Effect of Chemical Activators on the Compressive Strength of Cement-Slag Mortar

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Abstract. The reaction of ground granulated blast furnace slag (GGBFS) with water is slower compared to the hydration of ordinary Portland cement. This led researchers to concentrate on increasing the hydration rate of the GGBFS. Previous studies were done by (SCA) showed that GGBFS can be used with activators or a certain amount of Portland cement. Also, they found that alkali hydroxides and GGBFS can be reacted alone without any calcium hydroxide obtained from Portland cement hydration to obtain a strong cement paste in applications. This experimental study conducted by the TS EN 196-1 standard, with the ratio (79:21)% slag to cement and 0%, 1%, 2%, 3% and 4% levels of activators (CaCO₃, Ca (OH) 2, Na₂SO₄, K₂SO₄ and CaSO₄.2H₂O); results indicates that with above ratio slag can be used with activator of (Na₂SO₄, K₂SO₄ and CaSO₄.2H₂O , greater compressive strength of 5-6 MPa was obtained at 2 and 7-day curing ages when K₂SO₄ was used as an activator at the dosages of 3% and 4%, while the activator (CaSO₄.2H₂O ) can improve all ages, and there was not a clear difference among control mixture without activator and slag-mortars activated by CaCO₃ and Ca (OH).

Keywords: Slag-cement Mortar, Compressive Strength, Chemical Activation

1. Introduction
The most extensively used construction material all over the world is concrete which is mainly composed of Portland cement, several aggregate types, water, and admixtures (if required). Concrete production for each one of the human beings living on Earth accounts for approximately one ton and with this much of consumption all over the world, concrete is the second most used material after water.as a result of the production of individual ingredients of concrete, environmental concerns arise. Production of Portland cement can be given as a striking example for the environmental pollution so that each one ton of cement production is responsible for the release of 1 ton of carbon dioxide to the atmosphere and cement production accounts approximately for the 7% of the total greenhouse emissions all over the world.to consider regulations and limitations on CO2 emissions. In the view of global sustainable development, the utilization of pozzolanic materials as a partial replacement of cement stands as one plausible way to reduce the environmental impact caused due to cement manufacture. Along with the environmental effects, the usage of pozzolans could substantially reduce the final cost
of concrete mixtures since these materials are quite cheaper in comparison to Portland cement. According to ACI 116R-90 (1994), pozzolans is “a siliceous or siliceous and aluminous material, which in itself possesses little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically reacts with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties.” Mineral admixtures that are, or both cementitious and pozzolanic can be used as a partial replacement for Portland cement. Some of the most used materials are ground granulated blast furnace slag (slag hereafter), fly ash, condensed silica fume. When properly used as a portion of the cementitious material, these pozzolanic admixtures can improve the properties of the fresh and hardened concrete. Although several types of supplementary cementitious materials exist, the focus of this review will be mainly on slag. Throughout the world, loads of ground granulated blast furnace slag is manufactured from the iron-steel industry every year. Utilization of this by-product not only has a great impact on the reductions of environmental issues but also contributions to the economy. It has been reported by many researchers that utilization of such by-products in mortars and concrete mixtures has marked influences on durability characteristics which was found to be highly important for infrastructure types built-in or near aggressive environments. Overall, it can be stated that beneficial effects of slag on mechanical and durability properties have started to be widely recognized and this leaded the extensive usage of the material in Portland cement mortar and concrete mixtures by many authorities. Utilization of slag in concrete mixtures is advantageous since the material shows superior cementitious characteristics over ordinary Portland cement and it has both economic and environmental benefits. However, there is a limitation on the usage of slag in concrete mixtures due to the problems arising related to low early-age compressive strength (Bougara et al. 2009). It is generally being accepted that while increased fineness of slag increases the compressive strength of conventional concrete mixtures, increments in slag replacement rates decrease the compressive strength. However, the fineness of slag is not that influential at the later ages when compared to an early age. Major factors that are in relation to the development of early-age strength can be water-binder ratio, sand-binder ratio, the number of pozzolans used in mixtures, environmental conditions, size of the testing specimen and so on. As previously mentioned, ground granulated blast furnace slag in great quantities is being produced each year as a residue from iron-steel factories. Although slag is utilized as aggregate in concrete mixtures and as a filling material in the roadbases, much of these materials are still being environmental burden causing further pollution. Moreover, when slag is used as an aggregate and/or filling material, pozzolanic behavior and cementitious characteristics are being ruled out and an advantage in terms of these properties is not taken. In order to further reduce the environmental burden of by-products and provide assistance in terms of economy, slag was replaced with Portland cement in mortar mixtures in the present research. While doing this, special attention was paid so as not to have decreased compressive strength results from the mortar specimens. A detailed literature review showed that there are limited studies related to the chemical activation of slag. Therefore, in the research concentration was mainly placed upon the chemical activation of slag an experimental study is undertaken in which five different types of chemical additives were utilized inside of the mortar mixtures. Chemical additives were added to the mixtures at the levels of 1%, 2%, 3%, and 4% of the total binder amount (Portland cement+slag) and influence of chemical addition rates were also investigated in this way. Along with the production of mixtures with chemical additives, control mixtures incorporating no chemical additives were also produced for comparison purposes. A small summary of the detailed experimental program was presented in Figure 1. Overall, the main objective of the present study is to evaluate the effect of type and dose of some chemical activators on cement-slag mortar compressive strength at the highest possible level of slags.
2-Materials

2-1. Chemical Activation:

Ground granulated blast furnace slag is described as a cementitious material having high capability to show enhanced compressive strength results when alkali activators are used. Throughout this study, slag was tried to be activated by utilizing chemical activators having the formula of CaCO$_3$, Ca(OH)$_2$, Na$_2$SO$_4$, K$_2$SO$_4$ and CaSO$_4$.2H$_2$O. The dosage of chemical activators was set to be 1%, 2%, 3% and 4%, by mass of total binders (cement+slag). Addition of the chemical activators in the mixtures was made by first dissolving the chemicals in the mixing water.
2.2. Portland cement:

During the production of mortar specimens CEM I 42.5 N normal Portland cement satisfying the requirements stated by TS EN 197-1 (2012) was used. Portland cement was supplied from Karçimsa Cement Factory which is placed in Karabük, Turkey. The specific gravity of Portland cement was 3.06 and Blaine fineness was 325 m²/kg. The chemical composition of Portland cement was presented in Table 1.

![Figure 3. X-ray spectroscopy (EDX) of slag](image)

| Chemical Composition (%wt.) | Portland Cement | Slag |
|-----------------------------|-----------------|------|
| CaO (%)                     | 61.43           | 34.16|
| SiO₂ (%)                    | 20.77           | 39.57|
| Al₂O₃ (%)                   | 5.55            | 10.11|
| Fe₂O₃ (%)                   | 3.35            | 0.74 |
| MgO (%)                     | 2.49            | 6.40 |
| SO₃ (%)                     | 2.49            | 4.29 |
| K₂O (%)                     | 0.77            | 1.21 |
| Na₂O (%)                    | 0.19            | 0.28 |
| Loss of Ignition (%)        | 2.20            | 0.90 |
| SiO₂+Al₂O₃+Fe₂O₃            | 29.37           | 50.42|

2.3. Slag:

Slag used throughout the present study was the one obtained from Kardemir iron-steel factory which was then grinded to the desired fineness values. The chemical composition of the slag was given in Table 1. The specific gravity of the slag was 2.79 g/cm³. The elemental structure of slag used throughout the study was identified by energy dispersive X-ray spectroscopy (EDX) Shown in figure 3.

Morphological properties of slag were analyzed by using scanning electron microscopy, shown in Figure 4.
2-4. Water:

Water was with the requirements of TS EN 1008 (2003) standard.

2-5. Aggregate:

According to the TS EN 196-1 (2002) standard, CEN reference sand is used as a material, as shown in Table 2. Table 2. The sieve analysis of sand

| Sieve Size (mm) | Cumulative Sieve remaining (% wt.) |
|-----------------|----------------------------------|
| 2.0             | 0                                |
| 1.6             | 7 ± 5                            |
| 1.0             | 33 ± 5                           |
| 0.5             | 67 ± 5                           |
| 0.2             | 87 ± 5                           |
| 0.08            | 99 ± 5                           |

3-Mixing and Specimen Preparation:

The composition of Portland cements was explained in TS EN 196-1 (2002) in detail. According to the standard, minimum and maximum values for the slag usage ranges between the values the research used the ratio of (79% of slag with 21% of cement) in a total binder material as cementitious material, all of the mortar specimens were produced based on a constant fraction of 1 binders (cementitious) x 3(CEN reference sand) x ½(water). Water to binder (cementitious) ratio was set to be 0.5. Which are Twenty-one different mixtures were prepared in total during the research. One of the mixtures was prepared as a control without any chemical activator addition and four mixtures for the five different types of chemical activators (CaCO3, Ca(OH)2, Na2SO4, K2SO4 and CaSO4.2H2O) with the different activator addition levels (1%, 2%, 3% and 4%) in percentage were used.
4-Test Procedure
Twenty-one different mixtures were prepared, for each mixture, nine (9) samples of 40x40x160 mm prism moulds were prepared, and merged in control temperature water each of three (3) samples was tested at the end of the (2,7,28) days with the Compressive strength testers were performed in accordance with ASTM C 39 (2003).

5-RESULTS AND CONCLUSIONS:
Compressive strength test results of slag-mortars are summarized in charts:
1 - There was not a clear difference among control mixture without activator and slag-mortars activated by CaCO₃ and Ca (OH)₂.
2 - When the slag-mortars were activated by $\text{Na}_2\text{SO}_4$, compressive strength results were higher than control specimens by 1.0 and 2.0 MPa for 2 and 7-day of age, respectively. As a result of this, it was found that 7-day compressive strength greater than 16.0 MPa can be easily produced for 32.5 N type cement. However, 28-day compressive strength criteria ($\geq32.5$ MPa) were not satisfied with all dosages of activator of $\text{Na}_2\text{SO}_4$.

![Figure 9. Compressive strength of different amount (Na$_2$SO$_4$)](image)

3 - In comparison to control mixture, greater compressive strength of 5.0-6.0 MPa was obtained after 2 and 7-day of curing when $\text{K}_2\text{SO}_4$ was used as an activator at the dosages of 3% and 4%. 28-day compressive strength values were the same as other activators that were under 32.5 Mpa.

![Figure 10. Compressive strength of different amount (K$_2$SO$_4$)](image)

4 - Compressive strength of 20.0 MPa at 7-day curing age was obtained when gypsum was used as an activator while it was at about 30.0 MPa at 28-day curing age.
5 - When CaSO$_4$.2H$_2$O is used to activate the cementitious materials regardless of the age of testing and amount of activator used. Increments in the results were sometimes 27% more than that of obtained from control specimens with respect to age and dosage of activator used.

6-Conclusion:
Now a day using ground granulated blast furnace slag (GGBFS) as cementitious material instead of Portland cement in concrete are very common because of environmental issue, and it have slower reaction with water that cause low early strength in mortar and concrete, more than one way to activation slag in this study we used five chemical activators with high range (79%) of replacement of slag, by the test result:
1 - All activator can not to be used as chemical activation of cement –slag mortar.
2 - The activators (Na$_2$SO$_4$) and (K$_2$SO$_4$) improve the compressive strength at early age when compared with the control, while the 28 days result is less that control.
3 – Activator (CaSO$_4$.2H$_2$O) can improve and can be used as activator for all age.
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