Replacement of cement with industrial by-products in cement mortar: An experimental investigation

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Abstract. The manufacture of cement has been described as a significant exporter of carbon gases pollution and other contaminants, with (1000) kilograms of cement reportedly producing one ton of Carbon gases. The effects of these gases in the atmosphere on public health and the atmosphere are negative impacts. As a result, industrials by-products become more eco-friendly and sustainable comparing with Portland cement in terms of cement use and emissions of carbon gases. The effect of partial substitution in mortar by ground granulated blast furnace slag (GGBS) and coal fly ash (CFA) is the subject of this investigation. Three separate GGBS and CFA blends have been utilized, and they have been checked at 7 days, 14 days, and 28 days curing age. To investigate the mechanical properties of the three mixtures, the compression test has been utilized. The experiment indicates that raising the percentage of GGBS and CFA in the mixture reduced the compressive strength of these mixes. 20 to 33% was the reduction in the compressive strength of the mixtures with supplementary Cementous materials, which might be considered sufficient.

1. Introduction
Nowadays, have a significant role in building manufacturing, and the essential part of it is Portland cement [1-3]. However, the manufacture of Portland cement has been an increasing issue as a significant volume of carbon gases, and some other pollutants are emitted into the environment throughout this phase [4-7]. The available literature, reveals that the production of cement produces around 6% to 8% of the overall Co2 in the environment [8-10]. To put it another way, generating (1000) kilogram of Portland cement is expected to yield one ton of Carbon dioxide. Carbon dioxide and other pollutants gases caused a significant increase in air temperature and the atmosphere overall. This last phenomenon endangers global safety by increasing water contamination and causing drought in certain countries of the planet [11-13]. Furthermore, concrete factories generate vast volumes of waste effluents with high suspended particle concentrations, pH values (close to 11), and sedimentation [14-17], both of which pose a hazard to marine organisms in aquatic ecosystems [16, 18, 19]. As a result of the unfavorable effects of the construction materials factories on global safety and the atmosphere, effective management strategies, as well as articulate wastewater technologies such as filtering [20-27], combination technologies [24, 28-30], flocculation [13, 16, 23, 31-40], and electro-chemical techniques [26, 41-48], as well as drainage alternatives [49-51], are needed.
Several researchers have currently been tasked with discovering substitute supplementary cementitious materials that can supplement a portion of Portland cement, such as ground granulated blast furnace slab (GGBS) and coal fly ash (CFA) [52]. Utilizing these admixtures as a partial substitute material could save power, money and reduce greenhouse gas emissions. Because of the pozzolanic characteristic of coal fly ash (CFA) and ground granulated blast furnace slab (GGBS), they are widely utilizing to partially replace Portland cement. As a result, utilizing these ingredients has a substantial impact on the cement mixture characteristics [52, 53].
The influences of ground granulated blast furnace slab (GGBS) and coal fly ash (CFA) on conventional cement were investigated in this research. The major aim of this report is to check how these compounds influence the mechanical properties of cement mixtures at 7 days, 14 days, and 28 days of curing period.
2. Experimental program

To compare the compression strength of mixtures produced by partially substituting Portland cement with crushed fly ash (CFA) and ground granulated blast furnace slag (GGBS), several experiments have been carried out. The ratios of crushed fly ash (CFA) and ground granulated blast furnace slag (GGBS) utilized in samples, as well as the design of mixtures, are subsequently neglected.

2.1 Materials

The ground granulated blast furnace slag (GGBS) and coal fly ash (CFA) have been utilized as cementitious substitution substances in this research. The ground granulated blast furnace slag (GGBS) is a secondary product produced during the production of ferrous metals, and it is characterized as a “nonmetallic material composed mainly of Ca2SiO4 and other compounds that is formed in a molten state concurrently with iron in a kiln,” according to ACI-116R. Silicates comprise the essential component of GGBS. Slag cooling is specifically responsible for producing multiple kinds of blast furnace slag required by various end-users. Slag's characteristics change dramatically as it cools. GGBS is a non-toxic substance that can be used to make high-value, user-friendly cementitious materials for a variety of structural engineering fields [54, 55].

CFA is a secondary product of crushed burning coal in thermal energy stations. It is collected as quite thin, mainly circular glassy grains from the evaporator coils by dust collecting devices till they are emitted into the air from the energy stations. The fly ash atoms have a different dimension, where their radius varies from less than 0.5μm to more than 75μm. It has a smoother texture than conventional cement. The forms and proportional quantities of incombustible content in the coal utilized decide the chemical structure of fly ash [56, 57].

Portland cement was used as the basic binding material in this experiment because of its excellent mechanical properties, which aid in its binding with all other components of the mixture. BS-EN 196-2:2013 has been utilized to evaluate the cement used in this project. Figures 1 and 2 list the chemical characteristics of cementitious admixtures. Coal fly ash, Portland Cement, and the ground granulated blast furnace meet the requirements of BS-EN 450-1:2012, BS-EN 197-1:2011, and BS-EN 15167-1:2006.
2.2 Methods of testing

Three specimens (100x100x100 mm) were poured and measured for each sample to evaluate the compressive strength of Portland cement mixtures. Checking the cubes just with Portland cement and after that with separate substitution ratios of ground granulated blast furnace slag and coal fly ash to understand its effects on the compressive strength of the cement mixes. After pouring the cement cubes and handled them with care, the cubes have been molded and cured it’s at different periods of 7, 14, and 28 days, then, the compressive strength was calculated for each cube.

2.3 Design of Mixtures

The quantity of aggregate, supplementary cementitious products, water, and Portland cement, in a mortar mixture, is determined using the mix design approach used in this study. To match the classification scales, natural sand was selected. For all of the mixes, two parts of Portland cement to five parts of fine aggregate was the ratio of sand to binding materials (CFA + cement + GGBS). As well as, the percentage of water to binding materials was 0.4. Figure 3 presents the value of each element of mixing as well as the blend style proportions. To assess the strength of composite mortar, all cubes were subjected to a compression examination. Ground granulated blast furnace slag and coal fly ash could be utilized to evaluate the mechanical characteristics of cement mortar by 10x10x10 cm cubes. After 7, 14, and 28 days of cure, these cubes were examined by a compression instrument. Cubes were evaluated after gradually applying the load from the compression machine till these cubes were a failure. The impacted force was divided by an area of (10000) square millimeters to measure the compressive resistance of these cubes.
3. Results

Table (1) and Figure 4 show the examining results of the cubes for cement mortar with partial substitution of ground granulated blast furnace slab and coal fly ash at varying proportion and curing times, after examining them with a compression machine.

Table 1: the compressive strengths of the developed mortars at tested ages.

| Test No. | Portland cement % | CFA % | GGBS % | Average of compressive strength (MPa) at 7 days | 14 days | 28 days |
|----------|--------------------|-------|--------|-----------------------------------------------|---------|---------|
| 1        | 100                | 0     | 0      | 9.9                                           | 11      | 13.5    |
| 2        | 60                 | 20    | 20     | 7.24                                          | 9.07    | 10.4    |
| 3        | 40                 | 30    | 30     | 5.30                                          | 7.25    | 7.77    |

It is shown that partially adding ground granulated blast furnace slab and coal fly ash in cementitious mixtures leads to a decrease in the compressive strengths of these mixtures. When comparing mixture No. (2) with the third mixture, it is evident that mixture (2) has a lower compressive intensity decrease. For such as, after 7 days of pretreatment, the compressive intensity of the blends was reduced by 26% and 46%, respectively, as compared to the first blend (Figure 4). On another side, utilizing 40% partially replacing content reduced the compressive efficiency of cementitious mortar by 46% after 7 days, but this percentage slipped to 30% after 4 weeks. This suggests that it was at a young age, ground granulated blast furnace slab and coal fly ash are inert materials that require duration to interact with the elements of a cement mortar. To summarize, the limited substitution of CFA and GGBS can be achieved at a rate of 20 to 33% to achieve better quality while reducing emissions. This is because supplementary cementitious materials usually minimize the compressive properties of cementitious mixtures, which is an essential component in the manufacturing gel (C-S-H) in cement mixes. The findings show that specimens that have been cured for 28 days have a greater compressive characteristic. To explanation, as mention above the curing age affects the compressive strength of cementitious mortars. where, curing period influences the benefit and improvement of C-S-H, which contributes to a reduction in the number of Internal spaces or permeability in the mortar matrix, which influences the properties of concrete and increases the strength development of these mixes. When comparing mixture three at 14 and 28 days to the same specimens at 7 days, the improvement in compressive intensity was 27% and 32%, consecutive.
Figure 4: Shows the compressive strength of blends after 7, 14, and 28 days of curing.

The current study looked at the compressive strength of concrete specimens for 28 days; however, further research is needed to look at extended periods and equate the findings to conventional concrete samples of the same age. The built-in sensors can also be utilized for that [58, 59], as sensors have demonstrated high-quality results in a variety of engineering sector, including communications [60] and water quality [61].

4. Conclusions

Drawn from the results of this research, it can be concluded that when ground granulated blast furnace slag and coal fly ash are utilized to substitute Portland cement in mortars, the compressive intensity reduces as the ratio of GGBS and CFA is increased. Also, whenever the ratio of the cementitious material maximized, the curing time should be longer to ensure achieve better compression characteristics. Utilizing about 20 to 33% as a partial substitute for cement may be suitable values, as increasing this value reduces the concrete’s compressive characteristics.

Since the current report just looked at the compressive strength of concrete samples for 28 days, further ages must be studied in the future. The built-in sensors can be utilized for that as sensors have demonstrated a high-quality result in a variety of engineering sector.

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