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To Experimentally Investigate Self-Healing Concrete with Carbon Nanotubes and Partial Replacement of Cement with GGBS

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Abstract: This study presents the experimental research on Self Healing Concrete with Carbon Nanotubes and partial replacement of OPC with GGBS. This study aims at preparing the proposed concrete by Bacteria (Bacillus Subtilis) and Organic Mineral Precursor Compound (Calcium Lactate) with small addition of Carbon Nanotubes (CNTs) and making partial replacement of Ordinary Portland Cement in concrete with Ground Granulated Blast Furnace Slag (GGBS), Mix Design Proportioning as per IS Code Guidelines, determining the Workability of proposed concrete, preparing the requisite test specimens, testing the specimens for Compressive Test, Split Tensile Test and Flexural Test and draw out the major conclusions for the proposed concrete. As Conventional Concrete may experience cracks whether they may occur due to structural use in long term, or shrinkage and creep in short or long term, These cracks cause the bad effects on the structural components and making it less durable, less serviceable and even collapsing of some components. These cracks require regular maintenance from time to time to get repaired which requires cost and skilled workmen. It is very difficult to get them repaired time to time. So, Proposed Concrete is a Smart Material which can heal its cracks on its own without human intervention and get the cracks repaired when it is originated without deteriorating the strength and functional aspects of structure. Conventional concrete has good compressive strength but it may not have significant tensile strength because the concrete is a brittle material. But the Proposed Concrete will have the significant tensile strength than conventional concrete because little tensile behaviour is to be imparted by Carbon Nanotubes. Carbon Nanotubes have the greater axial strength, excellent stiffness, excellent Young's modulus of elasticity and ductility properties. Concrete is most widely used construction material and ordinary Portland cement is consumed in large quantity in making conventional concrete. The Production of Ordinary Portland Cement causes large scale CO2 emissions into our atmosphere. CO2 emissions is the main cause for large scale global warming. Proposed Concrete contains the partial replacement of OPC with GGBS which will reduce the consumption as well as production of OPC, which in turn will help in combating the global warming. Ground Granulated Blast Furnace Slag (GGBS) is an eco-friendly material produced during iron production. Proposed Concrete will have the better strength properties.

Keywords: Self-Healing Concrete, Bacillus Subtilis, Organic mineral precursor compound, Calcium lactate, Encapsulation, Clay Pallets, Multi walled carbon nanotubes, Ground granulated blast furnace slag,

I. INTRODUCTION

Concrete is a construction material which is brittle. It resists the load applied on it to a certain limit. When the load applied on the concrete exceeds the certain limit, cracks develop on it. There are some other factors also which leads to cracks generation on concrete like Shrinkage, Creep and so on. Due to these cracks, Durability and Permeability of concrete structure is badly affected leading to its Poor Serviceability. It is very expensive to repair these cracks from time to time.

Self Healing Concrete: By the concept of Self Healing Concrete, Concrete can heal its cracks on its own when it is generated without increasing the maintenance cost of concrete structure. Self Healing Concrete, also called Self Repairing or Bacterial Concrete, may be defined as "A Smart material containing the healing agents that has the structurally incorporated capability to repair cracks, by self filling up of crack when it generates." *Bacteria in Self Healing Concrete:* Selection of Bacteria to be used in Self Healing Concrete depends on its ability to survive in highly alkaline medium because many bacteria will die in medium having pH greater than 10. Concrete is a highly alkaline building material as the pH of Normal Cement Concrete approximately ranges from 12.5 to 13. But some bacteria have the capability to survive in highly alkaline medium such as for concrete.

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CNTs: Carbon Nanotubes (CNTs) are the allotropes of carbon nanostructures consisting of the rolled graphene sheets having diameter in nanometers. Due to Excellent properties of CNTs, CNTs are most widely used by many researchers in Concrete Matrix in order to modify and enhance the properties of Concrete. As the Concrete is a brittle material, it may have a good Compressive Strength but it doesn't have the significant Tensile Strength. CNTs have the Greater Stiffness and excellent axial strength. CNTs can be added in very small quantities in the concrete to improve its Tensile Strength.
GGBS: GGBS has the excellent cementitious properties and can be added in concrete, by replacing OPC to some extent, so as to enhance the properties of Concrete.

II. LITERATURE REVIEW

A. Review of Literature

[1]Ramezanianpour A.A., Talluri Rajesh, Mathangi Prathap and Hamidah S., "To Study Self Healing Concrete Using Bacteria Bacillus Subtilis Experimentally",The Asian Review of Civil Engineering ISSN: 2249 Vol.9 No.1, pp. 21-24 (2021). Only Compressive Strength Test was conducted on concrete mix M20 with 0%, 10% and 20% Self Healing and also on M20 with 0%, 10% and 20% Self Healing. M20 with 10% Self Healing gave 18.71% increase in Compressive Strength from the Conventional Concrete. M20 with 20% Self Healing gave 8.5% increase in Compressive Strength from the Conventional Concrete. M30 with 10% Self Healing gave 17.66% increase in Compressive Strength from the Conventional Concrete. M30 with 20% Self Healing gave 9.07% increase in Compressive Strength from the Conventional Concrete.
[2]Balachandra A., Barodawala Q.I., Labaj M., Mahar B., "Carbon Nano-tubes Cement Concrete Composites", Department of Civil Engineering, Faculty of Engineering, South Asian Institute of Technology and Medicine (SAITM), Sri Lanka (2019). M20 with 0.001% MWCNTs gave 6.5% increase in Compressive Strength from the Conventional Concrete. M20 with 0.005% MWCNTs gave 11.87% increase in Compressive Strength from the Conventional Concrete.
[3]Karri Kumar, Rao G.V.Rama, Raju P.Markandeya, "Strength and Durability Studies on GGBS Concrete", SSRG International Journal of Civil Engineering (SSRG-IJCE) – volume 2 Issue 10 (2015). Compressive strength was seen to increase with increase in GGBS percentage upto 40% and then decrease in Compressive Strength at 50% for both M20 and M40 Grades. Compressive Strength was higher than conventional concrete mix by 9.3% for M20 with 40% replacement. Split Tensile Strength and Flexural Strength was also found to be highest for M20 and M40 grades with 40% replacement of OPC with GGBS and lower values for 0%, 30% and 50 % replacement.
[4]Ganesh S., Ganie Muzafar Ahmad, Raina Chandandeep Singh and Danish Peerzada, Jessie Anita J, "Experimental Study on Self-healing Concrete with the Effect of Bacillus Subtilis Bacteria to Improve the Strength and Sustainability of the Concrete", Journal of Green Engineering (JGE) Volume-10, Issue-4 (2020). Bacteria and its food are added directly in concrete mix during the concrete mixing. Maintenance Cost of Concrete structure is decreased and its strength is increased.
[5]Shekha Hazhar, Abdi Mohammed Abukar and Khattab Ishraq Mohammad Ali, "Study on Self-healing Concrete types – A review", Sustainable Structure and Materials, Vol. 2, No .1, Page 76-87 (2019). Different processes of Self Healing were studied. Different bacteria with their favorable method of making Self Healing Concrete were studied.
[6]Luhar Salmabanu and Gourav Suthar, "A Review Paper on Self Healing Concrete", Journal of Civil Engineering Research, 5(3): Page 53-58 (2015). Self Healing Concrete was prepared with B.sphaericus Bacteria. Stress-Strain Behavior of Self Healing concrete was studied. Compressive Strength and Split Tensile Strength was calculated.
[7]Rawat Shaitan Singh, Kumar Chetan and Soni Swati, "A Review Paper On Self Healing Concrete", IJARIIE-ISSN(O)-2395-4396 Vol-6 Issue-1 (2020). Self Healing Concrete was prepared with B.sphaericus Bacteria. Various types of Self Healing Concrete were studied. Compressive strength is greater than conventional concrete such as 13.75% greater strength in 3 days, 14.28% in 7 days and 18.35% in 28 days.
[8]Nishanthi S. and Monishaa M., "Experimental Study On Strength Of Self-Healing Concrete", International Journal of Civil Engineering- (ICRTCETM-2017) - Special Issue (2017). Polyethylene fiber was added as an additive in concrete. Bacteria was added directly. More the Calcium Carbonate precipitations, greater is the Self Healing Effect.
[9]Rai Sharda Prasad and Joshi Rishabh "An Experimental Study On Self Healing Of Concrete Using Bacillus Subtilis In Cultured Form", IJCRT Volume 6, Issue (2018). M20, M25 and M30 Grades of Nominal Concrete Mix were prepared. 11% Increase in Compressive Strength was experienced for M20 Grade. Compressive Strength was studied by making partial replacement of water with bacteria in different proportions.

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[10]Ahmed Ba Rahma, Saleh Dahi, Hussein Al-Jaberi and Rashid Raizal S. M., "Influence of Carbon Nanotubes (CNTs) in the Cement Composites", Sustainable Civil and Construction Engineering Conference (2019). Microstructure of concrete containing CNTs was studied. It was also found that to obtain the best results, proper mixing is important.

[11]Rudzionis Zymantas, Adhikary Suman Kumar and Rajapriya R, "The Effect of Carbon Nanotubes on the Flowability, Mechanical, Microstructural and Durability Properties of Cementitious Composite: An Overview", MDPI Sustainability Journal (2020). It was found that Concrete containing CNTs having low Water-Cement ratio have higher durability. Study of Microstructure showed that compatibility of Cement and CNTs is good.

B. Research Gap

1) Compressive Strength of Self Healing Concrete was studied at 10% Self Healing Content and directly at 20% Self Healing Content and not studied in between 10% to 20%. So, it is not known, in between 10% and 20% Self Healing Content, Strength increases or not.
2) Self Healing in Concrete and Carbon nanotubes in Concrete are the two separate revolutionary technologies for Concrete. Not a Single Research is carried on the same concrete having both these technologies. Concrete having better ductile properties than conventional one which will be provided by Carbon nanotubes (CNTs) and also at the same time having the ability to heal its cracks without any maintenance costs. If this concrete is to be prepared, it will give Positive Results or not, in terms of Compressive Strength, Split Tensile Strength, Flexural Strength, Workability, Durability and Self Healing.

III.BASIC THEORY

A. Self Healing Concrete

Self Healing Concrete is defined as the structurally incorporated capability of concrete to autonomously or autogenously heal its cracks by adding certain materials or substances in concrete mix which can enhance the properties of concrete to heal its cracks when it originate.

B. Self Healing Process

Self Healing Process, also called Self Crack Remediation Process (SCRP) is the process through which the concrete repair its cracks without human intervention.

1) *Natural Self Healing Processes:* Concrete micro cracks may be filled naturally. Impurities present in water which is used in concrete mix can block micro cracks present in concrete structure. Sometimes unreacted cementitious material may present in concrete crack and when comes in contact with water, hydration reaction occurs which can block these cracks. Formation of Calcium Carbonate Hydroxide which can fill these cracks. Disadvantages of Natural Self Healing Process are it is not as much effective as compared to the Chemical and Biological Self Healing Processes and Absence of targeted materials whether it may be the impurities in water or the unreacted cementitious material.
2) *Chemical Self Healing Processes:* It is an Artificial Process of Self Healing. In this Process, Chemical components are filled into the cracks either by an active mode or by a passive mode. Active Mode includes the Vascular arrangement having an external link to a chemical substance which can fill crack. Passive Mode includes the Capsules containing the healing chemical substance and Vascular arrangement without having an external link to a chemical substance which can fill crack. Disadvantages of Chemical Self Healing Process are it is not as much effective as compared to the Biological Self Healing Processes, Making Proper Vascular arrangement in concrete is costly as compared to repairing the cracks manually, Chemicals added in this process may affect the properties of concrete.
3) *Biological Self Healing Processes:* Biological Self Healing Process is of two types namely Aerobic Process and Anaerobic Process. There are mostly two types precipitations formed which fills the cracks are Iron Alumino-Silicate and Calcium Carbonate. Organisms which are used in this process are Fungi and Bacteria.

C. Types of Self Healing Concrete

Self healing concrete can be classified into Biotic and Abiotic Self healing concrete depending upon whether microorganisms (bacteria or fungi) or some other chemical compound is used as healing agent.

1) Biotic Self Healing Concrete: *Biotic Self Healing Concrete is defined as that type of Self Healing Concrete which is prepared with the microorganisms like Bacteria and Fungi. Commonly used Fungi is Trichoderma Reesel. This type of Self healing Concrete is generally used where Moisture is generally present.*

2) *Abiotic Self Healing Concrete: Abiotic Self Healing Concrete is defined as that type of Self Healing Concrete which is prepared with the chemical compounds. Commonly used Chemical Compunds are DiCycloPentaDiene, Epoxy, Cyanoacrylate, Methyl Methacrylate and PolyUrethane. This type of Self healing Concrete is generally used where Moisture is not generally present.*

D. Two Component Healing System

1) *Bacteria added in Self Healing Concrete:* In most cases, Self Healing Concrete is produced by adding Bacteria in concrete so as to impart self healing properties. Bacteria will produce a material which fills crack. Required Qualities of Bacteria in Concrete are It should be an Alkali Resistant Bacteria. pH of Concrete approximately ranges from 12 to 13 on pH scale. So, concrete is a highly alkaline medium. Thus the Bacteria, to be added to make the self healing concrete, should survive in this highly alkaline medium, It should be easily available, It should have lesser cost, It should have longer life. Commonly Used Bacteria in Concrete are Bacillus Sphaericus, Bacillus Subtilis, Bacillus Pasteurii, Bacillus Megaterium, Bacillus Aerius and Bacillus Cohnii.
2) *Organic Mineral Precursor Compound in Self Healing Concrete:* Precursor Compound means a material or a compound from which another material or compound is produced, generally with the help of metabolic reaction. In Self Healing Concrete, along with Bacteria, an Organic Mineral Precursor Compound is added from which another substance is produced by metabolic reaction which fills or blocks the cracks and thereby making this concrete, a Self Healing Concrete. Commonly Used Precursor Compounds in Concrete are Calcium Lactate and Silicon Dioxide. Calcium Lactate is the most commonly used Organic Mineral Precursor Compound which is used in Self Healing Concrete. Bacteria convert this Calcium Lactate into Calcium Carbonate with the help of metabolic activity. This Calcium Carbonate, produced during the Self Healing Process, fills the cracks. Silicon Dioxide is the another most common used Mineral Precursor Compound which is used in Self Healing Concrete. Bacteria convert this Silicon Dioxide into Calcium Silicate Hydrate with the help of metabolic activity. This Calcium Silicate Hydrate, produced during the Self Healing Process, fills the cracks.

E. Carbon Nanotubes (CNTs)

1) *Definition:* Carbon Nanotubes may be defined as the allotropes of carbon (mainly graphene honeycombed sheets) rolled into the shape of hollow cylindrical tubes having diameters in nanometers.
2) *Structure of Carbon Nanotubes (CNTs):* Structure of Carbon Nanotubes consists of the Rolled Graphene Sheets. Carbon Atoms combine with other carbon atoms to form Hexagonal Rings. These Hexagonal Rings combine with other Hexagonal Rings to form Honeycombed sheets called Graphene Sheets. Graphene Sheets consists of the one carbon atom thick sheet of hexagonal rings. These Graphene Sheets are rolled in the form of hollow cylinders having diameters in range of nanometers to form Carbon Nanotubes.

F. Types of Carbon Nanotubes (CNTs)

There are most commonly two types of Carbon Nanotubes depending upon whether they contain a single graphene layer or many graphene layers.

1) *Single Walled Carbon Nanotubes (SWCNTs):* Single Walled Carbon Nanotubes (SWCNTs) consists of a single layer of graphene sheet rolled in the form of hollow cylinder. Diameter is approximately 1 to 2 nanometers. Length is approximately 2 to 3 micrometers. Require Catalyst during its synthesis. Very Difficult to synthesis in Bulk Quantity. Easily bendable. Higher Aspect Ratio (Length to Diameter Ratio) as compared with MWCNTs.
2) *Multi Walled Carbon Nanotubes (MWCNTs):* Multi Walled Carbon Nanotubes (MWCNTs) consists of Multiple layer of graphene sheets rolled in the form of Hollow Concentric Cylinders. Outer Diameter is generally greater than 2 nanometers. Length is approximately 5 to 8 micrometers. Don't require Catalyst during its synthesis. Cheaper than SWCNTs. Very Easy to synthesis in Bulk Quantity. Not Easily bendable. Lower Aspect Ratio (Length to Diameter Ratio) as compared with MWCNTs.

G. Importance of Carbon Nanotubes (CNTs) in Concrete

Concrete is a brittle material. It is very Good Compressive Strength but weak Tensile Strength. Carbon Nanotubes have Excellent Tensile strength, Stiffness and Very High Young's Modulus. By adding Carbon Nanotubes in concrete, Features attained are Good Tensile Strength of Hardened Concrete, More Compressive Strength as compared with Normal Concrete, Excellent Tenacity and Stiffness of Concrete, Greater Flexural Strength of structure, Greater Bond Strength as compared with normal concrete, Good

Workability of Fresh Concrete, Very Least Deformation in Concrete Structures, Greater Stress Carrying Capacity of Concrete Structures, Lesser chances of Micro Crack Formation and Greater Durability and Serviceability of Concrete Structures. Multi Walled Carbon Nanotubes (MWCNTs) are generally preferred in concrete over the Single Walled Carbon Nanotubes (SWCNTs) due to the reasons like MWCNTs are cheap as compared with SWCNTs, MWCNTs are easily available in bulk as compared with SWCNTs and MWCNTs are easy to synthesize as compared with SWCNTs.

H. GGBS as a Partial Replacement of OPC in Concrete

Ground Granulated Blast Furnace Slag (GGBS) is defined as the fine powder which is obtained by drying and grinding the grainy material which is obtained by cooling molten iron slag obtained from blast furnace in water or steam. Manufacturing of one ton OPC emits approximately 910 Kg of CO_2 emissions into our atmosphere. This large amount of CO_2 emissions leads to Global Warming and Climate Change. Thus, by making partial replacement of OPC with GGBS, a large amount of OPC consumption is reduced which leads to reduction in OPC manufacturing. Thus, CO_2 emissions can be reduced. By making Partial Replacement of OPC with GGBS, Features achieved in concrete are Good Compressive Strength as compared with normal concrete, Reduced Permeability, Durability of Structure is improved, Lesser Shrinkage Cracks, Greater Flexural Strength, Greater Resistance to Sulphate Attack, More workable Concrete Mix, Concrete Mix is easy to compact, Sustainable and Green Material, Lesser Chances of Reinforcement Corrosion, Chemically Stable Concrete, Lesser Heat of Hydration, Lower Risk of damaging of Alkali-Silica Reaction, Good Aesthetic Aspect as providing finishing surface and Eco-Friendly Material.

IV.MATERIAL

A. Ordinary Portland Cement

Ordinary Portland Cement is defined as the most widely used binding material that is grayish in color and when mixed with water and placed for drying, becomes hard mass. Its main constituents are Lime (CaO), Silica (SiO_2) and Alumina (Al_2O_3).It is produced from the raw materials like argillaceous materials (Clay or Shale) and Calcareous materials (Limestone or Chalk). There are two methods of manufacturing of Ordinary Portland Cement like Wet Process and Dry Process. Both the processes of manufacturing of OPC produces a large amount of CO_2 emissions into the atmosphere which leads to Global Warming and Climate Change on our Earth.

B. Ground Granulated Blast Furnace Slag (GGBS or GGBFS)

GGBS is a Off White colored fine powder which is obtained as a by-product during the manufacturing of Iron from iron ore. It has good cementitious properties. GGBS can be used as a partial replacement of OPC in Concrete. As stated above, OPC manufacturing causes large scale CO_2 emissions into our atmosphere which in turn causes Global Warming and Climate change which is a greater threat to human life.

C. Coarse Aggregates (Broken Stones)

Coarse Aggregates are the construction filler material that retain on 4.75 mm Sieve. Examples of Coarse Aggregates are Broken stones, broken bricks, clinkers, gravel, pebbles and so on. But in this study, Broken stones aggregates are used. These aggregates are very important for imparting the strength to concrete as well as enhancing its elastic and thermal properties and thereby making concrete a stable concrete.

D. Fine Aggregates (Sand)

Fine Aggregates are the construction filler material that pass through 4.75 mm Sieve but retain on 0.075 mm Sieve. Examples of Fine Aggregates are Sand, Surkhi, Burnt Clays, Stone Screenings and so on. But in this study, Sand is used as the fine aggregate. Fine aggregates have surface area more than the coarse aggregates.

E. Bacillus Subtilis (Bacteria)

Bacteria used in this study is Bacillus Subtilis which is sometimes also called Gram Bacillus and Hay Bacillus. It is an easily available bacteria. It is most commonly

F. Calcium Lactate (OMPC)

Organic Mineral Precursor Compound used in this study is Calcium Lactate. It consists of two lactate anions for each calcium cation. It is a white crystalline salt. It is easily available in the market and is also used in kitchens.

G. Multi Walled Carbon Nanotubes (MWCNTs)

Multi Walled Carbon Nanotubes are used in this study to impart tensile strength to the concrete due to easier availability and cheaper cost than SWCNTs. It is a black colored fine powder.

H. Clay Pallets

Clay Pallets can be prepared manually from the clay. The Clay used in this study is Paper Clay which is easily available in market. Paper Clay can be easily prepared in bulk manually by boiling the used papers and then grinding it and adding glue in it.

I. Water

Water is an important material for making Concrete as it plays a very important role in the hydration reaction of concrete. Water also plays a very important role in providing workability to concrete by making it easy to place and compact. Generally, the easily available portable water is used in making the concrete. Water plays a crucial role in imparting the strength to concrete. pH of water should be between 6.5 to 8.5.

V. EXPERIMENTATION

A. Preparation of Self Healing agent

Bacillus Subtilis and Calcium Lactate are mixed in equal quantities. This Bacillus Subtilis and Calcium Lactate Mixture is taken in very quantities and is enclosed inside the very small clay balls of the size of coarse aggregates. This Self Healing Agent, in the form of Clay Balls containing the mixture of Bacillus Subtilis and Calcium Lactate, was prepared upto the required quantity.

B. Tests on Cement (OPC)

1) *Determination of Specific Gravity of Cement by Le Chatelier: F*lask Method Specific Gravity of Cement found to be 3.12.
2) *Determination of Fineness of Cement by Sieving Method:* Fineness of Cement found to be 6%. As per the IS Code 4031 Part-1 (1996) provisions, Fineness of cement should not exceed 10%.

C. Tests on Coarse Aggregates

1) *Determination of Specific Gravity and Water Absorption of Coarse Aggregates:* Specific Gravity of Coarse Aggregates found to be 2.63. Water Absorption of Coarse Aggregates found to be 0.71%.

D. Tests on Fine Aggregates

1) *Sieve Analysis of Fine Aggregates:* After Comparing the values of Percentage passing of given aggregates with the Table 4 of IS Code 383 : 1970, Fine Aggregates for this study conforms to the Grading Zone II.
2) *Determination of Specific Gravity and Water Absorption of Fine Aggregates:* Specific Gravity of Fine Aggregates found to be 2.63. Water Absorption of Fine Aggregates found to be 1.01%

E. Designation of Design Mixes for this study

TABLE I
DESIGNATION OF DESIGN MIXES FOR THIS STUDY

Materials	Design Mix 1 DM1	Design Mix 2 DM2	Design Mix 3 DM3	Design Mix 4 DM4	Design Mix 5 DM5	Design Mix 6 DM6	Design Mix 7 DM7
Self Healing Content (Clay Pallets containing Bacillus Subtilis and Calcium Lactate in ratio 1:1)	0%	10% of cement- -itious content	15% of cement- -itious content	20% of cement- -itious content	10% of cement- -itious content	15% of cement- -itious content	20% of cement- -itious content
MWCNTs Content	0%	0.010% of ccement- -itious content	0.010% of cement- -itious content	0.010% of cement- -itious content	0.015% of cement- -itious content	0.015% of cement- -itious content	0.015% of cement- -itious content
Cement- -itious Content	100% OPC	8% GGBS 92% OPC	16% GGBS 84% OPC	24% GGBS 76% OPC	32% GGBS 68% OPC	40% GGBS 60% OPC	48% GGBS 54% OPC

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F. *Target Strength for Mix proportioning*

- As per clause 3.2 of IS Code 10262 : 2009

$$f'ck = fck + 1.65\ s$$

Where

f ´ck = target average Compressive Strength of Concrete in N/mm2 at the end of 28 days

f ck = characteristic Compressive Strength of Concrete in N/mm2 at the end of 28 days

s = Standard Deviation in N/mm2

- As per Table 1 of IS Code 10262 : 2009

  s = 4.0 N/mm2 for M20 Grade of Concrete

- For M20 Grade of Concrete

  fck = 20 N/mm2

- Therefore,

  Target Strength for Mix Proportioning, f ´ck = 20 + (1.65 * 4)

  f ´ck = 26.6 N/mm2

  After 28 days,

  Compressive Strength of Concrete should be greater than 26.6.

G. *Test of Workability on Fresh Concrete Mix*

1) *Slump Cone Test as per IS Code : 1199- 1959 and IS : 456 – 2000:* As per IS Code : 1199- 1959 (Methods of Sampling and Analysis of Concrete), Mould for this test consists of a frustum of cone having dimensions

Bottom Diameter	:	20 cm
Top Diameter	:	10 cm
Height	:	30 cm

Steel Tamping Rod of having dimensions of 16 mm diameter and 0.6 m length.

Workability of DM5 is found to be under high category as per IS : 456-2000 Clause 7.1.

H. *Casting and Compaction of Specimens as per IS Code : 516-1959*

Specimens were casted and hand Compaction was done during casting As per IS Code : 516-1959 (Methods of Tests for the Strength of Concrete)

TABLE 2

DESIGNATION OF TEST SPECIMENS FOR DIFFERENT TESTS

Materials (in Kg)	For Design Mix 1 DM1	For Design Mix 2 DM2	For Design Mix 3 DM3	For Design Mix 4 DM4	For Design Mix 5 DM5	For Design Mix 6 DM6	For Design Mix 7 DM7
Compressive Strength at the end of 7 days	3 Cubes C1 to C3	3 Cubes C10 to C12	3 Cubes C19 to C21	3 Cubes C28 to C30	3 Cubes C37 to C39	3 Cubes C46 to C48	3 Cubes C55 to C57
Compressive Strength at the end of 14 days	3 Cubes C4 to C6	3 Cubes C13 to C15	3 Cubes C22 to C24	3 Cubes C31 to C33	3 Cubes C40 to C42	3 Cubes C49 to C51	3 Cubes C58 to C60
Compressive Strength at the end of 28 days	3 Cubes C7 to C9	3 Cubes C16 to C18	3 Cubes C25 to C27	3 Cubes C34 to C36	3 Cubes C43 to C45	3 Cubes C52 to C54	3 Cubes C61 to C63
Split Tensile Strength at the end of 7 days	3 Cylinders CY1 to	3 Cylinders CY10 to	3 Cylinders CY19 to	3 Cylinders CY28 to	3 Cylinders CY37 to	3 Cylinders CY46 to	3 Cylinders CY55 to

	CY3	CY12	CY21	CY30	CY39	CY48	CY57
Split Tensile Strength at the end of 14 days	3 Cylinders CY4 to CY6	3 Cylinders CY13 to CY15	3 Cylinders CY22 to CY24	3 Cylinders CY31 to CY33	3 Cylinders CY40 to CY42	3 Cylinders CY49 to CY51	3 Cylinders CY58 to CY60
Split Tensile Strength at the end of 28 days	3 Cylinders CY7 to CY9	3 Cylinders CY16 to CY18	3 Cylinders CY25 to CY27	3 Cylinders CY34 to CY36	3 Cylinders CY43 to CY45	3 Cylinders CY52 to CY54	3 Cylinders CY61 to CY63
Flexural Strength at the end of 7 days	3 Prisms or Beams B1 to B3	3 Prisms or Beams B10 to B12	3 Prisms or Beams B19 to B21	3 Prisms or Beams B28 to B30	3 Prisms or Beams B37 to B39	3 Prisms or Beams B46 to B48	3 Prisms or Beams B55 to B57
Flexural Strength at the end of 14 days	3 Prisms or Beams B4 to B6	3 Prisms or Beams B13 to B15	3 Prisms or Beams B22 to B24	3 Prisms or Beams B31 to B33	3 Prisms or Beams B40 to B42	3 Prisms or Beams B49 to B51	3 Prisms or Beams B58 to B60
Flexural Strength at the end of 28 days	3 Prisms or Beams B7 to B9	3 Prisms or Beams B16 to B18	3 Prisms or Beams B25 to B27	3 Prisms or Beams B34 to B36	3 Prisms or Beams B43 to B45	3 Prisms or Beams B52 to B54	3 Prisms or Beams B61 to B63
	9 Cubes 9 Cylinders 9Prisms or Beams	9 Cubes 9 Cylinders 9Prisms or Beams	9 Cubes 9 Cylinders 9Prisms or Beams	9 Cubes 9 Cylinders 9Prisms or Beams	9 Cubes 9 Cylinders 9Prisms or Beams	9 Cubes 9 Cylinders 9Prisms or Beams	9 Cubes 9 Cylinders 9Prisms or Beams

1) *Cube Specimens:* Fill the Concrete Mix in Cube Specimens of specified dimensions (150mm*150mm*150mm) in three layers of 50 mm each (one-third of the height of specimen) and tamping the each layer by 35 times with tamping rod of 0.6m length and 16 mm diameter with bullet pointed at lower end as per IS Code : 516-1959.
2) *Cylinder Specimens:* Fill the Concrete Mix in Cylinder Specimens of specified dimensions (150mm(diameter)*300mm(length)) in six layers of 50 mm each (one-sixth of the length of specimen) and tamping the each layer by 30 times with standard tamping rod as per IS Code : 516-1959.
3) *Prism (Concrete Beam) Specimens:* Fill the Concrete Mix in Prism Specimens of specified dimensions (150mm(width)*150mm(height)*700mm(length)) in three layers of 50 mm each and tamping the each layer by 35 times with tamping rod.
4) *Removal of Moulds from the specimens:* After 24 hours of filling the concrete mix of designated Design Mix of DM1, DM2 and DM3, Moulds removed from the all specimens whether Cube, Cylinder or Prism and Specimens marked with Codes as C1, C2 and so on as written in Table 4.4.
5) *Curing of Specimens:* As soon as the specimens recovered from the moulds, all specimens soaked in water fully submerged for curing at room temperature in a large tub which can accommodate all specimens. Curing is important for maintaining the adequate moisture of Concrete Mix so as to undergo adequate hydration of cement in concrete. This Hydration is important for getting strength and hardening of concrete mix.

I. Tests on Hardened Proposed Concrete Specimens

Various Tests performed on the specimens of different Design Mix DM1, DM2, FM4, DM5, DM6 and DM7 like Compressive Strength Test, Split Tensile Strength Test and Flexural Strength Test by taken into consideration the various clause laid down in IS Code : 516 – 1959 (Methods of Tests for Strength of Concrete) and IS Code : 5816 – 1999.

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VI. RESULTS AND ANALYSIS

A. *Results of Compressive Strength Test*

TABLE 3
RESULT OF COMPRESSIVE STRENGTH TEST
AT THE END OF 7 DAYS

Design Mix	**Specimen No.**	**Compressive Strength (N/mm2 or MPa)**	**Average Compressive Strength at 7 days (N/mm2 or MPa)**
DM1	C1	16.03	16.05
	C2	16.14	
	C3	15.97	
DM2	C10	21.52	21.49
	C11	21.34	
	C12	21.62	
DM3	C19	20.33	20.47
	C20	20.43	
	C21	20.65	
DM4	C28	19.45	19.60
	C29	19.63	
	C30	19.71	
DM5	C37	22.72	22.53
	C38	22.37	
	C39	22.49	
DM6	C46	21.41	21.47
	C47	21.52	
	C48	21.49	
DM7	C55	20.45	20.48
	C56	20.43	
	C57	20.55	

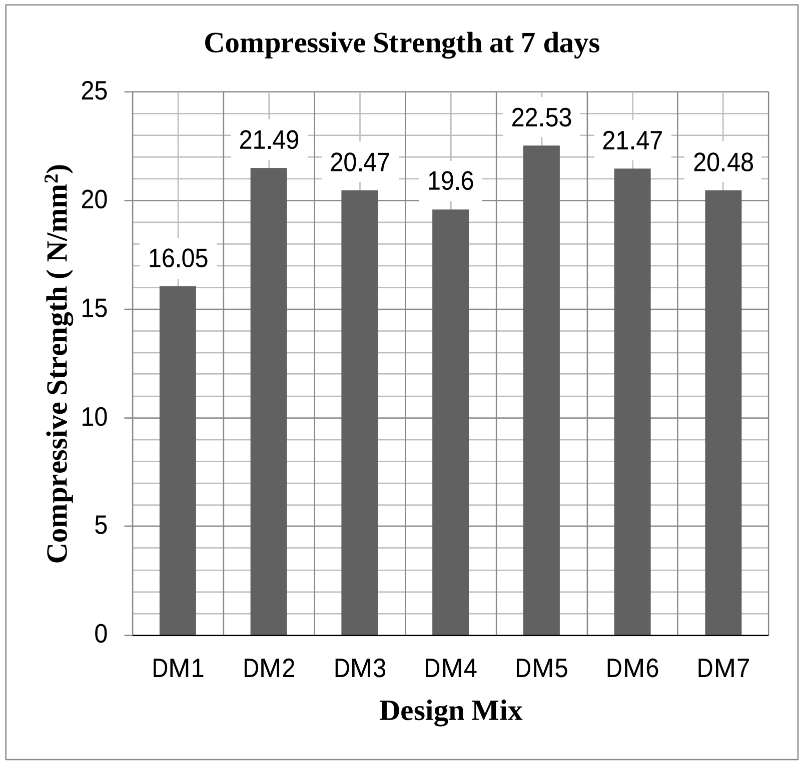

Fig. 1 Analysis of Compressive strength test data at the end of 7 days

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TABLE 4
RESULT OF COMPRESSIVE STRENGTH TEST
AT THE END OF 14 DAYS

Design Mix	**Specimen No.**	**Compressive Strength (N/mm2 or MPa)**	**Average Compressive Strength at 14 days (N/mm2 or MPa)**
DM1	C4	21.60	21.65
	C5	21.47	
	C6	21.89	
DM2	C13	28.85	29.05
	C14	29.25	
	C15	29.05	
DM3	C22	27.45	27.59
	C23	27.64	
	C24	27.67	
DM4	C31	26.56	26.70
	C32	26.87	
	C33	26.65	
DM5	C40	29.65	30.07
	C41	30.34	
	C42	30.21	
DM6	C49	28.43	28.38
	C50	28.14	
	C51	28.57	
DM7	C58	27.56	27.64
	C59	27.65	
	C60	27.71	

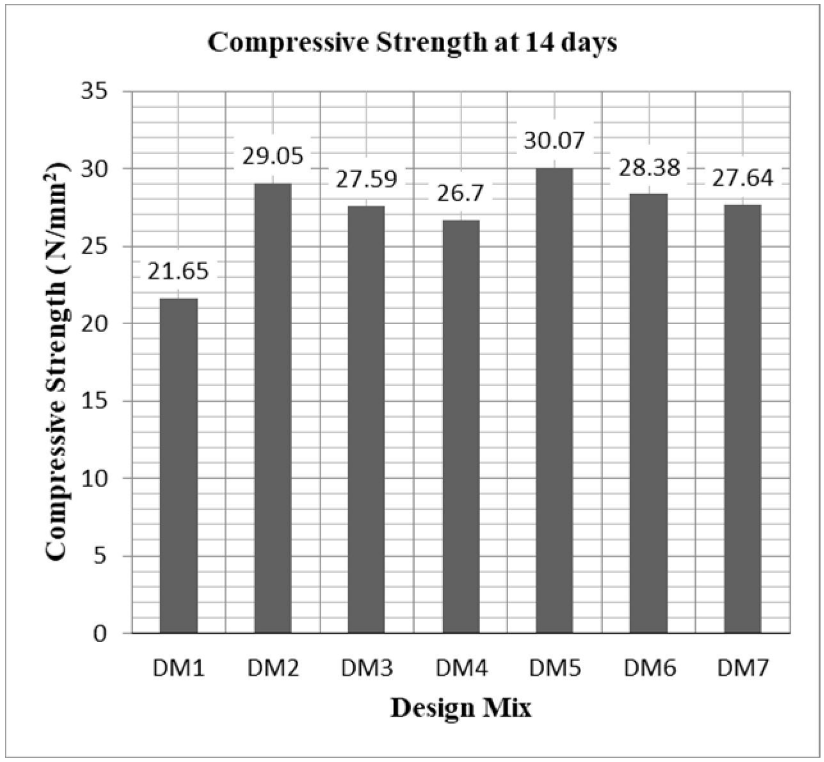

Fig. 2 Analysis of Compressive strength test data at the end of 14 days

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TABLE 5
RESULT OF COMPRESSIVE STRENGTH TEST
AT THE END OF 28 DAYS

Design Mix	**Specimen No.**	**Compressive Strength (N/mm2 or MPa)**	**Average Compressive Strength at 28 days (N/mm2 or MPa)**
DM1	C7	26.67	26.73
	C8	26.50	
	C9	27.02	
DM2	C16	35.62	35.86
	C17	36.11	
	C18	35.86	
DM3	C25	33.89	34.06
	C26	34.12	
	C27	34.16	
DM4	C34	33.56	33.39
	C35	33.45	
	C36	33.15	
DM5	C43	36.62	36.86
	C44	37.11	
	C45	36.86	
DM6	C52	34.89	35.05
	C53	35.12	
	C54	35.16	
DM7	C61	34.56	34.39
	C62	34.45	
	C63	34.15	

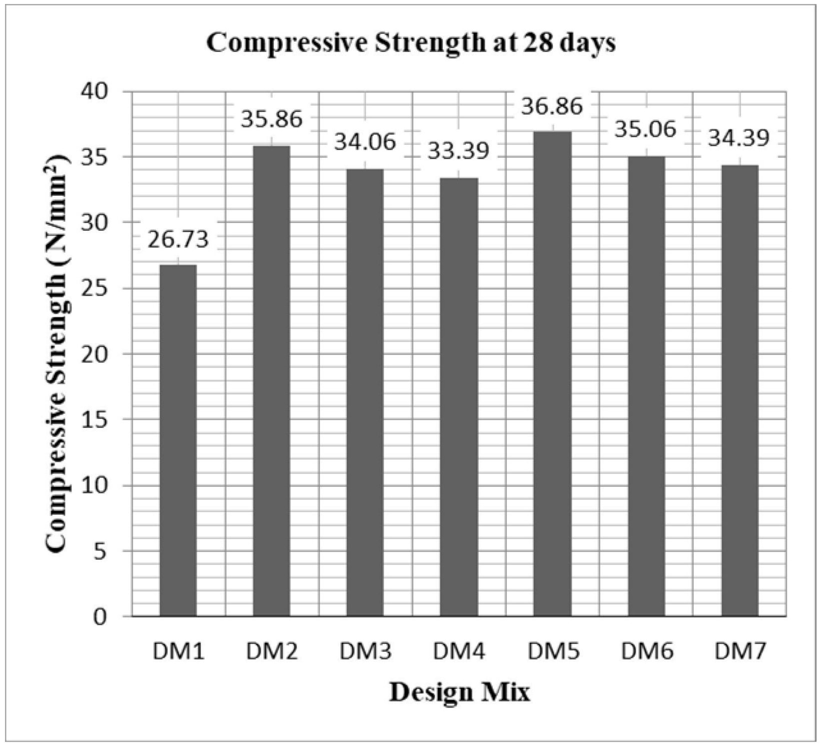

Fig. 3 Analysis of Compressive strength test data at the end of 28 days

B. Results of Split Tensile Strength Test

TABLE 6
RESULT OF SPLIT TENSILE STRENGTH TEST
AT THE END OF 7 DAYS

Design Mix	**Specimen No.**	**Split Tensile Strength (N/mm2 or MPa)**	**Average Split Tensile Strength at 7 days (N/mm2 or MPa)**
DM1	CY1	2.01	2.02
	CY2	2.05	
	CY3	1.99	
DM2	CY10	2.66	2.65
	CY11	2.62	
	CY12	2.67	
DM3	CY19	2.50	2.54
	CY20	2.55	
	CY21	2.58	
DM4	CY28	2.34	2.34
	CY29	2.38	
	CY30	2.31	
DM5	CY37	2.75	2.77
	CY38	2.78	
	CY39	2.79	
DM6	CY46	2.67	2.66
	CY47	2.66	
	CY48	2.64	
DM7	CY55	2.51	2.52
	CY56	2.54	
	CY57	2.52	

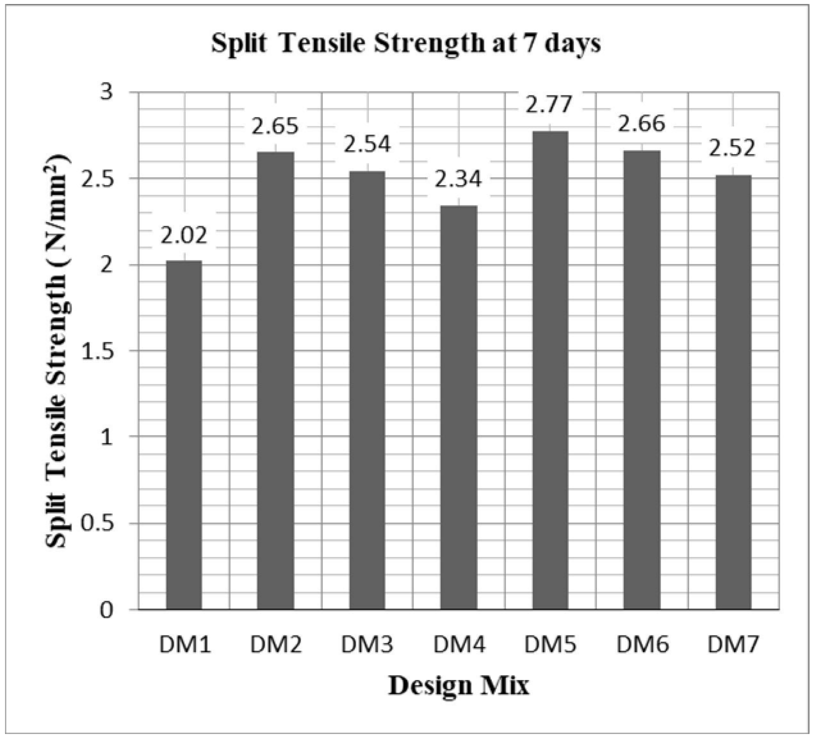

Fig. 4 Analysis of Split tensile strength test data at the end of 7 days

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TABLE 7
RESULT OF SPLIT TENSILE STRENGTH TEST
AT THE END OF 14 DAYS

Design Mix	**Specimen No.**	**Split Tensile Strength (N/mm2 or MPa)**	**Average Split Tensile Strength at 14 days (N/mm2 or MPa)**
DM1	CY4	2.26	2.30
	CY5	2.30	
	CY6	2.33	
DM2	CY13	3.02	3.01
	CY14	3.02	
	CY15	2.98	
DM3	CY22	2.88	2.91
	CY23	2.92	
	CY24	2.94	
DM4	CY31	2.79	2.77
	CY32	2.78	
	CY33	2.75	
DM5	CY40	3.13	3.14
	CY41	3.15	
	CY42	3.14	
DM6	CY49	2.95	2.97
	CY50	2.99	
	CY51	2.98	
DM7	CY58	2.86	2.87
	CY59	2.87	
	CY60	2.89	

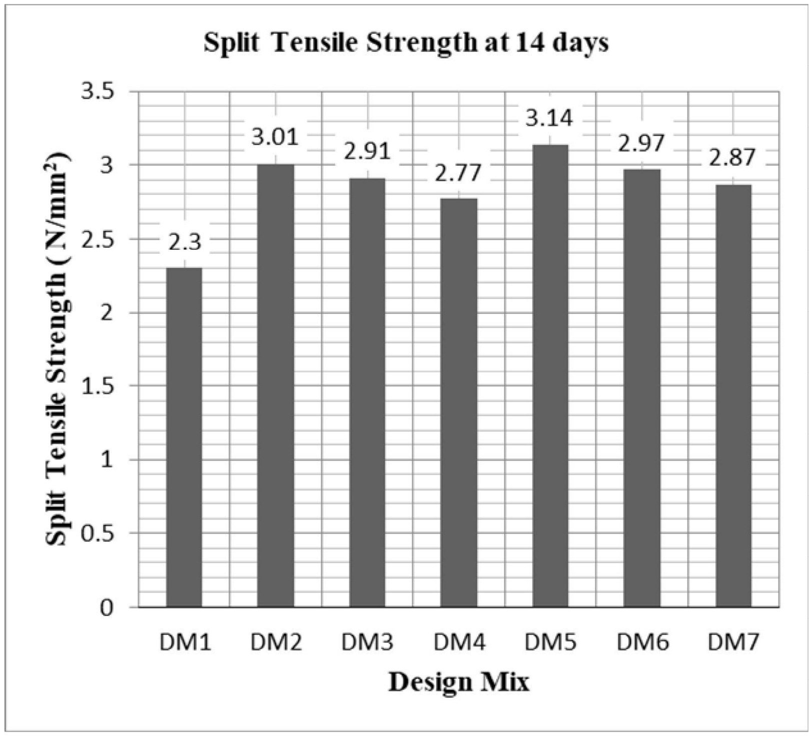

Fig. 5 Analysis of Split tensile strength test data at the end of 14 days

TABLE 8
RESULT OF SPLIT TENSILE STRENGTH TEST
AT THE END OF 28 DAYS

Design Mix	**Specimen No.**	**Split Tensile Strength (N/mm2 or MPa)**	**Average Split Tensile Strength at 28 days (N/mm2 or MPa)**
DM1	CY7	2.83	2.87
	CY8	2.87	
	CY9	2.91	
DM2	CY16	3.77	3.76
	CY17	3.78	
	CY18	3.72	
DM3	CY25	3.60	3.64
	CY26	3.65	
	CY27	3.67	
DM4	CY34	3.55	3.56
	CY35	3.56	
	CY36	3.58	
DM5	CY43	3.87	3.88
	CY44	3.89	
	CY45	3.88	
DM6	CY52	3.76	3.77
	CY53	3.75	
	CY54	3.79	
DM7	CY61	3.65	3.66
	CY62	3.65	
	CY63	3.67	

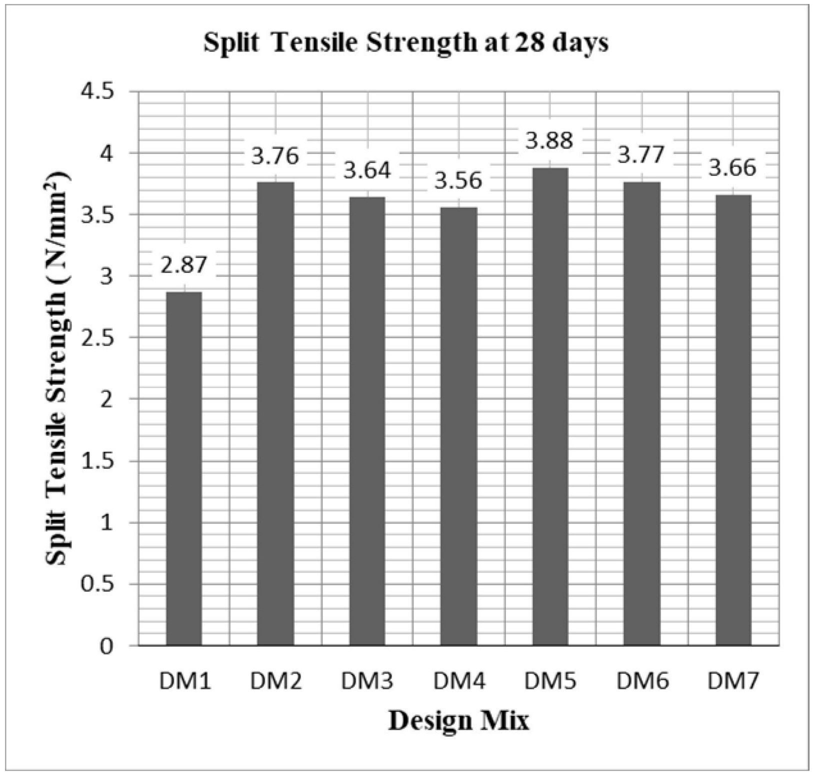

Fig. 6 Analysis of Split tensile strength test data at the end of 28 days

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C. Results of Flexural Strength Test

TABLE 9
RESULT OF FLEXURAL STRENGTH TEST
AT THE END OF 7 DAYS

Design Mix	**Specimen No.**	**Flexural Strength (N/mm2 or MPa)**	**Average Flexural Strength at 7 days (N/mm2 or MPa)**
DM1	B1	2.15	2.18
	B2	2.17	
	B3	2.21	
DM2	B10	2.97	3.01
	B11	2.99	
	B12	3.05	
DM3	B19	2.85	2.90
	B20	2.89	
	B21	2.95	
DM4	B28	2.78	2.77
	B29	2.77	
	B30	2.76	
DM5	B37	3.06	3.08
	B38	3.08	
	B39	3.10	
DM6	B46	2.98	2.96
	B47	2.95	
	B48	2.96	
DM7	B55	2.87	2.86
	B56	2.86	
	B57	2.84	

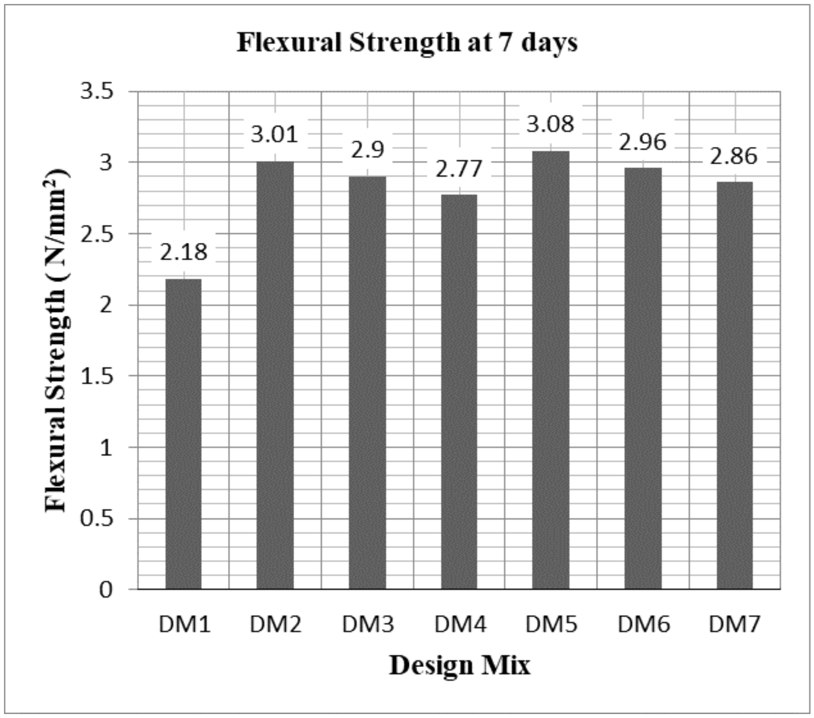

Fig. 7 Analysis of Flexural strength test data at the end of 7 days

TABLE 10
RESULT OF FLEXURAL STRENGTH TEST
AT THE END OF 14 DAYS

Design Mix	**Specimen No.**	**Flexural Strength (N/mm2 or MPa)**	**Average Flexural Strength at 14 days (N/mm2 or MPa)**
DM1	B4	2.42	2.45
	B5	2.46	
	B6	2.49	
DM2	B13	3.38	3.39
	B14	3.42	
	B15	3.38	
DM3	B22	3.31	3.29
	B23	3.27	
	B24	3.30	
DM4	B31	3.22	3.22
	B32	3.23	
	B33	3.21	
DM5	B40	3.46	3.47
	B41	3.47	
	B42	3.46	
DM6	B49	3.41	3.42
	B50	3.42	
	B51	3.42	
DM7	B58	3.31	3.33
	B59	3.33	
	B60	3.34	

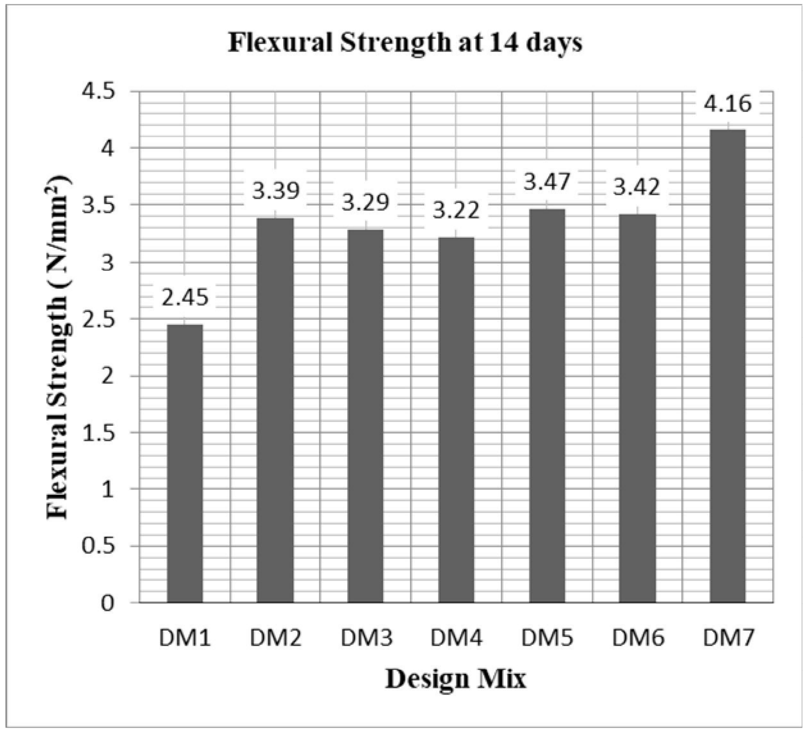

Fig. 8 Analysis of Flexural strength test data at the end of 14 days

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TABLE 11
RESULT OF FLEXURAL STRENGTH TEST
AT THE END OF 28 DAYS

Design Mix	Specimen No.	Flexural Strength (N/mm2 or MPa)	Average Flexural Strength at 28 days (N/mm2 or MPa)
DM1	B7	3.02	3.07
	B8	3.07	
	B9	3.11	
DM2	B16	4.23	4.24
	B17	4.27	
	B18	4.22	
DM3	B25	4.14	4.12
	B26	4.09	
	B27	4.12	
DM4	B34	4.03	4.03
	B35	4.04	
	B36	4.01	
DM5	B43	4.33	4.33
	B44	4.34	
	B45	4.33	
DM6	B52	4.26	4.27
	B53	4.28	
	B54	4.27	
DM7	B61	4.14	4.16
	B62	4.16	
	B63	4.18	

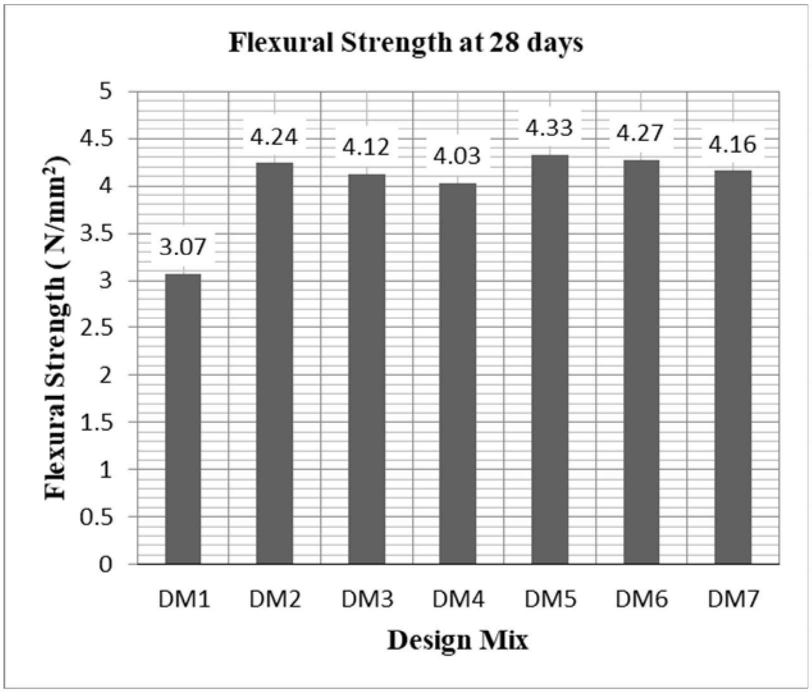

Fig. 9 Analysis of Flexural strength test data at the end of 28 days

VII. CONCLUSIONS

Self Healing Concrete with Carbon Nanotubes shows excellent potential to be the concrete for the future because it is not only an Effective Technique for healing the cracks in concrete structures but also a Revolutionary Material for reduction of Corrosion of Reinforcement which starts with cracking by appropriate Utilization of Corrosion causing Moisture as a Catalyst for activating the Healing System of this concrete and thus filling up the cracks. Self Healing Concrete with CNTs and partial replacement of OPC with GGBS is an innovative and environment friendly material to be used for applications in future because it exhibits human-like self healing characteristics but without the intervention of human during the repair process. Proposed Concrete is Smart Material and an effective Crack Remediation Technique for sealing off the cracks. It is also very effective for filling up of MicroCracks. It is the main purpose of every Structural Engineer to have the least or no MicroCracks as these MicroCracks lead to the less Strength and thus causing the Failure of Structure. Proposed Concrete is prepared by partial replacement of OPC with GGBS, which is a waste material produced during iron production, will reduce the consumption and production of large scale OPC and its results will be seen in combating with Global Warming in near Future. Proposed Concrete has shown the excellent Split Tensile Strength in addition to the Good Compressive and Flexural Strength and more research should be carried in the future to make full advantage of Carbon Nanotubes (Nanotechnology) in Concrete.

Future Study in the field of practical and commercial applications of the Proposed Concrete should be carried out as this concrete has the full potential to be used for applications and has shown excellent Tests Results.

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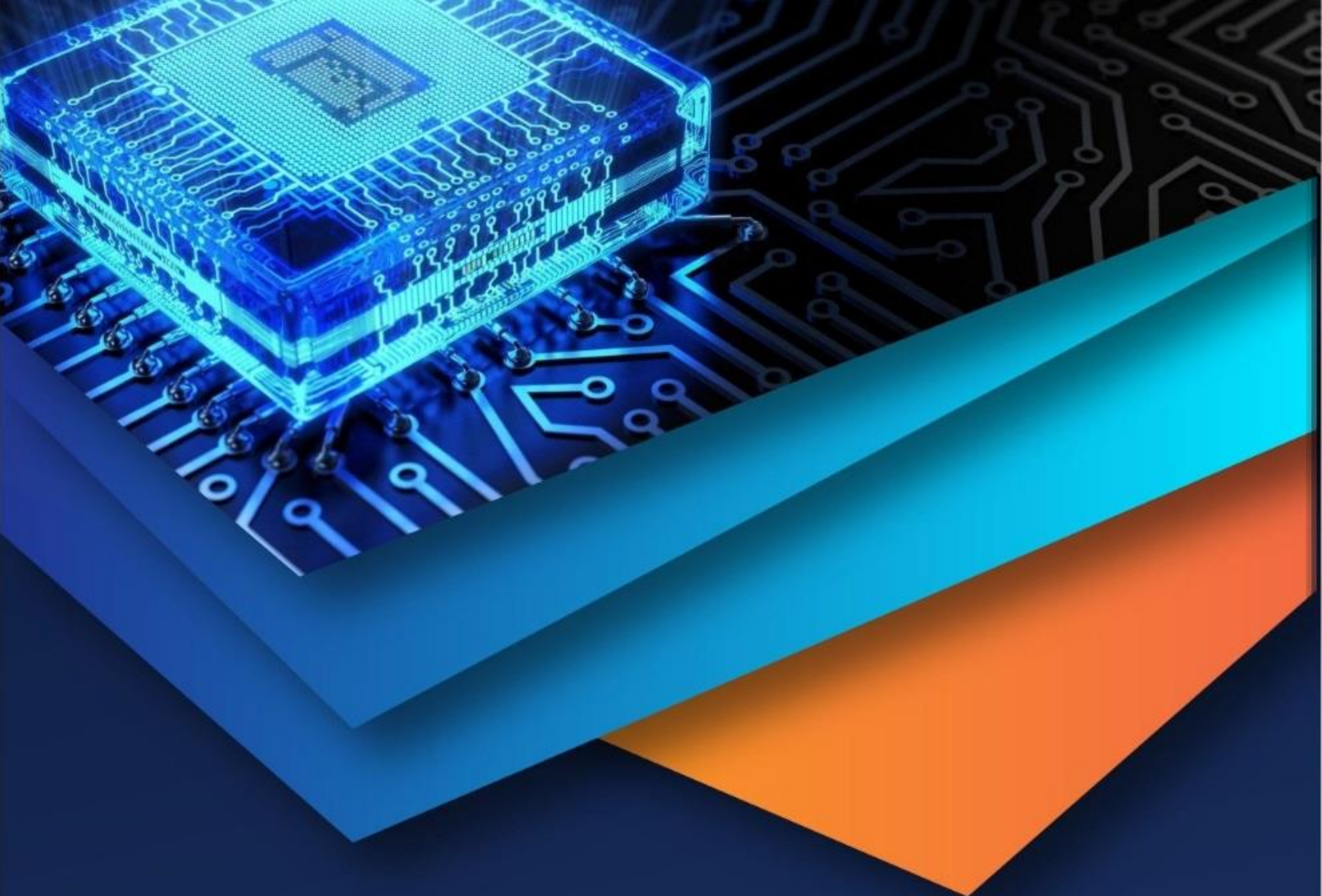

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