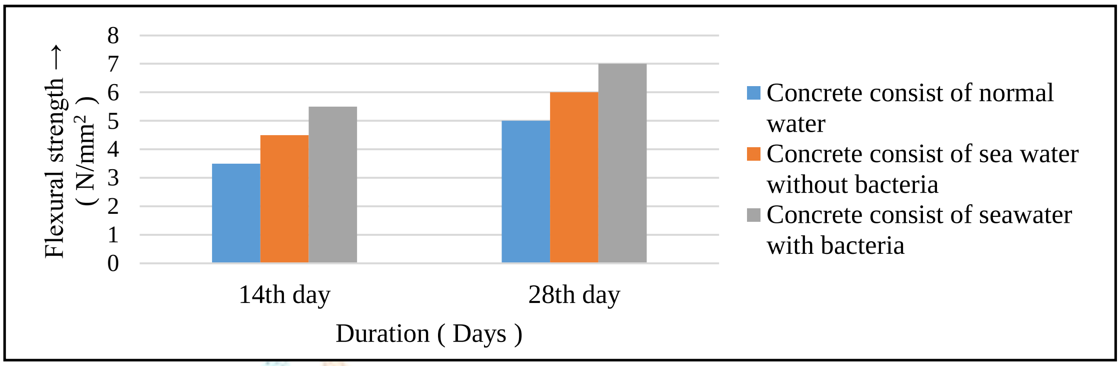

Fig 4.3: Graph of Flexural strength test

From the observations shown in table 4.3 and figure 4.3, it is clear that there occur a gradual increase of flexural strength in all the combinations of concrete mix. In both stages concrete consist of normal water have lowest value of flexural strength. The concrete consist of seawater with bacteria have higher value of flexural strength in both cases.

4.4 Comparison of strength of concrete

Strength of concrete can be defined as the ability to resist force. The strength of concrete is determined by testing their compressive strength, split tensile strength and flexural strength. In our project work the strength of concrete against different forces such as compression, tension and flex are taken. With the obtained values we can compare the strength of concrete consist of seawater with and without bacteria against the strength of conventional concrete which is made up of normal water. The percentage increase in strength of different mix is given in table 4.4.

Table 4.4: Comparison of strength with concrete consist of normal water

Strength of Concrete	Duration (days)	Percentage increase in strength (%)	
		Concrete consist of Seawater without bacteria	**Concrete consist of Seawater with bacteria**
Compressive strength	14	37.55	25.03
	28	6.95	20.93
Split tensile strength	14	-9.62	0
	28	-8.59	4.29
Flexural strength	14	28.57	57.14
	28	20	40

To determine the strength chart of concrete consist of seawater with and without bacteria we have taken the measurements in 14th day and 28th day after casting. The compressive strength test for the duration of 14 days, concrete consist of seawater without bacteria have 12.52% more strength than the concrete consist of seawater with bacteria. But the compressive strength of concrete consist of seawater with bacteria shows 20.93% of increase in their strength at 28 days, whereas concrete consist of seawater without bacteria only have 6.95% increase in their strength.

In case of split tensile strength test, strength of concrete consist of seawater without bacteria shows a decrease in strength at their 14th day and 28th day. The negative sign indicates the decrease in the percentage of strength. The concrete consist of seawater with bacteria have same value of split tensile strength at their 14th day as per concrete consist of normal water, but after 28 days its strength increased to 4.29%. It shows that the split tensile strength of concrete consist of seawater with bacteria is high.

In case of flexural strength test, both 14th day and 28th day strength was low for concrete consist of seawater without bacteria than concrete consist of seawater with bacteria. So, from the whole test results it is clear that the concrete consist of seawater with bacteria shows better strength characteristics than other two combinations of concrete mix.

4.5 Accelerated corrosion test

Corrosion is a very slow process, electrochemical techniques have been used to reduce the time of reinforced bar corrosion to a desirable time-scale. One of which is Impressed Voltage Test (IVT). In this method, rapid corrosion is induced by increasing the potential difference between two electrochemical sites. The flow of electrical energy influences the amount of mass consumed.

4.5.1 Impressed voltage test

The impressed voltage test consists of a DC power supply, 3 stainless steel rods, multimeter, test specimen with embedded reinforcement steel and the container containing the required dosage of salt solution. The experiment includes 3 cylinders each from the early mentioned combinations. Sodium Chloride salt was used to prepare the 5% salt water concentration by weight. For the accelerated corrosion test, these cylinders with embedded steel bar are used.

Fig 4.4: Laboratory setup of Impressed voltage test

The experimental setup for impressed voltage test is shown in figure 4.4. The stainless steel plates are connected to the negative terminal of the DC power source and steel bar of the specimen is connected to the positive terminal. The corrosion process was started by applying a constant voltage (28V) to the system. The current response is continuously monitored and recorded. In addition, the specimens are daily inspected visually for cracks .The accelerated corrosion test is terminated when cracks are formed on the specimens and the rate of increase of corrosion current with time was negligible. The test results are enumerated in table 4.5 and graph given in figure 4.5.

Table 4.5: Result of Impressed voltage test

Time of observation (Day)	Current passed (mA)		
	Concrete consist of normal water	Concrete consist of Seawater without bacteria	Concrete consist of Seawater with bacteria
0	0	0	0
2	28.50	33.70	6.10
4	43.20	92.80	21.3
6	72.80	121.60	38.80
8	65.20	113.60	44.60
10	78.50	118.50	50.00
12	110.50	211.40	68.50
14	104.00	191.30	68.40

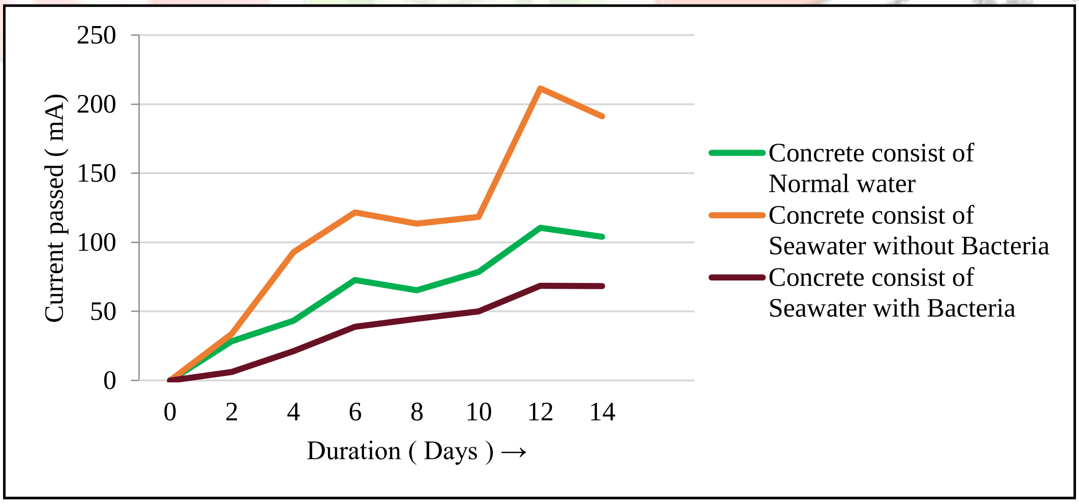

Fig 4.5: Graph of Impressed voltage test

From the observations of impressed voltage test it is clear that the rate of increase in corrosion is most rapid in concrete consist of seawater without bacteria. Concrete consist of seawater with bacteria shows less rate of corrosion than concrete consist of normal water.

V. CONCLUSIONS

Potable water is generally considered suitable for mixing and curing of concrete. As per IS456:2000, it is mentioned in clause 5.4 that water used for mixing and curing of concrete should be clean and free from high amounts of salts, oils, sugar, acids, organic materials and other substances that may deleterious to concrete or steel. Use of seawater for mixing or curing is not recommended because of the presence of harmful salts in seawater. Under some circumstances seawater may be used for mixing and curing of plain cement concrete without reinforcement bars after having some consideration to the possibility of demerits. This project analyse the adverse effect of seawater in the concrete structure which is made up by mixing with seawater. The strength of concrete having different combinations are analysed in this project. The strength of concrete is tested by compressive strength test, split tensile strength test and flexural strength test and rate of corrosion is examined by accelerated corrosion test.

- As per the results, it shows that the use of seawater in concrete have poor strength as compared to the concrete consist of normal water. The rate of increase in corrosion is most rapid in concrete consist of seawater without bacteria.
- The concrete consist of seawater without bacteria shows 6.95% increase in compressive strength, 8.59% decrease in split tensile strength and 20% increase in flexural strength at 28 days.
- The addition of Bacillus subtilis JC3 bacteria in the concrete consist of seawater will increase it's compressive strength by 25.03%, split tensile strength by 4.29% and flexural strength by 40% at 28 days.
- The addition of bacteria in the concrete matrix improve it's strength and the use of reinforcement bars which is pre-treated with the same bacteria will reduce the chance of corrosion as compared with concrete consist of normal water and seawater. To reduce the adverse effect of seawater in concrete structure addition of Bacillus subtilis JC3 bacteria is recommended.
- In the future, the use of seawater in concrete will be necessary to avoid the scarcity of water in mixing and curing of concrete. The bacteria used in this project work is not harmful to animals and humans. It can be produced easily in the laboratory and it is proven to be safe. The scope of this project is extended in the areas where use of seawater is unavoidable. This will result into save fresh water.

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