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Experimental Studies on Mechanical Properties of Bacterial Concrete with Fly Ash

Prof. S .Vijaya Bhaskar Reddy[1] and Ankathi. Ravikiran[2]

[1]*Head Of The Department of civil Engineering, CMR Technical Campus, Kandlakoya(V),Medchal(M),R.R Dist.,Telangana, India.*

[2]*Student, In Structural Engineering, CMR Technical Campus, Kandlakoya(V),Medchal(M),R.R Dist.,Telangana, India.*

Abstract

Concrete, a strong, durable material composed of cement, aggregate and water, is the most used building material in the world. Concrete has an ultimate load bearing capacity under compression but the material is weak in tension. That is why steel bars are embedded in the concrete for the structures to carry tensile loads. The steel reinforced bars take the load when the concrete cracks in tension. On other hand the concrete protects the steel reinforced bars from the environment and prevents corrosion. However, the cracks in the concrete form a major problem which affects the durability of the structures. Here the ingress of water and chloride ions takes place and deterioration of the structure starts with the corrosion of the steel. To increase the strength and durability of the structure either the cracks that are formed should be repaired conventionally using epoxy injection or latex treatment or by providing extra reinforcement in the structure during the design phase to ensure that the crack width stays within a permissible limit. This extra reinforcement is only needed for durability reasons (to keep the crack width small) and not for structural capacity. Especially with current steel prices on rise providing extra steel is not economically viable. Main reason to prevent cracks or limit crack width is to enhance the durability of the structure. If in some way a reliable method could be developed that repairs cracks in concrete automatically (self healing), this would increase and ensure durability of the structure enormously. On the other hand it would also save a lot of money, time and energy.

Investigations have shown that the bacteria Bacillus pasturii can be used for improving the resistance of concrete to alkali or sulphate attack, drying shrinkage etc., which will increase the strength and durability of concrete. However, not much investigation is reported in India for producing bacterial concrete using Bacillus subtilis. Keeping this in view, the present experimental investigations are taken up to study the strength characteristics in ordinary grade concrete and standard grade of concrete with and without addition of bacteria Bacillus subtilis JC3.

The utilization of fly ash in concrete as partial replacement of cement is gaining immense importance, mainly on account of the improvements in the long term durability of concrete combined with ecological benefits. Technological improvements in thermal power plant operations and fly ash collection systems have resulted in improving the consistency of fly ash. To study the effect of partial replacement of cement by fly ash, studies have been conducted on concrete mixes by replacing cement content by 10%, 20% and 30% with fly ash. In this investigation the effect of fly ash on compressive strength, split tensile strength and flexural strength are studied.

INTRODUCTION

Concrete is a construction material that is used worldwide because of its first rate properties. However, the drawback of this material is that it easily cracks due to its low tensile strength. Cracks can occur during any stage of a life of a concrete structure. They can be due to concrete material itself as in the case of volume instabilities or due to external factors such as external loading, harsh environmental exposure, poor construction procedures or design error. There cracks have many negative effects on mechanical performance and durability of concrete structures.

The development of concretes which can automatically regain this loss of performance is very desirable. Along these lines, self healing of cracked concrete is often studied phenomenon.

Experimental investigation and practical experiences have demonstrated that crack in cementitious materials have the ability to seal themselves rapid crack healing is necessary since it is easier for substances to ingress into concrete through cracks than through the concrete. It is known that it is costly to inspect, monitor and repair cracks, monitor and repair cracks. Moreover, some repair methods currently used are not so sustainable. The chemical and physical process of self healing of cracks in concrete has been previously investigated by other researchers. The effects of self healing by crack width, water pressure, pH of healing water, temperature, water chloride concentration and concrete composition have been discussed by many researchers. For autogeneous healing to occur, the following reasons have been cited.

Further hydration of un reacted cement, expansion of concrete in the cracks flanks (swelling), crystallization (calcium carbonate), closing of cracks by solid matters in the water (impurities) and closing of cracks by spilling of loose concrete particles resulting from cracking. Among these reasons, most researchers has indicated that the crystallization of calcium carbonate within the cracks was the mechanism self healing of mature concrete. Therefore, it would be desirable if concrete cracks could be healed autonomously by releasing healing agents inside the matrix when cracks appear

In 1885, an American engineer named William LeBaron Jenny became the creator of the modern skyscraper when he realized that an office building could be constructed using totally different materials. He chose structural steel and incorporated it into a revolutionary system that was to make possible the soaring office towers that mow symbolize the modern metropolis.

Two technological developments, the elevator and modern metal frame construction, removed the prevailing limitations on the height of the buildings, and the race for tallness was on. In 1913, the Woolworth building was the first to reach 60stories, soaring up 732 ft (242 m) in lower Manhattan.

This Gothic cathedral style building is still in vigorous use after 70 years of service and the installation of conditioning and automatic elevators.

The demand for tall buildings increased because large corporations recognized the advertising and publicity advantages of connecting their names with imposing high-rise office buildings even though their operations required a relatively small percentage of floor space.

The collapse of the financial market during the depression put an end to speculative high rises, and only in the late 1940s in the wake of world war2 did a new era of high rise building set in addition to the stimulus of new resources provided by technology was the spur of necessity, with the population doubling in almost every generation and production growing at an even faster pace, developers could scarcely keep up with the demand for space.

SELECTION OF REPAIRS PROCEDURES

Based on the careful evaluation of the extent and cause of cracking procedures can be selected to accomplish one or more of the following objective:

- Restore or increase strength
- Restore or increase stiffness
- Improve functional performance
- Provide water tightness
- Improve appearance of the concrete surface
- Improve durability and
- Prevent development of corrosive environment at reinforcement.

Self healing bacterial concrete

Self healing bacterial concrete refers to a new generation of concrete in which selective concentration by microbiologically induced $CaCo_3$ precipitation has been introduced for remediation of micro cracks. Self healing concrete could solve the problem of concrete structure deteriorating well before the end of their service life. The bacterial remediation technique can be used for repairing structures of historical importance to preserve the aesthetic value, and conventional technique, such as epoxy injection cannot be used to remediate cracks in those structures. Its prospective application include remediation of surface cracks and fissures in various structural formations, in base and sub base stabilization and surface soil consolidation.

Incorporating living matter into structural concrete material to enhance its strength and durability performance is a great innovation. This can be done in two ways. The first way will see bacteria in water with nutrients are used as mixing water for concrete preparation. The second way will see the bacteria and food nutrients dissolved into a liquid that is sprayed onto the surface of the concrete from where it can seep into the crack.

Most of the works done on this subject have clearly indicated that bio mineralization of some specific bacteria with urease activity is mainly responsible for the enhancement of mechanical properties of modified cement sand mortar and depend on type of mineral precipitating bacteria, cell concentration of the bacteria, age and environmental conditions (moisture, temperature e.,).

Bio mineralization

Natural processes, such as weathering, faults, land subsidence, earthquakes and human activities create fractures and fissures in concrete structures and historical monuments. These fractures and fissures are detrimental since they can reduce the service life of the structure. In case of monuments and buildings of historic importance, these cracks tend to disfigure and destroy the structure. Use of synthetic agents such as epoxies for remediating these structures will reduce the aesthetic appearance of the structure. Therefore a novel technique for remediating damaged structural formation has been developed by employing a selective microbial plugging process, in which microbial metabolic activities promote calcium carbonate (calcite) precipitation is shown in figure 2.1. The technique is called microbiologically induced crack remediation (MECR). This technique comes under a broader category of science called bio mineralization. It is a process by which living organisms from inorganic solids, bacterial deposition of a layer of calcite on the surface of the specimens resulted in a decrease in capillary water intake and permeability towards it. This bacterial treatment resulted in a limited change of the change of the chromatic aspect of mortar and concrete structures. The type of bacterial culture and medium composition had impact on $CaCo_3$ crystal morphology.

Autonomous healing

Concrete constructions are currently designed according to set norms that allow cracks as form up to 0.2 mm wide. Such micro cracks are generally considered acceptable as these do not directly impair the safety and strength of a construction. Moreover micro cracks sometimes heal themselves as many types of concrete feature a certain crack healing capacity. Research has shown that this so called ‘autonomous’ healing capacity is largely related to the number of non reacted

cement particles present to the concrete matrix. On crack formation, ingress water reacts with these particles, resulting in closure of micro cracks. However because of the variability of autonomous crack healing of concrete constructions, water leakage as a result of micro crack formation in tunnel and underground structures can occur. While self healing of 0.2 mm wide cracks occurred in 30% of the control sample, complete closure of all cracks was obtained in all bacteria based samples. Moreover, the crack sealing capacity of the latter group was forced to be extended to 0.5 mm cracks.

History of bacteria

Bacteria are microscopic organisms, single celled creatures which live mostly on the surface of objects where they grow as colonies. Bacteria come in different shape and the size of bacteria is measured in micro meters (which is a millionth part of a meter).

Bacteria are ubiquitous in every habitat on earth, growing in soil, acidic hot springs, radioactive waste, water and deep in the earth's crust, as well as organic matter and the live bodies of plants and animals. There are typically 40 million bacterial cells in a gram of soil and a million bacterial cells in a milliliter of fresh water, in all there are approximately five nonillion ($5*10^{30}$) bacteria on earth, forming each of the world's biomass.

Bacteria were first observed by Antoine Van Leeuwenhoek in 1676, using a single lens microscope of his own design. He called them "animalcules" and published his observations in a series of letters to the royal society. The name bacterium was introduced much later by Christian Gottfried Ehrenberg in 1838.

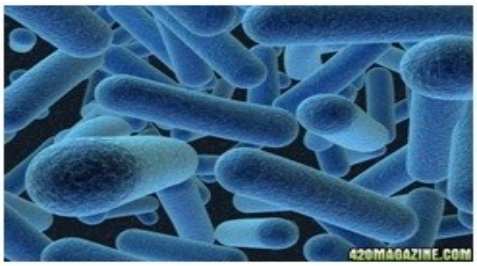
Classification of bacteria:

- On the basis of shape
- On the basis of gram stain
- On the basis of oxygen requirement

Classification on the basis of shapes:

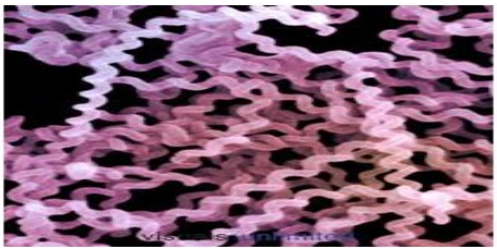
Bacteria are usually classified on the basis of their shapes. Broadly they can be divided into:

- Rod shaped bacteria (bacilli)



- Sphere shaped bacteria (Cocci)

- Spiral shaped bacteria (Spirillia).



Classification on the basis of Gram Stain:

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. Gram staining is a quick procedure used to look for the presence of bacteria in tissue samples and to characterize bacteria as gram positive or gram negative based on the chemical and physical properties of their cell walls. The gram positive and the gram negative bacteria refer to the two different types of bacteria. Both have different features. Bacteria that retain the crystal violet dye and change into purple is the gram staining identification method are referred to as gram positive bacteria, conversely those species that do not retain the crystal violet dye are referred to as gram negative bacteria those generally stain pink. It is the property of the cell wall that actually gives rise to those difference. The cell wall in gram negative bacteria is thinner where as in grain positive bacteria is much thicker made up of close to twenty times the amount of cell membrane that is present in gram negative bacteria.

Examples of gram positive bacteria:

- Bacillus
- Clostridium
- Enterococcus
- Lactobacillus
- Staphylococcus

Examples of gram negative bacteria:

- Acetobacter
- Borrelia
- Campylobacter
- Leptospiria
- Proteus

Classification on the basis of Oxygen Requirement

This classification is based on the requirement of oxygen for the survival of the bacteria. They are:

- Aerobic (requires oxygen to grow)
- Anaerobic (do not require oxygen to grow)

Isolation, Growth and culturing bacteria

Isolating bacteria from soil is an importance first step in many microbiology experiments. Once they are isolated, bacteria can be further analyzed to determine things such as their species and their functions in the soil environment. Even a tiny amount of soil can contain millions of bacteria, which makes it necessary to dilute a soil sample before isolating bacteria from the sample. Isolation of a specific bacterium from other bacterial species in a given samples allows microbiologists to study its structure and functions, characteristics used in its identification. Microbiologists frequently isolate bacteria using one of several streak plate techniques. Microbiologists grow bacteria for streak plate isolation in shallow, round petri dishes filled with a solid medium called agar. Agar mimics the environment to which the bacteria naturally grow bacteria can only be involved if they grow. The media filled dishes are sterile and added to prevent growth of unwanted organisms. The streak plate technique is the most popular method for isolating specific bacteria from a sample containing a mixture of microorganisms. It allows microbiologists to distinguish and isolate individual bacterial colonies.

All of the bacteria in a single colony originate from the same bacterial cell. Consequently individual colonies are "pure" colonies. The pure colony is transplanted to another plate to produce a pure culture consisting of one type of bacteria.

Factors affecting bacterial growth

Physical factors:

- pH- Alkliphiles thrive in high pH (Bacillus Subtilus)
- Temperature- affects bacteria growth. Most bacteria can grow over a 30^0c temperature range
- Oxygen- the quantity of oxygen in the environment affects the growth of bacteria
- Moisture – Single cells require nutrients to be dissolved in solvent for transport
- Hydrostatic pressure
- Chromatic pressure

Nutritional factors (food to survive)

All microorganisms require the following nutrients to grow, repair themselves and to replicate:

- Carbon
- Nitrogen
- Sulfur
- Phosphorous
- Various trace elements (various vitamins as well as additional organic factors specific amino acids)

METHODS TO MEASURE CELL CONCENTRATION OF BACTERIA

When culturing bacteria it is often necessary to count how many bacteria are there. There are a variety of methods used to determine this.

Haemocytometry: it is a total count method where every cell (dead or alive) is counted. It works by introducing a standard amount of bacteria in to the haemocytometer a glass slide with lots of grid lines. This is placed under a microscopic and the number of cells counted using a standard method.

Turbidmetry : which works on the principal that a more turbid (cloudy) solution has more cells. The light absorbed in recorded and can be compared with reference graphs as to estimate the number of cells. This is also called as total cell count method.

Dilution Plating: in dilution plating 1 cm^3 of original bacterial solution is taken and diluted with 9 cm^3 of water. A sample from each dilution is cultured. Once individual colonies can be seen, it means each of those represents a single bacterium that was in the solution. The number is multiplied by the dilution factor. This is a viable cells count method which only counts those bacteria which are alive since dead bacteria cannot grow colonies.

Bacterial cell viability

Bacterial cell viability tests are used to determine if a sample of cells is alive. Tests can determine is a sample is alive even when the cells are not producing. The tests methods range from simple staining, testing of reproductive ability to more advanced technique.

Count the CFUs: cell viability can be determined simply by the ability of the bacteria to reproduce. This is determined by growing bacteria on an agar plate and then placing the plate under a microscope. While looking under the microscope you must count how many colony formation units are present.

Grain stain under microscope: gram stains allow you to visualize the presence of bacteria as a sample because the cells will dye purple. This test is most commonly performed using a glass microscope slide with a small sample of bacteria placed on it. The bacterial sample is briefly heated so it will attach and is then dyed with crystal violet solution. The sample is dyed after the sample incubation times for a bacterial culture has been provided. After dying the sample is washed and placed under a microscope and viewed. All cells that have grown will be dyed purple.

Dye exclusion: in most biological experiments involving cell culture, a critical step inclusion knowing which cells are alive and which are dead in your sample. Dye exclusion is most

popular method of measuring cell viability. Dye exclusion is based on the theory that live cells contain intact membranes and dead cells do not thus dead cells absorbs the dye into the cytoplasm. Trypan blue is a common dye used to measure cell viability because of the procedure can be done in five to ten minutes and costs only the amount of the dye reagent. Trypan blue is a dye that is only absorbed by dead cells so when it is added to a cell sample only the dead ones turn blue. From there it is just a matter of counting the cells and calculating the percentages.

Bacillus Subtilis JC3

Researchers with different bacteria proposed different bacterial concretes. The various bacteria used in the concrete are Bacillus pasteruii, Bacillus Sphaericus, E-coli etc. in the present study and attempts was made by using the bacteria bacillus Subilies JC3. The main advantage of embedding bacteria in the concrete is that it can constantly precipitate calcite. This phenomenon is called microbiologically induced calcite precipitation (MICP). Calcium carbonate precipitation a widespread phenomenon among bacteria has been investigated due to its wide range of scientific and microbiological implications. Calcite formation by bacillus Subtilis JC3 is a laboratory cultured soil bacterium and its effect on the strength and durability is studied here.

Characterization of bacillus subtilis JC3

Bacillus Sbutilis is also known as the hay bacillus or grass Bacillus is a gram positive, bacterium. A member of the genus bacillus B subtilis is rod shaped and has the ability to form a tough, protective endospore, allowing the organism to tolerate extreme environmental conditions. Bacillus Subtilis cells are rod shaped gram positive bacteria that are naturally found in soil and vegetation. Bacillus Subtilis grow in the mesophilic temperature range. The optimal temperature is 25-35 degrees Celsius. Stress and starvation are common in this environment; therefore Bacillus Subtilis has evolved as a set of strategies that allow survival under these harsh conditions. One strategy, for example is the formation of stress resistant endospores. Bacillus Subtilis bacteria have been considered strictly aerobic, meaning that they require oxygen to grow and they cannot undergo fermentation. They are non Pathogenic. They can contaminate food; however they seldom result in food poisoning. There are many research studies that are currently being done on Bacillus Subtilis. One recent research project focuses on the resistance of Bacillus Subtilis spores to heat, radiation and chemicals. It has been known that spores can survive hundreds, even millions, of years in a dormant state.

Need of Self healing concrete

Concrete will continue to be the most important building material for infrastructure but most concrete structures are prone to cracking. Tiny crack on the surface of the concrete make the whole structure vulnerable because water seeps in to these cracks degrade the concrete and corrode the steel reinforcement, greatly reducing the lifespan of the structure. Concrete can withstand compressive forces very well but when it is subjected to tension it starts to crack, which is why it is reinforced with steel to withstand the tensile forces. Structures built in a high water environment such as underground basements and marine structures are particularly vulnerable in corrosion of steel reinforcement. Motorway bridges are also vulnerable because salts used to design the roads penetrate into the cracks in the structures and can accelerate the corrosion of steel reinforcement. In many civil engineering structures tensile forces can lead to cracks and these can occur relatively soon after the structures tensile forces can lead to cracks and these can occur relatively soon after the structure is built. Repair of conventional concrete structures usually involves applying a concrete mortar which is bonded to the damaged surface. Sometimes the mortar needs to be keyed into the existing structure with metal pins to ensure that it does not fall away. Repairs can be time consuming and expensive because it is often very difficult to gain access to the structure to make repairs, especially if they are underground or at a great heights.

Two components self healing agent:

1. Bacteria (catalyst)
2. Mineral precursor compound (chemical/food)

Healing mechanism for bacteria based specimen:

$2\ Ca(CHO_2)_2 + 2O_2 \quad 2CaCo_2$ (calcium precipitation) $+2CO_2+2H_2O$

This microbiologically induced calcium carbonate precipitation (MICCP) comprises of series of complex biochemical reactions. As part of metabolism B.Subtilius produces… which catalyzes urea to produce CO_2 and ammonia resulting in an increase of pH in the surrounding where ions Ca^{2+} and CO_3^{2-} precipitate as $CaCO_2$ possible biochemical reaction in medium to precipitate $CaCO_3$ at the cell surface that provides a mediation site can be summarized as follows

$Ca^{2+} + Cell \rightarrow cell\text{-}Ca^{2+}$….. (1)

$Cl^{-}+HCO^{3-}+NH_3 \rightarrow NH_4Cl + CO_3^{2-}$…. (2)

$Cell\text{-}Ca^{2+} + CO_3^{2-} \rightarrow Cell\text{-}CaCO_3\downarrow$…. (3)

Estimation of amount of $CaCo_3$ precipitation from bacterial culture can be done by carrying nitration with EDTA. The morphology and microbiological composition of the deposited $CaCo_3$ crystals were investigated with scanning electron microcopy and X ray diffraction tests. The unique imaging and micro analysis capabilities of SEM established the presence of calcite precipitation inside cracks, bacterial impressions and a new calcite layer on the surface of concrete.

The calcite layer improves the impermeability of the specimen, thus increasing the resistance to alkaline, sulfate and freeze thaw attack. Calcite has a coarse crystalline structure that readily adheres to surfaces in the form of scales. In addition to the ability to continuously grow upon itself it is highly insoluble in water. Due to its inherent ability to precipitate calcite continuously bacterial concrete can be called as a “smart bio material”.

Microbial calcite plugging was selective and its efficiency was affected by the porosity of the medium, the number of

cells present and the total volume of nutrient added. Concrete made with bacteria suspended in water did not perform well as expected because bacteria cannot survive in water.

Microbiologically induced calcite precipitation

Cracks width in concrete structure should be limited, mainly for durability reasons. If cracks widths are too large the cracks need to be repaired or extra reinforcement is sealed in the design. If a method could be developed to automatically repair cracks in concrete this would save an enormous amount of money, both on the costs of injection fluids for cracks and also on the extra steel has no meaning. A reliable self healing method for concrete would lead to a new way of designing durable concrete structures which is beneficial for national and global economy.

The "bacterial concrete" can be made by embedding bacteria in the concrete that are able to constantly precipitate calcite. This phenomenon is called microbiologically induced calcite precipitation (MICP). As per the present investigation it has been shown that under favorable conditions for instance Bacillus Subtilis JC3, a common soil bacterium, can continuously precipitate a new highly impermeable calcite layer over the surface of an already existing concrete layer. Furthermore the bacteria should be suspended in a certain concentration in a certain medium for growth before they are mixed through the concrete ingredients. Optimization is needed here, which involves experimental testing.

Application of bacterial concrete.

Areas where it is not possible to shut down the plant or hazardous for human beings such as nuclear power plants where fuel storages should be leak proof, repair of waste water sewage pipes etc.

- reating surfaces of structures with strategic and historic heritage importance
- Reme of surface cracks and fissures in various structural formations, in base and sub base stabilization and surface soil consolidation.
- Self healing of 0.2 mm wide cracks occurred in 30% of the control samples, complete closure of all cracks was obtained in all bacteria based samples. Moreover the cracks sealing capacity of the latter group was found to be extended to 0.5 mm cracks.

Fly ash:

Fly ash is defined in Cement and Concrete Terminology (ACI Committee 116) as "the finely divided residue resulting from the combustion of ground or powdered coal, which is transported from the firebox through the boiler by flue gases." Flyash is a by-product of coal-fired electric generating plants.

Flyash is one of three general types of coal combustion byproducts (CCBP's). The use of these byproducts offers environmental advantages by diverting the material from the waste stream, reducing the energy investment in processing virgin materials, conserving virgin materials, and allaying pollution.

Although flyash offers environmental advantages, it also improves the performance and quality of concrete. Flyash affects the plastic properties of concrete by improving workability, reducing water demand, reducing segregation and bleeding, and lowering heat of hydration. Flyash increases strength, reduces permeability, reduces corrosion of reinforcing steel, increases sulphate resistance, and reduces alkali-aggregate reaction. Flyash reaches its maximum strength more slowly than concrete made with only portland cement. The techniques for working with this type of concrete are standard for the industry and will not impact the budget of a job.

Chemical composition of fly ash according to (ASTM C618):

The standard physical requirements of ASTM C 618includes fineness, SAI with standard Portland cement, water requirement and soundness. The standard chemical requirements of ASTM c 618 include the sum of SiO_2, Al_2O_3 and Fe_2O_3 content (≥70% for class F and ≥50% for class C), SO_3 content, moisture content and loss on ignition.

Two classifications of flyash are produced, according to the type of coal used. Anthracite and bituminous coal produces flyash classified as Class F. Class C flyash is produced by burning lignite or sub bituminous coal. Class C flyash is preferable for the applications presented in the Green Building Guide and is the main type offered for residential applications from ready-mix suppliers.

Class F fly ash:

Class F fly ash is designated in ASTM C 618 and originates from anthracite and bituminous coals. It consists mainly of alumina and silica and has a higher LOI than Class C fly ash. Class F fly ash also has a lower calcium content than Class C fly ash. Additional chemical requirements are listed in the following table

Class F fly ash chemical composition	ASTM C618 requirement in %age
SiO_2+Al_2O_3+Fe_2O_3 minimum	70
SO_3 maximum	5
Maximum moisture content	3
Maximum loss on ignition	6

When used in Portland cement, class F flyash can be used as a Portland cement replacement ranging from 20-30% of the mass of cementitious material. Advantages: When used as a Portland cement replacement, Class F fly ash offers the following advantages when compared to unmodified Portland cement:

- Increased late compressive strengths (after 28 days)
- Increased resistance to alkali silica reaction (ASR)

- Increased resistance to sulfate attack
- Less heat generation during hydration
- Increased pore refinement
- Decreased permeability
- Decreased water demand
- Increased workability
- Decreased cost.

Class C fly ash:

Class C fly ash is designated in ASTM C 618 and originates from sub bituminous and lignite coals. Its composition consists mainly of calcium, alumina, and silica with a lower loss on ignition (LOI) than Class F fly ash. Additional chemical properties are listed in the following table

Class C fly ash Chemical Composition	Requirements (ASTM C618), %
SiO_2 plus Al_2O_3 plus Fe_2O_3, min	50
SO_3, max	5
Moisture content, max	3
Loss on Ignition, max	6

When used in Portland cement, Class C fly ash can be used as a Portland cement replacement ranging from 20-35% of the mass of cementitious material.Advantages: When used as a Portland cement replacement, Class C fly ash offers the following advantages when compared to unmodified Portland cement:

- Increased early and late compressive strengths
- Increased resistance to alkali silica reaction (ASR) when >15% is added
- Less heat generation during hydration
- Increased pore refinement
- Decreased permeability
- Decreased water demand
- Increased workability
- Decreased cost.

Fly ash in Asphalt concrete: asphalt concrete is a composite material consisting of an asphalt binder and mineral aggregate. Both class F and class C fly ash typically be used as a mineral filler to fill the voids and provide contact points between larger aggregate particles in asphalt concrete mixes. This application is used in conjuction with or a replacement for, other binders such as (Portland cement or hydrated lime) for use in asphalt pavement, the fly ash must meet mineral filler specification outlined in ASTM D242 the hydrophobic nature of fly ash gives pavement better resistance to stripping. Fly ash also been shown to increase the stiffness of the asphalt matrix, improving rutting resistance increasing mix durability.

Fly ash in geo polymers: more recently, fly ash has been used as a component in geo polymers, where the reactivity of the fly ash glasses is used to generate a binder comparable to a hydrated Portland cement in appearance and properties, but with dramatically reduced Co_2 emission.

Fly ash in roller compacted concrete: another application of using fly ash in a roller compacted concrete dams. Many dams in US have been constructed with high fly ash contents. Fly ash lowers the heat of hydration allowing thicker placement to occur. Data for these can be found at the US bureau of. This has also been demonstrated in the Ghatghar dam project in India.

Fly ash in waste management: fly ash and its alkalinity maybe used to process waste into fertilizer. Similarly the Rhemipal process uses fly ash as an admixture to stabilize sewage and other slude. This process has been used since 1996 to stabilize large amount of chromium leather sladges in Alcanena, Portugal and can be implemented in developing countries like India and China.

Fly ash in Portland cement concrete:

Fly ash can be used in Portland cement concrete to enhance the performance of the concrete. Portland cement is manufactured with calcium oxide (CaO), some of which is released in a free during hydration. As much as 20 pounds of free lime is released during hydration of 100 pounds of cement. This liberated lime forms the necessary ingredient for reaction with fly ash silicates to form strong and durable cementing compounds, thus improves many of the properties of the concrete. Some of the resulting benefits are:

- Higher ultimate strength
- Increased durability
- Improved workability
- Increased resistance to sulfate attack
- Reduced shrinkage
- Reduced bleeding.

Fly ash utilization especially in concrete has significant benefits including:

- Increasing the life of concrete roads and structures by improving concrete durability
- Net reduction in energy use and greenhouse gas and other adverse air emission when fly ash is used to replace or displaced manufactured cement.
- Reduction in amount of coal combustion produces that must be disposed in landfills
- Contamination of other natural resources and materials.
- Typically, 15 to 30 percent of the Portland cement is replaced with fly ash.

Results

Cement

Ordinary Portland cement of 53 grade from the market was used and tested for physical and chemical properties as per IS 4031

Physical properties of Portland cement:

Properties	Test results
Normal consistency	32%
Specific Gravity	3.15
Setting time: Initial setting Final setting time	45 minutes 4 hours and 5 minutes
Fineness of cement	33%
Compressive strength (Mpa) 3 days 7 days 28 days	36 36 54

Fine aggregate:

Sample of 1kg of fine aggregate is taken for sieve analysis.

Sieve analysis of fine aggregate:

IS sieve size	Weight retained (gm)	Cumulative weight retained (gm)	Cumulative Weight retained (gm)	Cumulative percentage passing
10mm	0	0	0	100
4.75mm	15	15	1.5	98.5
2.36 mm	40	55	5.5	94.5
1.18 mm	26	81	8.1	91.9
600 micron	440	521	52.1	47.9
300 micron	389	910	91.0	9
150 micron	84	994	99.4	0.6

From above observation the fine aggregate comes under zone 2

Physical properties of fine aggregate:

S.No.	Properties	Results
1	Fineness Modulus	2.57
2	Specific Gravity	2.6
3	Bulk Density In loose state In compacted state	1.62 gm/cc 1.70 gm/cc

Coarse aggregate:

Sieve analysis of Coarse aggregate:

IS sieve size (mm)	Weight retained (gm)	Cumulative Weight retained (gm)	Cumulative weight retained (gm)	Cumulative percentage passing
80	0	0	0	100
63	0	0	0	100
40	0	0	0	100
20	200	200	20	80
16	582	782	78.2	21.8
12.5	176	959	95.9	4.1
10	38	996	99.6	0.4
4.75	4	1000	100	0
2.36	-	-	100	-

Physical properties of coarse aggregate:

S.No	Properties	Results
1	Fineness modulus	4.93
2	Specific gravity	2.7
3	Bulk density In loose state In compacted state	1.43 gm/cc 1.57 gm/cc

Typical Oxide composition of Indian fly ash:

S.No	Characteristics	Percentage %
1	Silica (SiO_2)	49-67
2	Alumina (Al_2O_3)	16-28
3	Iron Oxide (Fe_2O_3)	4-30
4	Lime (CaO)	0.7-3.6
5	Magnesia (MgO)	0.3-2.6
6	Sulphur Trioxide (SO_3)	0.1-2.1
7	Loss on Ignition	0.4-1.9
8	Surface area, m^2/Kg	230-600

Chemical Requirement of fly ash:

S.No	Characteristic % by mass	Requirement in %	Composition of Fly ash in %
1	$Si+Al_2O_3+Fe_2O_3$	70.0 (min)	96.42
2	SiO_2	35.0 (min)	62.67
3	MgO_2	5.0 (max)	0.30
4	Total sulphur as SO_3	2.75 (max)	0.92
5	Available alkali as sodium oxide (Na_2O)	Maximum	0.63
6	Loss of ignition	12.0 (max)	0.15

Physical Requirement of Fly ash:

S.No	Characteristics	Requirements for grade of fly ash	Experimental results
1	Fi. By blains permeability in m^2/kg minimum		311
2	Lime reactivity, average compressive strength in MPa minimum		6
3	Compressive strength at 21 days in MPa. Minimum	Not less than 0% of the strength of the corresponding plain cement mortar cubes	82
4	Drying shrinkage %		0.04
5	Autoclave expansion %, Maximum		nil

Compressive Strength:

Mix of concrete	M20 Grade of concrete	M40 grade of concrete
Without bacteria and 0% fly ash	42.1034 MPa	50.24 MPa
With bacteria and 10% replacement of cement with fly ash	43.177 MPa	57.26 MPa
With bacteria and 20 % replacement of cement with fly ash	45.63 MPa	61.32 MPa
With bacteria and 30% replacement of cement with fly ash	47.245 MPa	62.803 MPa

Percentage increase in compressive strength at 28 days of curing:

Type of Mix	M20 grade	M40 grade
With bacteria and 10% replacement of cement with fly ash	2.54%	13.9%
With bacteria and 20% replacement of cement with fly ash	8.38%	22.05%
With bacteria and 30% replacement of cement with fly ash	12.2%	25%

Split tensile strength:

Mix of concrete	M20 grade of concrete	M40 grade of concrete
Without bacteria and 0% fly ash	3.253 MPa	3.12 MPa
With bacteria and 10% replacement of cement with fly ash	4.088 MPa	3.38 MPa
With bacteria and 20% replacement of cement with fly ash	3.62 MPa	4.97 MPa
With bacteria and 30% replacement of cement with fly ash	4.41 MPa	4.37 MPa

Percentage increase in split tensile strength for 28 days of curing:

Type of mix	M20 grade	M40 grade
With bacteria and 10% replacement of cement with fly ash	25.7%	8.33%
With bacteria and 20% replacement of cement with fly ash	11.28%	59.2%
With bacteria and 30% replacement of cement with fly ash	35.56%	40.06%

Flexural Strength:

Mix of concrete	M20 grade of concrete	M40 grade of concrete
Without bacteria and 0% fly ash	5.65 MPa	6.65 MPa
With bacteria and 10% replacement of cement with fly ash	7.1 MPa	6.9 MPa
With bacteria and 20% replacement of cement with fly ash	6.4 MPa	7.3 MPa
With bacteria and 30% replacement of cement with fly ash	6.5 MPa	6.9 MPa

Percentage increase in flexural strength at 28 days of curing:

Type of mix	M20 grade	M40 grade
With bacteria and 10% replacement of cement with fly ash	25.6%	3.75%
With bacteria and 20% replacement of cement with fly ash	13.2%	9.7%
With bacteria and 30% replacement of cement with fly ash	15.04%	3.75%

Mix design of m20 grade of concrete:

Using Erntroy and Shacklock method

Required characteristic strength required in field at 28 days = 20MPa

Maximum size of aggregate =20mm

Specific gravity of cement =3.15

Specific gravity of fine aggregate = 2.6

Specific gravity of coarse aggregate =2.7

Free surface moisture for coarse aggregate = nil

Free surface moisture for fine aggregate = 2% (assumed)

Step 1: Targeted mean strength

$f_{ck}= f_{ck} + (t*s)$

$= 20 + (1.65*4.6)$

$= 27.59$ MPa

Step 2: Selection water cement ratio

From fig 10.1 for 28 days of compressive strength the water cement ratio is 0.5

Step 3: Selection of water and cement content

From table 10.9 for 20mm maximum size of aggregate, sand confining to zone 2 water content per cubic meter of concrete is 186 kg and sand content as percentage of total aggregate by absolute volume is 35%

Adjustment of values in water content and sand percentage for other conditions

Change in condition	Water content	Percent sand in total aggregate
For sand conforming to grading zone 1, zone 3 and zone of table 4 IS 383-1970	0	0
Increase or decrease in the value of compaction factor by 0.1	+3	0
Each 0.05 increase or decrease in water cement ratio	0	-2
Total	+3	-2

Sand as percentage of total aggregate to absolute volume = 35-2= 33%

Required water content = 186+5.58 = 191.58 liters

Step 4: Determination of cement content

Water/cement ratio = 0.5

Water content W = 191.58 liters

Cement content C = 191.58/0.5 = 383.16 kg

Step 5: Determination of fine aggregate and coarse aggregate

Maximum size of aggregate is 20 mm and assumed amount of entrapped air in wet concrete is 2%

For F.A

$V=[W+(C/S_c)+f_a/(p*S_{fa})]/1000$

And f_a= 572.09 kg

$C_a= [1-p/p]*f_a*[S_{ca}/S_{fa}]$

$=1206.189$ kg

Where

V= absolute volume of fresh concrete, which is equal to gross volume (m^3) minus the volume of entrapped air,

W = Mass of water (kg) per m^3 of concrete

C = Mass of cement (kg) per m^3 of concrete

S_c = Specific gravity of cement

p = Ratio of FA to total aggregate by absolute volume

f_a, C_a = Total masses of FA and CA (kg) per m^3 of concrete respectively and

S_{fa}, S_{ca} = Specific gravities of saturated, surface dry fine aggregate and coarse aggregate respectively.

The mix proportion is

0.5:1:1.5:3.15

Water	Cement	Fine aggregate	Coarse aggregate
191.58	383.16	572.09	1206.189

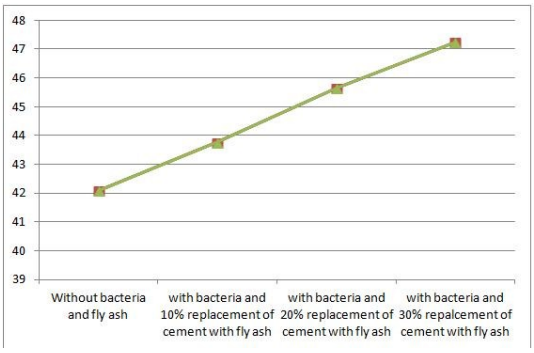
fine aggregate and coarse aggregate respectively.

The mix proportion is

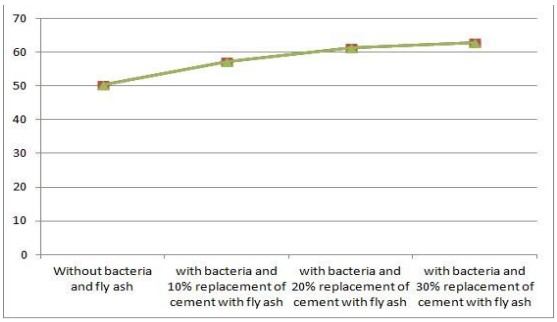
GRAPHS

Compressive strength

For M20 grade concrete

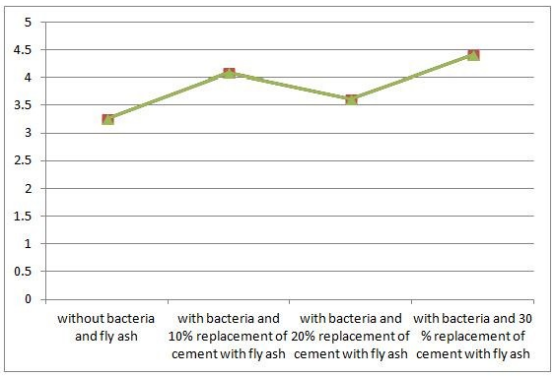


For M40 grade of concrete

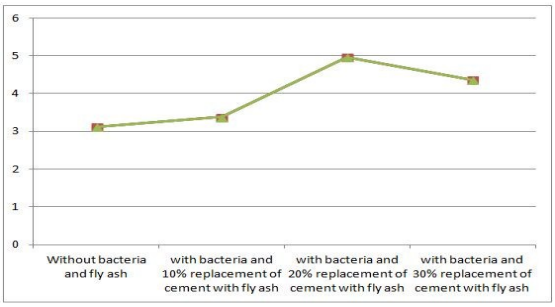


Split Tensile Strength:

For M20 Grade of concrete

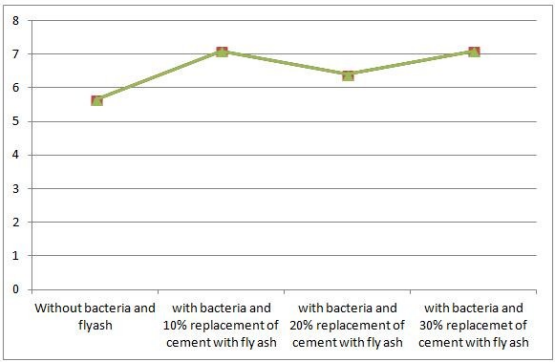


For M40 grade of concrete

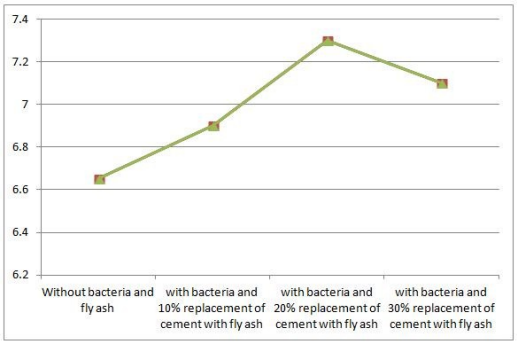


Flexural Strength:

For M20 Grade concrete

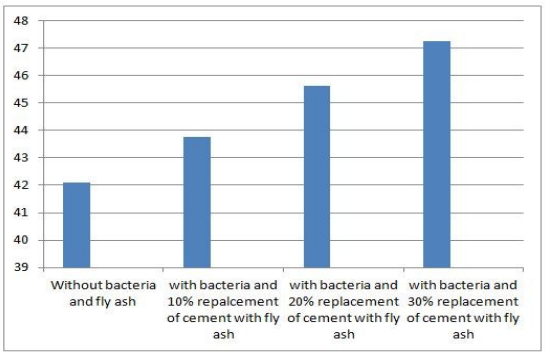


For M40 grade concrete

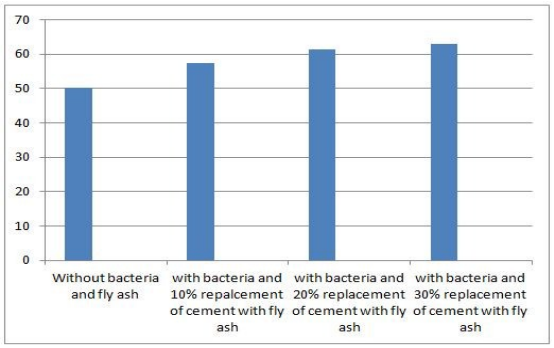


Compressive strength:

For M20 grade of concrete

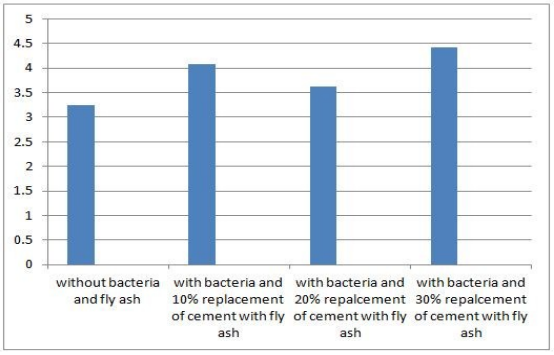


For M40 grade of concrete

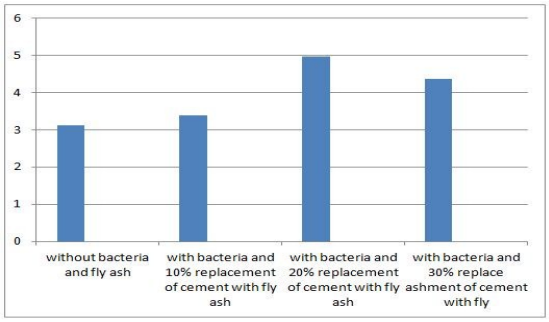


Split tensile strength

For M20 Grade of concrete

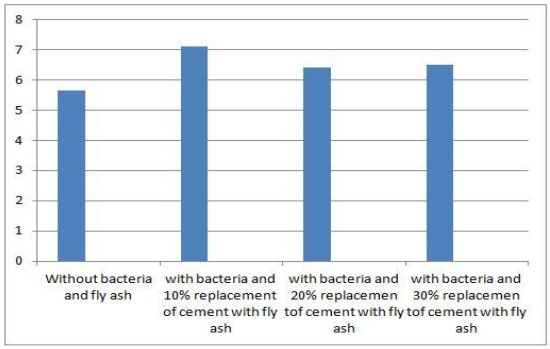


For M40 grade of concrete

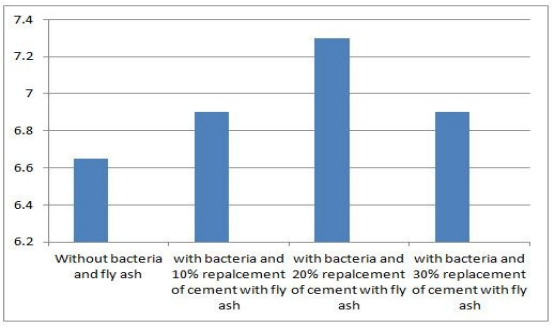


Flexural Strength

For M20 Grade of concrete



For M40 grade of concrete



RESULTS

Properties of cement:

The physical properties of ordinary Portland cement used in the present investigations and they confirm to I.S specifications. The 28 days compressive strength of cement used is 50 MPa.

Properties of Aggregates:

The properties of aggregates used in present investigations. The fineness modulus of the fine aggregate is found to be 2.57. The fineness modulus of coarse aggregate is found to be 4.93. The bulk density of fine aggregate is 4.62 kg/l and for coarse aggregate is 1.57 kg/l.

Properties of Fly Ash:

The typical oxide composition of the Indian Fly ash is given in the table 6.4. The Fly ash used in the present investigation is obtained from and the chemical composition is rich in silica content, which reacts with calcium hydroxide to form C-S-H gel. This gel is responsible for the strength of mortar or concrete. The 16%-28% of alumina is useful in the formation of calcium aluminium hydrates, which is responsible for the setting time of concrete. Table 6.5 gives the physical requirements and the experimental results for the physical test for the fly ash in present investigations and it confirms to the IS specifications of grade I fly ash.

Mix Proportion:

In the present investigation, the mix proportioning is done using Erntroy and Shacklock method for both M20 and M40 grade concrete. Test specimens of cubes, beams and cylinders are casted by varying percentages of fly ash from 0% to 30% of cement replacement.

Compressive strength of concrete:

- In the present investigation 100mm X100mm X100mm size cubes are used. Compressive strength was determined on these specimens, which were cured in clean water until the date of test. Three cubes are tested in every case and the average value is taken assessing compressive strength for different %age of fly ash for 28 days of curing.
- Table 6.6 shows the compressive strength of concrete for different mix i.e., by replacing cement with fly ash by 10%, 20% and 30% respectively.
- Table 6.6.1 shows the percentage increase in compressive strength at 28 days of curing when compared to normal conventional concrete.

Split tensile strength of concrete:

- In the present investigation 300mmX150mm size cylinders are used. Split tensile strength was determined on these specimens, which were cured in clean water until the date of test. Three cylinders are tested in every case and the average value is taken assessing split tensile strength for different %age of fly ash for 28 days of curing.
- Table 6.7 shows the split tensile strength of concrete for different mix i.e., by replacing cement with fly ash by 10%, 20% and 30% respectively.
- Table 6.7.1 shows the percentage increase in split tensile strength at 28 days of curing when compared to normal conventional concrete.

Flexural strength of concrete:

- In the present investigation 500mm X 100mm X100mm size beams are used. Flexural strength was determined on these specimens, which were cured in clean water until the date of test. Three beams are tested in every case and the average value is taken assessing flexural strength for different %age of fly ash for 28 days of curing.
- Table 6.8 shows the flexural strength of concrete for different mix i.e., by replacing cement with fly ash by 10%, 20% and 30% respectively.
- Table 6.8.1 shows the percentage increase in flexural strength at 28 days of curing when compared to normal conventional concrete.

CONCLUSIONS

The following conclusions are drawn based on test results:

- Compressive strength of concrete has increased by adding Bacteria and fly ash in concrete.
- Improvement in compressive strength of M20 and M40 grade of concrete is observed at 28 days in comparison with 10%, 20% and 30% fly ash as replacement of cement and was found to increase of strength by 2.54%, 8.38% and12.2% respectively for M20 grade of concrete when compared to the concrete of having 0% fly ash and bacteria
- And the increase of strength by 13.9%, 22.05% and 25% for 10%, 20%, 30% fly ash as replacement of cement respectively for M40 grade of concrete when compared to the concrete of having 0% fly ash and bacteria
- The similar improvement is found in split tensile strength and flexural strength
- Addition of Bacillus Subtilis bacteria and fly ash has increased the split tensile strength of concrete by 25.7%, 11.28% and35.56% for 10%, 20% and 30% fly ash as replacement of cement respectively for M20 grade of concrete when compared to normal conventional concrete
- Similarly for M40 grade of concrete it was found to increase by 8.33%, 59.2%, and 40.06% for 10%, 20% and 30% fly ash as replacement of cement respectively when compared to normal conventional concrete
- Addition of Bacillus Subtilis bacteria and fly ash has increased the flexural strength of concrete by 25.6%, 13.5% and 15.01% for 10%, 20% and 30% fly ash as replacement of cement respectively for M20 grade of concrete when compared to normal conventional concrete
- Similarly for M40 grade of concrete it was found to increase by 3.75%, 9.7% and 3.75% for 10%, 20% and 30% fly ash as replacement of cement respectively when compared to normal conventional concrete.
- Bacillus Subtilis bacteria can be produced in the laboratory which is proved to be safe and cost effective.

SCOPE FOR FUTURE STUDY

Further investigations can be done to study the shear strength, impact strength and durability etc.., on bacterial concrete with fly ash

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