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Studies on Effect of Sulphuric Acid Attack on Concrete Made with Colloidal Silica as Replacement and Addition to Cement

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ABSTRACT

Rapid face of urbanization has lead to increase in concrete production, rising concerns about its implications for climate change, depletion of resource materials and environmental degradation. Concrete is prone to attacks by various aggressive environment effects. Depending upon the requirements, different types of concrete have been developed using nano based materials. One of the most used materials at nano scale is nano silica. The effect of use of nano silica in the form of colloidal silica is used in the present study as replacement and addition to cement to study the sulphuric acid attack on concrete. Colloidal silica with 30% of nano solids of SYCOL-TX is replaced and added to cement in different proportions i.e., 0, 0.5, 1, 1.5, 2, 2.5 and 3% respectively. Optimum mix is found out by conducting compressive strength test to concrete specimens after 28 days of curing. The test samples prepared with optimum content of colloidal silica are immersed in different concentrations of 1.5, 3, 4.5 and 6% sulphuric acid solution for a time period of 28, 56, 90 and 180 days, after 28 days of water curing. Visual appearance, weight loss and compressive strength lossare determined in the study to study the effect of sulphuric acid attackon concrete specimens. From the results it is observed that incorporation of colloidal silica in concrete enhances its compressive strength and resistance to acidic environments in terms of durability.

Keywords: compressive strength, colloidal silica, sulphuric acid, visual appearance, weight loss.

INTRODUCTION

Concrete is extensively used material in construction industry. The increased demand for concrete has lead to environmental pollution with the emission of carbon dioxide to reduce the amount of carbondioxide released into the atmosphere, the concrete made with various available mineral admixtures have been developed. In the recent past, the inclusion of nano silica supplementary cementations material or mineral admixture can enhance the properties of concrete, due to high pozzolonic activity. Due to high filler effect micro structure of concrete become less porous and resistant to ingress fluids. The durability aspect of concrete as drawn interest about the properties of concrete made with nano silica against aggressive environment. Due to the rapid industrial expansion and wide usage of fossil fuels leads to environmental pollution and ecological destruction (Yong, 2020). Random spillage of sulphuric acid in industries, acid rains and sewagesystems are some of the major sources of the acid attack, which impacts thedurability of the concrete (Hadigheh et al., 2017). In long term after concrete is attacked by acid it causesloss of compressive, split tensile and flexural strength of the concrete, cracks areformed across the corroded layer and formation of gel like layers consisting hydrogels of silica, alumina and ferric oxide, which deteriorates the concrete (Alamanda et al., 2018). Resistance to chemicals and the durability of concrete is effected by its curing and finishing etc., and composition of concrete such as type of cement, aggregate and admixtures (Umale et al., 2019). Durability is an important property of concrete which determines the service life of concrete. In aggressive environments, concrete resistance to acid plays a crucial role as it affects the durability and impacts the concrete life. Portland cement does not have resistance to acids. This impacts the mechanical properties and structural performance of concrete. It is necessary to develop a concrete technology which can perform better under aggressive conditions withoutany loss to durability and mechanical properties of concrete (Aswin et al., 2023). Concrete used in sewage system constructions required to be durable for longer periods as it is themajor concern in concrete sewer pipes. This might be becauseof aggressive waste water and sewer atmosphere. So it is crucial to regulate the durability of concrete to different corrosive circumstances (Madraszewski et al., 2023). Farismatalkah et al. (2018) conducted an experiment to study the durability properties of concrete using with alkali alumino silicate and Ordinary Portland cement. From their observations, concluded that the concrete with alkali aluminosilicate as an admixture showed better results in loss of compressive strength and weight when compared to ordinary Portland cement when samples exposed to acid solution. Turkel et al. (2007) conducted their studies on effects of various acids on pozzolanic cement and compared with Portland cement. From their studies it is observed that the Portland cement performed better when compared with pozzolanic cement. They concluded that with increase in concentration of acid, greater the weight loss of cement mortar. Omkaret al. (2017) conducted their tests on concrete using fly ash and correlated with nominal concrete. From their observations they concluded that concrete incorporated with fly ash had low resistance to sulphuric acid when compared to control concrete. Pandey et al. (2020) researched on effects of aggressive environment and accelerated carbonation curing on concrete using rice straw ash as admixture. They concluded that there is improvement in the resistance of concrete to acid attack is more significant when micro silica is used as admixture. Naseeruddin et al. (2019) investigated on effects of acid curing environment on the strengths and durability of concrete with various percentages of sulphuric acid and hydrochloric acid. From their observations they concluded that acidic curing has shown negative effect on strength and durability of concrete and did not achieve desired serviceability. Strength declined with respect to increase in acidic concentration. To increase the durability of structures to acid attacks novolac epoxy floor resins need to be used. Irico et al. (2020) studied on effects of sulfuric acid on SCC with Granulometrically enhanced blast furnace slag as a sample and compared with Ordinary Portland Cement. They stated that the cement type does not affect concrete with lower water cement ratio and optimized (improved, revised) concrete technology. Incorporation of fly ash might perform better to acid attack. Granulometrically optimized slag cement can be used to increase the durability characteristics of concrete. Anwar et al. (2024) conducted their research on resistance of Ternary blended concrete compound adapted with graphene oxide for concrete sewers. Their study focused on enhancing durability of concrete to acid attacksfor sewers using GOTBNCCs. They prepared samples with different proportions of GO and immersedin sulfuric acid solution with a pH value of 1.0. The incorporation of GO based ternary blended concrete technology had significantly improved the acid resistance of concrete. Min et al. (2018) conducted their study on sulfuric acid corrosion mechanism for concrete in soaking environment based on reaction boundary layer theory. Concluded from their observations that decomposed layer of concrete does noteffected by pH value. From the results it is observed that when the pH value decreased and the water-cement ratio and cement proportion increased. Raghunathan (2021) reviewed on acid attack on concrete to study durability and vulnerability aspects. Specimens of 150 mm cubes were exposed to hydrochloric acid, sulphuric acid and lactic acid and compared these specimen results with conventional concrete. From their observations they concluded that intrusion of polyethylene or polyvinyl liner inside the sewer pipe. Even though it is costly, but when compared to replacing the whole system in metropolitan areas it is economical. Nano silica, carbon nano tubes and nano alumina have significantly increased the performance of concrete with incorporation of these materials. Kumar et al. (2024) conducted their experiments with bottom ash geopolymer concrete (BAGPC) to different aggressive environments and compared with conventional concrete. The strength loss and weight loss of bottom ash geopolymer concrete (BAGPC) showed better results when compared to conventional concrete. They concluded that geopolymer concrete showed better bonding strength among steel and concrete and from microstructural studies it is observed that the concrete is less porous. Madraszewski et al. (2022) conducted their experiments to acquire knowledge on durability and performance of concrete in an aggressive environment on ordinary Portland cement (OPC), Sulfate resistance concrete (SRC) and ultra-high-performance concrete (UHPC). The main aim of their studies is to get insights on the impact of mechanical abrasion on the progress of concrete corrosion in different types of acid attacks on concrete. They concluded that when compared to OPC remaining two samples performed better. Rao et al. (2021) investigated on properties of concrete under acid attacks. Primary objective of their study was to assess the concrete properties prepared with single and blended binders to mild, severe and really severe conditions using vitrol solution. They have used Portland lime stone cement and SCM (fly ash, silica and nano-silica. Several studies reported that alkali activated cement showed better resistance to chemicals over Portland cement. Umale et al. (2021) in this paper, they study the effects of acid exposure on strength of concrete. The samples are exposed to sulfuric acid, hydrochloric acid and nitric acid for 30 and 60 days after completion of water curing for 28 days. Specimens are immersed in 5% and 10% concentration of acids. From their observations they concluded that there is a negative impact on density and compressive strength of concrete specimens exposed to acid.

MATERIALS AND TEST METHODS

The various materials used in the study are Cement, Fine Aggregate, Coarse Aggregate, Colloidal Silica and super plasticizer.

Cement

Ordinary Portland cement of Grade 53 confirming to IS code 8112-2013 is used in the study. Basic tests on cement are conducted as per IS codes to find out the physical and chemical properties of cement. Specific gravity of cement is 3.11 and chemical properties of cement are presented in Table 1.

Aggregates

Concrete is filled with both fine and coarse aggregate, around 60 to 70% of its volume. Fine and coarse aggregate plays crucial role on properties of concrete.

Coarse aggregate

Locally available crushed stone passing through 20 mm and 10 mm having specific gravity of 2.78 and 2.74 respectively confirming to IS 380-2016 are used as Coarse aggregate. Coarse aggregate plays a crucial role in concrete for achieving better strength and durability.

Fine aggregate

Aggregate passing through 4.75 mm sieve having specific gravity of 2.63 confirming to zone II is used as fine aggregate.

Water

Water plays an important role in concrete. It initiates the process of hydration and improves the workability of concrete. Appropriate proportion of water cement ratio is necessary to attain desired firmness of concrete. Locally available potable tap water is used for preparation of concrete according to IS code recommendation.

Mineral admixture

Colloidal silica of SYCOL-TX consisting of 30% of nano solids content is used in the present study. Properties of colloidal silica are presented in Table 2.

Super plasticizer

Conplast SP-430 is a sulphonated naphalene polymers based plasticizer. The Specific gravity of Conplast SP-430 is 1.20 at 20 °C

Table 1. Chemical composition of cement

Chemical composition	SiO_2	Al_20_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	Loss on ignition
Percentage available	21.98	4.71	4.13	63.85	1.11	0.05	0.55	2.50	1.12

Table 2. Colloidal silica properties

Property	Colloidal silica (SYCOL-TX)
Nano solids	30%
pH	9–10
Specific gravity	1.20–1.21
Viscosity	4–6 cp

Sulphuric acid

Sulphuric acid of 98% purity is used in the study.

Mix proportion

M40 grade concrete mix design is carried out corresponding to IS 10262-2019, use of colloidal silica of type SYCOL-TX containing 30% of solid content. The mix proportions of M40 grade reference concrete is 1:1.56:2.82 with water cement ratio of 0.39.

Casting

Concrete cubes of size 150×150×150 mm are cast with different percentages of colloidal silica (0, 0.5, 1, 1.5, 2, 2.5 and 3%) as replacement and addition to cement to determine compressive strength of M40 grade concrete for finalizing the optimum content of colloidal silica. Further concrete cubes of size 100×100×100 mm are cast with optimum content of colloidal silica and cured at 28 days for immersing then in of sulphuric acid solution at different concentrations to study the effects of sulphuric acid attack on M40 grade concrete.

Compressive strength test

Compressive strength test is performed on cube samples of size 150×150×150 mm according IS 516-2019 in compressive testing machine at 7 and 28 days of curing period.

Sulphuric acid attack

For creating acidic environment to concrete, diluted sulphuric acid solutions were prepared for different concentrations of 1.5, 3, 4.5 and 6 % respectively as shown in Figure 1. The concentration of acid was checked thoroughly by using titration method and kept constant concentration by adding extra sulphuric acid, if needed. The tests were conducted at a time period of 28, 56, 90, 180 days and conducted compressive strength test and loss of weight to find out the impact of sulphuric acid on concrete to different proportions.

RESULTS AND DISCUSSIONS

Compressive strength

The results of compressive strength of M40 grade concrete with and without colloidal silica with different percentages 0, 0.5, 1, 1.5, 2, 2.5, 3% as addition and replacement to cement are shown in Figures 2 and 3. From the Figure 2 it is observed that the concrete mixes made with colloidal silica as replacement to cement showed higher compressive strength than conventional concrete. The compressive strength of concrete incorporated with colloidal silica specimens is enhanced when cement is replaced up to 2% colloidal silica and decreased slightly as increasing the colloidal silica. The compressive strength of concrete incorporated with colloidal silica are improved by 1.86, 3.5, 7.37, 13.92, 9.02 and -2.47% respectively at a replacement of 0.5, 1, 1.5, 2, 2.5 and 3% when compared to conventional concrete. The increase

Figure 1. Different concentrations of sulphuric acid solution

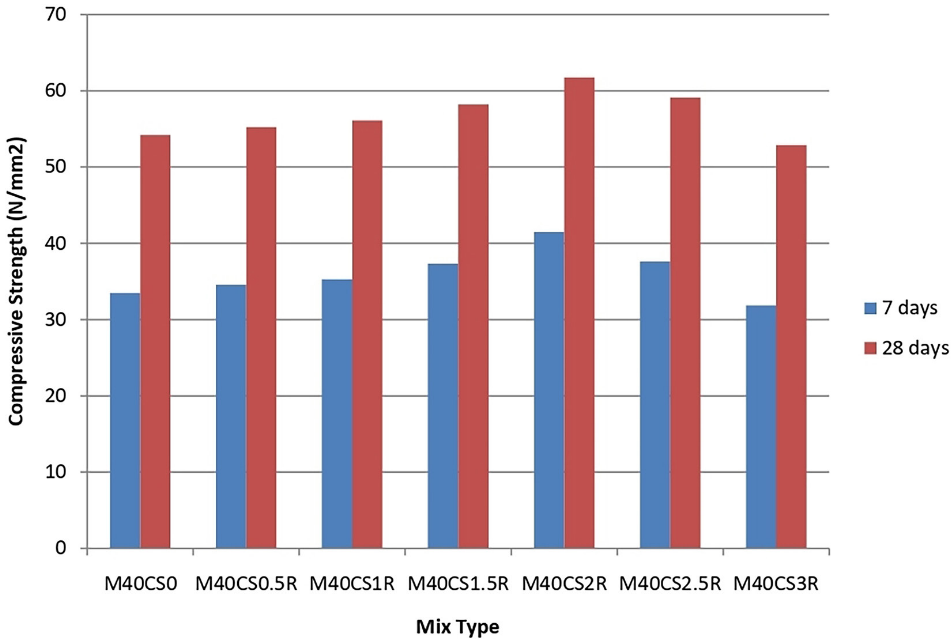

Figure 2. Compressive strength comparison of M40 grade concrete made with colloidal silica as replacement to cement

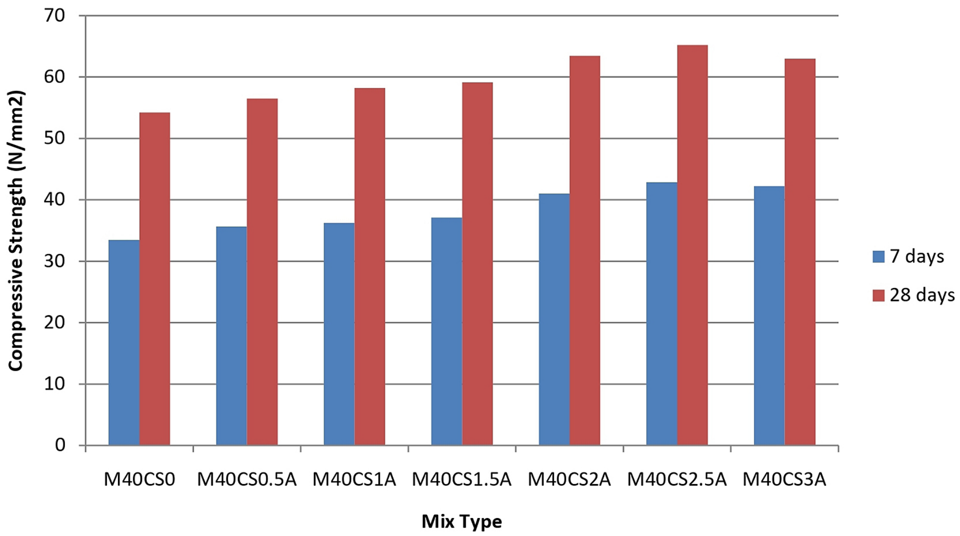

Figure 3. Compressive strength comparison of M40 grade concrete made with colloidal silica as addition to cement

in compressive strength of concrete is observed to be maximum for concrete made with 2% colloidal silica. The improvement in strength is due to filling of voids with colloidal silica. The compressive strength of concrete incorporated with colloidal silica as addition to cement increases with the increase of colloidal silica up to 2.5% and further decreased as the addition of colloidal silica increases. The compressive strength of concrete with colloidal silica are improved by 4.17, 7.36, 9.03, 17.00, 20.27 and 16.15% respectively at addition of 0.5, 1, 1.5, 2, 2.5 and 3% when compared to conventional concrete. The decrease is due to usage of excess nano solids particles. These particles react with calcium hydroxide paste, thus reducing the compressive strength of the concrete (Prasanna Kumar et al., 2022).

Sulphuricacid attack

Concrete specimens which are cast with optimum content of colloidal silica as 2%

replacement to cement and 2.5% of colloidal silica as addition to cement are demoulded after 24 hrs and are kept in water for curing for a period of 28 days. After that, the specimens are weighed and exposed to different concentrations of sulphuric acid at different time periods. The specimens are taken out dried and wiped out with a clean cloth. The deterioration of concrete specimens when exposed to different concentrations of sulphuric acid solution is identified by visual appearance, loss of weight and compressive strength loss.

Visual appearance

The preliminary investigation is to observe change in texture, discoloration and surface deterioration of concrete specimens by visual appearance.The visual appearanceof concrete specimens exposed to different concentrations of suphuric acid solution is shown in Figs. 4 to 15.

Weight loss

Weight loss of M40 grade concrete specimens made with colloidal silica as replacement and addition to cement is determined by weighing the specimens before and after exposing the specimens to different concentrations of sulphuric acid solutions at 28, 56, 90 and 180 days. The results of weight loss of all type of specimens are represented in Figs. 16 to 19.

From to Figs.16 to 19, it is observed that the percentage weight loss observed that the percentage weight loss obtained for conventional concrete M40CS0 specimens immersed under 1.5% concentration of sulphuric acid are 0.56, 0.93, 1.75 and 2.4% at 28, 56, 90 and 180 days respectively. Whereas the specimens immersed in 3% sulphuric acid concentration the percentage weight loss are 4.8, 5.52, 7.72 and 10.79%. Similarly the specimens immersed in 4.5% of

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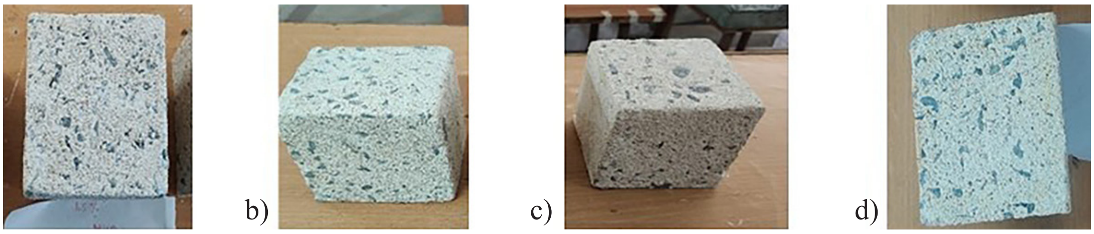


Figure 4. Visual appearance of M40CS0 specimens after exposure to 1.5% concentration of sulphuric acid solution, (a) 28 days, (b) 56 days, (c) 90 days, (d) 180 days

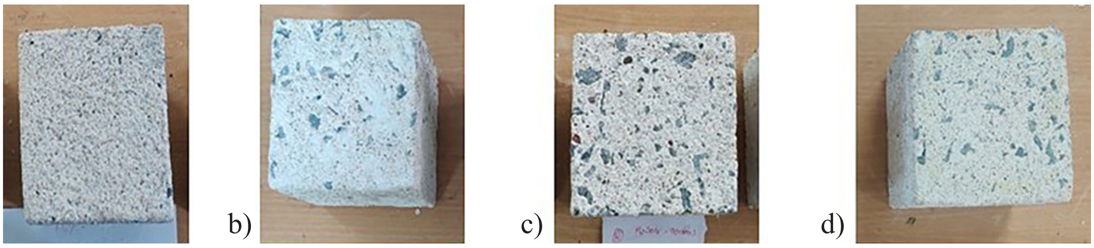
a) b) c) d)


Figure 5. Visual appearance of M40CS2R specimens after exposure to 1.5% concentration of sulphuric acid solution, (a) 28 days, (b) 56 days, (c) 90 days, (d) 180 days

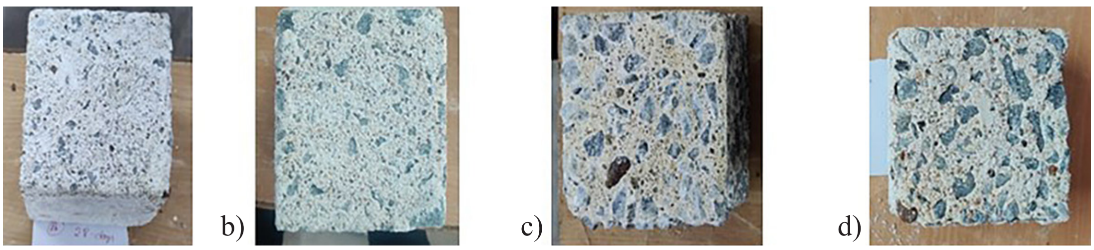
a) b) c) d)


Figure 6. Visual appearance of M40CS2.5A specimens after exposure to 1.5% concentration of sulphuric acid solution, (a) 28 days, (b) 56 days, (c) 90 days, (d) 180 days

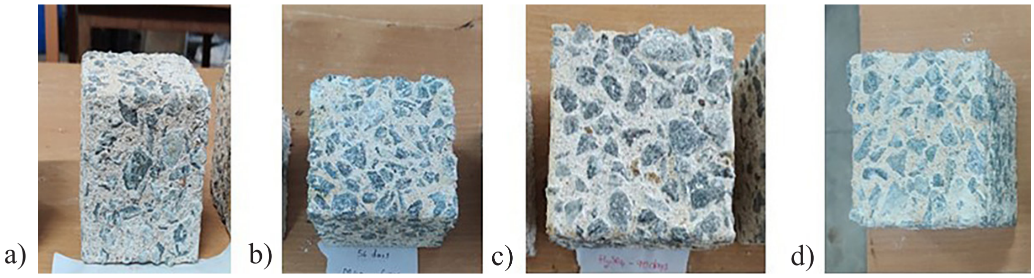


Figure 7. Visual appearance of M40CS0 specimens after exposure to 3% concentration of sulphuric acid solution, (a) 28 days, (b) 56 days, (c) 90 days, (d) 180 days

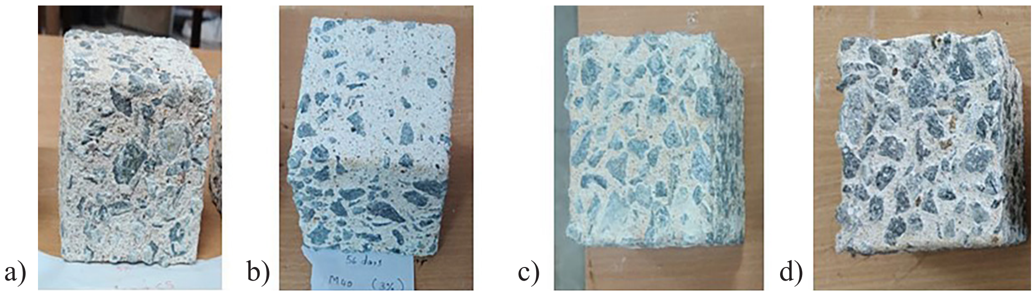


Figure 8. Visual appearance of M40CS2R specimens after exposure to 3% concentration of sulphuric acid solution, (a) 28 days, (b) 56 days, (c) 90 days, (d) 180 days

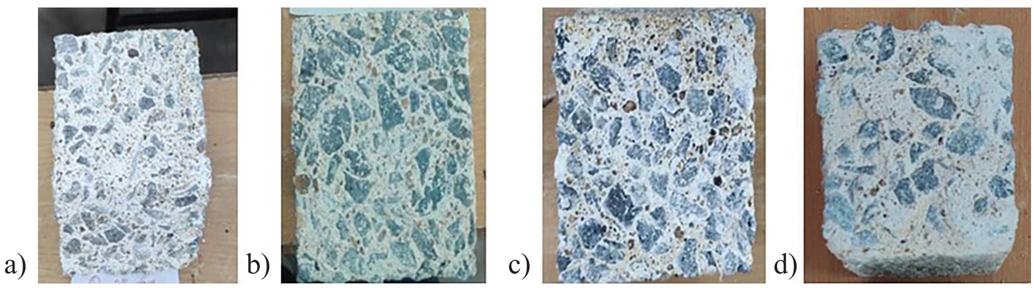


Figure 9. Visual appearance of M40CS2.5A specimens after exposure to 3% concentration of sulphuric acid solution, (a) 28 days, (b) 56 days, (c) 90 days, (d) 180 days

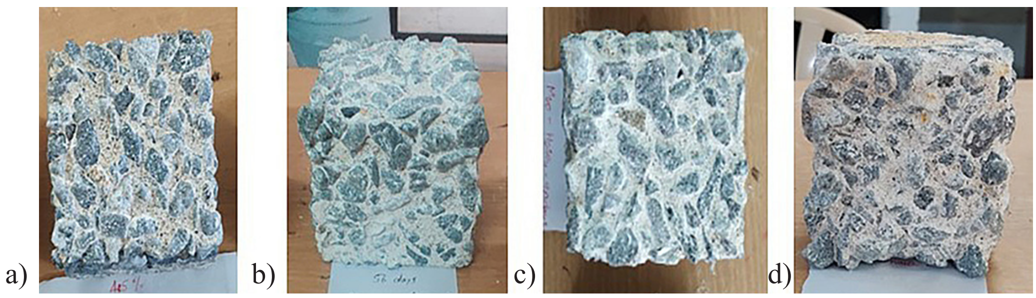


Figure 10. Visual appearance of M40CS0 specimens after exposure to 4.5% concentration of sulphuric acid solution, (a) 28 days, (b) 56 days, (c) 90 days, (d) 180 days

sulphuric acid concentration, the percentage weight loss are 10.32, 12.78, 20.20 and 23.3% and for specimens immersed in 6% sulphuric acid concentrations the percentage weight loss are 15.34, 18.74, 26.21 and 31.24% is observed at different immersion periods of 28, 56, 90 and 180 days respectively.Similar observations are obtained for concrete M40CS2R and M40CS2.5A specimens. The percentage weight loss observed for concrete M40CS2R and M40CS2.5A are

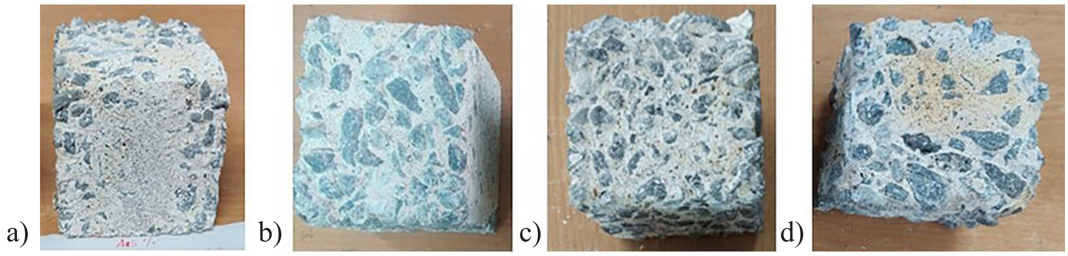


Figure 11. Visual appearance of M40CS2R specimens after exposure to 4.5% concentration of sulphuric acid solution, (a) 28 days, (b) 56 days, (c) 90 days, (d) 180 days

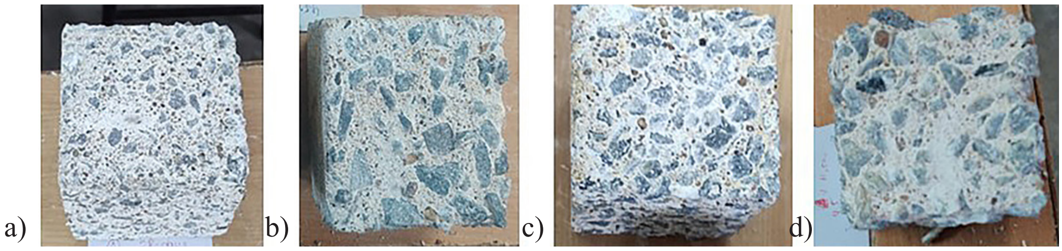


Figure 12. Visual appearance of M40CS2.5A specimens after exposure to 4.5% concentration of sulphuric acid solution, (a) 28 days, (b) 56 days, (c) 90 days, (d) 180 days

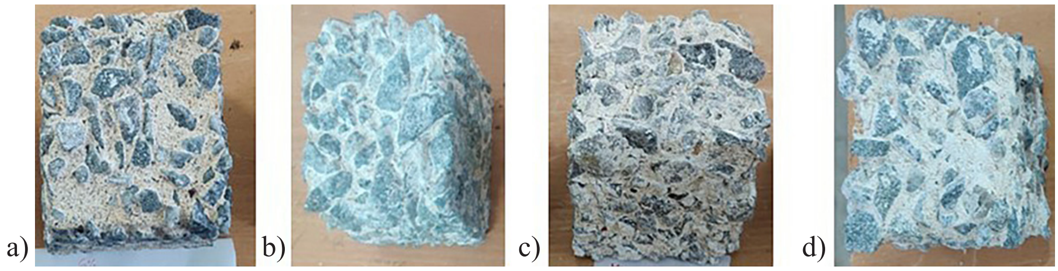


Figure 13. Visual appearance of M40CS0 specimens after exposure to 6% concentration of sulphuric acid solution, (a) 28 days, (b) 56 days, (c) 90 days, (d) 180 days

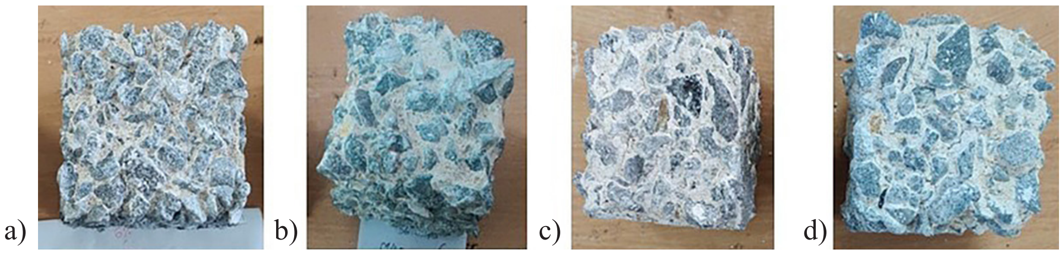


Figure 14. Visual appearance of M40CS2R specimens after exposure to 6% concentration of sulphuric acid solution, (a) 28 days, (b) 56 days, (c) 90 days, (d) 180 days

found to be very less compared to conventional concrete (M40CS0) at all concentrations of sulphuric acid. The percentage weight loss observed for M40CS2R is in the range of 0.38 to 25.61% whereas for M40CS2.5A is in the range of -1.07 to 27.42% is observed. As the concentration of sulphuric acid increases the percentage weight loss also increases.

Loss in compressive strength of concrete to acid attack

The percentage loss of compressive strength of M40 grade concrete made with colloidal silica as replacement and addition to cement is determined by ratio of strength loss to the values of compressive strength before immersing the

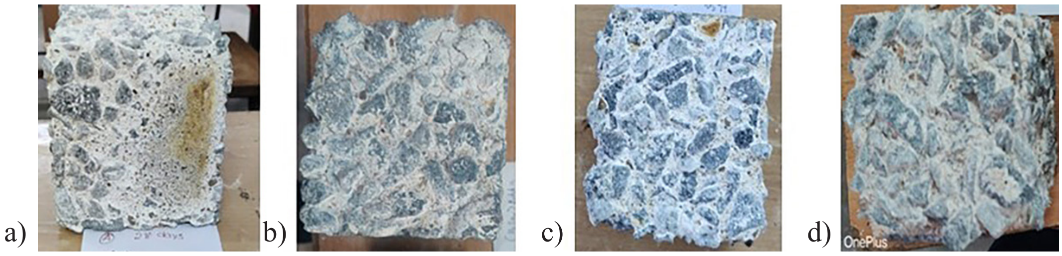


Figure 15. Visual appearance of M40CS2.5A specimens after exposure to 6% concentration of sulphuric acid solution, (a) 28 days, (b) 56 days, (c) 90 days, (d) 180 days

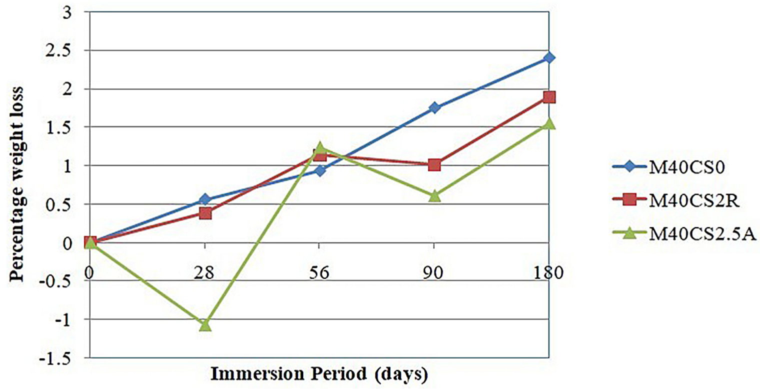


Figure 16. Variation of percentage weight loss of specimens immersed in 1.5% concentration of sulphuric acid solution

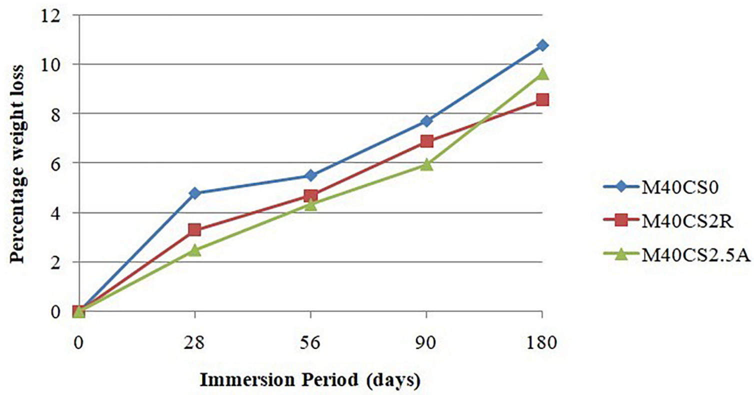


Figure 17. Variation of percentage weight loss of specimens immersed in 3% concentration of sulphuric acid solution

samples in different concentrations of sulphuric acid solution at 28, 56, 90 and 180 days respectively. The results of percentage relative compressive strength of M40CS0, M40CS2R and M40CS2.5A concrete specimens are shown in Figures 20 to 23.

From Figs. 20 to 23, the percentage loss in compressive strength for M40CS0 are found to be 5.88%, 11.76%, 21.56% and 31.37% at 1.5% of sulphuric acid concentration. Whereas at 3% sulphuric acid concentration, the percentage loss of compressive strength are 9.80%, 17.65%, 23.53% and 35.29%. Similarly at 4.5% and 6% of sulphuric acid concentration the percentage loss of compressive strength are15.67%, 21.57%, 33.33%, 41.18%and21.57%, 27.45%, 41.18%, 47.06% of at different immersion periods of 28, 56, 90 and 180 days respectively.

The percentage loss in compressive strength for M40CS2R is observed to be 3.28%, 11.48%, 19.67% and 26.22% at 1.5% concentration of sulphuric acid. At 3% sulphuric acid concentration

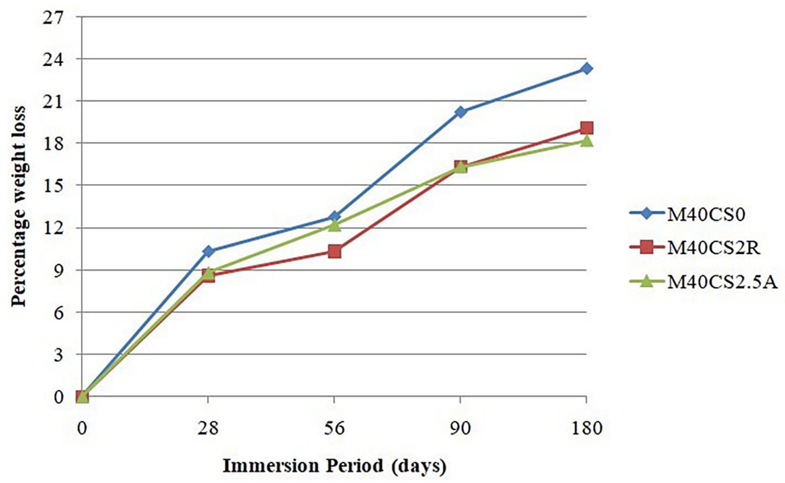


Figure 18. Variation of percentage weight loss of specimens immersed in 4.5% concentration of sulphuric acid solution

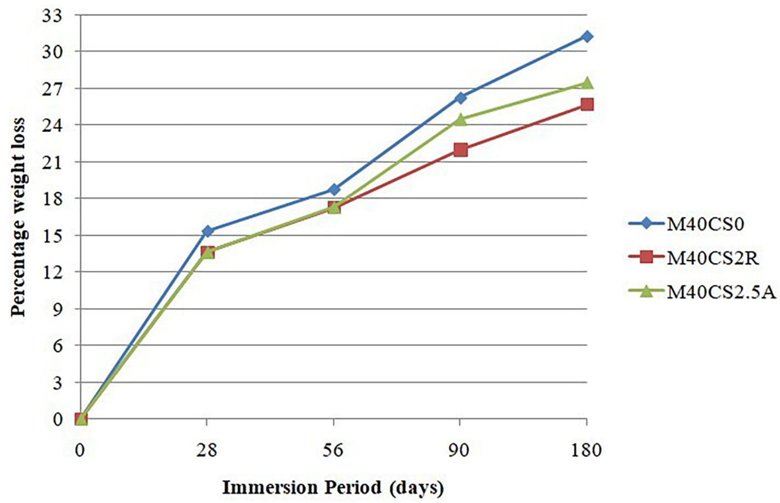


Figure 19. Variation of percentage weight loss of specimens immersed in 6% concentration of sulphuric acid solution

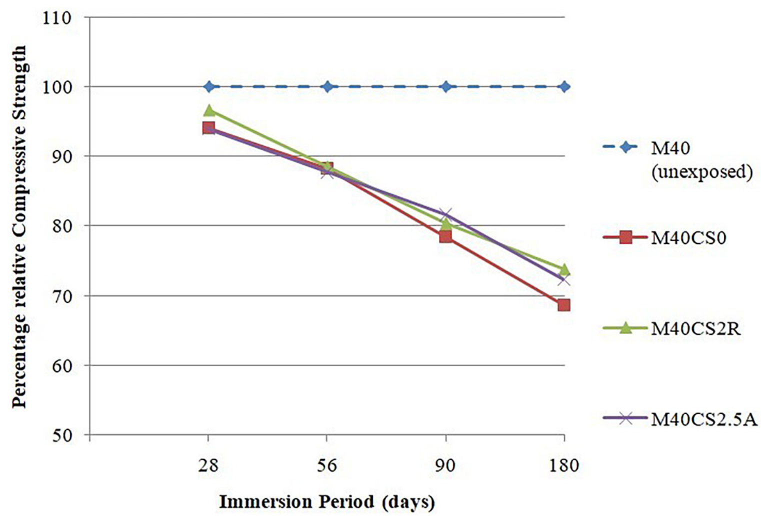


Figure 20. Percentage variation of relative compressive strength of specimens immersed in 1.5% sulphuric acid concentration with immersion period

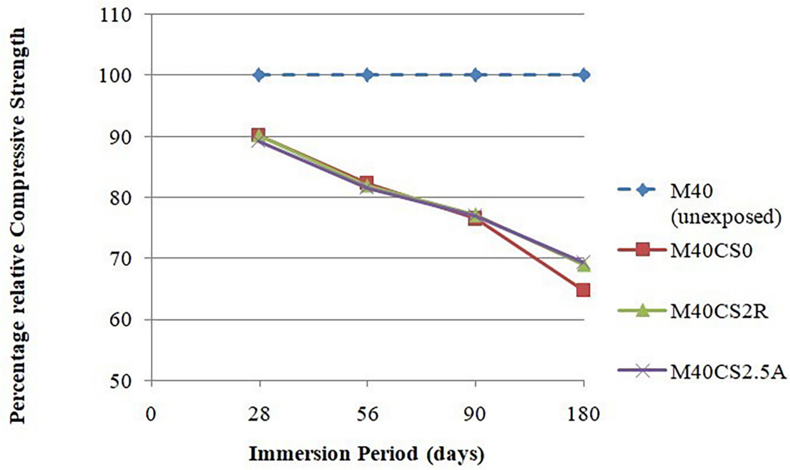


Figure 21. Percentage variation of relative compressive strength of specimens immersed in 3% sulphuric acid concentration with immersion period

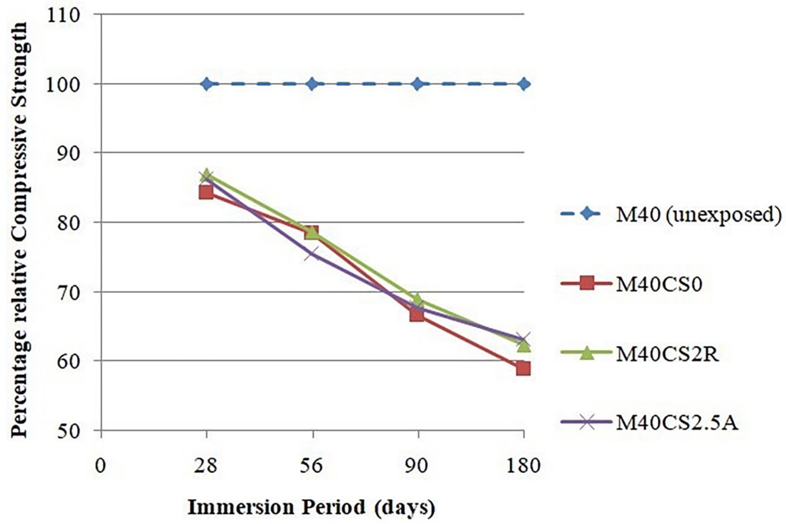


Figure 22. Percentage variation of relative compressive strength of specimens immersed in 4.5% sulphuric acid concentration with immersion period

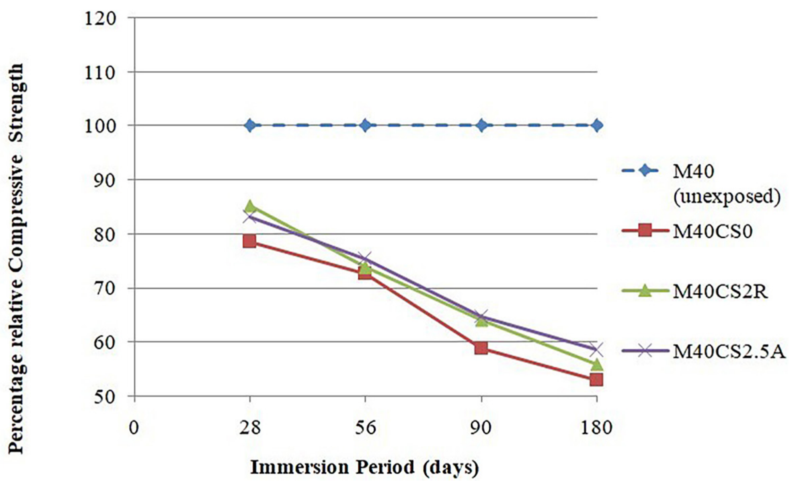


Figure 23. Percentage variation of relative compressive strength of specimens immersed in 6% sulphuric acid concentration with immersion period

the percentage loss of compressive strength is 9.84%, 18.03%, 22.95% and 31.15%. The percentage loss of compressive strength for 4.5% of sulphuric acid concentration is 13.11%, 21.31%, 31.15% and 37.70%, whereas for 6% sulphuric acid concentrations is 14.75%, 26.23%, 36.06% and 44.26% of compressive strength is observed at different immersion periods of 28, 56, 90 and 180 days respectively.

The percentage loss in compressive strength for M40CS2R isfound to be 6.15%, 12.30%, 18.46% and 27.69% at 1.5% concentration of sulphuric acid. At 3% sulphuric acid concentration the percentage loss of compressive strength is 10.77%, 18.46%, 23.07% and 30.77%.The percentage loss of compressive strength for 4.5% of sulphuric acid concentration is 13.84%, 24.61%, 32.31% and 36.92%, whereas for 6% sulphuric acid concentrations is 16.92%, 24.62%, 35.35% and 41.54% of compressive strength is observed at different immersion periods of 28, 56, 90 and 180 days respectively. With the use of colloidal silica the decrease in compressive strength is observed to be very less in concrete mixes M40CS2R and M40CS2.5A when compared to M40CS0.

CONCLUSIONS

Increase in compressive strength of concrete mix specimens is 13.92% for replacement to cement with 2% colloidal silica by weight of cement and 20.27% for addition of 2.5% of colloidal silica by weight of cement when compared to nominal concrete. The visual appearance of concrete specimens immersed in sulphuric acid solution shown surface deterioration, discoloration and texture changes. The intensity of damage and deterioration of M40CS0, M40CS2R and M40CS2.5A concrete specimens are highly depends on the sulphuric acid solution concentrations and exposure duration.

The M40CS2R and M40CS2.5A concrete specimen has shown minimum weight loss when compared to M40CS0. The weight loss of specimens observed to be increasing with the increase of sulphuric acid concentration. The percentage decrease in compressive strength of concrete specimens is observed with the increase of sulphuric acid concentration at 28, 56, 90 and 180 days of immersion period for M40CS0, M40CS2R and M40CS2.5R concrete specimens.

Percentage loss of compressive strength of concrete replaced with2% colloidal silica to cement is observed to be minimum when specimens immersed in 1.5% of sulphuric acid among all concentrations when compared to conventional concrete. Similar observations are found in the case of concrete added with 2.5% of colloidal silica immersed in 1.5% of sulphuric acid concentrations.

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