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Characterization Of Saline Water And Mgso4 Exposure On Concrete Incorporating Industrial Waste

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Abstract

Concrete is a highly costly and widely used material in modern building, where cement serves as the primary component. We produce a billion tonnes of concrete annually. In other words, cement manufacture contributes to global warming by producing an excessive amount of CO_2. India is mostly affected by the pollution issue. Utilizing industrial by products has gained popularity as an environmentally friendly alternative to disposal as people are becoming more conscious of the environment and its potentially dangerous impacts. This study uses industrial by products including ground granulated blast furnace slag (GGBS), by product of the steel industry, and silica fume (SF), by product of the smelting process in the silicon and ferrosilicon industries. In the current investigation, different amounts of industrial by products, including GGBS up to 50% and SF up to 20%, were employed to prepare the concrete. After a 28-day curing period, the compressive strength of hardened concrete was assessed. To measure degradation in a harsh environment, concrete was then subjected to salty water (NACL) and $MgSO_4$ for 90 and 180 days, respectively. In order to evaluate the strength deterioration of concrete, non-destructive testing (NDT) was also used. Positive study findings showed that concrete with the best waste replacement improves physical properties.

Keywords: GGBS, SF, NACL Exposure, $MgSO_4$ Exposure, Weight Reduction, Non-destructive testing.

I. Introduction

Due to its durability and affordability, concrete is one of the most often utilised construction materials today. Every year, India utilises tonnes of ready-mixed concrete. It is employed in the construction of roads, buildings, highways, tunnels, dams, railways, and other structures. On average, each individual on earth uses three tonnes of concrete. CO_2 is one of the main greenhouse gases that contributes to global warming. Only the cement industry contributes 7% of the total 65 percent CO_2 contribution. Most concrete manufactured is typically consumed by India, China, and the USA. According to estimates, the quantity of CO_2 generated during cement manufacture is increasing by 2.5% yearly. One tonne of cement is thought to create around one tonne of carbon dioxide [1].

On the other hand, cement may be substituted with a wide variety of industrial by products. It significantly contributes to the reduction of CO_2 emissions. Industrial by products including fly ash, slag, rose husk, GGBS, and SF are utilised as replacements.

Because of its chemical characteristics, blast furnace slag, which is produced as pig iron in blast furnaces, is significant (presence of alumino-silicates). Granulated slag, also known as non-crystalline glassy granules, are generated when the molten slag cools quickly and has latent hydraulic capabilities [2]. It is known as "Ground Granulated Blast Furnace Slag (GGBS)" after it has been further ground into a fine powder with micron-sized particles. It is already widely recognized that GGBS may be used as supplemental cementing material (SCM). Its usage as SCM began in the USA in 1905, and after 1950, it has become extensively used in several nations [3]. When used as SCM, blast furnace slag just has to be ground and processed before being mixed with new concrete [4]. ACI Committee E 701 [5] states that the processing techniques include "air chilling, expanding, palletizing, and granulating," which are less energy-intensive than the manufacturing of cement, which necessitates high temperatures and involves the expenditure of 4 BJ/t of energy. Therefore, it will still have a significant impact on cost and energy savings when used as a partial binder replacement in concrete. However, it should be remembered that when GGBS blended cements are used in concrete, the anticipated properties of the resulting concretes depend largely on their level of reactivity and latent hydraulic properties, which are directly related to "slag source, type of raw material used, method, and the rate of cooling" [2,6]. Since GGBS has gained widespread recognition as an SCM in concrete, several researchers have worked to analyse various underlying mechanisms, explore the qualities of the resultant concrete, and identify solutions to any potential drawbacks [7, 8]. Evidence provided of the positive impacts of GGBS addition on concrete's compressive strength, porosity, and long-term durability properties [9]. Later studies [10], which also showed decreased chloride ion penetration potential and higher resistance to sulphate attack, validated the beneficial effects of GGBS on the porosity and permeability of such concretes. Even though GGBS was employed as SCM, it wasn't until later that it was examined for extremely high weight fractions for manufacturing various forms of concrete [11,12], which has also showed promising results, that it was utilised in substantial numbers. For plain concretes incorporating GGBS, hydration modelling and microstructural studies have also been conducted [13, 14].

A by-product of the smelting process in the silicon and ferrosilicon industries is silica fume (SF). It is also referred to as micro silica, volatilized silica, silica dust, and condensed silica fume. Premium white or grey silica fume are the two available colours. Very small, vitreous particles with a surface area of 13,000 to 30,000 m^2/kg make up silica fume. Its particles are around 100 times smaller than a cement particle on average. Silica fume is a very potent pozzolanic substance due to its great fineness and high silica concentration. To enhance the characteristics of concrete, silica fume is employed. Silica fume has been proven to enhance compressive strength, bond strength, and abrasion resistance. It also lowers permeability, which helps to prevent corrosion of the steel used for reinforcing [15].

II. Materials & Methods

A. Cement, GGBS & Silica Fume

Ordinary Portland Cement 53 grade in accordance with IS 269: 2015 [16] was used in this investigation. GGBS and SF were supplied by Stallion Energy Pvt. Ltd. of Rajkot, Gujarat, India. The components of the GGBS, SF, and OPC Cement utilised in this investigation are listed in Table 1.

Table 1 Ingredients of OPC Cement, GGBFS and SF

Oxides	OPC	GGBFS	SF
SiO_2	21.44%	35.47%	92.80%
Al_2O_3	4.90%	14.27%	0.60%
Fe_2O_3	3.48%	2.41%	0.30%
CaO	62.76%	35.89%	----
MgO	1.64%	8.06%	0.60%
SO_3	2.34%	1.58%	0.10%
$Na_2O + K_2O$	0.66%	0.20%	1.17%

B. Fine Aggregates

Fine aggregate that met the requirements of IS 383: 2016[17] and IS 2386-1963 (Part-I-III) [18-19] was used from the Surendranagar area of the Bhogavo river for concrete production.

C. Coarse Aggregates

Coarse aggregate available locally that complied with IS 383: 2016[17] and IS 2386-1963 (Part-I-III) [18-19] was used to made concrete.

D. Concrete Mix Design

According to IS 10262-2019, M-40 concrete was produced for this study [20]. 10%, 20%, 30%, 40%, and 50% GGBS were employed as partial cement replacements in concrete, with 5%, 10%, 15% and 20% silica fume, designated by mixes M1 to M20, respectively. A total of 21 mixes, including a control mix, were produced for this investigation. The pozzolanic strength index was assessed for 7 and 28 days, using the control concrete's compressive strength as a baseline, to ascertain the impact of GGBS and Silica Fume on concrete's compressive strength. Based on the pozzolanic strength index, it was determined that 30% GGBFS and 5% silica fume were the appropriate replacement percentages for the manufacture of concrete mixes. The concrete mix design for M-40 grade control mix and with partial cement substitution is shown in Table 2 below.

Table 2 Concrete Mix Design for M-40 Grade

Material	PC40	PC40GSF35
OPC (kg)	440	286
GGBS (kg)	-	132
SF (kg)	-	22
Sand (kg)	645	645
Agg. 20 mm (kg)	711	711
Agg. 10 mm (kg)	471	471
Water (kg)	176	176
Admixture (%)	0.15%	0.20%
W/C Ratio	0.4	0.4
Slump (mm)	59	75
Compaction Factor	0.93	0.86

While in solution, solid salts can react with hardened cement paste, they do not affect concrete. The rate of attack is greatest when sulphate-bearing water pressure is applied to one side of concrete. In a similar manner, cycling between soaking and drying quickens the deterioration process. Concrete that has been exposed to sulphate has a whitish appearance. The typical progression of damage is from the edges and corners to racking and spalling. Pozzolanas are added, and this increases resistance to sulphate attack. The MgSO4 solution utilised in the current investigation has a water content of 5% v/v. After 28 days of regular curing, specimens were exposed to $MgSO_4$ solute for 90 days and 180 days.

The concrete compressive strength after curing and mixing with saltwater showed that a drop in strength occurs with an increase in display time, which may be connected to the composition of salt crystallisation in relation to the increase in strength [21]. In the current investigation, the effect of a saline environment on concrete was evaluated using a NACL content of 3.5 percent. Specimens were treated to NACL solute for 90 days and 180 days after 28 days of normal cure.

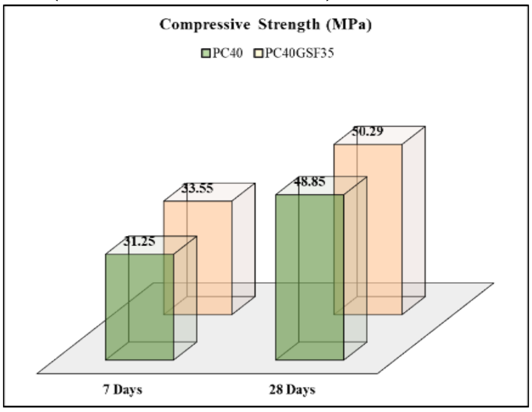
All specimens were subjected through a rebound hammer test in accordance with IS 13311 (Part 2): 1992 [22], with nine readings being taken on each of the cubes' two sides. The test findings were obtained after 28 days of water curing and after 90 and 180 days of exposure to NACL and MgSO4. Surface hardness of concrete mix is therefore thought to be related to compressive strength. The grading establishes the rebound value, sometimes referred to as the rebound or rebound index. The compressive strength may be determined by taking a quick look at the graph on the hammer.

In order to conduct the Ultrasonic pulse velocity test, an electro-acoustic transducer must be in contact with one surface of the concrete mix component being tested, and a contact sensor Surface must receive the ultrasonic pulse at the other end. A concrete quality rating based on pulse velocity was produced in the lab using ultrasonic pulse velocity testing on cubes in accordance with IS 13311 (Part 1): 1992 [23]. The test results were obtained following 28 days of water curing, 90 days, and 180 days of NACL and MgSO4 exposure.

I. Results & Discussion

A. Compressive Strength

Concrete cubes measuring 150 mm x 150 mm were tested for compressive strength in accordance with IS 516: 1959[24] after 7 days and 28 days of curing. Concrete specimens with a 35% waste replacement (30% GGBFS + 5% Silica Fume) are denoted by PC40GSF35 in Figure 1 together with M-40 control concrete specimens denoted by PC40, which were tested after 7 and 28 days. Figure 1 indicates that concrete's After 7 and 28 days of curing, the compressive strength increased from 31.25 MPa to 33.55 MPa and from 48.85 to 50.29 MPa, respectively. It was shown that compressive strength increased with longer curing times. As a result of the matrix's inclusion of GGBS and silica fume, the cement paste is more tightly bound to the aggregate particles and has a higher density, both of which greatly boost the concrete's compressive strength. This is a result of the GGBS's filler effect and the use of silica fume to create dense concrete. Strength was also increased because to the pozzolanic properties of GGBS and silica fume. To obtain a strength greater than that of traditional concrete at 28 days, a combined replacement of 35% (GGBS and silica fume) in total cementitious



ingredients was employed.

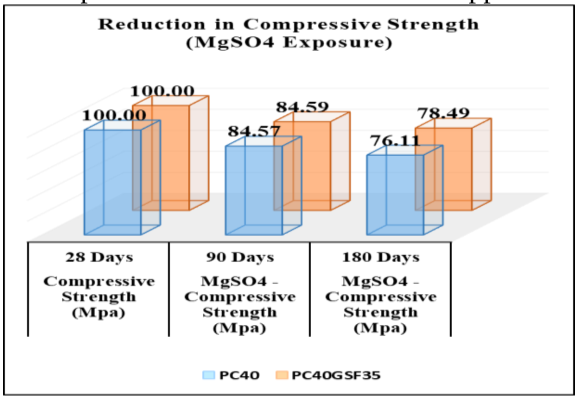
Figure 1 Compressive Strength of Concrete for 7 days and 28 days

B. Effect of $MgSO_4$ Exposure

After being submerged in $MgSO_4$ solution for 90 and 180 days, followed by 28 days of water curing, M-40 grade concrete cubes were evaluated. Figure 2 shows the test results for the identical sample

Figure 2 Compressive Strength Results for $MgSO_4$ Exposure of 90 days & 180 days

Figure 2 shows that the compressive strength of PC40 specimens was found to have dropped from



48.85 MPa after 28 days of water curing to 44.04 MPa and 41.86 MPa after 90 and 180 days, respectively, of MgSO4 exposure. When exposed to MgSO4 for 90 or 180 days, the compressive strength of PC40GSF35 specimens was discovered to have dropped from 50.29 MPa after 28 days of water curing to 45.34 MPa and 44.04 MPa, respectively.

Figure 3 Percentage Reductions in Compressive Strength after $MgSO_4$ Exposure

Figure 3 shows that, compared to 100% for 28 days of water curing, the percentage drop in compressive strength of PC40 specimens was found to be 84.57%, 76.11%, and correspondingly for 90 and 180 days of $MgSO_4$ exposure. Compressive strength of PC40GSF35

specimens decreased by 84.59 and 78.49%, respectively, following 90 and 180 days of $MgSO_4$ exposure, as opposed to 100% for 28 days of water curing.

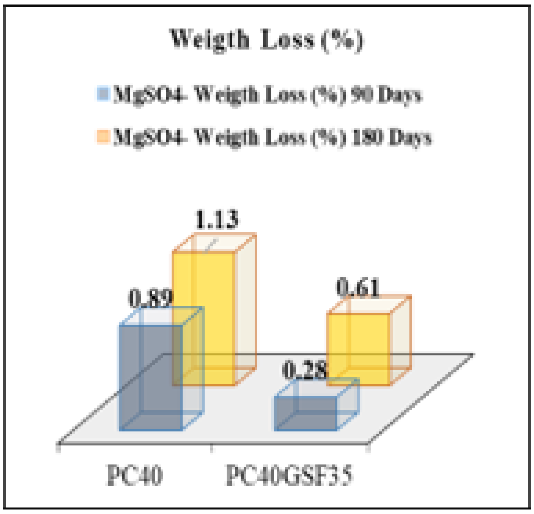
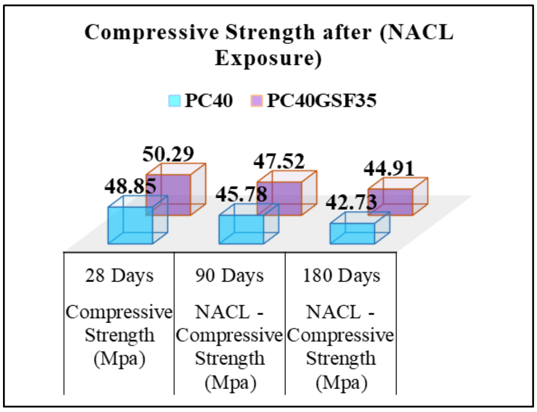


Figure 4 Concrete weight loss percentages after $MgSO_4$ Exposure

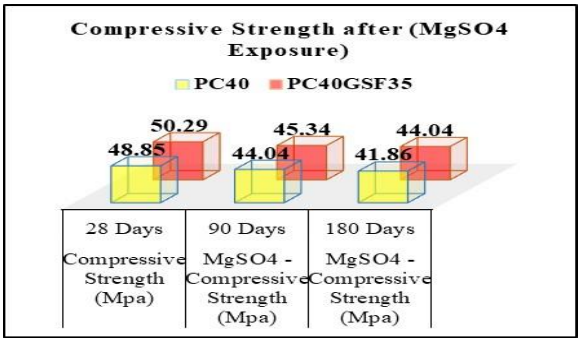
As seen in figure 4, the weight of PC40 cube specimens decreased by 0.89% and 1.13 %, respectively, during 90 and 180 days of $MgSO_4$ exposure as opposed to 28 days of water curing. When exposed to $MgSO_4$ for 90 or 180 days, respectively, there was a 0.28% and 0.61% weight reduction in PC40GSF35 cube specimens compared to 28 days of water curing.

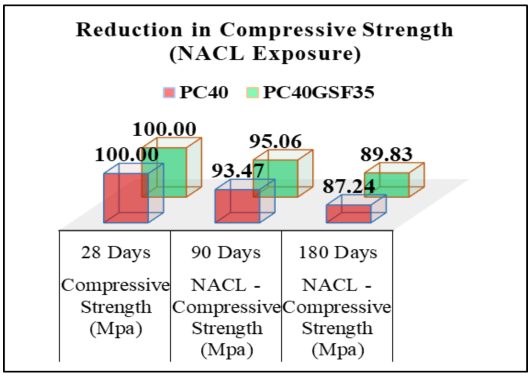
C. Effect of NACL Exposure

M-40 grade concrete cubes were tested after being immersed in NACL solution for 90 and 180 days, followed by 28 days of water curing. The test results for the same sample are shown in Figure 5. According to Figure 5, after 28 days of water



curing, the compressive strength of PC40 specimens decreased from 48.85 MPa to 45.78 MPa and then to 42.73 MPa after 90 and 180 days, respectively, of NACL exposure. The compressive



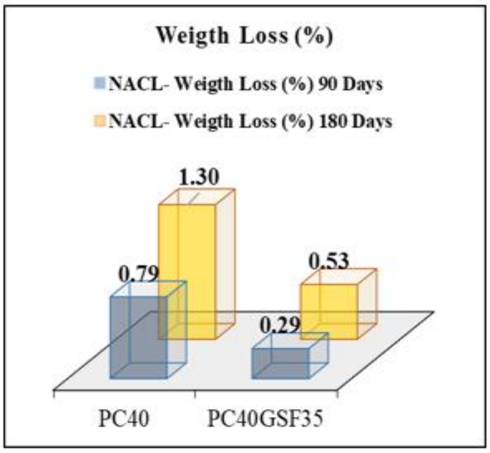


strength of PC40GSF35 specimens was shown to have decreased from 50.29 MPa after 28 days of water curing to 47.52 MPa and 44.91 MPa, respectively, when exposed to NACL for 90 or 180 days.

Figure 5 Compressive Strength Results for NACL Exposure of 90 days & 180 days

Figure 6 demonstrates that the percentage decline in compressive strength of PC40 specimens was determined to be 93.47%, 87.24%, and accordingly for 90 and 180 days of NACL exposure, when compared to 100% for 28 days of water curing. Following 90 and 180 days of NACL exposure, the compressive strength of PC40GSF35 specimens fell by 95.06 and 89.83%, respectively, as contrasted to 100% for 28 days of water curing.

Figure 6 Percentage Reductions in Compressive Strength after NACL Exposure



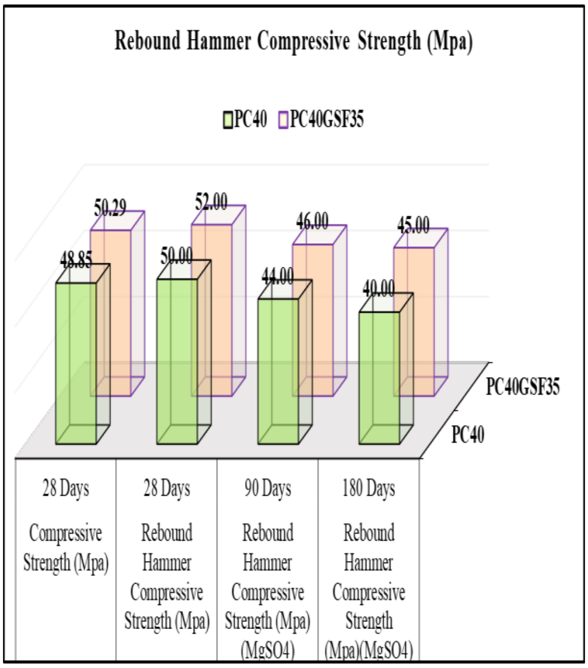
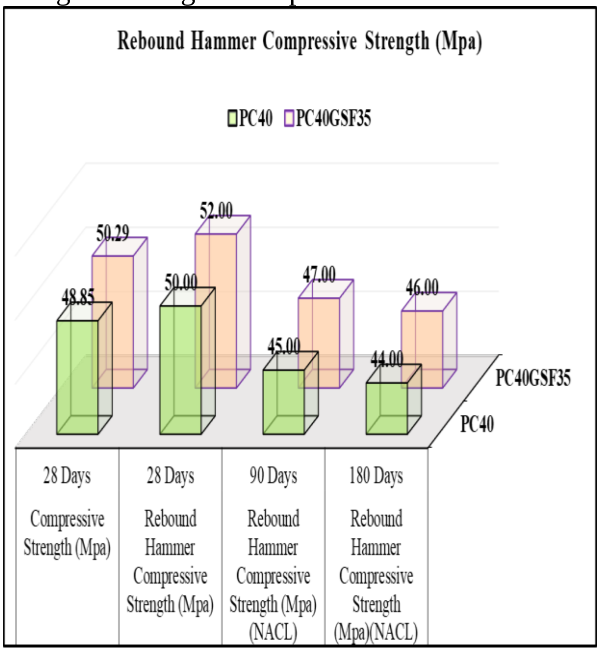


Figure 7 Concrete weight loss percentages after NACL Exposure

Figure 7 shows that, in comparison to 28 days of water curing, the weight of PC40 cube specimens dropped by 0.79 and 1.30% over 90 and 180 days of NACL exposure, respectively. In comparison to 28 days of water curing, PC40GSF35 cube specimens had a weight loss of 0.29% and 0.53% after being exposed to NACL for 90 or 180 days, respectively.

D. Non-Destructive Testing – Rebound Hammer

All $MgSO_4$ and NACL exposed cube specimens were subjected to a rebound hammer test, followed by 28 days of water curing. The compressive strength for MgSO4 exposure from the rebound



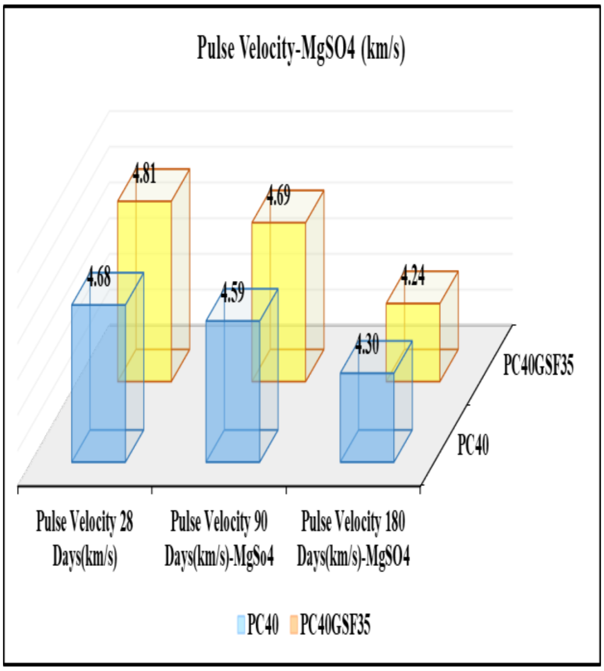
hammer test is shown in Figure 8 as findings.

Figure 8 Rebound hammer test results for $MgSO_4$ exposure

Compressive values of 48.85 MPa and 50.29 MPa for PC40 and PC40GSF35 mixes, respectively, were discovered after 28 days of water curing. The rebound hammer compressive strength of PC40 and PC40GSF35 mix for the same curing duration was 50 MPa and 52 MPa, respectively. After 90 days of $MgSO_4$ exposure, the compressive strength as evaluated by the rebound hammer test was 44 MPa for PC40 and 46 MPa for PC40GSF35 mix, respectively. The compressive strengths of the PC40 and PC40GSF35 mixes were 40 MPa and 45 MPa, respectively, after 180 days of $MgSO_4$ exposure. This decrease in compressive strength was seen as the $MgSO_4$ exposure period was prolonged due to the emergence of microcracks and an increase in the quantity of voids in the concrete.

Figure 9 Rebound hammer test results for NACL exposure

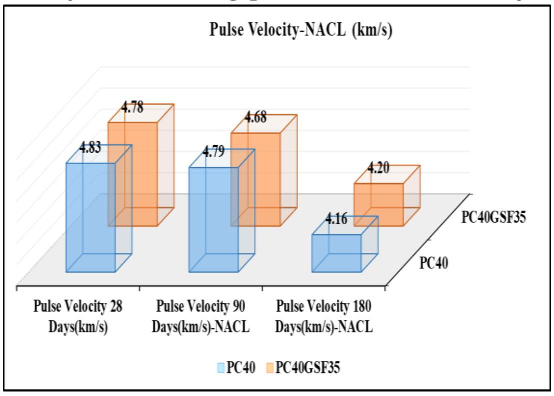
The findings of the rebound hammer test in terms of compressive strength for NACL exposure are shown in Figure 9. Compressive values of 48.85



MPa and 50.29 MPa for PC40 and PC40GSF35 mixes, respectively, were discovered after 28 days of water curing. The rebound hammer compressive strength of PC40 and PC40GSF35 mix for the same curing duration was 50 MPa and 52 MPa, respectively. After 90 days of NACL exposure, the compressive strength as evaluated by the rebound hammer test was 45 MPa for PC40 and 47 MPa for PC40GSF35 mix, respectively. The compressive strengths of the PC40 and PC40GSF35 mixes were 44 MPa and 46 MPa, respectively, after 180 days of NACL exposure.

E. Non-Destructive Testing – Ultrasonic Pulse Velocity

A 28-day water curing period was followed by an



ultrasonic pulse velocity measurement on all MgSO4 and NACL exposed cube specimens. Figure 10 shows the concrete quality for $MgSO_4$ exposure as a function of pulse velocity.

Figure 10 Ultrasonic Pulse Velocity Test Results for MgSO4 exposure

Figure 10 demonstrates how the ultrasonic pulse velocity dropped as the $MgSO_4$ exposure period increased. After 28 days of curing, 90 days, and 180 days of $MgSO_4$ exposure, respectively, it was observed that the PC40 mix pulse velocity lags ranged from 4.68 km/s to 4.59 km/s to 4.30 km/s. Additionally, for PC40GSF35 mix, postponement in pulse velocity was seen, decreasing from 4.81 km/s, 4.69 km/s, to 4.24 km/s, respectively, during 28 days of curing, 90 days, and 180 days of $MgSO_4$ exposure. Due to concrete deterioration in an aggressive environment and the emergence of voids and fractures, a drop in pulse velocity was noticed.

Figure 11 Ultrasonic Pulse Velocity Test Results for NACL exposure

As the NACL exposure duration lengthened, Figure 11 shows how the ultrasonic pulse velocity decreased. It was shown that the PC40 mix pulse velocity delays varied from 4.83 km/s to 4.79 km/s to 4.16 km/s after 28 days of curing, 90 days, and 180 days of NACL exposure, respectively. Additionally, with 28 days of curing, 90 days, and 180 days of NACL exposure, 4.78 km/s, 4.68 km/s, and 4.20 km/s, respectively, of postponement in pulse velocity for PC40GSF35 mix were observed.

IV. Conclusions

The efficacy of GGBFS and silica fume replacement with cement in partial amounts during the production of concrete was evaluated using hardened concrete testing, durability testing, and non-destructive testing. The following important conclusions may be made in light of the study's findings:

1. There was a decrease in compressive strength of PC40 specimens ranging from 84.57% to 76.11% when 28 days of water curing was contrasted with 90 days and 180 days of $MgSO_4$ exposure.
2. Compressive strength of PC40GSF35 specimens decreased between 84.59% and 78.49% for 90 days and 180 days of $MgSO_4$ exposure compared to 28 days of water curing, indicating a slight marginal decrease in concrete strength following the combined use of GGBS and silica fume in concrete compared to control concrete.
3. Weight loss of PC40 specimens following 90 and 180 days of $MgSO_4$ exposure varied from 0.89% to 1.13% as compared to 28 days of water curing.

4. In comparison to 28 days of water curing, weight loss of PC40GSF35 specimens varied from 0.28 to 0.61% after 90 and 180 days of MgSO4 exposure, demonstrating that the PC40GSF35 concrete mix had better densification and particle packing.
5. When 28 days of water curing were compared with 90 days and 180 days of NACL exposure, the compressive strength of PC40 specimens decreased by a range of 93.47% to 87.24%.
6. Compressive strength of PC40GSF35 specimens decreased between 95.06% and 89.83% during 90 days and 180 days of NACL exposure compared to 28 days of water curing.
7. Weight loss of PC40 specimens following 90 and 180 days of NACL exposure varied from 0.79% to 1.30% as compared to 28 days of water curing.
8. When compared to 28 days of water curing, weight loss of PC40GSF35 specimens after 90 and 180 days of NACL exposure varied from 0.29 to 0.53 percent, showing that the PC40GSF35 concrete mix exhibits greater densification and particle packing.
9. After 90 and 180 days of MgSO4 and NACL exposure, the results of a non-destructive test on surface hardness showed that PC40GSF35 has a better surface quality than reference mix PC40.
10. Ultrasonic pulse velocity experiments showed that concrete constructed with 35% waste, known as PC40GSF35, was dense and homogenous with superior pulse velocity compared to control mix PC40 concrete mix after 90 days and 180 days of MgSO4 and NACL exposure.
11. By using industrial waste instead of cement to prepare concrete, the carbon emissions from cement manufacture may be somewhat decreased, improving the sustainability of the environment.

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