Evaluation of Strength Deterioration Factor on Blended Concrete Exposed to Magnesium Sulphate Solution

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Abstract. This paper reports the combined effects of industrial waste as fly ash (FA) and agro-waste such as silpozz on the compressive strength and strength deterioration factor (SDF) of blended cement concrete exposed to 5% and 10% MgSO₄ solution and normal water. Silpozz is manufactured by burning of agro-waste rice husk in designed furnace in between 600° to 700°C which is one of the main agriculture al residues obtained from the outer covering of rice grains during the milling process. There are four mix series taken with control mix. The control mix made 0% replacement of FA and silpozz with Ordinary Portland Cement (OPC). The first mix series made 0% FA and 10-30% replacement of silpozz with OPC. The second mix series made with 10% FA and 10-40% replacement of silpozz with OPC. The third mix series made 20% FA and 10-30% replacement of silpozz with OPC and the fourth mix series made 30% FA and 10-20% silpozz replaced with OPC. The samples (cubes) are prepared and cured in normal water and 5% and 10% MgSO₄ solution for 7, 28 and 90 days. The studied parameters are compressive strength and strength deterioration factor (SDF) for 7, 28 and 90 days. The regression equations and value of correlation coefficient R² between compressive strength and partial replacement of silpozz is obtained and revealed from these results that value of correlation coefficient is varied from 0.9602 to 1.

1. Introduction
Durability of concrete is completely dependable on amount of moisture and its rate of diffusion and also other dangerous chemicals which may enter into the concrete from the outer environment. The corrosion formation is completely because of diffusion of sulphate ions from the cover or outer layer of concrete to its inner implanted reinforcing bars is normally considered as one of the direct process of deterioration in reinforcement of concrete structures. Normally, there are various phases of damages in concrete structures with reinforcement due to corrosion but among them only three phases are considered. The first phase is influenced by the perforation of sulphide, during which sulphide ions are said to be dispersed throughout the concrete and reaches toward the bars of reinforcement. When the sulphate concentration increases and its critical value are reached inside the concrete then the steel begins to corrode and the first phase hereby ends. In the second stage, there is almost formation of rust between reinforcement steel bars and concrete due to which expansion is caused [1-10].
Some of the researchers have reported the utilization of supplementary cementitious materials to improve concrete properties in marine climate. Jena and Panda [7] studied the development of compressive strength in blended concrete made with silpozz and fly ash which is used as a partial replacement of cement to improve the durability of marine structures. Jena and Panda [6] studied the mechanical properties on concrete blended with silpozz which is can be used as an effective material and substitute of silica fume (SF) improves the structural durability. Anwar and Roushdi [5] found the properties of concrete blended with PC, FA and SF for improvements in concrete to resist deterioration due to environmental effects. Andrade et al. [4] have conducted accelerated chloride migration test and done the modeling of chloride penetration into concrete to analyze chloride content in concrete exposed to saline climate. Yildirim et al. [10] analyzed on the effect of types of cement on chloride diffusion for the given compressive strength and the cement blended with blast-furnace slag have better resistance against chloride diffusion than OPC and sulfate resisting cement. Wegian [9] investigated the strength properties such as the compressive, tensile, flexural and bond strengths of concrete mixing and curing with sea water and the strength reduction factor increases with exposure duration. Aburawi and Swamy [3] reported the effects of salt weathering and exposure to curing on the properties of high durability concretes containing chlorides. This article focuses the study of SDF of precast concrete samples with FA and silpozz in magnesium sulphate solution for 90 days curing period. Sunil [8] investigated the properties of precast plain and blended cement concrete made with FA were cured in seawater for a period of 1 year and the precast concrete samples performed better than the cast in situ samples.

2. Materials and Methods
The materials such as OPC 43 grade, FA, Silpozz, fine aggregate, coarse aggregate, normal water, magnesium sulphate solution and super plasticizer are used in this study. The experimental physical properties of OPC such as initial setting time 160 min, final setting time 360 min, standard consistency 32%, fineness 333 m²/kg and specific gravity 3.15 are determined confirming to IS 8112:1989.

| Oxides (%) | Cement (OPC) | Silpozz | FA |
|------------|--------------|---------|----|
| SiO₂       | 20.99        | 88.18   | 58.13 |
| Al₂O₃      | 6.05         | 1.61    | 31.00 |
| Fe₂O₃      | 6.01         | 0.56    | 4.10 |
| Carbon     | -            | 2.67    | -   |
| CaO        | 62.74        | 1.59    | 0.60 |
| MgO        | 1.33         | 1.63    | 0.10 |
| K₂O        | 0.40         | 1.67    | 0.90 |
| Na₂O       | 0.04         | -       | 0.05 |
| SO₃        | 1.82         | -       | 0.12 |
| TiO₂       | .025         | -       | 1.63 |
| Others     | -            | 2.09    | 0.011 |
| Moisture content (%) | - | 0.79 | 3.0 |
| Loss on ignition (%) | 1.14 | 0.04 | 0.29 |

| Physical properties |
|---------------------|
| Bulk Density (gm/cc) | 1.43 | 0.23 | 1.2 |
| Specific gravity    | 3.15 | 2.3  | 2.12 |
| Particle size (Micron) | 35  | 25   | 34  |
| Specific surface, m²/g | 0.33 | 17   | 33  |
| Color               | Gray | Gray black | Gray |
The physical properties of coarse aggregates obtained as per IS: 383-1970 such as fineness modulus 7.0, specific gravity 2.86, water absorption 0.2% and crushing value 24% as well as the properties of fine aggregates such as fineness modulus 3.03 (Zone-III), water absorption 0.6% and specific gravity 2.68. CERA HYPERPLAST XR-W40 high end super plasticizers are used [11-13]. The chemical and physical properties of FA and silpozz given by the supplier are shown in Table 1.

2.1. Preparation of MgSO₄ solution
Magnesium sulfate is a complex chemical compound simply containing magnesium, sulphur and oxygen (MgSO₄). It is of two types: heptahydrate and monohydrate. Heptahydrate (MgSO₄·7H₂O) is commonly known as Epsom salt or sulfate mineral epos mite which usually comes in crystal form. The monohydrate (MgSO₄·H₂O) is normally found in mineral kieserite. It comes in powder form. In this work, heptahydrate is being used to form magnesium sulfate solution. We have taken 5 gm and 10 gm MgSO₄ in 100 ml of water to prepare 5% and 10% MgSO₄ solution respectively. The following equation represents how to prepare the MgSO₄ solution. The samples such as cubes, cylinders and prisms are cured in sulphate solution which is shown in Figure 1.

\[ \text{[MgSO}_4\text{(5gm) + H}_2\text{O (100 ml) = 5% MgSO}_4\text{ solution}]} \]  
\[ \text{[MgSO}_4\text{(10gm) + H}_2\text{O (100 ml) = 10% MgSO}_4\text{ solution}]} \]

3. Results and Discussions

3.1 SDF (%) obtained from compressive strength in 5% and 10% MgSO₄ solution curing
The compressive strength test was performed on 150 mm cube specimens at the age of 7, 28 and 90 days for NWC, 5% and 10% MgSO₄ solution curing samples. The SDF obtained from compressive strength of 5% and 10% MgSO₄ solution curing samples are shown in Figure 1 - 2 respectively. It is observed from Figure 1 that the minimum SDF from 5% MgSO₄ solution is 0.18%, 0.35% and 0.74% at the age of 7, 28 and 90 days for the sample M1C80F10S10 respectively.

The maximum SDF from 5% MgSO₄ solution is 1.15%, 1.56% and 1.98% at the age of 7, 28 and 90 days for the sample M1C50F30S20 respectively. The maximum SDF from 10% MgSO₄ solution is 2.18%, 2.30% and 2.37% at the age of 7, 28 and 90 days for the sample M1C50F30S20 respectively. The 7, 28 and 90 days SDF in 5% and 10% MgSO₄ solution verses concrete mix is shown in Figure 3-
5 respectively. It observed from Figure 3 that the SDF obtained from 10% MgSO₄ solution-curing samples are more compared to 5% MgSO₄ solution curing samples including control mix. Similar trend is found from Figures 10 and 11 for 28 and 90 days respectively. The rate of SDF is studied more in between 7 to 28 days, but 28 to 90 days, the rate of SDF is slowly processed as compared to first 28 days. For each case, the silpozz-based specimens are giving low SDF as compared to FA based samples. The combined replacement of 10% FA and upto 20% silpozz with OPC showed optimal resistance against sulphate attack. Even without FA and upto 40% silpozz replaced with OPC also performed better in sulphate solution.

**Figure 2.** SDF obtained from 10% MgSO₄ solution verses Concrete Mix

**Figure 3.** 7 Days SDF in MgSO₄ Solution Verses Concrete Mix
3.2 Compressive Strength Verses Partial Replacement of Silpozz

The regression equations and value of correlation coefficient $R^2$ between compressive strength and partial replacement of silpozz for NWC samples at the age of 28 and 90 are shown in Figure 6-7. As evident from these results that value of correlation coefficient is varied from 0.9602 to 1. The high values of correlation coefficient indicate that there is strong relationship for compressive strength and replacement of silpozz in percentage. From the study, it is observed that the limitation of SP varies from 0.2 to 0.6% for 0% FA with silpozz 10% to 40%. For 10% FA with 10% to 40% silpozz, the range of SP varies from 0.22 to 0.72% and for 20% FA with 10-30% silpozz, SP range is 0.25 to 0.56%. The correlation factor is very high and it means that, inclusion of silpozz in concrete gives better affect to its strength properties. It makes the matrix dense due to its particle fineness. Due to this, the quality of concrete in term of its density, homogeneity and lack of imperfections improved.
Figure 6. Replacement of Silpozz versus 28 Days Compressive Strength (FA 0-20 series)

Figure 7. Replacement of Silpozz versus 90 Days Compressive Strength (FA 0-20 series)

4 Conclusion
It may be concluded from this study that the 10% FA and 10-20% silpozz replacement with OPC contributes higher compressive strength as compared to control mix cured in normal water, 5% and 10% MgSO₄ solution. When the percentage replacement of FA and silpozz increases more than 40% with OPC the strength properties decreases with respect to control sample for all types of curing specimens. It may be recommended that a suitable combination of silpozz and fly ash show satisfactory performance in both fresh and hardened concrete with proper doses of super plasticizer. It is predicted from regression analysis that good correlation obtained for strength properties of concrete and the partial replacements of silpozz varies from 10-40% with 0% FA and 10% FA series and 20% FA with 10-30% silpozz series. The addition of SCM such as FA and silpozz with super plasticizer enhances the homogeneity of cement paste and densify the microstructure of the cement considerably as well as improves the strength and durability properties of concrete in sulphate environment.

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