Abstract: The basic oxygen furnace slag is a major waste by-product generated from steel-producing plants. It possesses excellent characteristics and can be used as a natural aggregate. Chemically, the basic oxygen furnace slag encloses free CaO and free MgO, which is the main reason for the expansion crisis since these free oxides of alkaline earth metals react with water to form their hydroxide yields. The objective of the present research study is to stabilize the basic oxygen furnace slag by using innovative geopolymer technology, as their matrix contains a vast quantity of free silicon, which can react with free CaO and free MgO to form stable silicate compounds resulting in the prevention of the basic oxygen furnace slag expansion predicament. Lab-scale and ready-mixed plant pilot-scale experimental findings revealed that the compressive strength of fine basic oxygen furnace slag-based geopolymer mortar can achieve a compressive strength of 30–40 MPa after 28 days, and increased compressive strength, as well as the expansion, can be controlled less than 0.5% after ASTM C151 autoclave testing. Several pilot-scale cubic meters basic oxygen furnace slag-based geopolymer concrete blocks were developed in a ready-mixed plant. The compressive strength and autoclave expansion test results demonstrated that geopolymer technology does not merely stabilize the basic oxygen furnace slag production issue totally, but also turns the slags into value-added products.

Keywords: basic oxygen furnace slag; autoclave test; geopolymer technology; expansion behavior; recycling

1. Introduction

The Basic Oxygen Furnace (BOF) slag is a left-behind residual waste generated from the steelmaking industry. There are 1.5 million tons of BOF slags produced annually in Taiwan [1]. This high quantity leads to environmental and ecological issues together with health concerns. This waste demonstrates excellent physical and mechanical attributes, such as far-above-the-ground hardness, a higher compressive strength, and a near-to-the-ground abrasion ratio. It is capable of substituting natural aggregates to produce structural materials, road pavements, and more. Unfortunately, the key setback of BOF slags is their expansion behavior because of their gigantic content of free lime, as a consequence, a hindrance in the context of BOF slag recycling and reuse takes place [2–6]. Most of the coarse BOF slags, larger than four mesh, are mixed with asphalt to produce asphalt-concrete...
which can be employed as road pavements. However, approximately 0.7 million tons of fine BOF slags, which is less than four mesh, are unable to be utilized effectively, especially used in the Portland cement system [7]. For that reason, the way in which a BOF slag can be reutilized as a fine aggregate has become an imperative issue.

Previous studies on BOF slags used as aggregates in concrete and their advantageous properties have been extensively reported [4,5,8–11]. However, the BOF slag contains free-CaO and free-MgO that can result in volumetric instability due to their reaction with water, yielding alkaline earth metal hydroxides. This must be addressed, employing appropriate treatment to prevent expansion. There are several ways to stabilize BOF slags, such as stabilization in the hot or molten stage [12–14], and stabilization by employing a carbonation process [12,15,16]. Singh et al. supplemented oxalic acid into cement mortar to improve the densification and mechanical properties of concrete [17], while Ding et al. utilized scrubbing attrition and chelating reagent treatment to remove free lime from BOF slags [5].

On the other hand, Lin et al. immersed BOF slags into the water to provide sufficient stabilization reactions [18]. According to previous research results, the adding up of silica sand in the molten stage can complete the solution and get rid of free lime crisis. This brings into question whether or not analogous reactions can occur at room temperature. If possible, they will entirely resolve the quandary of BOF slag expansion and achieve the goals of waste recycling following the principles of the Circular Economy.

Nowadays, innovative geopolymer technology is drawing the attention of researchers on account of not only its nine-times lower carbon footprint and six-times lower energy consumption as compared to the OPC (Ordinary Portland Cement) system [19], but also due to the demonstration of excellent properties by geopolymer composites, such as high initial strength, brilliant resistance to chemicals and freeze-thaw as well as thermal and fire calamities, sustainability, and strength and durability. This means simply that novel geopolymer technology can lend a hand in solving the great dilemma of global warming and the saving of natural resources of rocks and minerals. On top of that, it is cost-effective, since it can incorporate profusely accessible various wastes in the manufacture of geopolymer composites, which otherwise create problems of landfilling and pollution of the environment, soil, surface and subsurface waters besides health hazards [20,21]. Accordingly, it also extends to an organized solution of the disposal of these wastes. Inorganic geopolymers are analogous to natural zeolite minerals but possess an amorphous microstructure, they are classed as three-dimensionally networked materials synthesized through the reaction of rich aluminosilicate materials, such as precursors and alkaline solutions, as activators [22–24]. During the geopolymerization reaction, Si gel and Al gel were produced on the solid particle surface, and thus, they formed the Si-O-Al framework. SiO$_4$ and AlO$_4$ tetrahedra are linked to each other by sharing all O$_2$ atoms [25,26]. Their unique internal structure is the core reason for why geopolymer has superior chemical and physical properties such as high compressive strength, high durability, favorable structural integrity, and low permeability. These exothermic and complex geopolymer processes contain large amounts of free silicon. This free silicon can react with oxides of free lime and free magnesium in the BOF slag, and hence, the formation of stable compounds takes place, thereby inhibiting the expansion of the BOF slag.

In this original research, BOF slags, granulated blast furnace slag (GGBS) powder, coal fly ash (FA) and alkali activator solutions were employed as raw materials to manufacture BOF slag-based geopolymer mortar. The effect on compressive strength and expansion behavior from the GGBS/FA ratio and the SiO$_2$/Na$_2$O ratio in geopolymer mortar are presented in this investigation. For testing the expansion behavior of BOF slag-based geopolymer mortar, the application of the autoclave testing method as the accelerated test was made [27]. Lab-scale and ready-mixed plant pilot-scale recycling processes are also investigated in this study.

2. Assumption of the Mechanism for Stabilization BOF Slags in Geopolymer System

In general, the expansion phenomenon of the BOF slag is mainly due to the f-CaO, and f-MgO content presented. When the BOF slag makes contact with water, f-CaO will undergo a hydration
reaction, causing volume expansion. The f-MgO hydration reaction is relatively slow, and about 30 days later, it will also cause volume expansion. After the BOF slag absorbs water, f-CaO will become calcium hydroxide “Ca(OH)\(_2\)”, the volume will expand by 127% [28], and f-MgO will become magnesium hydroxide “Mg(OH)\(_2\)”. The volume expansion is about 118% [29]. Therefore, this study conceived that utilizing free silicon to react f-CaO into a stable calcium silicate compound would prevent the expansion. The relevant reaction Equations (1) and (2) are as follows:

\[
\begin{align*}
  \text{f-CaO} + \text{Si} & \rightarrow \text{CaSiO}_3 \\
  \text{f-MgO} + \text{Si} & \rightarrow \text{MgSiO}_3
\end{align*}
\]

After the geopolymer reaction is completed, the excessively free silicon will remain in the matrix of BOF slag-based geopolymer. If other factors caused the geopolymer matrix and/or BOF slag aggregates to be broken, the f-CaO may be released again. At this time, if water infiltrates from the crack, the free silicon remaining in the geopolymer product will dissolve in the water, and then react with f-CaO to form a stable calcium silicate to prevent expansion. The reaction schematic diagram is shown in Figure 1.

![Figure 1. Schematic diagram of f-CaO reaction with free silicon in geopolymer matrix.](image)

### 3. Experimental

#### 3.1. Materials

BOF slag aggregates with a particle size less than four mesh original fine with a D\(_{50}\) at 0.75 mm obtained from CHC Resources Corporation were utilized. The chemical composition of fine BOF slags is depicted in Table 1. The key composition in BOF slag was CaO and Fe\(_2\)O\(_3\); it also contains 4.7 wt% of free lime. Additionally, GGBS and FA were obtained from CHC Resources Corporation in Taiwan. GGBS possesses a particle size between 0.6–135.7 \(\mu\)m with D\(_{50}\) at 12.3 \(\mu\)m while those of FA range among 0.7–201.9 \(\mu\)m with a D\(_{50}\) at 22.2 \(\mu\)m. The chemical composition of GGBS powder and FA were also represented in Table 1. Alkali activator solutions with various SiO\(_2\)/Na\(_2\)O molar ratios were prepared by mixing sodium silicate solution (9.5 wt% Na\(_2\)O, 29 wt% SiO\(_2\)) and 6M sodium hydroxide. The molar ratio for SiO\(_2\)/Al\(_2\)O\(_3\) was kept at 50 and was controlled by sodium aluminate. The alkali solutions were prepared and ready to use the day before the experiment.

#### Table 1. Chemical composition of basic oxygen furnace (BOF) slag, granulated blast furnace slag (GGBS) and coal fly ash (FA).

| Composition | SiO\(_2\) | CaO | Al\(_2\)O\(_3\) | Fe\(_2\)O\(_3\) | MgO | f-CaO | LOI | Others |
|-------------|-----------|-----|----------------|----------------|-----|-------|-----|--------|
| BOF Slag    | 9.4       | 37.1| 4.2            | 24.1           | 7.1 | 4.7   | 0.8 | 12.6   |
| GGBS        | 27.7      | 57.9| 11.2           | 0.4            | –   | –     | –   | 2.8    |
| FA          | 60.2      | 2.7 | 19.1           | 8.7            | –   | –     | –   | 6.4    |
3.2. Methods

GGBS and FA were mixed at the designed weight ratio with an additional 3 wt% of wollastonite added during blending. Subsequent to pre-mixing for 3 min, the mixture was then activated with alkali solutions. After thorough mixing for 3 min, the fine BOF slags were then added into geopolymer paste for an additional 3 min blending to prepare geopolymer mortar with various geopolymer: BOF slag ratios. The geopolymer mortar was then cast into cylindrical molds of size (Φ50 × 100 mm). Following 24 h of de-molding, the samples were then cured at room temperature until certain days for testing. In order to measure the volume stability, all the BOF slag-based geopolymer mortar samples were tested using the autoclave testing method according to ASTM C151 standard.

Before and after autoclave testing, the length, diameter, and volume change rate of the cylindrical specimen were calculated by dividing the circle portion of the cylindrical specimen into three sections with the center point of the circle. A Vernier caliper was used for measuring the length varieties of the cylindrical sample. For diameter measurements, an arbitrarily selected marked two points at the middle of the height of the cylindrical test body was measured and another two points were made at a position rotated by 90°, which were also measured. The change in total volume is calculated from the above results.

4. Results and Discussion

4.1. BOF Slags Expansion Behavior and Powdering Rate

The powdering rate measurement was based on GB/T 24175-2009 (Test method for stability of steel slag). Before collecting an 800 g oversize part to put into an autoclave, the BOF slags were screened using a No. 4 sieve. The autoclave maintained the pressure at 20.8 ± 0.7 kgf/cm², temperature 215.7 ± 1.7 °C for 3 h. Subsequently after drying and sieving again by employing the No. 4 sieve, the powdering rates were calculated as illustrated in Equation (3).

Table 2 demonstrates the results of powdering rates for various size ranges of BOF slags after autoclave tests. The powdering rate increased from 17.4% to 29.9% with decreasing particle size ranges from >3/4 inch–3/8 inch–No. 4 mesh. This implies that the finer particle size range of BOF slags contained more free lime.

Table 2. Powdering rate for different size range BOF slags after autoclave test.

| Particle Size Range | Powdering Rate (%) |
|---------------------|--------------------|
| 3/8 inch–#4 mesh    | 29.9               |
| 3/4 inch–3/8 inch   | 27.8               |
| >3/4 inch           | 17.4               |

\[
\text{Powdering Rate} = \frac{\text{Weight of less than 4 mesh part}}{\text{Total Sample weight}} \times 100\% \quad (3)
\]

In order to compare the performance of BOF slags (aggregate) in the Portland cement system and geopolymer system (binder), the binder/aggregate weight ratio was kept at 1:2.75 for the BOF slag expansion test. The expansion behavior of the BOF slag in the Portland cement system and geopolymer technology is presented in Table 3. Based on the experiment results, it is seen that in the case of the BOF slag in the Portland cement system, the sample totally collapsed after the autoclave test due to the steam, which accelerated the reaction of free lime, thus causing expansion. Nevertheless, in the case of the BOF slag in the geopolymer system, the sample still maintained its integrity after the autoclave test as displayed in Table 3. The average height, diameter, and volume changes recorded are 0.18%, 0.07%, and 0.35%, respectively. After the autoclave test, the samples were crushed, grinded and analyzed by XRD (X-ray Diffraction) (Figure 2). The mineral phase of calcium silicate was found, indicating that the geopolymer technique can stabilize the untreated BOF slag fines. This is ascribed to
the enormous quantities of free silicon present in the geopolymer matrix. This free silicon reacted with free lime or free-MgO on the BOF slag surface to form a stable compound. When the BOF slag-based geopolymer is subjected to an external force and cracks crop up, the moisture will enter into the BOF slags. The free silicon in the geopolymer matrix will be dissolved and brought into internal BOF slag to react with free-CaO or free-MgO to form stable calcium silicate or magnesium silicate. This reaction can effectively inhibit the expansion of the BOF slags.

**Table 3.** BOF slag expansion behavior in Portland cement system and geopolymer system after autoclave test.

| BOF Slag in Different System | Before Autoclave Test | After Autoclave Test |
|----------------------------|----------------------|---------------------|
| Portland Cement System     |                      |                     |
| Geopolymer System          |                      |                     |
| Ave height change          | 0.18%                |
| Ave diameter change        | 0.07%                |
| Ave volume change          | 0.35%                |

**Figure 2.** Results of XRD (X-ray Diffraction) analysis of the BOF slags in the geopolymer system after autoclave test.
4.2. Effect of SiO$_2$/Na$_2$O Molar Ratio on the Properties of BOF Slag-Based Geopolymer Mortar

In order to understand the effect of the SiO$_2$/Na$_2$O molar ratio on the features depending on the BOF slag-based geopolymer mortar, the experimental parameters were adjusted, and the experimental results exhibit that the compressive strength depending on the SiO$_2$/Na$_2$O ratio of the BOF slag-based geopolymer mortar is augmented as the ratio of SiO$_2$/Na$_2$O increases, as portrayed in Figure 3. Both tend to enhance the compressive strength as the curing time increases. When the ratio of SiO$_2$/Na$_2$O was between 1.28 and 1.5, the compressive strength at the age of 56 days was about 32–38 MPa. Likewise, when the ratio of SiO$_2$/Na$_2$O was 1.6, the compressive strength achieved 53 MPa on the day 56. However, only the decrease of compressive strength after 56 days for SiO$_2$/Na$_2$O = 1.4 was found. The reason for this is large amounts of micropores generated in the structure of the geopolymer that hinder the development of compressive strength, and no such phenomenon is found in a ratio higher or lower than the SiO$_2$/Na$_2$O ratio of 1.4 [30]. Moreover, it is found that most of the specimens subjected to the autoclave expansion treatment according to the ASTM C151 standard possess a tendency to increase the compressive strength, and the strength on day 56 can obtain 40–55 MPa as illustrated in Figure 3b. A careful observation of the surface of the specimen after the autoclave test revealed that it still has a small amount of surface peeling, which may be due to the fact that the BOF slag particles on the surface of the specimen cannot be entirely covered by the geopolymeric slurry, or maybe because of the highly thin coating. Therefore, there is still a small part of the reaction expansion phenomenon. However, due to its substantial increase in compressive strength, it indicates that the overall performance of the test body subsequent to the autoclave expansion test is still very stable.

![Figure 3](image-url)

*Figure 3. Effect of SiO$_2$/Na$_2$O molar ratio on the curing age and compressive strength of BOF slag-based geopolymer mortar before autoclave expansion test (a) and after autoclave expansion test (b).*

The effect of the SiO$_2$/Na$_2$O molar ratio on the curing age of the BOF slag-based geopolymer mortar was subjected to an autoclave expansion test specimen, and its linear expansion, diameter expansion, and bulk expansion characteristics were analyzed. The results are shown in Figure 4. As illustrated in Figure 4, the volume expansion ratio of each of the samples was 0.4% or less, of which, the expansion ratio of SiO$_2$/Na$_2$O = 1.4 and 1.5 is the lowest and is only 0.1% or less. Furthermore, the linear expansion ratio and the diameter expansion ratio were analyzed ahead, and the linear expansion ratio was mostly less than 0.1%, and the diameter expansion ratio was also 0.15% or less. This shows that the untreated BOF slag has high stability under the geopolymer system. According to the results of this experiment, the subsequent selection of the BOF slag-based geopolymer mortar was carried out with a ratio of SiO$_2$/Na$_2$O of 1.5.
Figure 4. Effect of SiO$_2$/Na$_2$O molar ratio on the length, diameter, and volume changes after autoclave test, (a) volume expansion ratio (b) linear expansion ratio (c) diameter expansion ratio.
4.3. Effect of GGBS/FA Ratio on the Properties of BOF Slag-Based Geopolymer Mortar

The results of the compressive strength of the BOF slag-based geopolymer mortar, with varying proportions of the GGBS and FA, are shown in Figure 5. The compressive strength increased with increased GGBS content (Figure 5a). This could be due to the fact that the structure of geopolymer mortar is denser and more increased with curing age. The BOF slag-based geopolymer mortar of different powder ratios was subjected to a compressive strength test after an autoclave treatment, and the results are shown in Figure 5b. According to the experimental results, it can be found that although the surface of the test piece has a small part of peeling after the autoclave test, the compressive strength is still significantly increased. This means that the test specimen is still very stable after the autoclave expansion test. The higher the content of fly ash, the significantly higher the strength of the sample after the autoclave test. This may be due to the high silicon content of fly ash in the system to suppress the BOF slag expansion [31].

The autoclave expansion test, ASTM C151, was carried out to understand the stability and volume expansion rate of BOF slag-based geopolymers, with different proportions of GGBS:Fly ash, shown in Table 4. Table 4 highlights that in the BOF slag-based geopolymer mortar sample, the excessive GGBS or the excessively high FA content has a high expansion rate. Moreover, with a ratio of GGBS:FA = 6:4, the volume expansion rate is 0.53% after 56 days of curing, but the GGBS:FA = 3:7, after 56 days of curing, has an expansion rate as high as 0.71%. Only between the GGBS:FA = 5:5, an expansion rate of less than 0.1% exists. The linear expansion ratio and the diameter expansion ratio were less than 0.3%.

| GGBS:FA | Diameter Expansion (%) | Length Expansion (%) | Volume Expansion (%) |
|---------|------------------------|----------------------|----------------------|
|         | 7d  | 28d  | 56d  | 7d  | 28d  | 56d  | 7d  | 28d  | 56d  |
| 6:4     | 0.18| 0.18 | 0.18 | 0.24| 0.22 | 0.15 | 0.62| 0.59 | 0.53 |
| 5:5     | 0.03| 0.02 | 0.02 | 0.01| 0.02 | 0.03 | 0.07| 0.05 | 0.10 |
| 3:7     | 0.24| 0.21 | 0.26 | 0.16| 0.19 | 0.19 | 0.66| 0.63 | 0.71 |

Similarly, in the ratio of GGBS:FA = 5:5, both the diameter and linear expansion rate were less than 0.03%. Although the FA in the system can provide more silicon to inhibit the expansion of the BOF slag, the powder itself has large shrinkage and insufficient strength, thus cannot add too much. On the other hand, in the sample with higher GGBS content, although the content of silicon—which
can react with free lime—is reduced, it is still sufficient to inhibit the expansion of the BOF slag due to its own strength, and its volume expansion is still 0.53%. In the GGBS:FA = 5:5, the strength provided by the GGBS in the system and the FA that can react to inhibit free calcium reached the optimum amount, and consequently the expansion rate and age are the best, <0.1% for 7–56 days curing.

4.4. Laboratory Horizontal Double Shaft Mixer Tests

This phase of the test is mainly to simulate the large-scale test of the actual plant. GGBS and FA (5:5) are used as source materials. The alkaline liquid has NaOH concentration of 6M, the SiO$_2$/Na$_2$O molar ratio is 1.5, the SiO$_2$/Al$_2$O$_3$, as well as molar ratio, is 50. The moisture content of the BOF slag is controlled at 10%, where the BOF slag is not pretreated before the tests. To simulate the actual factory test, this experiment prepared a BOF slag-based geopolymer mortar with a horizontal biaxial mixing machine and poured a test specimen of Φ10 cm×20 cm for the compression test and the autoclave expansion test. The mixture proportion and process are shown in Table 5. Table 6 shows the hardening time of the BOF slag-based geopolymer mortar. According to the hardening time test results, the initial setting time is about 3 h; the final setting time is about 9 h.

Table 5. Simulation the large-scale experiment for BOF slag-based geopolymer mortar.

| Mix No. | Source Materials | Binder: Aggregate | Wollastonite | I/S | BOF Slags Water Content |
|---------|------------------|-------------------|--------------|-----|------------------------|
| GC-BOF10% | FA 5 GGBS 5 | 1:2.75 | 5% | 0.49 | 10% |

Table 6. Hardening time result of simulation of large-scale experimental for BOF slag-based geopolymer mortar.

| Mix No. | Setting Time |
|---------|--------------|
| GC-BOF10% | Initial 3 h 15 min Final 8 h 40 min |

The compressive strength of the simulated large-scale experimental BOF slag-based geopolymer mortar is shown in Figure 6. As the curing age increases, the strength of the test body increases. At seven days of age, the strength reached about 27 MPa; at 28 days of age, the strength reached 40 MPa. It is said that the simulation of the large-scale experimental of BOF slag-based geopolymer mortar has excellent strength performance.

![Figure 6. The compressive strength of simulation large-scale experimental BOF slag-based geopolymer mortar.](image-url)
The autoclave expansion test of the simulated large-scale experimental BOF slag-based geopolymer mortar is shown in Table 7. After the autoclave expansion test, the BOF slag-based geopolymer mortar sample is complete, and only a slight surface is peeling. The compressive strength test before and after autoclave found that the surface peeling did not affect the stability of the test specimen.

| Test Specimen  | Before Autoclave Test | After Autoclave Test | Volume Changed |
|----------------|-----------------------|----------------------|----------------|
| GC-BOF10%      |                       |                      | 0.27%          |

Table 7. Autoclave expansion test (seven days) results of simulating the large-scale of the experimental BOF slag-based geopolymer mortar.

4.5. BOF Slag-Based Geopolymer Mortar Tests in Ready-Mixed Plant

4.5.1. Ready-Mixed Plant Small Scale Tests

The mixed proportion for Ready-mixed plant small scale test is shown in Table 8. The main difference between the two tests is the ratio of binder and aggregate, which is the additional amount of the BOF slags.

| NO. | L/S | Binder/Aggregate | GGBS | FA | Mixture Proportion (kg) | Total Weight (kg) |
|-----|-----|------------------|------|----|-------------------------|-------------------|
|     |     |                  |      |    | BOF (15% water)         |                   |
|     |     |                  |      |    | Alkali Solution          |                   |
| Test-1 | 0.41 | 1:2.90          | 15.12| 15.12| 100.85 (87.70)         | 143.59            |
| Test-2 | 0.38 | 1:1.98          | 19.70| 19.70| 90.00 (78.26)         | 144.40            |

The fresh properties of the ready-mixed plant small-scale test mixture are shown in Table 9. According to the results, it is found that the BOF slags of the high-water content of BOF slag-based geopolymer mortar showed excellent workability. The initial slump flow of Test-1 is 540*580 mm, and it is allowed to stand for 45 min after, and the slump flow is reduced to only 520*520 mm. Test-2’s initial slump flow is 470*480 mm, and after allowing it to stand for 45 min, its slump flow is reduced to 440*440 mm. The results of the two tests were found to have low slump flow loss performance.
The compressive strength of the ready-mixed plant small scale tests is shown in Table 10 and Figure 7. As the curing age increases, the strength of the test body increases. The strength of the late Test-2 is higher than that of Test-1 because the strength source of the geopolymer system is from the geopolymer slurry rather than an aggregate. Therefore, in Test-2, where the BOF fine aggregate is relatively low, the compressive strength will be higher than Test-1. However, after the autoclave test, the compressive strength decreases in Test-2. The reason for this is due to water release and formed cracks.

![Figure 7. Compressive strength of the ready-mixed plant small scale test.](image-url)
4.5.2. Ready-Mixed Plant Pilot-Scale Tests

Ready-mixed plant pilot-scale test parameters are shown in Table 11. The ratios of FA and GGBS are 5:5 and 6:4, the ratios of binder and aggregate are 1:2.936 and 1:3.575. The total test volume is 1.5 cubic meters, and the total weight in each test is approximately 3.5–3.6 tons.

Table 11. Mixture proportion of ready-mixed plant pilot-scale test.

| NO. | FA:GGBS | L/S | Binder:Aggregate | Alkali Solution | GGBS | FA | BOF Slag | BOF Slag Water Content | Water Added | Total Volume and Weight |
|-----|---------|-----|------------------|-----------------|------|----|---------|------------------------|-------------|------------------------|
| Test-3 | 5.5 | 0.50 | 1.2936 | 374 | 375 | 2,400 | 9.0% | 20.0 | 1.5 m³ 3544 kg |
| Test-4 | 6.4 | 0.52 | 1.3575 | 349 | 267 | 400 | 7.4% | 60.0 | 1.5 m³ 3636 kg |

The fresh properties of the ready-mixed plant pilot-scale tests are shown in Table 12. The test number of Test-3 and Test-4 have a slump flow of 380*390 mm and 510*490 mm, respectively. The reason for this difference is the increase in the use of FA in Test-4 samples, which is spherical in shape and contributes to its fluidity [32,33].

Table 12. Fresh properties of ready mixed plant pilot-scale tests.

| NO. | FA:GGBS | Slump | Slump Flow |
|-----|---------|-------|------------|
| Test-3 | 5:5 | 260 mm | 380*390 mm |
| Test-4 | 6:4 | 270 mm | 510*490 mm |
The compressive strength and their autoclave test of ready-mixed plant pilot-scale experiments are shown in Table 13 and Figure 8. As the curing age increases, the strength of the test body increases. The compressive strength of Test-3 is slightly higher than that of Test-4. The main reason is the adjustment of the ratio of FA to GGBS. Test-4 is higher in the amount of FA, and the reactivity of FA itself is poorer than that of GGBS powder which causes its intensity to be slightly lower than Test-3. According to the results of the autoclave expansion test, as the curing age increases, the structure of the test body is more complete, and the test specimen has no break point after the autoclave expansion test. The expansion changes after the autoclave test for the ready-mixed plant pilot-scale tests are shown in Table 14. All the expansion test results can be controlled around −0.41% for diameter and liner changes.

| NO. | FA: GGBS | Compressive Strength (MPa) | Autoclave Test |
|-----|----------|-----------------------------|----------------|
|     | 1d Ave  | 3d Ave | 7d Ave | 28d Ave | 28d |
| Test-3 | 5.5 | 20.3 | 20.9 | 33.9 | 33.4 | 37.2 | 37.5 | 39.7 | 41.6 | 45.4 |
| Test-4 | 6.4 | 14.1 | 13.9 | 24.9 | 25.4 | 31.1 | 31.4 | 40.4 | 39.9 | 31.7 |

Table 13. Compressive strength and autoclave test of ready-mixed plant pilot-scale tests.

Table 14. Expansion changes after autoclave test for ready-mixed plant pilot-scale tests (curing time 28 days).

| NO. | Expansion Ratio After Autoclave Test (%) |
|-----|------------------------------------------|
|     | Diameter Change | Length Change |
| Test-3 | −0.41 | −0.41 |
| Test-4 | −0.41 | −0.41 |

5. Conclusions

The present study and its findings were piloted, and conclude that:

- Reduction concerning CO₂ emissions and consumption of copiously available BOF slag wastes is possible by employing geopolymer technology. Not merely that, it stabilizes the BOF slag production absolutely by turning them into valuable products.
- Stabilization of the BOF slag through geopolymer technology is successfully determined, since their matrix encompasses a large amount of free silicon (Si) which can react with free CaO and free MgO to form stable silicate compounds leading to the addressing of the quandary of BOF slag expansion.
• Lab-scale and ready-mixed plant pilot-scale experimental upshots unveiled that the compressive strength of fine BOF slag-based geopolymer mortar achieved the compressive strength of 30–40 MPa after 28 days, and increased compressive strength. The expansion can be controlled also, less than 0.5% after ASTM C151 autoclave testing.

• A systematic solution for the disposal of the waste accumulation of BOF slags is extended through this novel geopolymer technology since its incorporation is possible in manufacturing, user and eco-friendly green geopolymer composites, otherwise filling land spaces and causing the contamination of environments, ecology, soils, surface and subsurface waters as well as health hazards.

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