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Behaviour of High-Density Concrete and Low-Density Concrete in Alkaline Environment

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***Abstract*: Every year, various industries throughout the world create more than two billion metric tons of alkaline residue. The effectiveness and strength of concrete are significantly impacted by these leftovers. It's critical to comprehend how alkaline residues behave in concrete in order to minimize or lessen the issues they create. The purpose of the current research is to compare the strength characteristics of high- and low-density concrete in an alkaline environment. Various low-density aggregates, including pumice and vermiculite, are used to create low-density concrete mixtures. To create low-density concrete, one mixture substitutes pumice material for all of the typical coarse aggregate, while another substitutes vermiculite for 30% of the fine aggregate. Utilizing various high-density aggregates, such as barite and haematite, allows for the creation of high-density concrete mixtures. Barite and haematite are used as coarse aggregate in two distinct mixes to create high-density concrete by completely replacing the conventional coarse aggregate in each mix. Concrete examples are subjected to two distinct curing processes after casting. In one curing condition, concrete specimens are cured using regular water; in the other, they are cured using alkaline water after being cured in normal water for seven days. Using NaOH pellets, an alkaline solution with a pH of 13 is produced. Rapid Chloride Penetration, Split-Tensile Strength, Flexural Strength, and Compressive Strength To determine the impact of alkaline curing on concrete specimens, test results from specimens that were cured in an alkaline environment were compared to those of standard specimens.**

***Key words:* High-density concrete, low density concrete, Pumice and Vermiculite, NaOH pellets alkaline solution, Compressive Strength, Flexural Strength, Split-Tensile strength, and Rapid Chloride Penetration Test**

1. INTRODUCTION

Concrete is a most common material which is used in construction. It is composed of Cement, which is a binding material, Fine aggregate (Sand), Coarse aggregate (Stones), Water. These are the basic ingredients which are used to produce Concrete. Along these, materials like Fly Ash, Super-plasticizer are also used to produce concrete. It is the leading and most extensively used construction material in the world as the materials used in this mixture are easily available. Wherever there is a construction work we can find usage of concrete there. In early 1970s experts predicted that the maximum strength achieved by the ready-mix concrete would be unlikely to exceed compressive strength greater than 75MPa. Over the past decades, due to development in the high strength concrete, engineers can surpass this limit of strength. The main difference between the High Strength Concrete and the Normal Concrete is the Compressive strength. High Strength Concrete is typically a concrete which has a 28days Compressive strength greater than 40MPa. Concrete is one of the most widely used construction material in the world because of its good strength and durability properties. Cost of construction is also less using the concrete “Dinesh. A [10]” Concrete gains its strength due to the formation of compounds like C2S, C3S, C3A and C4AF1. Cement used in concrete is a complex compound and contains minerals like sulphates, aluminates in the form of Gypsum which is added to cement. When these compounds undergo hydration reaction initial setting of concrete takes place and calcium silicate and calcium aluminate compounds are formed. When further hydration of these calcium silicate and calcium aluminate takes place we get a gel type compound known as CSH gel. This is Calcium-Silicate-Hydrate gel and is responsible for the hardening and strength of concrete. Throughout the process of development of CSH gel, hydration of concrete paste takes place and for this process water is required for curing of concrete so that concrete does not loss its internal water. Water used for curing purpose must be clean and free from any foreign materials so that concrete does not get affected through it.

1.1 Alkaline Environment

Structures which are constructed in and around water bodies such as oceans, seas will continuously get affected by the surrounding environment and the structures always will be subjected to wetting and high amounts of humidity. Sea or Ocean water is an aqueous solution which principally contain Sodium Chloride and Magnesium sulphate. The water in the oceans on an average contain about 35 parts per thousand dissolved salts in it. The major cat-ions present in sea water are Na^{+}, Ca^{++}, Mg^{++} and K^{+}. These compounds are almost found in an un-complex state in this water. The major an-ions are Cl^{-}, OH^{-}, $HCO3^{-}$, $CO3^{-2}$, $SO4^{-2}$. These are also found in un-complex state. The concentration of sea or ocean water may change from place to place but on testing it has been confirmed that there are six major elements which are found almost in all places. They are expressed as milligrams per litre of sea water and are Chlorine 19,000; Sodium 10,600; Magnesium 1,300; Sulphur 900; Calcium 400 and Potassium 380. These six elements almost make 99 percent of the dissolved salts in Ocean water. Other minerals are also present in sea water but no mineral can make it beyond 65 mg/l. The specific gravity of sea water will be in the range of 1.03, due to the presence of excess of alkali metals.

1.2 Objective of the research

In this study we are going to design High Strength Concrete with Normal aggregates. For this mix, High Density Concrete and Low-Density Concrete are achieved by replacing aggregates on the basics of the specific gravity of the aggregate materials and there properties. The objectives of this study are:

- To develop High Density Concrete and Low-Density Concrete using different high-density aggregates and low-density aggregates.
- To compare densities of Conventional Concrete, High density Concrete and Low-Density Concrete.
- To know the effect of different curing conditions such as Normal curing and Normal + Alkaline curing on different concrete mixes.
- The important objective of this study is to compare the strength features of Conventional Concrete, High Density Concrete and Low-Density Concrete like Compressive Strength, Split-Tensile strength, Flexural Strength and RCPT test results which are cured in different curing conditions.
- To know the essential properties of materials used as a part of mix to obtain normal Conventional concrete.

Conventional Concrete is designed to achieve High Strengths up-to 60MPa, and are known as High Strength Concrete. High Density Concrete is achieved using aggregates such as Barite and Haematite. Low Density Concrete is achieved using aggregates such as Pumice and Vermiculite. For these mixes Cubes, Cylinders and Beams are casted and tested for 28 days curing and 56 days curing. Rapid Chloride Penetration Test (RCPT) is also conducted to know the durability of mixes. The difference between densities and strengths of these mixes are compared.

2. EXPERIMENTAL STUDIES ON MATERIALS

High Strength Concrete are made with extreme low water-cement ratio. The use of low water-cementitious ratio will decrease the workability of concrete and high cementitious material will increase thermal expansion during strength development and drying shrinkage in longer term. Hence a High strength Concrete is not necessarily a High-Performance Concrete.
In this study, the effect of Alkaline environment on High Density Concrete and Low-Density Concrete, which are obtained using different High-Density Aggregates and Low Density Aggregates, are compared with the results of Conventional Concrete of M60 grade. For this experiment Cube specimens of size 15cm*15cm*15cm, Cylinders of size 15cm in diameter and 30cm length and Prismatic members of size 15cm*15cm*70cm are used. Also, Rapid Chloride Penetration Test (RCPT) is also done which have size of 5cm in height and 10cm in diameter.

This chapter deals with the materials used in this study to achieve the required Conventional Concrete, High Density Concrete and Low-Density Concrete. To achieve High Density Concrete materials like Barite aggregates and Haematite aggregates are used and for Low Density Concrete Pumice stone and Vermiculite are used.

2.1 Cement

according to the IS: 12269-1987 OPC 53 grade cement attains High early Strength than compared to any other cement but does not increase much after 28 days. It attains high early strength because of its faster heat of hydration. Due to this, the chances of developing micro cracking in concrete are higher. Hence OPC 53 grade cement should be used where there is requirement of higher strength with ("S. Kilincarslan, et.al[1]" explained about the properties of concrete containing barite) good supervision and quality assurance measures are in place and where proper precautions are taken to relieve the high heat of hydration by following a proper curing process.

Table 1: Properties of Cement

Tests	Results
Specific gravity	3.09
Compressive strength (MPa)	53.5
Fineness	7.5%
Initial setting time	36 min
Final setting time	328 min
Consistency	35%

2.2 Fly ash

Fly ash is generally stored in coal plants or in landfills. Fly-ash particles are generally spherical in nature ranging size from 0.5µm to 300 µm. "Osmen Gencel[4]" To replace cement with fly ash, "Ch, V. Manikanta, M. Simhachalam[8]" it must satisfy certain standard regulations such as fineness of 75% of fly-ash should be 45 µm or less and have a carbon content measured through loss of ignition of less than 4%.Depending upon the lime content, fly ash is divided into two groups. Class F fly ash and Class C fly ash.

Table 2: Properties of Fly-Ash

Tests	Results
% Coarser than 45 microns	5.6
Specific gravity	2.24
Loss of ignition, mass percentage	0.57

2.3 Fine Aggregate

In this study locally available fine aggregate which is free from moisture is used. This sand is free from any clayey matter, salts or any other inorganic matter. Fine aggregates which has to be used in the concrete mix has to be tested for properties like specific gravity, "R.S. Muralitharan, V Ramasamy[7]"Fineness modulus and grading zone of aggregate. "R Rajesh Kumar, M Venkatadinesh[6]" The following tests are performed on the fine aggregate and are given in the table.

Table 3: Properties of Fine Aggregate

Tests	Results
Zone	II
Fineness modulus	2.71%
Specific gravity	2.64
Water Absorptions	0.6%

2.4 Coarse Aggregate

In this study, 20mm aggregate crushed stone is used which was brought from Stone Crushing Plant near Gandipet area. For this aggregate test like Specific Gravity, Water Absorption and sizes are tested. Following results are obtained for the coarse aggregate.

2.5 High Density Aggregate

High Density aggregates are used to achieve High Density Concrete. Specific Gravity of these aggregates will be in the range of 3.5 to 7.0. Materials such as Goethite, Limonite, Barites, Magnetite, Haematite, Steel punches are used to produce "Harshavardhan.C, BalaMurugun[2]" High Density Concrete. Steel punches will have a specific gravity of 6.8 -7.8. The usage of these materials in concrete requires proper care so that they have no effect on the concrete mix. "Athira Suresh, Ranjan Abraham [3]"Usually, these aggregates properties differ from Normal Aggregate properties like Specific Gravities, Water Absorption, which have effect on the concrete mix. Hence before using these aggregates directly for mixing purpose, properties of these aggregates must be tested. As mentioned above in this study, Barites and Haematite High Density Aggregates are used to design High Density Concrete.

2.6 Low Density Aggregate

Low Density Aggregates are used to produce concrete with low density. Materials such as Pumice, Scoria, Volcanic cinders, Sintered Fly-ash, Vermiculite, Perlite are used to produce concrete with low density. As these materials have less density compared to normal aggregate when they are replaced with normal aggregate density of the concrete will be reduced and we get Low Density Concrete" Dinesh. A, et.al[10]". In this study, Pumice and Vermiculite are used as low-density aggregates to get Low Density Concrete. For these materials tests like Specific Gravity, Water Absorption are performed so that after knowing these values we can calculate the effect of these aggregates on the concrete mix.

Table 4: Properties of Coarse Aggregates

Tests	Results
Specific gravity	2.64
Water Absorptions	0.7%
Size	20 mm

Properties of Barite Aggregate

Specific gravity	4.0
Water Absorptions	0.3%
Size	20 mm

Properties of Haematite Aggregate

Specific gravity	4.2
Water Absorptions	2.0%
Size	20 mm

Properties of Pumice Aggregate

Specific gravity	0.87
Water Absorptions	11.1%
Size	20 mm

Properties of Vermiculite

Specific gravity	2.06
Water Absorption	2.6%

2.7 Super Plasticizer

In this study, MasterGlenium SKY 8630 is used as Super Plasticizer. MasterGlenium SKY 8630 is an admixture based on modified poly-carboxylic ether. This super plasticizer has been developed for application in High Strength Concrete and High-Performance Concrete where the highest durability and performances are required. Masterglenium SKY 8630, is a super plasticizer which is free from chloride and has low alkali. It can be used with all types of cement.

Table 5: Properties of Super Plasticizer

Properties	Valves
Colour	Light brown
Relative Density	1.08±0.01 at 25°C
PH	6
Chloride ion content	<0.2%
Density	1.06

2.8 Water

The water which is used for casting purpose should be clean from chemicals and foreign materials. The pH of the water should be in the range of 6.5 to 8.5 which is normal and can be used for casting and curing purpose of concrete. To achieve strength for concrete curing is also one of the main processes.

2.9 Mix Design of M60 Grade Concrete

The mix design procedure for M60 grade concrete is done using codes such as ACI 2114R-93 and by using the materials which are good for this mix and test results of these materials known with the help of IS 10262: 2009.

Cement = 530-106= 424 kg

Flyash = 106 kg

Fine aggregate = 550 kg

Coarse aggregate = 1182 kg

Water-cement ratio = 0.31

Superplasticizer = 1%

Table 6: Mix Design Ratios

Concrete type	Mix ratios (Cement+ FA+CA)	W/C ratio	Super Plasticizer
M60 Grade of concrete	1: 1.15: 1.95	0.29	0.47%
HDC-A- Barite High Density Concrete	1:1.2:3.15	0.29	0.47%
HDC-B- Haematite High Density concrete	1:1.5:3.0	0.31	0.49%
LDC-A- Vermiculite Low Density concrete	1:1.11:1.9	0.29	0.47%
LDC-B- Pumice Low Density Concrete	1:1.15:1.3	0.32	0.50%

3. RESULTS AND DISCUSSIONS

In this study, different concretes are studied like Conventional Concrete (CC), High Density Concrete and Low-Density Concrete which are made with high density aggregates and low-density aggregates. In this study two High Density Concretes and two Low Density Concretes are made. One of the high-density concretes is made with Barite and is designated as HDC-A, and the other high density concrete is made with Haematite and is designated as HDC-B. Low Density concretes are made with Vermiculite and Pumice and designated as LDC-A and LDC-B respectively

3.1 Compressive strength

The compressive strength of concrete is tested for 28 days and 56 days curing period for different curing conditions. The results of concrete cured in normal water for 28days and 56days are given in the table.

Table 7: Compressive strength for 28 days normal curing and alkaline cured

Types of Concrete mix	Average Compressive strength of Normal curing (Mpa)	Average Compressive strength of alkaline curing (Mpa)
CC	66.09	64.5
HDC-A	78.01	76.59
HDC-B	46.9	44.41

LDC-A	31.52	28.19
LDC-B	15.193	13.2

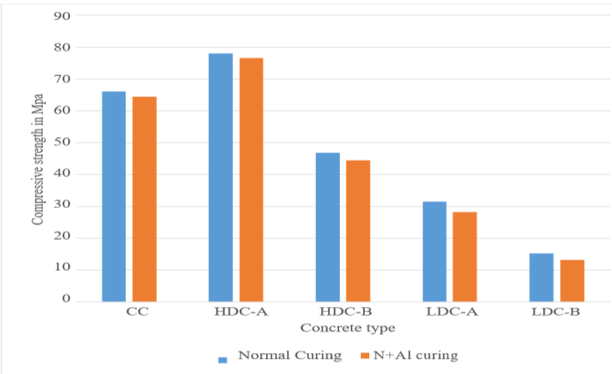

Fig 1: Comparison of Compressive strength values for 28 days curing

Table 8: Compressive strength for 56 days normal curing and alkaline cured

Types of Concrete mix	Average Compressive strength of Normal curing (Mpa)	Average Compressive strength of Normal+alkaline curing (Mpa)
CC	68.90	65.04
HDC-A	80.45	78.149
HDC-B	47.75	45.843
LDC-A	32.13	28.70
LDC-B	15.501	13.75

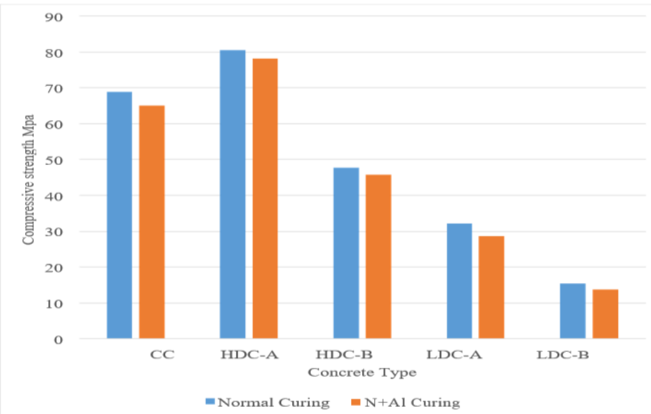

Fig 2: Comparison of Compressive strength values for 56 days curing

3.2 Split Tensile Strength

Now cylinders which are 150mm in diameter and 300mm in length and beams of dimensions 150×150×700mm are cured in all curing conditions for 56 days and are tested. A total of 15 cylinders and 15 beams are casted one as a sample for each mix and curing condition.

The Split-Tensile strength of the cylinder is calculated after 56 days of curing by using the formula:

$$T = 2P/\pi LD$$

Table 9: Split-Tensile Strength for 56 Days Curing

Types of Concrete mix	Tensile strength of Normal curing (Mpa)	Tensile strength of Normal+ alkaline curing (Mpa)
CC	4.173	3.884
HDC-A	4.849	4.815
HDC-B	3.81	3.61
LDC-A	3.038	2.81
LDC-B	1.967	1.79

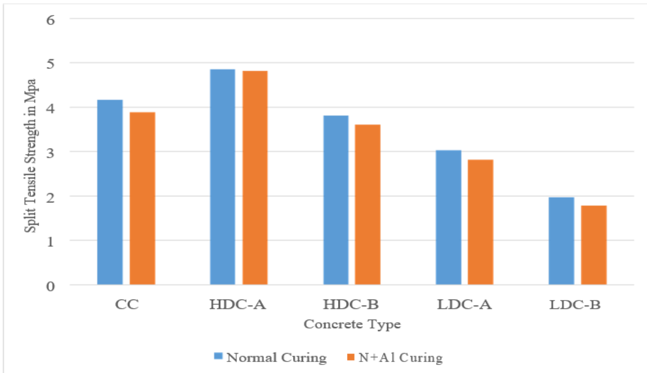

Fig 4: Comparison of Split tensile Strength for 56 days curing

3.3 Flexural Strength

Now beams are tested for flexural strength. As mentioned in, calculation of the flexural strength depends on the distance between the crack and to its nearest support. Based on this distance flexural strength is calculated as per the conditions. The distance of the crack from nearest support for every beam and the load values are given in the table.

Table 10: Flexural Strength of Beams for 56 Days Curing

Types of Concrete mix	Flexural strength of Normal curing (Mpa)	Flexural strength of Normal+alkaline curing (Mpa)
CC	5.99	5.28
HDC-A	6.42	6.36
HDC-B	4.32	3.95
LDC-A	4.05	3.7
LDC-B	2.98	2.61

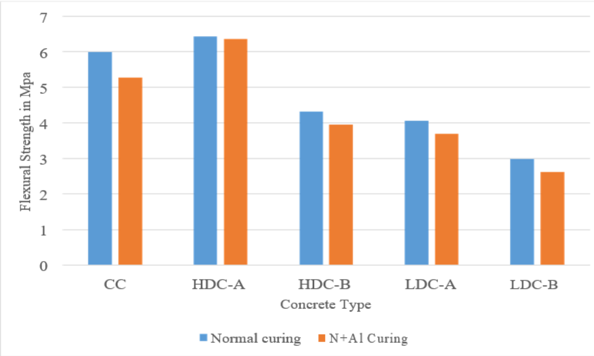

Fig 5: Comparison of Flexural strength of beams for 56 days curing

3.4 Rapid Chloride Penetration Test

Concrete is a structure which consists of many tiny pores in it. Due to the presence these pores there are chances of penetration of chemicals and other harmful elements which can cause damage to the structure like corrosion of reinforcement. As there is an increase in the usage of concrete, there is a great demand for the durability of the concrete. The more durable a concrete the longer lifespan it has. To know this RCPT test is introduced which deals with the chloride penetration into the concrete. "D. Ramachandran[9][5]" Chloride causes corrosion of steel reinforcement in the concrete due to ingress of the chloride ions. It is the most common type of problem concrete structures face in the environment. Corrosion related problems mainly occur in the bridge deck overlays, parking garages, marine structures, and other manufacturing plants.

The current is recorded from the display of the digital meter of the device for every half-hour continuously for 6 hours. The noted values are substituted in a formula to know the charge, so that it will match with the value displayed on the meter with some variation.

Specimen-1 = Conventional M60 grade concrete

Specimen-2 = Vermiculite Low density concrete made with Vermiculite

Specimen-3 = Barite High density concrete made with Barite

Specimen-4 = Haematite High density concrete made with Haematite

Table 11: Comparing Charge Values of Specimens

Types of specimens	Monitor display valves (Coulombs)	Calculated coulombs
Specimen -1	2284	2076.57
Specimen -2	3247	3318.84
Specimen -3	999	992.61
Specimen -4	1126	1125.27

3.5 Discussions

- When the compressive strength of concrete is tested after a curing period of 28 days and 56 days, the results show that under different curing conditions, the maximum strength in HDC-A occurred at 78.01 MPA and 76.59 MPA after the 28-day curing period, while at 56 days it was 80.45 MPA and 78.149 MPA.
- The tensile strength of concrete is evaluated after a curing time of 56 days under a variety of curing circumstances to determine the maximum strength in HDC-A, which ranges between 4.849 and 4.815 MPA. Tensile strengths that are at their maximum are HDC-A.
- The flexural strength of concrete is evaluated after a curing time of 56 days under a variety of situations to determine its maximum strength in HDC-A, which ranges between 6.42 and 6.36 MPA. Tensile strengths that are at their maximum are HDC-A.

- Specimen-1 is a conventional M60 grade concrete has got charge value as 2284 coulombs which has moderate chloride permeability and typically has a W/C ratio of 0.40-0.50 of conventional PCC.
- Specimen-2 is a Vermiculite Low Density Concrete made with Vermiculite has got charge value as 3247 coulombs which has moderate chloride permeability and typically has a W/C ratio of 0.40-0.50 of conventional PCC.
- Specimen-3 is a Barite High Density Concrete made with Barite has got charge value as 999 coulombs which has very low chloride permeability and is typically of Latex-modified concrete or internally-sealed concrete.
- Specimen-4 is a Haematite High Density Concrete made with Haematite has got charge value as 1126 coulombs which has low chloride permeability and typically has low W/C ratio as < 0.40 of conventional concrete.

4. CONCLUSIONS

The density of Barite concrete is 3111.11 Kg/m3 and Haematite concrete is 3007.40 Kg/m3. The density of Vermiculite concrete is 2268.24 Kg/m3 and Pumice concrete is 1521.97 Kg/m3. The Compressive strength of Conventional concrete after 56 days normal curing was 68.90Mpa and Split tensile strength was 4.173Mpa. Flexural strength was found to be 5.99Mpa.

- On comparing Compressive strengths of normally cured concrete mixes, Barite concrete has 14.35% greater strength than Conventional concrete. Haematite concrete has 30.6%, Vermiculite concrete has 53.36% and Pumice concrete has 77.5% less strength than the conventional concrete.
- Split tensile strength of Barite concrete is 13.9% greater than the Conventional concrete. Haematite concrete has 8.6%, Vermiculite concrete has 27.2% and Pumice concrete has 52.68% less Split tensile strength than the conventional concrete.
- Similarly in case of Flexural Strength also Barite concrete has 6.6% greater strength than the Conventional concrete. Haematite concrete has 25.8%, Vermiculite concrete has 32.38% and Pumice concrete has 50.25% less Flexural strength than the conventional concrete.
- The Compressive strength of alkaline cured conventional concrete is 5.6% less than normally cured concrete. Similarly, Barite concrete has 2.8%, Haematite concrete has 3.99%, Vermiculite concrete has 10.6% and Pumice concrete has 11.3% less compressive strength than the normally cured concretes.
- In case of Split tensile strength also alkaline cured conventional concrete has 6.9% less strength than the normally cured concrete. Similarly, Barite concrete has 2.8%, Haematite concrete has 5.24%, Vermiculite concrete has 7.5% and Pumice concrete has 8.9% less Split tensile strength than normally cured concrete.
- Flexural strength of alkaline cured conventional concrete is 10.05% less than the normally cured concrete. Barite concrete has 0.93%, Haematite concrete has 5.1%, Vermiculite concrete has 11.64% and Pumice concrete has 12.41% less Flexural strength than the normally cured concrete.
- From RCPT test values it shows that Barite concrete which has a charge of 999 Coulombs has Very Low chloride permeability then follows Haematite concrete whose charge is 1126 Coulombs has Low chloride permeability. Conventional concrete has a charge value of 2284 Coulombs which has Moderate chloride permeability and charge of Vermiculite concrete is 3247 Coulombs whose chloride permeability falls in Moderate range.
- From all the above discussions, it can be said that Barite concrete is least affected by the alkaline environment than the other mixes. Then follows the Haematite Concrete, Conventional concrete, Vermiculite concrete and last is Pumice concrete.

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