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Experimental Study on Performance of Hardened Concrete Using Nano Materials

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ABSTRACT

Various challenges encountered in the construction industry has led to the production of concrete, with not just high strength, but also with enhanced durability properties. Several research works have been carried out using replacement of constituent materials and introduction of various admixtures in concrete. Alccofine is one of such promising micro fine material. This study investigates the performance of hardened concrete using nano materials. Effects of alccofine (AL) and zinc oxide (ZnO) on the durability and strength of hardened concrete were explored. Series of tests were conducted by substituting cement by weight with 10% AL and adding ZnO in proportions, 0.25%, 0.5%, 0.75% and 1%. Based on the results obtained, the strength properties of concrete reduced as cement replacement level rose beyond 10%. The durability performance of the concrete, in terms of rapid chloride permeability, water permeability test, sea water attack and chloride resistance, was within acceptable limit, even as the ZnO was increased. This study has generally proposed a sustainable solution to produce durable concrete that could have useful aaplication in the construction industry.

1. Introduction

In general, concrete is a heterogeneous mixture used in most of the construction works. Concrete has a complex nature, in that its properties in its fresh and hardened state are different. After concrete curing, excess water from the concrete evaporates, creating ultra fine pores in the concrete. This pores in the concrete pave way to water absorption and chloride ion penetration from the atmosphere, which in turn leads to reinforcement corrosion. Hence for sustainable development, cementitious composites are employed widely to enhance the traditional concrete. But cementitious composites are multi-phased, and multi-scaled materials in nature with time variant characters annexing more complexities (Han et al., 2019). This has led to other studies focusing on the effect of nano sized cementitious composites on concrete, since the performance of concrete is also mostly affected by nano size paticles as well as the micro/ macro scaled contents (Han et al., 2017).

One of such nano sized cementitious composite is Alccofine (1203), which is used as a porous filler and other is Zinc Oxide, employed as a corrosion inhibitor. Alcofine (1203) is an ultrafine low calcium silicate compound, manufactured in India (Micro Materials Private Ltd-Goa). It is a high reactivity slag containing large amount of glass content, manufactured by controlled granulation. The fineness of the alccofine is greater than 12000 cm^2/gm and it has been used to replace cement in concrete to reduce the voids, thus making the concrete impermeable. (Vikram and Banarase, 2015). A study that explored the mechanical properties of alcofine based concrete, has shown that higher values of compressive and flexural strengths were obtained for 10% alcccofine replacement level for cement (Rajesh et al., 2015).

An examination into strength development attributes also make clear that 11% Alcofine addition showed acceptable results in terms of flexural strength, compressive strength and split tensile strength of concrete (Prasanna et al., 2015).

Another study, also showed that performance of concrete using Fly Ash and Nano Silica Fume replacements for cement increased, not only the 28 days compressive strength, but also the

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Table 1. Mix Proportion of Concrete

Mix ID	Mix description	W/C Ratio	Cement kg/m^3	Alccofine kg/m^3	Zinc Oxide kg/m^3	Coarse aggregate kg/m^3	Fine aggregate kg/m^3
CC	Control concrete	0.45	394.00	0	0	1205.54	646.27
AZ-0.25	ZnO 0.25% + Alccofine 10%	0.45	353.15	39.40	0.98	1205.54	646.27
AZ-0.5	ZnO 0.5% + Alccofine 10%	0.45	352.63	39.40	1.97	1205.54	646.27
AZ-0.75	ZnO 0.75% + Alccofine 10%	0.45	351.64	39.40	2.955	1205.54	646.27
AZ-1	ZnO 1% + Alccofine 10%	0.45	347.77	39.40	3.94	1205.54	646.27

Note: AL and ZnO are symbol of Alccofine and Zinc Oxide material.

early strength development (Suresh and Revathi, 2016).

Moreover, the increased strength properties was not only limited to freshwater concrete, but also to salt water concrete (Preeti et al., 2014). The increased compactness and reduced permeability of concrete owing to alkali effect influence the increased strength achieved (Yatin et al., 2013). Attempts made into the durability studies of alcofine and copper slag replaced cement concrete has shown that 10% AL replacement in cement is adequate for optimus performance (Thangapandi et al., 2017).

Similarly, it has been shown that ZnO could reduce the voids within cement composite (Behfarnia and Keivan, 2013). This has been highlighted by extensive research on corrosion inhibition performance of Sodium Nitrite and Zinc Oxide in concrete mixes (Devi and Kannan, 2013). Additionally, studies have shown that incorporation of ZnO reduced the corrosion effect on concrete (Saraswathy and Song, 2007; Nivethitha and Dharmar, 2016). Besides, durability tests on ZnO replaced cement also revealed that addition of super plasticizer becomes essential to ensure workability (Anshul and Archana, 2017) and higher percentage of ZnO addition could really aid strength development in concrete (Arefi and Rezaei-Zarchi, 2012).

With numerous studies focusing on the effect of alcofine and ZnO on the strength and durability characteristics of hardened concrete. However, in this study, an acceptable replacement limits of cement by alccofine and ZnO is proposed for development of hardened concrete that satisfies both strength and durability requirements.

2. Experimental Program

2.1 General

In the present research, the fresh and hardened state properties are determined for M_{35} grade of control- concrete (designated as CC), M_{35} grade of concrete with alccofine and zinc oxide with various percentages. The hardened state properties are limited to compressive strength, tensile strength and flexural strength tests as per IS 516 (1959). Cube specimens of size 150 mm × 150 mm × 150 mm are used to determine the compressive strength at 7, 28 and 56 days of age and water permeability test is conducted at 28 days and 56 days in accordance with IS 3085 (1965). Also, same size of cube is used to determine the chloride resistance and sea water attack test at 28 days and 56 days. Standard specimens of size 150 mm diameter and 300 mm height cylinders are used to determine the tensile strength at 7 and 28 days. Standard specimens are prepared at a standard size of 700 mm × 150 mm × 150 mm to determine the 7 and 28 days flexural strength. Standard cube Specimens 100 mm × 50 mm (for RCPT) are used to measure 28 and 56 days chloride penetration by rapid chloride penetration test (RCPT) as per ASTM C1202 (2010) guidelines.

2.2 Methodology

Mix design was carried out as per Indian Standard code of IS 10262 (2009). The concrete mixtures were made by replacing cement with 10% alccofine and 0.25% to 1% of ZnO were added on weight basis. The mix without alccofine and ZnO is taken as control mix. The adopted concrete mix ratio was 0.45: 1: 1.72: 3.22. Similarly the mix proportion of all the proposed mixes are presented in Table 1.

3. Materials Properties and Mix Proportioning

3.1 Cement

This study used a grade 53 cement for production of test samples. Its properties were obtained in accordance with the requirements of IS 12269 (1987).

3.1.1 Initial Setting Time for Combined Cement, Alccofine and Zinc Oxide

The initial setting time for combined cement and with nano materials (Alccofine and ZnO) are tested in the laboratory. Because the ZnO is insoluble and it affects the setting time and binding property of cement. Hence, ZnO is first dissolved in water and then it was added in cement. The materials are tested as per Indian standard code of IS 12269 (1987). Following mix proportions are used to find the initial setting time. 10% of alccofine with different combinations of ZnO of 0.25%, 0.5%, 0.75% , 1% are added as replacement of cement. The test results are graphically shown in Fig. 1. The results of setting time show an increasing trend with the increasing percentage of ZnO owing to the insoluble nature of ZnO. The physical properties of grade 53cement are given in the Table 2.

3.2 Fine Aggregate and Coarse Aggregate

Fine aggregates are obtained from the river sand available in the

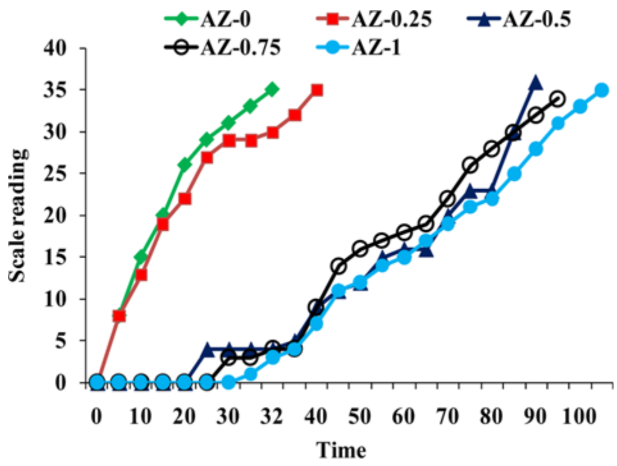

Fig. 1. Initial Setting Time for Combined Cement, Alccofine and Zinc Oxide

Table 2. Physical Properties - Cement

Sl. No.	Physical Properties	Values
1	Consistency (%)	28
2	Specific gravity	3.14
3	Fineness (%)	5%
4	Initial setting time	35 min
5	Final setting time	165 min
6	7 days - compressive strength	38 N/mm^2
7	28 days - compressive strength	55 N/mm^2

Table 3. Properties - Fine and Coarse Aggregates

S. No	Properties	Aggregate	
		Fine	Coarse
1	Specific gravity	2.64	2.77
2	Water absorption in %	1.72	0.45
3	Fineness modulus	4.11	4.12
4	Bulkdensity (kg/m^3)	1563	1625

locality. River sand has similar aggregate grading of zone II. Coarse aggregate is naturally crushed aggregate with the maximum size of 20 mm. Both materials are tested using IS 383 (1970) guidelines. The properties of fine and coarse aggregate are given in Table 3.

3.3 Alccofine

In this study, alccofine 1203 is used. Alccofine 1203 is a product obtained which is processed in a special way through controlled granulation process. It contains slag of highly reactive glass. Alccofine is also used as pozzolanic material due to economical purpose. It has good physical and chemical properties when compared to cement (Parveen et al., 2017). The physical and chemical properties of Alcofine are given in Tables 4 and 5, respectively.

Table 4. Physical Properties - Alccofine

Sl. No.	Properties	Result
1	Water absorption (%)	0.21
2	Specific gravity	2.9
3	Fineness	> 12,000
4	Bulk density (kg/m^3)	836

Table 5. Chemical Properties of Alccofine

C_2O	SiO_2	Al_2O_3	Fe_2O_3	SO_3	MgO
61–64%	21–23%	5–5.6%	3.8–4.4%	2–2.4%	0.8–1.4%

Table 6. Design Parameters for Control Concrte

Sl No	Description	Standard values
1	Grade of concrete	M35
2	Type of cement	OPC 53 Grade
3	Maximum nominal size of C.A	20 mm
4	Maximum water cement ratio	0.55 (IS 456:2000)
5	Workability	100 mm
6	Exposure condition	Severe

3.4 Zinc Oxide

Zinc Oxide (ZnO) is a white, inorganic, water insoluble compound, which is used as an inhibitor in concrete.

3.5 Design Parameters for Concrete

The mix design data for the control concreet is presented in Table 6.

4. Results and Discussion

4.1 Compressive Strength

The compressive strength of concrete was determined after 7, 28, and 56 days of curing. The compressive strength of concrete is given in terms of the characteristic of compressive strength of 150 mm size and the cubes are tested as per the guidelines given in IS 516 (1959). The test results show that average compressive strength for conventional concrete gradually increased through the testing regimes 7th, 28th and 56th days. But compared with concrete having ZnO and alccofine, the average compressive strength for control concrete is less. As depicted in Fig. 2, a rising pattern could be observed in the compressive strength for addition of ZnO upto 0.5%, which could be attributed to the pore filling capacity of ZnO and alccofine (Awoyera et al., 2019). Moreover, the fine materials (AL and ZnO) are also somewhat cementitious in nature, evident by the presence of reactive oxides in their composition, and this may further strengthen the bond zone between the paste and coarse aggregate. This ascertion is backed by the fact that concrete strength development is largely dependent on the density of the interfacial transition zone (Awoyera et al., 2018). Thus, the bonding strength of particles contributed to improved compactness and resulting strength properties of the concrete. The relative compressive

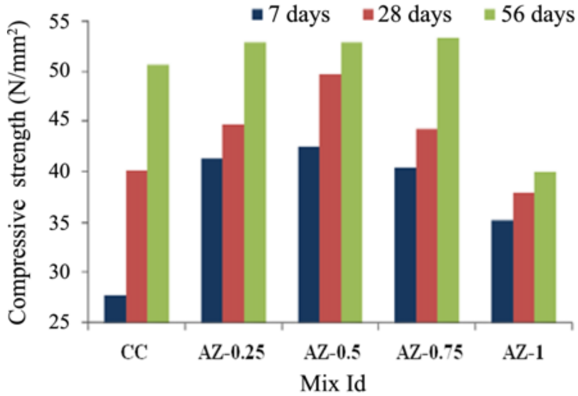

Fig. 2. Compressive Strength of Concrete

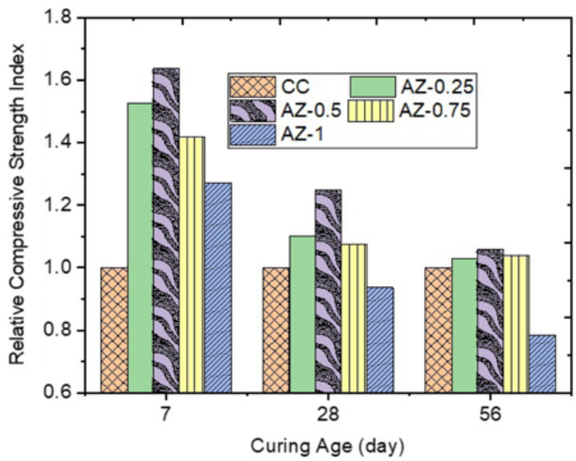

Fig. 3. Relative Compressive Strength Index

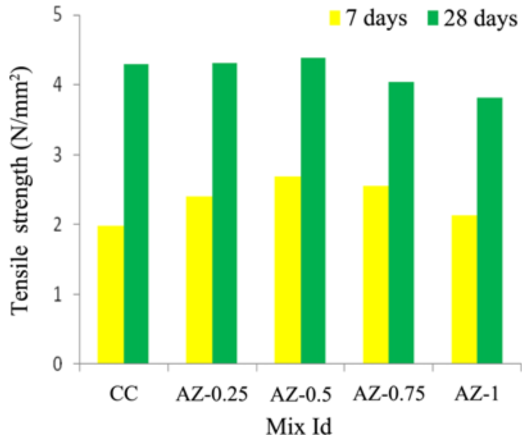

Fig. 4. Tensile Strength of Concrete

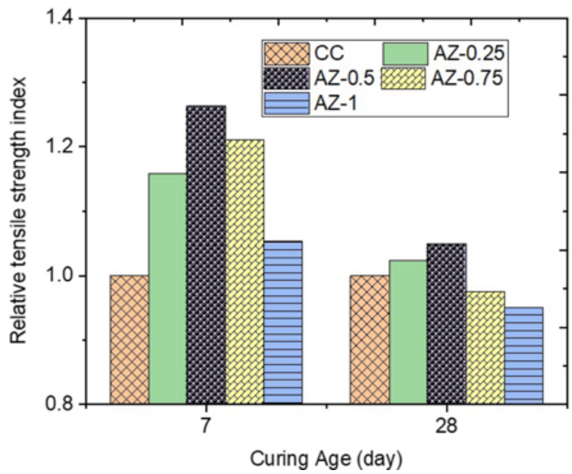

Fig. 5. Relative Tensile Strength Index

strength index (ratio of strength of modified concrete to conventional mix) is presented in Fig. 3. During the early age (7 days curing), the modified mix gained higher strength than the control mix, but this variation in strength redused with increasing uring regimes.

Similary a gradual decrease in compressive strength is also felt beyond 0.5% addition of ZnO owing to the impedence of hydration products formation on ZnO addition.

4.2 Tensile Strength of Concrete

The tensile strength of concrete is determined after curing for 7 and 28 days. The specimens were prepared using designed concrete mix as cylinders of 150 mm dia and height of 300 mm. The specimens are tested as per the guidelines given in IS 516 (1959). The test results exhibit that average tensile strength for conventional concrete is gradually increasing for 7 and 28 days. Fig. 4 shows the concrete tensile strength for different percentage of ZnO. The tensile strength is gradually decreasing with the increase of ZnO percentage for the addition of ZnO beyond 0.5 percentage. The relative tensile strength index (ratio of strength of modified concrete to conventional mix) is presented in Fig. 5. During the early age (7 days curing), the modified mix gained higher strength than the control mix, but this variation in strength redused with increasing.

4.3 Flexural Strength of Concrete

The flexural strength of concrete is determined after curing for 28 days. However, testing was carried out after 7 and 28 days' curing. The prism is prepared with the designed concrete mix of size 700 mm × 150 mm × 150 mm. The prism are tested as per

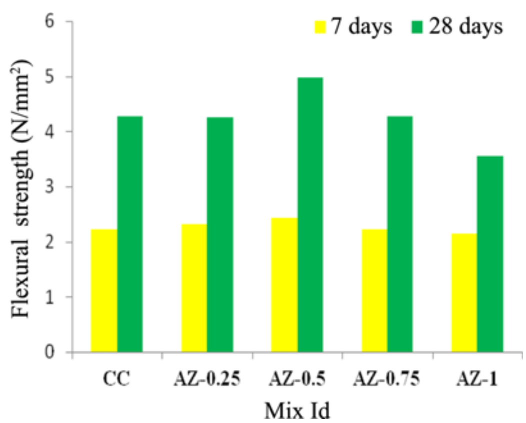

Fig. 6. Flexural Strength – Concrete

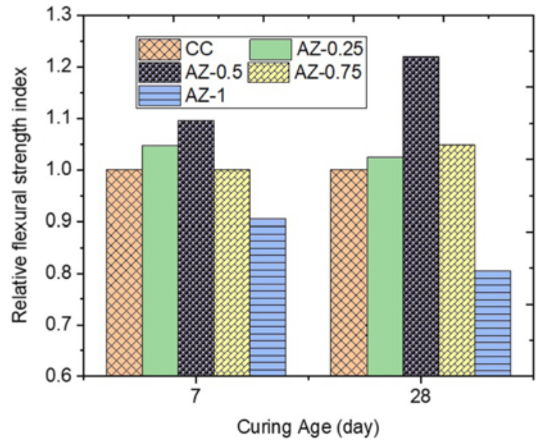

Fig. 7. Relative Flexural Strength Index

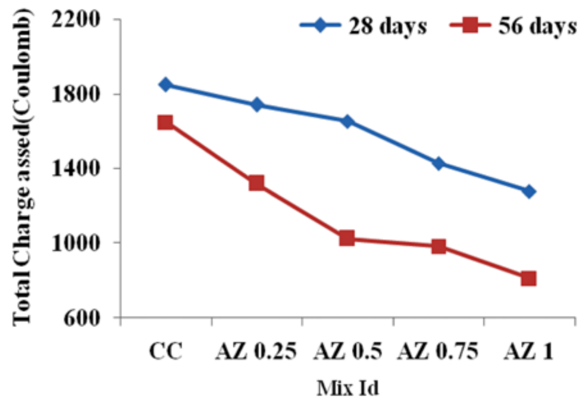

Fig. 9. Depth of Penetration in Water Permeability Test

the guidelines given in IS 516 (1959). The test results make clear that average flexural strength for conventional concrete is gradually increasing for 7th and 28th days. Fig. 6 shows the concrete flexural strength for different percentage of ZnO. The flexural strength is gradually decreasing with the increase of ZnO percentage. The relative flexural strength index (ratio of strength of modified concrete to conventional mix) is presented in Fig. 7. During the early age (7 days curing), the modified mix gained higher strength than the control mix, but this variation in strength redused with increasing.

4.4 Rapid Chloride Permeability Test (RCPT)

This test determines the chloride ion penetration depth of concrete for a period of 28 and 56 days. The test measures the amount of electrical charge (in coulombs) which passes through a 50 mm thick × 100 mm diameter saturated concrete specimen during a 6-hour period. The electrode in the NaCl (3N) solution reservoir is taken as the anode and the positive terminal is connected to the electrode with the NaOH (0.3N) solution. 60 V potential difference is maintained across the specimen ends. A concrete which has a total charge passed of less than 2,000 coulombs and more than 4,000 coulombs are considered to have a low permeability and a high permeability, respectively (Chandramouli et al., 2010). The experimental test results are shows in the Fig. 8. The test results show a decreasing trend of pores with the increasing percentage of ZnO. Thus reduction of pores decreases the permeability and increases the durability of concrete due to the pore filling attribute of ZnO and alccofine. The same has been conformed in the test results from water permeability, Sea water attack test and chloride resistace test as shown below.

4.5 Water Permeability Test

The water permeability test is accepted as a relatively quick and easy test method. The air dried concrete cubes (150 × 150 × 150 mm) were mounted on the table with the suitable rubber gaskets below the cubes. 5 bars of pressure was retained during the tests for a period of 72 hours. The maximum water penetration level was observed from the burette tank and the concrete cube (Erhan, 2014). The samples were taken after 28 days and 56 days of concrete.The tested result shows (Fig. 9) decreasing trend of permeability with the increasing percentage of ZnO. The permeability is reduced and durability of concrete increased.

4.6 Sea Water Attack Test

The sea water (5%) is mixed with distilled water and the sample is cured for 30 days. The weight of the sample is measured. The

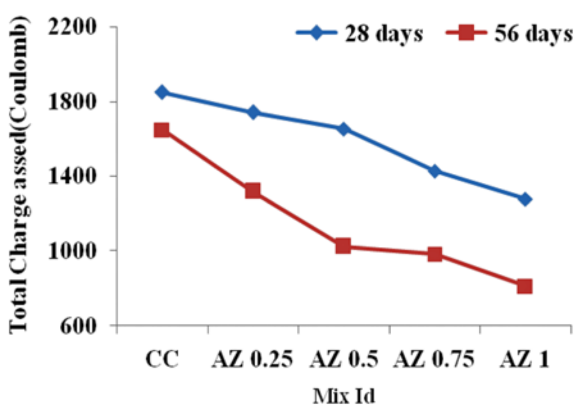

Fig. 8. Total Charge Passed by RCPT

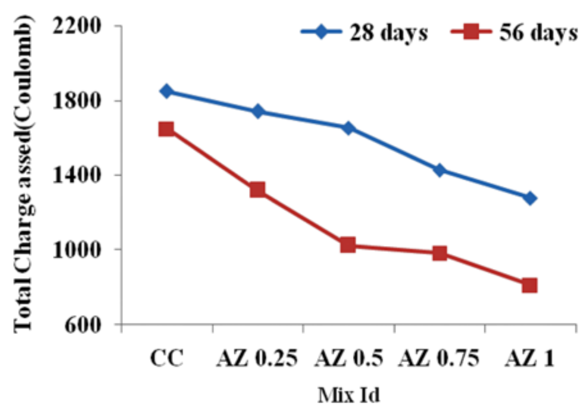

Fig. 10. Percentage of Losses in Sea Water Attack Test

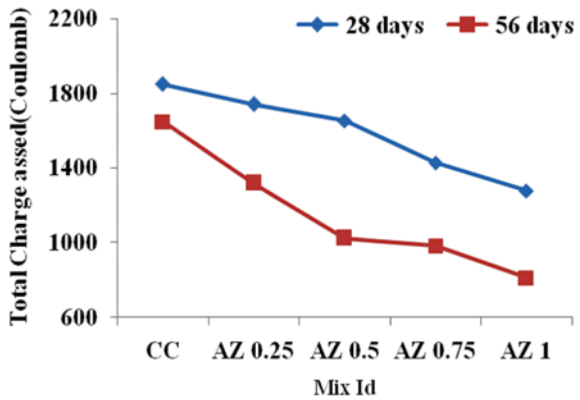

Fig. 11. Loss of Weight and Strength in Chloride Resistance Test

compressive strength of sample is done by compressive testing machine. Both the strength and weight values are compared with the normal curing concrete (Yatin et al., 2013). The seawater attack test result is shown in Fig. 10. As can be seen, both loss in weight and strength of the concrete decreased steadily, with increasing AZ content. Thus, it is an indication that these admixtures are suitable for enhancing the durability performance of concrete.

4.7 Chloride Resistance Test

This test was perfomed in accordance with ASTM C1202 (2010). Sodium chloride (5%) is mixed with the distilled water and the sample is cured for 30 days. The weight of the sample is measured. The compressive strength of sample is done by compressive testing machine. Both the strength and weight values are compared with the normal curing concrete (Yatin et al., 2013). The Chloride resistance test result shows (Fig. 11) that the percentage of strength loss is decreasing and the durability is increased.

5. Conclusions

This study determined the performance of hardened concrete using nano materials. the following conclusions were drawn from the study:

1. Considering the various strength tests, compressive, flexural and split-tensile, the modified concretes reached maximum strength after 10% replacement of Alccofine and 0.5% Zinc Oxide. Thus from the results obtained, it could be deduced that the optimum content of ZnO and alccofine could be demarcated to 0.5% considering the strength and durability properties of concrete.
2. It is observed that conventional concrete has greater permeability when compared to the concrete containing Alccofine and Zinc Oxide. When cement is replaced by alccofine and Zinc Oxide, the permeability of concrete decreased. Also, the tensile strength, compressive strength and flexural strength are increased.
   Overall, the rapid chloride permeability test, water permeability test, sea water attack test and chloride resistance test of concrete with 10 percentage Alccofine and 0.25%, 0.5%, 0.75% & 1% Zinc oxide replacement, ensures increased durability properties than the control concrete. The maximum RCPT value occurred for replacement of cement by 10% Alccofine and 1% Zinc Oxide.
3. The depth of penetration of water decreased with increased replacement content of Zinc Oxide in concrete. to that of Control Concrete in water permeability test. Similarly, in sea water attack test, the resistivity decreased with an increase in Zinc Oxide. While the 1% Zinc Oxide shows 0.81% decrease in weight and 1.66% decrease in strength were observed in modified concrete, compared to that of control concrete.

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