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Original Article

An Experimental Study on Influence of Colloidal Silica on Durability Properties of Concrete

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Abstract *- Concrete plays a vital role among the different construction materials which are available in the world. The major properties of concrete are related to strength and durability aspects. Concrete is a very durable material with less maintenance. For many years, various civil engineering structures have shown deterioration effects. Many research studies have been carried out to analyze the durability characteristics of concrete to reduce the effects. The life of concrete in various structures is determined by important factors such as mix proportions, constituents of the mix, methods of curing, and the surrounding environment. Durability is highly affected by the porous nature of concrete, which enhances the permeability of different materials like water and chlorides. It can be lowered by using various supplementary materials to fill the pores. To withstand the resistance against durability, the application of various nanomaterials in concrete has been developed recently. In the present study, the nanomaterial used is colloidal silica. To study the effect of colloidal silica on the permeability of concrete, an experimental investigation is carried out on the concrete prepared with and without using colloidal silica by conducting water absorption and rapid chloride penetration tests. The results are satisfied with relevant international standards and also revealed that concrete with 40% nano solids content is more resistant to the ingress of water and chlorides when compared to the concrete mix with 30% nano solids content in colloidal silica.*

Keywords *- Colloidal silica, Chloride permeability, Durability, Nanomaterials, Water absorption.*

1. Introduction

Concrete is an important construction material used worldwide because of its versatility. Strength and durability parameters play a crucial role in structures built with concrete. Nowadays, durability characteristics are prioritised more than concrete's strongest aspects. The durability property of the concrete directly resembles the quality of the structures. Concrete is considered durable if it withstands quality, safety, and serviceability when exposed to severe environmental effects. Thus it can be defined as the resistance of concrete against various deterioration conditions. The environment surrounding the structures also affects the durability property. As concrete is a porous material, the pores get filled when exposed to various chemical substances, which will enhance severe durability problems resulting in damage to the structures. It also reduces the life span of the structure. Hence, it is essential to study the concrete resistance to the percolation of water and other chemical materials into concrete pores. This phenomenon can be overcome by using substitute materials in concrete ingredients.

In recent times, the development of nanotechnology has been applied in the civil engineering field by using nanomaterials in concrete. These nanomaterials contain nano-sized particles with a more reactive surface area, resulting in pore-filling activity in the concrete mix and improving the densification of the cement matrix. Colloidal silica is the most important nanomaterial considered in the study. The experimental work uses two different types of colloidal silica based on the percentages of nano solids content. The cement is replaced with the colloidal silica, and the specimens are cast. The results obtained are compared with normal concrete without the nanomaterial. There are different durability tests performed on concrete. Water absorption, permeability, sorptivity, and chloride penetration tests are important. Water absorption and rapid chloride penetration tests are performed on the cast specimens, and the results are analyzed. Matrix densification, absorption, and voids percentages in hardened concrete have been evaluated qualitatively by conducting durability tests on concrete prepared with and without colloidal silica.

2. Literature Review

Dhipanaravind et al. (2022) studied the effect of mineral admixtures on the durability properties of concrete, and the results showed improvement compared to normal concrete.[1] Manish Kewalramani(2021) et al., had studied the impact of different supplementary cementitious materials on concrete mixes by conducting water absorption and rapid chloride penetration tests.[2]Vora1(2019) et al., had used supplementary cementitious materials, such as Ground Granulated Blast furnace Slag and nano-silica combinations with Ordinary Portland Cement to find the effect of High durability properties of strength concrete.[3] Prashanth (2019) et al., had examined the durability properties of concrete added with nanomaterials which showed positive effects. The pore size distribution also showed that nano silica refined the large capillary pores, subsequently decreasing the permeability nature of concrete and enhancing its durability.[4] Arunabh Pandey(2019) et al., had studied the effects of rice straw ash and micro silica on durability properties (water absorption and chloride ion penetration) of M40 grade pavement quality concrete and observed a reduction in the water absorption and chloride ion penetration in concrete samples with an increase in the curing age as well as with an increase in the proportion of rice straw ash and micro silica.[5] Jemimah Carmichael et al. (2018) assessed the properties of concrete by replacing coarse aggregate with nanomaterials.[6] Rex et al. (2018) introduced concrete bacteria and studied concrete's mechanical properties at various dosage percentages.[7] Ahmed Al Ghabban et al. (2018) studied the individual. They combined the effect of nano silica and nano calcium carbonate as partial cement replacements on concrete's strength, durability, and flowability characteristics.[8] Prathebha et al. (2017) presented an experimental study on the effect of nanomaterials in various percentages in cement mortar by evaluating the strength and durability aspects.[9] Darshan et al. (2017) presented the impact of mineral admixture like nano-silica in cement and also studied its effect on the various properties of concrete.[10]Lanjewar Pranay et al. (2017) summarized the effect of cement replacement with nano-silica on the strength and durability aspects of concrete. Results concluded that a huge amount of these nanomaterials decrease the properties of concrete.[11] Ranjith(2017) assessed the effect of various fibres on concrete. Also, durability tests such as a rapid chloride penetration test, sorptivity, water absorption, acid attack, and sulphate attack were measured.[27] Palla et al. (2017) studied the effect of silica nanoparticles in concrete mixed with fly ash. These particle insertions in concrete have developed the strengths at optimum content.[13] Swapnil Walzade (2016) et al. studied the effect of colloidal nano-silica at different percentages, incorporating high-strength concrete and fly ash.[14] Karthika (2016) compared the properties between conventional concrete and nano concrete in terms of strength and durability. It resulted in the development of nanomaterials for paving the path to reduce the cement content in conventional concrete mixes, leading to greener concrete production.[15] Dharma raj (2016) et al., had studied the combined effect of fly ash and corrosion inhibitor on self-compacting concrete to obtain durability characteristics. To find durability, the Rapid Chloride Permeability Test (RCPT) was conducted for 7 and 28 days of curing periods. The results revealed that adding Corrosion Inhibitor mixes would have lesser permeable voids than conventional concrete.[16] mixes. Eskandari (2015) et al., had presented the effect of various additives on mechanical properties and durability, which was investigated by Electrical Resistivity (ER) and Rapid Chloride Penetration Test (RCPT) at the ages 28 and 90 days.[17] Nasution(2015) et al. discussed incorporating nanomaterials in concrete, enhancing durability.[18] Shohana Iffat et al. (2014) conducted tests to carry out Rapid Chloride Permeability Test (RCPT) using improvised apparatus made of readily available low-cost materials. Several RCPT tests were performed using this simple method, and results showed marked variation in chloride permeability for concrete with different qualities.[19] Constantinides et al. (2013) et al. studied the most suitable materials for replacing cement to reduce its environmental effects. And also presented the importance of theoretical and experimental results using these materials.[20] Amudhavalli (2012) et al., had investigated concrete's strength and durability characteristics at various curing periods.[21] Omer Mohammad Abdul(2012) et al., had assessed the mechanical strength and durability performance of the concrete by incorporating various contents of ordinary Portland cement and w/c.The study results showed that the increase of cement content and the reduced w/c leads to more durable concrete because of loss of absorption and porosity characteristics.[28] Shekari et al. (2011) investigated the durability properties through chloride penetration tests and concrete permeability. Results have shown that nanoparticles can effectively improve concrete's mechanical properties and durability.[23] Fred Andrews Phaedonos (2008) et al., had introduced the principles underpinning the VPV durability test method and high lightened its advantages over other durability test methods.[24] He Xiaodong et al. (2008) examined the chloride permeability and microstructure of Portland cement mortar with nano materials admixed at 1% by weight of cement.[25] Brouwers(2006) et al. discussed using nanotechnology in concrete to attain sustainability. Also assessed was the application of the mineral oxides and particle sizes in the engineering field aspects. [26]Hence based on the above literature, it has been observed that nanomaterials have greatly impacted various properties of concrete. In the present study, the percentage variation of nano solids content in silica is varied, and its effect on the durability characteristics of concrete is considered as the primary objective of the work.

3. Materials and Properties

3.1. Cement

OPC 43 grade of Sagar brand having a specific gravity of 3.11 is used as the cement in the study.

3.2. Fine Aggregate

River sand belonging to Zone-II is used as fine aggregate in the study.

3.3. Coarse Aggregate

Aggregate of sizes 20mm and 10mm is used in the present study.

3.4. Water

Fresh and clean potable water free from organic impurities, acids and alkalies is used in the study.

3.5. Colloidal Silica

Colloidal silica used in the study is of two different types based on the percentage of nano solids content present in the liquid.

4. Experimental Investigation

An experimental investigation is conducted in this study to assess the durability properties of concrete made with and without using colloidal silica along with a conplast SP-430 superplasticizer. Tests are conducted on materials to know their physical properties. Also, tests are performed on hardened concrete to study its durability. The water absorption of concrete made with and without colloidal silica is determined by conducting tests on concrete cube specimens of 150x150x150 mm. Chloride penetration of concrete made with and without colloidal silica is determined by performing tests on cylindrical concrete specimens of 100 mm diameter and 50 mm thickness. Results are studied to assess the effect of both types of colloidal silica on the durability aspects of concrete.

The nomenclature used for prepared concrete specimens is given below:

- C20 represents concrete specimens of M20 grade.
- C40 represents concrete specimens of M40 grade.
- S0 represents concrete specimens consisting of 0% nano solids of silica.
- S30 represents concrete specimens consisting of 30% nano solids of silica.
- S40 represents concrete specimens consisting of 40% nano solids of silica.

5. Results and Discussions

5.1. Density, Absorption, and Voids in Hardened Concrete

To evaluate the effect of colloidal silica of both types on concrete durability, the water absorption test is conducted on concrete specimens of size 150x150x150 mm made with 30 % and 40% nano solids content of silica as per ASTM C642.

After 28 days of curing, specimens are taken out from the curing tank, air-dried, and then the weights of the specimens are noted. After that, these specimens are oven dried for 48 hours and subjected to a temperature of 100^0 C. The weights of the specimens are taken after cooling them to room temperature. Then the specimens are immersed in water for 48 hours. They are taken out at the end of 48 hrs, and weights are noted to determine the Saturated Mass. To determine soaked, boiled, surface-dried mass, the specimens are boiled continuously for 5 hrs at a temperature of 100^0C using an accelerated curing tank. After boiling, the specimens are taken outside, and the weights are noted. Finally, the specimens are suspended in water by a wire to determine the apparent mass in the water. Water absorption, bulk density, and voids percentage are calculated from all the weights obtained.

Fig. 1 (a) Oven-dried specimens

Fig. 1 (b) Immersed specimens in curing tank for saturation

The values of water absorption, percentage of void ratio, and bulk density obtained for M20 and M40 grades of concrete made with and without colloidal silica are presented in Table 1. Figs. 1(a) to 1(d) show the specimens in various stages to determine the oven-dry mass, saturated mass after immersion, saturated mass after boiling, and immersed apparent mass in water.

Fig. 1 (c) Immersed specimens in an accelerated curing tank for boiling

Fig. 1(d) Specimens under suspension in water by a wire

Table 1. Values of density, Water Absorption, and percentage voids of concrete specimens made with and without colloidal silica

Mix Type	Water Absorption (%)		Bulk Density (gm/cc)		Void Ratio (%)	
	C20	C40	C20	C40	C20	C40
S0	3.36	2.69	2.44	2.52	7.76	6.11
S30	3.24	2.50	2.46	2.54	7.49	5.74
S40	3.05	2.42	2.48	2.57	7.25	5.54

A decrease in water absorption of M20 grade concrete made with colloidal silica having 30% nano solids is observed by 2.68 % compared to the reference mix. Whereas concrete made with colloidal silica of type 40% nano solids had shown a 5.36% decrease in water absorption.

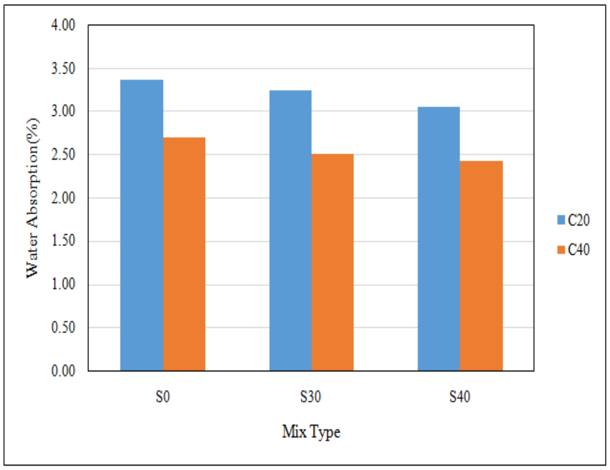

Fig. 2 Comparison of values of water absorption of concrete with and without colloidal silica

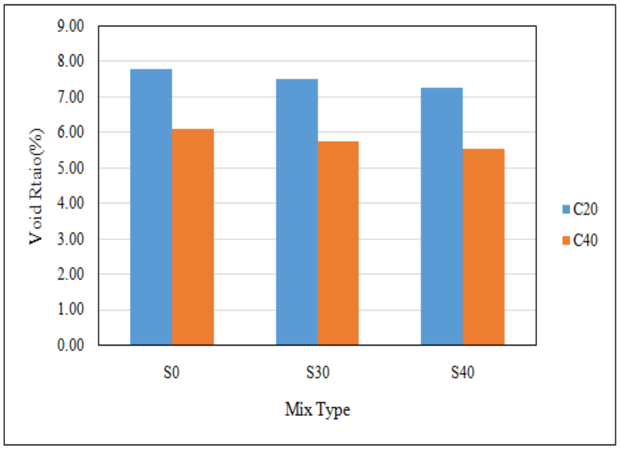

Fig. 3 Comparison of values of the void ratio of concrete with and without colloidal silica

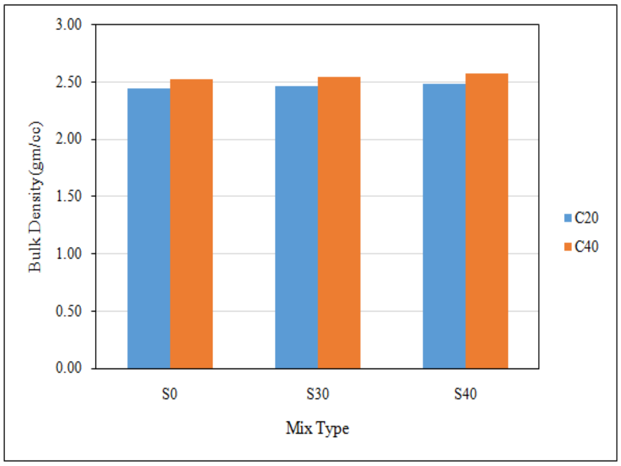

Fig. 4 Comparison of values of bulk density of concrete with and without colloidal silica

Similarly, the decrease in values of water absorption for M40 grade are 1.17 % and 4.69%, respectively, for concrete made with 30% and 40% nano solids content of silica compared to the reference mix. The values of water absorption obtained for M20 grade concrete specimens are observed to be maximum when compared to M40 grade concrete.Fig.2 compares the water absorption values of hardened M20 and M40 grade concrete specimens with the colloidal silica type at 28 days. The test results showed that the colloidal silica type significantly affects hardened M20 &M40 concrete specimens for water absorption.

The decrease in values of void ratio for M40 grade are 4.27% and 4.43%, respectively, for concrete made with 30% and 40% when compared to reference mix. Similarly, the decrease in values of void ratio for M20 grade concrete made with colloidal silica having 30% nano solids is observed to be 0.13% compared to the reference mix. Whereas concrete made with colloidal silica of type 40% nano solids has shown a 1.55% decrease in void ratio. The 30 % nano solids content of silica in M20 concrete has shown higher water absorption and voids ratio values, respectively, compared to concrete made with 40% nano solids content. This trend is the same for M40-grade specimens.

The values of bulk density obtained for both mixes made with two types of colloidal silica are similar. There has not been much difference in the values obtained. The values of bulk density obtained for M40 grade concrete are the maximum compared to M20 grade concrete specimens.

5.2. Correlations between Water Absorption and Void Ratio

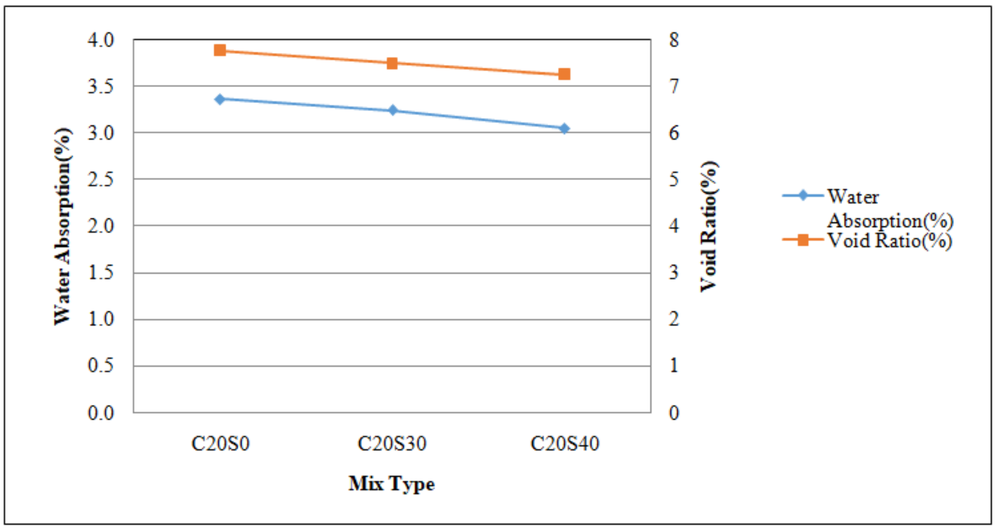

Fig. 5 Comparison of water absorption and void ratio for M20 grade concrete made with both types of colloidal silica and reference concrete

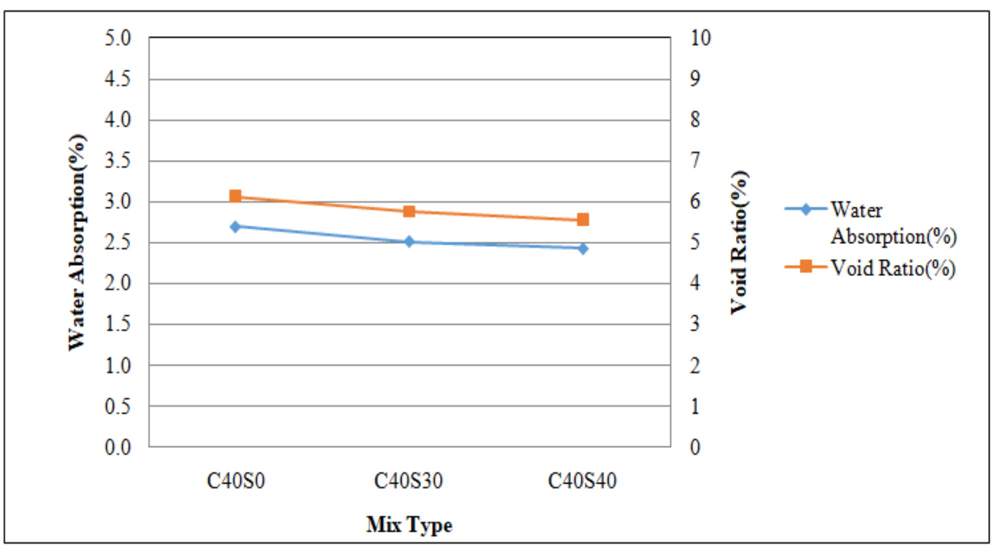

Fig. 6 Comparison of water absorption and void ratio for M40 grade concrete made with both types of colloidal silica and reference concrete

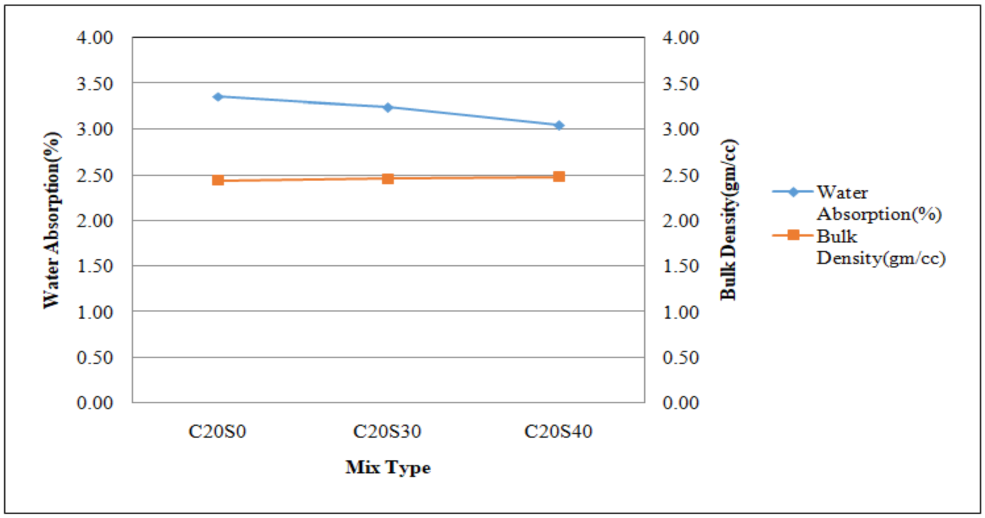

Fig. 7 Comparison of water absorption and bulk density for M20 grade concrete made with both types of colloidal silica and a reference concrete

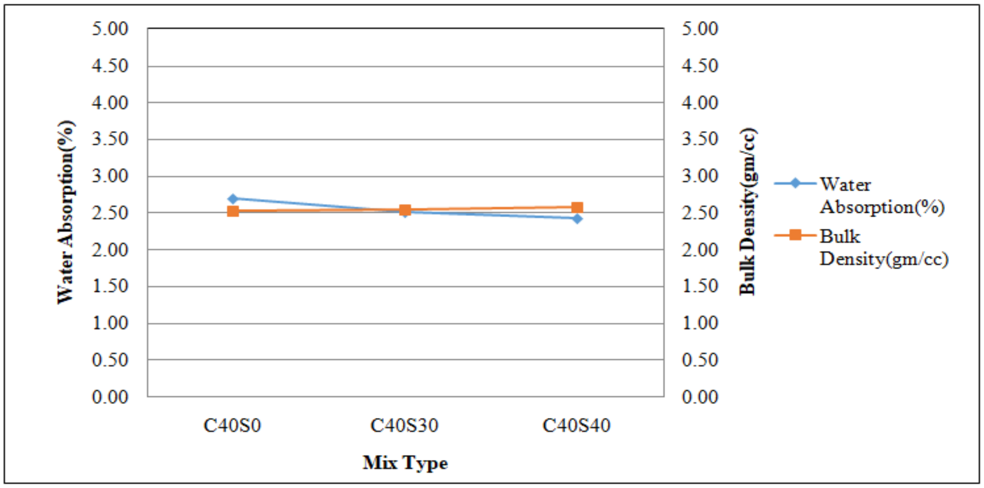

Fig. 8 Comparison of water absorption and bulk density for M40 grade concrete made with both types of colloidal silica and reference concrete

Fig. 7 and 8 shows the correlation between water absorption and bulk density for concrete made with colloidal silica of both the types and reference concrete.

5.2 Rapid Chloride Penetration Test (RCPT)

The RCPT test is conducted as per the ASTM C1202 code. This test method monitors the amount of electrical current passed through test specimens for 6 hours. Concrete specimens of 100 mm diameter and 50mm thickness are cast and allowed to cure for 28 days to conduct RCPT. After curing, the concrete specimens are subjected to an RCPT test by passing through a voltage of 60 V between two glass containers filled with 3% NaCl solution and 0.3N NaOH solution. Current in amperes was measured every 30 minutes up to 6 hours. One side of the glass container filled with NaCl is connected to the negative terminal of the power supply, whereas; the other side of the container filled with NaOH is connected to the positive terminal of the power supply. The experimental setup is shown in Fig.6. Chloride permeability was calculated in Coulombs at the end of 6 hours using the resulting current and time. The total charge passed in coulombs has been found to be related to the resistance of the specimen to chloride ion penetration. The current measured should be in amperes.

The charge passed through the specimens is calculated based on the equation given below:

$$Q = 900\ (I_0 + 2I_C + I_{360})$$

where,

$I_C = I_{30} + I_{60} + I_{90} + I_{120} + I_{150} + I_{180} + I_{210} + I_{240} + I_{270} + I_{300} + I_{330}$

Q= charge passed (coulombs),

I_0=Current in amperes immediately after the voltage is applied, and I_t=Current in amperes at t minutes after the voltage is applied from 0 min to 6 hours at an interval of 30 minutes.

Fig. 9 RCPT Set up in the laboratory

The results of chloride charged ions obtained for both mixes are compared to the values given in Table 2 to determine the chloride permeability based on charge passed as per ASTM C1202 specifications.

The values of charge passed through M20, and M40 grades of concrete made with and without colloidal silica are presented in Table 3.

Table 3 and Fig.10 show that the values of chloride ion charge passed through M20 grade concrete specimens with 30% of nano solids are observed to be decreased by 11.45% compared to 0% nano solids. The charge passed through concrete having 40% nano solids of silica is increased by 44.8 % when compared to 0% nano solids. However, chloride-charged ions passed through concrete having 40% nano solids are decreased by 37.69 % when compared to concrete having 30% nano solids of silica content.

Table 2. Limits of Chloride ion permeability along with charge passed

Charge passed (coulombs)	Chloride ion penetrability
>4000	High
2000-4000	Moderate
1000-2000	Low
100-1000	Very low
<100	Negligible

Table 3. Values of charge passed through concrete made with and without colloidal silica

Charge passed, Q(Coulombs)		
Mix Type	**C20**	**C40**
S0	1634.4	1553.4
S30	1447.2	1287
S40	901.8	783.9

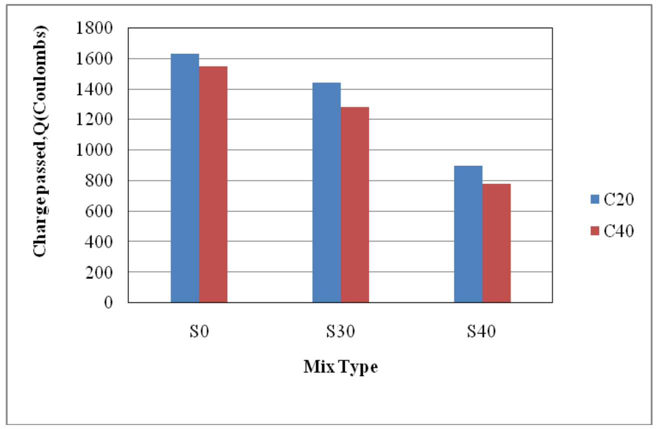

Fig. 10 Comparison of values of charge passed through concrete made with and without colloidal silica

Similar to M20 grade specimens, the results of chloride-charged ions for M40 grade are observed to be increased for concrete with 30% of nano solids compared to concrete with 40% of nano solids. The decrease is 17.15% for concrete with 30% of nano solids when compared to 0% nano solids. At the same time, the decrease is 49.54% for concrete having 40% of nano solids. Chloride-charged ions passed through concrete having 40% nano solids are decreased by 39.09 % when compared to concrete having 30% nano solids of silica content. From the above "Q" values, it is observed that the chloride ion permeability is very low for concrete mix types M20 and M40 concrete with 40% nano-silica solids. Table 3 shows that the chloride ion permeability is low for M20 and M40 grade concretes made with 0 % and 30% nano solids.

6. Conclusion

The effect of using both types of colloidal silica on water absorption and chloride permeability is studied.

(i) Colloidal silica in concrete can greatly affect water absorption. The water absorption is observed to be decreased for both grades of concrete using both types of colloidal silica.

(ii) The percentages of both water absorption and void ratio for all the types of concrete made with and without colloidal silica have decreased as the grade of concrete increased from 20 to 40. The use of 40% nano solids content of silica in concrete decreased the water absorption compared to the use of 30% nano solids content of silica. It may be due to the increase in the percentage of solids content in colloidal silica.

(iii) The positive correlation is observed between water absorption and void ratio for concrete mixes made with both types of colloidal silica and reference mixes.

(iv) The chloride permeability of the concrete made with and without colloidal silica has exhibited low penetration of water, indicating the resistance of concrete against the ingression of chemical solutions is good.

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