

Resistance of Concrete Protective Coatings in Different Chemical Environments

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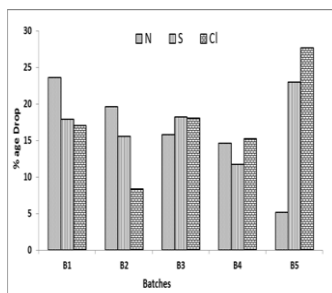
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Graphical abstract



Abstract

The objective of this research study was to introduce concrete protective coatings which provide maximum resistance against chemical attacks. The admixtures-silica fume and fly ash were also used to enhance the impermeability of concrete to a greater extent. Tests conducted at various stages of the curing process allowed us to study the destructive and non-destructive strengths of the specimens. The mortar samples were coated with three different types of epoxy coatings and bitumen. They were then subjected to different chemical environments by immersing them in 10% standard solutions of each ammonium nitrate, sodium chloride and sulphuric acid. Drop in strength as a result of chemical exposure was considered as a measure of chemical attack. This was achieved by measuring the drop in compressive strength after 14 and 28 days of chemical exposure. The compressive strength results following chemical exposure indicated that the samples containing silica fume and fly ash (5% replacement of each by weight of cement) and the protective coating Epoxy-2 (E-2) proved to be more resistant to attacks. The control sample (without admixtures) showed a much greater degree of deterioration. Therefore, the application of E-2 coating in addition to silica fume and fly ash was invariably much more effective in improving the compressive strength as well as the resistance of concrete against chemical attacks. The results also indicated that among all the aggressive attacks, the sulphate environment has the most adverse effect on concrete in terms of lowering its strength.

Keywords: Chemical; protective coating; concrete; resistance; silica fume; epoxy coating

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1.0 INTRODUCTION

Even structures built with the best of concrete are prone to developing durability problems. The properties of concrete and the environment it is exposed to play a vital role in determining the concrete structures' ability to withstand the environmental stress, onslaught of chemical and physical reactions in protecting the concrete. Concrete is known to suffer from ingress of chloride, sulfate and ammonium ions, carbonation stress as well as freezing and thawing, and possibly alkali-aggregate reaction [1-4]. Hence the deterioration of concrete structures' reinforcement in particular due to corrosion poses a formidable challenge.

The aggressive attacks on concrete are often a result of chemical reactions due to chloride, sulfate and nitrate which affect concrete's strength. In this project, these three principal agents are primarily considered.

The characteristic porosity of concrete in sea walls and other marine structures remains most susceptible to chloride attack as sea

water is largely comprised of chloride ions. Similarly, chemical manufacturing and processing plants, bridges, car parking facilities and underground structures are also at risk, especially where deicing salts must be used on roads, highways and bridges in winter [6].

As the plant manufactured concrete always contains a complicated system of pores and capillaries, it is subject to reinforcement corrosion under damp conditions. In order to prevent steel corrosion in concrete, it becomes imperative to use adequate damp-proofing agents to increase the durability of reinforced concrete structures. Whether the corrosion is due to chlorides and oxygen or due to the presence of sulfates, bridges and parking garage structures undergo large-scale repairs to restore their functional life and structural integrity. Chlorides can be formed through the use of deicing salts that are used in wintry conditions to melt snow or ice, or from seawater, as well due to certain ingredients present in concrete mixture [7].

Nitrate is most commonly found in fertilizer industry. The presence of sulfates in bricks can be gradually released over a long period of time, resulting in mortar attack, especially when they are concentrated due to moisture movement [8].

It has been researched that 0.2% sulfate content in ground water may cause the concrete to come under stress. Magnesium sulfate has been recognized as more aggressive than sodium. There are three important chemical reactions between sulfate ions and hardened cement. These reactions are:

- Recrystallization of calcium sulfo-aluminate referred to as ettringite;
- Formation of gypsum; and
- Decalcification of the main cementitious phase (C-S-H).

When calcium hydroxide is formed in cement concrete, and the cement comes into contact with sulfate ions, the alumina containing hydrates are converted to the concentrated sulfate forming ettringite. Ettringite compound grows, expands, or swells causing cracks [9].

In order to overcome such problems, different types of coatings and sealers are recommended. Sealers and coatings are used to reduce various forms of concrete deterioration by limiting penetration of water and water-borne deleterious agents (chlorides and sulfates) [10]. Moreover, sealers and coatings are used to resist chemical attack and corrosion damage due to de-icing and anti-icer chemicals, such as NaCl, CaCl₂, and MgCl₂. They also facilitate moisture vapour transmission, to aid rapid drying and mitigate the effects of corrosion [11].

When cement concretes (of 28-day strength and 7 day initial curing) are lowered in seawater, the concrete containing fly ash exhibits significantly more resistance to chloride penetration than Portland cement concrete as shown in Figure 1 [12].

A corrosion distress situation where everything else is held constant, the corrosion rate of steel is minimized in concrete possessing high resistivity and resistance to ionic movement. Higher resistivity and higher resistance to ionic movement are characteristic of concrete containing fly ash when compared to equivalent Portland cement concretes [13], [14].

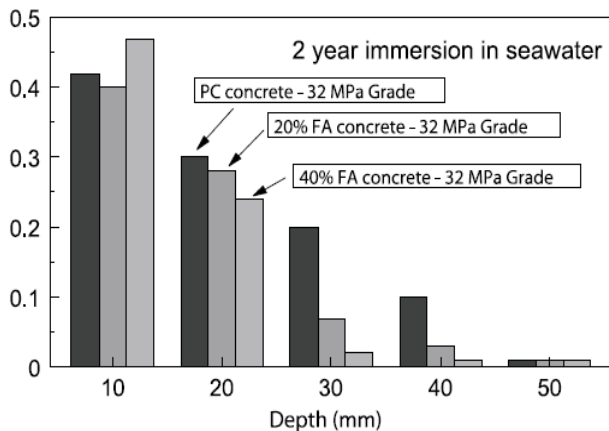


Figure 1 Chloride penetration into equivalent 32 MPa concretes incorporating Australian fly ash [12]

2.0 METHODOLOGY

Various types of materials with various specifications (according to ASTM standards) were used for the preparation of the required mortar cubes.

50 x 50 x 50 mm mortar cubes were prepared as per ASTM C109. The water-to-cement ratio of 0.38 was used in the preparation of the mortar cubes to achieve the maximum workability that could be attained without decreasing durability.

2.1 Materials

The cement used in experiment was ordinary Portland cement locally available in the market. The sand used in the mix was passed through Sieve no. 16 and retained on Sieve no. 30 [15]. Throughout the preparation of cubes 2750 grams of sand was mixed.

Silica Fume was added in powder form to increase the durability of one of the batches to check the effect of admixture addition. 5% by weight of silica fume was used as replacement of cement.

Class C Fly Ash, 5% by weight of cement was also added in one batch to increase the durability. Super-plasticizer was added to each batch of mortar cubes (except for the control sample) to increase the workability of the mixture.

2.2 Protective Coatings

The protective coatings applied on the six batches of prepared mortar cubes were:

Epoxy-1: Based on epoxy resin, Epoxy-1 is described as a coating material that is solvent free and is 2-components. It is known for being a nonabrasive coating material which is best suited for normal to moderately aggressive chemical environments. It is used as an anti-corrosion coating which is self-supportive and exhibits good crack bridging properties.

Epoxy-2: Epoxy-2 is a high chemical resistance, non-toxic epoxy coating. It is a two component, solvent free, non-toxic epoxy coating with outstanding mechanical and chemical properties. It is approved for contact with potable water and for food processing and pharmaceutical industries. (Issued by the Egyptian National Organization for Water and Sewage).

Epoxy-3 is a protective membrane that is known for excellent chemical resistance. Epoxy-3 is a dual-component, solvent-free, coating material with epoxy resin matrix. It is considered suitable for use in tropical and hot climatic conditions. It is ideal for use on concrete, stone structures and cementitious mortars. Understandably so, it offers optimal protection against corrosion and moderate to severe chemical attacks. It can also be used for lining storage tanks and silos and to form glass fiber-reinforcement epoxy coating that is virtually crack-bridging when used in storage tanks and embankment quays.

Bitumen is a protective coating which is a byproduct of fractional distillation of bitumen. Bitumen is normally available in the market and is commonly used as a waterproofing agent. During the application of coatings bitumen was used in molten form.

2.3 Aggressive Chemicals

Three types of aggressive chemicals were used in this study, namely;

Sulphuric Acid (H₂SO₄): It was used to provide an artificial sulphate attack on the prepared mortar cubes. A 10% concentrated solution was used for this purpose. It is supposed to replicate an environment in which sulphate attack occurs in concrete.

Ammonium Nitrate (NH₄NO₃) (10% concentration) was used to artificially produce an environment in which concrete was subjected to nitrate attacks.

Sodium Chloride (NaCl) 10% concentration) was used to induce a chloride attack on the coated mortar cubes.

2.4 Sample Preparation

The preparation process consisted of preparing six batches of mortar. From each batch, 50 x 50 x 50 mm standard mortar cubes were prepared.

- Batches 1,2,3,4 (B1, B2, B3, B4) were prepared by using cement (1000 gm), sand (2750 gm), water (300 gm) and super plasticizer (100 gm).
- In Batch 5 (B5) silica fume and fly ash were used as admixtures so as to increase the durability properties of concrete (with respect to strength and resistance to corrosion).
- Batch 6 (B6) served as the control sample which was prepared without the addition of any admixture/superplasticizer, simply for comparison purposes.

The six samples were allowed to cure for 28 days. Destructive and non-destructive tests were carried out on the 7th, 14th and 28th day of curing.

From each batch eight samples were coated with the protective coatings. Two samples from each batch were coated with Epoxy-1, two with Epoxy-2, two with Epoxy-3 and the remaining two with bitumen.

After the coatings had been allowed to harden over a duration of 5 days at normal room temperature and pressure, the samples were then submerged in three different aggressive chemical solutions (10% concentration) which were used to represent the three different types of attacks.

2.5 Coating of Samples

After 28 days curing, protective coatings were applied to samples and were allowed to harden over duration of five days (Figure 2).



Figure 2 Application of protective coatings

Two cube samples from each batch were coated with single type of protective coating provided by SIKA and remaining two samples were coated with bitumen. Protective coatings used were Epoxy-1 (E-1), Epoxy-2 (E-2) and Epoxy-3 (E-30). Control samples were left uncoated.

2.6 Chemical Exposure

After the hardening of coatings, samples were then immersed in each of 10% concentrated solutions of sulphuric acid, sodium chloride and ammonium nitrate at normal temperature and pressure.

After 14 days of chemical exposure, non-destructive strength test was performed by using rebound hammer in order to prevent the destruction of samples and to monitor the strength drop.

2.7 Tests

Compressive strengths of all the samples were measured at different stages of curing by performing destructive and non-destructive (rebound hammer) strength tests. Destructive strength of samples was measured at age of 7, 14 and 28 day of curing by using Universal Testing Machine (UTM).

During chemical exposure of coated samples strength tests were performed again. At the end of 14 days of chemical exposure, non-destructive strength was conducted by using rebound hammer and at the end of 28 days, destructive strength was measured. The details of compressive strengths are given in Figure 3.

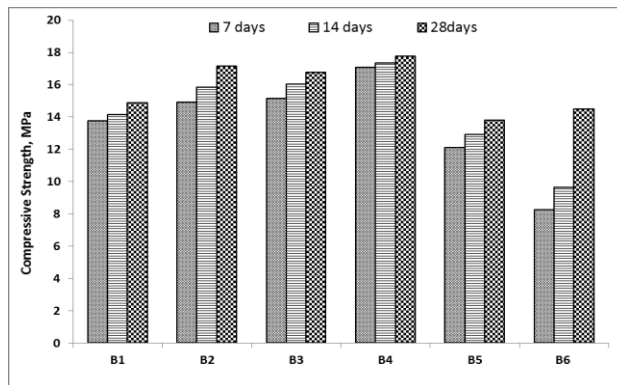


Figure 3 Details of strengths of different batches after 7, 14 and 28 days of curing

3.0 RESULTS AND DISCUSSION

3.1 Drop in Strength of Control Sample

Figure 4 shows the performance of control sample in different chemical environments. It presents % drop in strength of control sample after 28 days of chemical exposure.

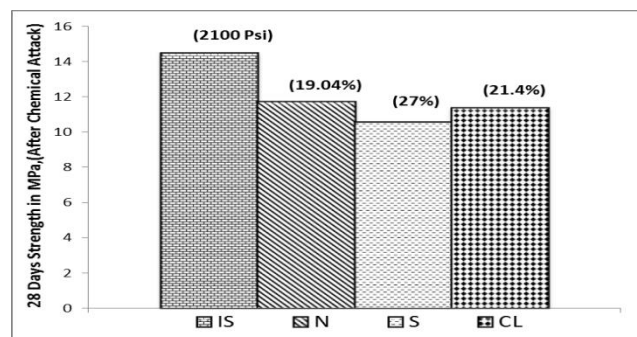


Figure 4 Comparison of control sample strength in different chemical environments (IS: initial strength, N: Nitrate environment, S: sulfate environment, CL: Chloride Environment)

Initial strength of control sample was 2100 psi and it showed 19.04% strength drop in nitrate environment, 27% strength drop in sulfate environment and 21.4% strength drop in chloride environment. From Figure 4 it is concluded that sulfate environment is the most aggressive environment for control sample, as it showed maximum strength drop.

3.2 Drop in Strength during and after Chemical Exposure

3.2.1 Nitrate Solution (14 and 28 days of exposure)

Figures 5 and 6 show strength of different batches in nitrate environment after 14 and 28 days of chemical exposure, respectively, when protective coatings were applied to them.

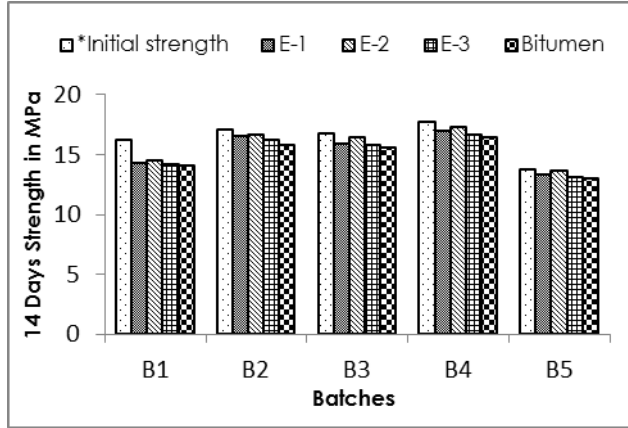


Figure 5 Compressive strength of different batches after application of protective coatings at 14 day of chemical exposure in nitrate solution

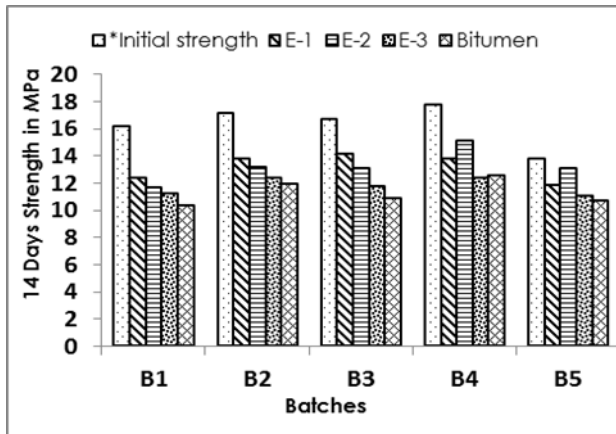


Figure 6 Compressive strength of different batches after application of protective coatings at 28 day of chemical exposure in nitrate solution

From Figures 5 and 6, the % drop in compressive strength of the specimens in nitrate solution was calculated and plotted in Figure 7. It shows that there is minimum % drop in strength in nitrate environment when E-2 is applied.

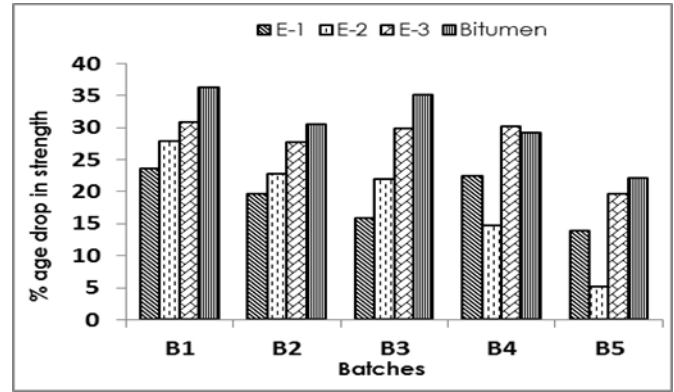


Figure 7 % drop in strength at the end of 14 and 28 days of nitrate attack after application of protective coatings

3.2.2 Sulfate Solution (14 and 28 days of exposure)

Figures 8 and 9 show strengths of different batches in sulfate environment after 14 and 28 days of chemical exposure, respectively, when protective coatings are applied to them.

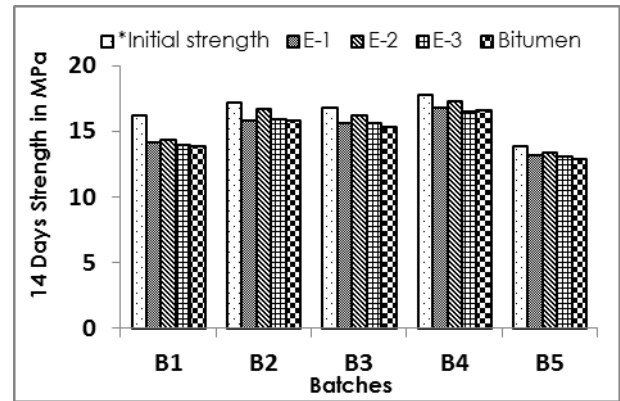


Figure 8 Strength of different batches after application of protective coatings and 14 days of chemical exposure in sulfate solution

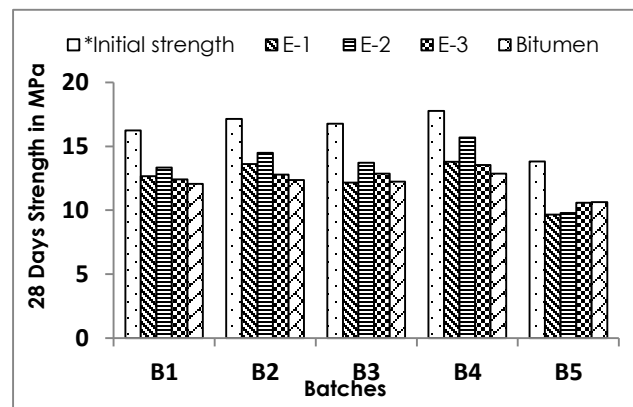


Figure 9 Strength of different batches after application of protective coatings and 28 days of chemical exposure in sulfate solution

From Figures 8 and 9, the % drop in compressive strength of the specimens in sulfate solution was calculated and plotted in Figure 10. It shows that among all other batches, B4 and B5 have minimum % drop in strength in sulfate environment when E-2 and bitumen are applied, respectively.

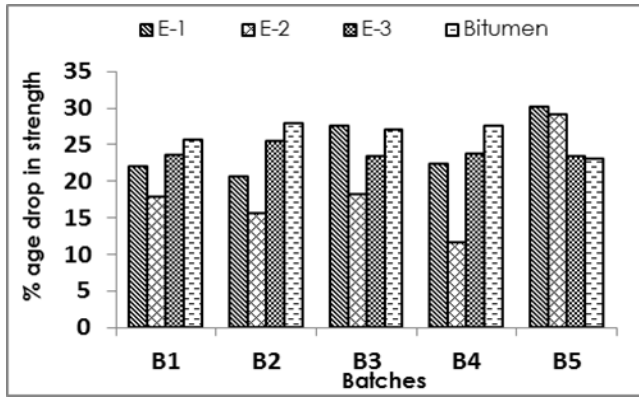


Figure 10 % drop in strength of B1 at the end of 14 and 28 days of sulfate attack after application of protective coatings

3.2.3 Chloride Solution (14 and 28 days of exposure)

Figures 11 and 12 show strengths of different batches in chloride environment after 14 and 28 days of chemical exposure when protective coatings are applied to them.

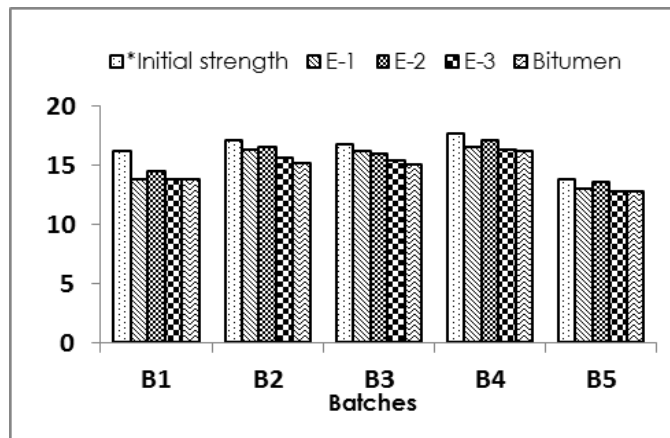


Figure 11 Strengths of different batches after application of protective coatings and 14 days of chemical exposure in chloride solution

From Figures 11 and 12, the % drop in compressive strength of the specimens in chloride solution was calculated and plotted in Figure 13. It shows that B5 has minimum % drop in strength in chloride environment when E-2 is applied.

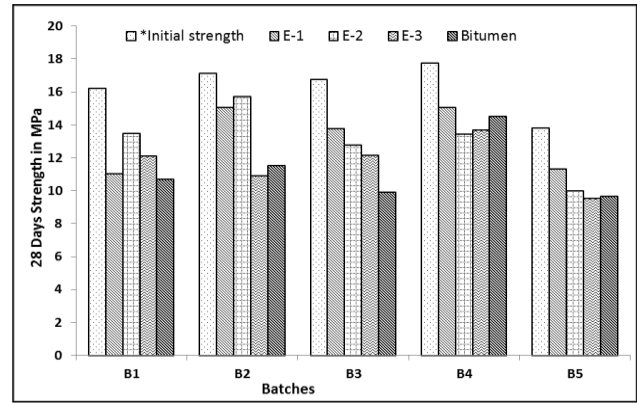


Figure 12 Strengths of different batches after application of protective coatings and 28 days of chemical exposure in chloride solution

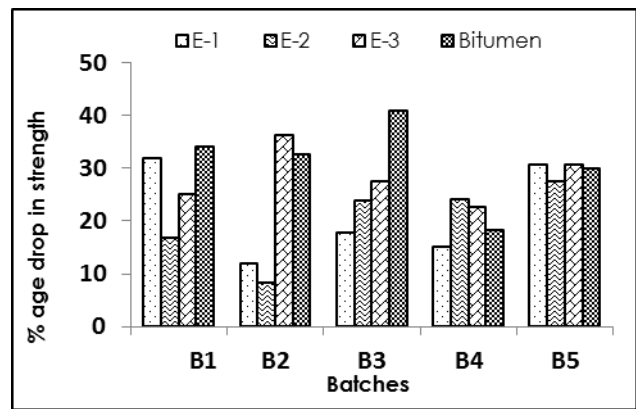


Figure 13 % drop in strength of different batches

Table 1 shows the details of % drop in all batches after application of protective coatings. Table 1 shows that B5 has minimum strength drop of 5.17% in nitrate environment when E-2 has applied to it.

Similarly in sulfate environment B4 shows minimum strength drop of 11.66% when same coating has been applied to it. B2 shows minimum strength drop of 8.30% in chloride environment under the same coating. After comparing the results, it is concluded that protective coating E-2 has performed the best in all aggressive chemical environments.

Figure 14 shows the details of % drop in strength of all batches in different chemical environments. It is concluded from Figure 14 that:

- B1 has minimum strength drop in chloride environment and maximum strength drop in nitrate environment.
- B2 has minimum strength drop in chloride environment and maximum drop in nitrate environment.
- B3 shows minimum % drop in nitrate environment and maximum % drop in sulfate environment.

B4 shows minimum % drop in sulfate environment and maximum % drop in chloride environment. B5 shows minimum % age drop in nitrate environment and maximum % drop in chloride environment.

Table 1 Comparison of % drop in three aggressive environments

Batch	Coating(N)	%Drop(N)	Coating(S)	%Drop(S)	Coating(Cl)	%Drop(Cl)
B1	E-1	23.55	E-2	17.86	E-2	17.01
B2	E-1	19.56	E-2	15.54	E-2	8.30
B3	E-1	15.74	E-2	18.20	E-1	18.00
B4	E-2	14.57	E-2	11.66	E-1	15.19
B5	E-2	5.17	Bitumen	22.99	E-2	27.63

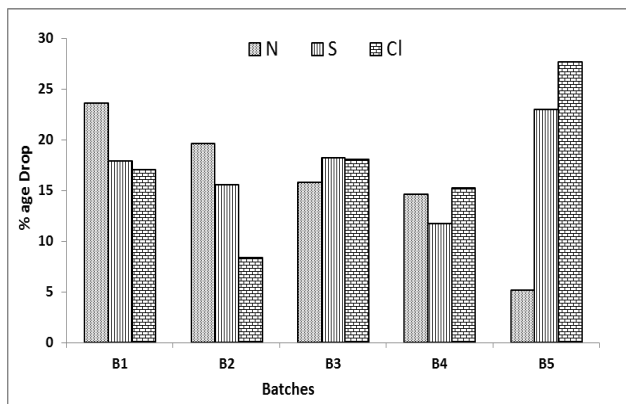


Figure 14 % drop in strength of all batches in all chemical environments

From Figure 15, it is observed that sulfate environment is the most aggressive environment and nitrate environment is the least aggressive environment for mortar batches, while chloride environment has intermediate aggressiveness.

From figure it is also concluded that E-2 has best performance in all three chemical environments.

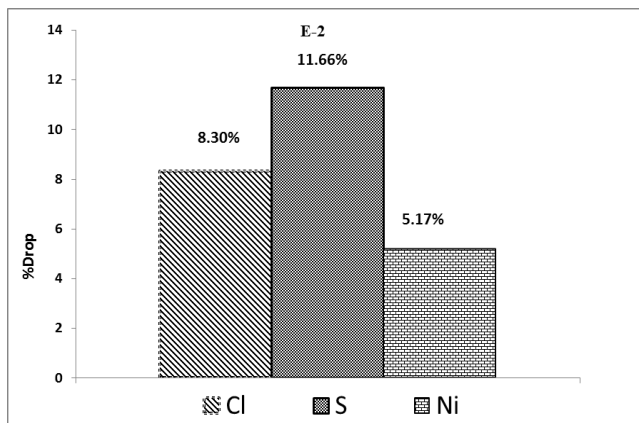


Figure 15 Comparison of aggressiveness of three chemical attacks

4.0 CONCLUSION

The results obtained in the reported study led us to the following conclusions.

Concrete is affected by chemical reactions which occur as a result of coming into contact with different chemicals present in various

environments. In the study three primary types of chemical reactions are considered:

- Sulphate attack occurring in sewerage networks
- Nitrate attack occurring in fertilizer manufacturing industries
- Chloride attack occurring in the coastal and marine regions

The resistance offered by the concrete is calculated by measuring the strength drop of the mortar cubes after the application of coatings and immersion in the three acidic solutions.

Protective coatings help to provide a great amount of resistance against deterioration and corrosive actions caused by the effect of chemicals on concrete.

Addition of admixture also helps to make the concrete impermeable resulting in greater resistance of concrete against the chemicals as it does not allow the acid to seep excessively into the cube samples.

From the results it can be seen that batch 5 samples were least affected by the acid attacks. Thus it can be concluded that addition of admixtures such as silica fume and fly ash as well as use of protective coating increased the resistibility of the mortar cubes.

5.0 RECOMMENDATIONS

- In order to last longer in harsh environments such as the chemical attacks like ammonium, sulphate and chloride, suitable concrete admixtures and protective coatings should be utilized. They increase not only the strength and make the concrete less permeable, but also provide resistance to chemical penetration. Chemical admixtures such as silica fume and fly ash should also be used along with protective coatings.
- Aside from strength tests, other characteristics of deteriorated samples should also be carried out by using various microscopic and analytical techniques such as Scanning electron microscopy and X-ray diffraction analysis.
- Similar tests can be conducted on concrete cylinders or cubes in order to get a more detailed picture of the problem.
- Various other types of protective coatings and combination of these with some other permeability reducing admixtures can also be studied.

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