

Article

Effect of EAF Slag on the Performance of Wollastonite Mixes Inspired by CO₂ Curing Technology

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Abstract: Replacement of cement with electric arc furnace (EAF) slag at higher volumes causes volumetric expansion; therefore, such blends are not recommended in concrete production. In this study, the effect of this slag on the performance and microstructure of mortar samples based on wollastonite (CaSiO₃) was examined. The samples were cured in a CO₂-rich environment, resulting in the formation of non-expansive products, including aragonite, calcite, and traces of tobermorite in the microstructure. The addition of slag above 20% affected the workability and strength developments. However, the formation of pores above 100 nm reduced with increasing slag content to 60%, highlighting the beneficial effect of slag when used in higher volumes. EAF slag contains a higher amount of Fe₂O₃ which limits its disposal at landfills, but its increased use in the production of CO₂ gas-cured wollastonite concrete can reduce the environmental burdens caused by the Portland cement and steel manufacturing industries.

Keywords: wollastonite; electric arc furnace slag; carbonation; performance; microstructure

1. Introduction

Global warming is the major negative phenomenon of our living environment. The CO₂ gas and its emission are the main contributing agent to this phenomenon. The recent research trend is to find a practical solution to reduce the carbon footprint on the Earth. One of the main challenges of the construction industry is how to reduce the carbon footprint caused by the production of Portland cement, which accounts for approximately 5% of total CO₂ emissions from human-made actions [1]. Wollastonite is a naturally occurring calcium silicate mineral, and its application in concrete production can reduce cement consumption due to its relatively lower production temperature [2]. This non-carbonate material is composed of 48% CaO and 52% SiO₂ and this shows its potential to mix with cementitious materials during the production of concrete [3]. This white mineral is naturally available as aggregates and fibers with a hardness of approximately 4.5 on the Moh scale. These aggregates and fibers have acicular and needle morphologies and generally exist in two polymorphic forms with different crystal structures [4]. Wollastonite is not hydraulic, but it reacts in the presence of CO₂ and moisture and subsequently hardens [5]. This has the significant benefit of permanently sequestering CO₂ within the concrete during the curing process [6]. It also reduces the amount of water required for concrete production [7]. Due to their similarity to cement, wollastonite binders can be produced using existing equipment and conventional raw materials, but they require lower quantities of limestone in the raw mix and energy input to the process. As a result, their manufacture produces fewer emissions [4]. Concrete production requires only the addition of a CO₂ curing system to traditional systems. Curing is also quick and particularly effective in thin concrete with a large surface area [8]. Wollastonite resources are concentrated in the United States, China, India, and Mexico [9], and existing wollastonite reserves are over 800 million MT. Some



Citation: Muthu, M.; Kumar, S.; Chajec, A.; Sadowski, Ł. Effect of EAF Slag on the Performance of Wollastonite Mixes Inspired by CO₂ Curing Technology. *Appl. Sci.* **2024**, *14*, 4485. <https://doi.org/10.3390/app14114485>

Received: 6 May 2024

Revised: 21 May 2024

Accepted: 22 May 2024

Published: 24 May 2024



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unique properties of this binder [10] in concrete manufacturing include higher whiteness and lower shrinkage, thermal expansion, moisture absorption, and dielectric constant and loss [11].

Active research on carbon capture, utilization, and storage (CCUS) technology has been carried out throughout the world to reduce 20% of global CO₂ emissions by 2050 by limiting CO₂ emission levels to 6000 MT per year [12]. Mineral CO₂ sequestration is a chemical storage route in which CO₂ is bound to an inorganic material [13]. The concept of this method is deduced from the natural weathering of metasilicates based on calcium and magnesium [14]. Metasilicates based on calcium and magnesium that are suitable as feedstock for mineral CO₂ sequestration include wollastonite and olivine minerals, and solid alkaline industrial residue such as steel slag. Zulumyan, et al. [15] added the NaOH solution to the CaO-SiO₂-H₂O system that allowed interaction between portlandite and this silica under normal conditions and thus avoided the autoclave treatment commonly used in the production of wollastonite. Electric arc furnace slag is a solid waste produced by the steelmaking process. The United States generates this industrial residue in approximately 130 facilities [16]. It is one of the three types of slag that comprise more than 100 MT of steel slag produced in China each year [17]. However, only 30% of the slag generated in China is used after it is created, due to outdated treatment approaches and the lack of an established framework for treating, recycling, and managing slag [18]. Being able to reuse electric arc furnace (EAF) slag can reduce the amount of landfill waste created and, therefore, can be beneficial both to the environment and to the economy [19]. The use of EAF slag in concrete as an aggregate has become somewhat common recently [20]; due to its rock-like structure, EAF slag can replace aggregates in concrete mixes. Despite the lack of information on the safety hazards of the use of unencapsulated EAF slag, it is safe to use in an encapsulated environment [21]. Concrete mixes containing this slag as aggregate were found to have a deeper penetration of CO₂ under pressure [22], slightly higher expansion, and similar compressive strength compared with limestone aggregate concrete [23]. Compared with natural aggregates, concrete containing EAF slag aggregate has been found to have higher strength levels [24] due to the relatively porous nature of the slag particles, which allows cement to penetrate the aggregate, leading to an interlocking effect that contributes to strength [25]. As the demand for sustainable materials increases, research has been conducted worldwide on the use of EAF slag as a supplementary cementitious material [26].

Ground granulated blast furnace slag (GGBFS) is one of the three slags and has been widely used in concrete production for several years [27]. There is no significant reduction in compressive strength due to the use of EAF slag and GGBFS up to 30% in cement mixes, but there was a notable delay in their hydration reaction at the beginning of the age [28]. Hekal, et al. [29] used EAF slag up to 20% in cement mixes and found that as the amount of slag increased, the compressive strength decreased until the end of 90 days. In both studies, it was observed that there was a high Fe₂O₃ content in EAF slag, which was not present at such levels in alternative binders. Kim, et al. [30] attempted to reduce the amount of Fe₂O₃ present in EAF slag before including it as a mineral additive. This was achieved by first performing an Al-dross reduction reaction, followed by a direct reduction in carbon, resulting in a final Fe₂O₃ content of less than 5%. The processed EAF slag was mixed with cement and exhibited physical properties comparable to those of commercialized GGBFS. If properly treated, processed EAF slag can be used in traditional cement-based materials while also meeting the necessary standards for hydraulic properties for commercial use [30]. CO₂ can be stored in untreated EAF slag [22], which has not been well studied. Since EAF slag contains large amounts of calcium, it could form CaCO₃ that can sequester CO₂ in its microstructure [31]. Until now, other steel slags, such as ladle furnace slag, have been suggested to be more efficient in sequestering CO₂ than EAF slag, but if hydrated matrices and leachates are separated, the capacity of EAF slag to sequester CO₂ gas can increase [32]. Another study developed a supercritical carbonation process that involves combining EAF slag with water and processing it for 48 h with supercritical CO₂ at a temperature and

pressure of up to 80 °C and 120 bar [22]. The introduction of a dose of fine EAF slag to wollastonite mortar mixes can promote the formation of additional carbonates, resulting in better sequestration of CO₂ in the concrete microstructure, and it can promote the formation of calcium silicate hydrate (CSH) with crystalline structure.

In this study, the potential use of untreated EAF slag in wollastonite mortar mixes was investigated. Wollastonite and EAF slag blends have shown higher efficiencies in CO₂ storage under specific CO₂ pressure and temperature conditions and have also indicated superior performance. Wollastonite was substituted for EAF slag in the range of 20%, 40%, and 60% by weight to ensure reasonable levels of homogeneity between mortar samples. After curing them in CO₂-rich environments for up to 7 days, their workability and compressive and flexural strengths were evaluated. The results of the X-ray diffraction (XRD), scanning electron microscopy (SEM), thermogravimetric analysis (TGA), and mercury intrusion porosimetry (MIP) studies revealed the microstructure of mortar samples cured in a CO₂-rich environment. The results obtained led to a discussion of the replacement levels of EAF slag with respect to the performance of the wollastonite mixes. These mixes could enable the development of low-CO₂ concrete products suitable for precast applications.

2. Materials and Methods

2.1. Sample Preparation

Mortar samples were made using wollastonite, EAF slag, distilled water, NaOH pellets, and crushed stones of granite origin. Untreated slag was obtained from a local steel manufacturer, while highly pure NaOH and wollastonite were obtained from a local chemical supplier. The binder materials were sieved to a size of less than 45 µm and scanned with an Epsilon model X-ray fluorescence (XRF) instrument (PANalytical, Almelo, The Netherlands). Table 1 lists the XRF results in which the untreated slag was found to have a relatively higher amount of Fe₂O₃. The loss in ignition (LOI) of these binder materials was found to be lower, indicating a lesser presence of organic species in them. Samples were heated to 1000 °C in a hot air oven to obtain information on such losses. The binder materials were scanned using a Malvern Panalytical model XRD at a rate of 0.02° 2θ/min for a 5–55° 2θ range to obtain mineralogical information. Figure 1 shows the XRD results. The main X-ray peaks indicate the main presence of CaSiO₃ and SiO₂ compounds in wollastonite and EAF slag. Figure 1 also shows the particle size distribution of these raw materials, which was determined using a laser particle analyzer (Cilas, Orléans, France). The EAF slag particles were found to be coarser than that of wollastonite. The SEM image in Figure 1 reveals the angular morphology. The slag sample was mounted on a metal stub using a carbon adhesive, gold coated for 80 s, and scanned with the JSM-6610A SEM operated (JEOL, Tokyo, Japan) at higher voltage. The specific gravity and water absorption of the crushed aggregates were determined according to EN 1097-6 [33] and were 2.75 and 0.48% by weight. In this study, wollastonite mortar mixtures containing 0%, 20%, 40%, and 60% EAF slag were labeled WS0, WS20, WS40, and WS60. The liquid-to-powder ratio of these mixes was maintained at 0.25, while the aggregate-to-powder ratio was 3. The liquid used was a 0.3 molar concentrated NaOH solution. To prepare the mortar samples, the ingredients were mixed in a high-speed stand mixer for 3 min, and the fresh mix was loaded into iron molds of different sizes in two equal layers. The samples were demolded after 24 h and stored in a carbonation chamber for up to 7 days. The pressure and temperature of CO₂ within this chamber were 1 MPa and 90 °C, and this environment is explained in Figure 2.

Table 1. Oxide composition of raw materials.

Sample (%)	CaO	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	Na ₂ O	MgO	TiO ₂	MnO	SO ₃	Cr ₃ O ₅	LOI
Wollastonite	39.89	47.12	3.91	2.76	0.23	1.46	0.21	-	-	-	4.42
EAF slag	36.02	12.86	7.52	31.07	0.13	1.73	0.63	2.68	0.32	2.46	4.58

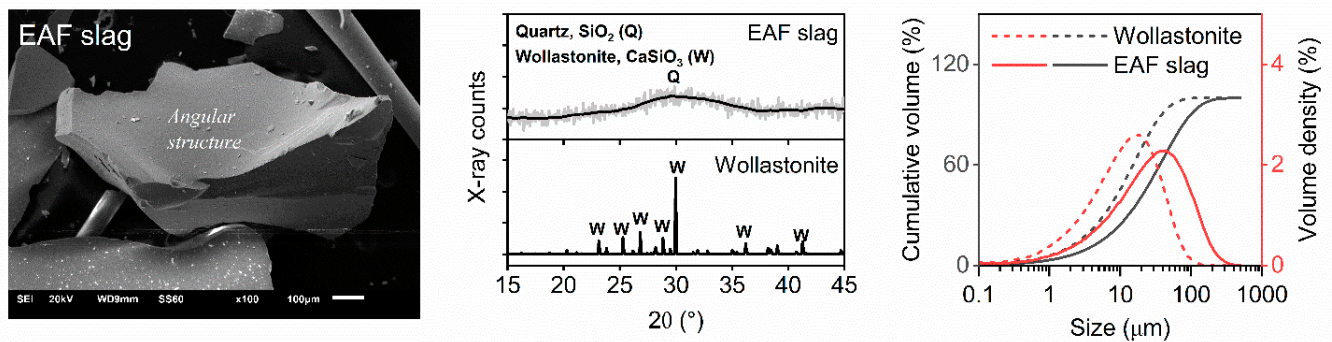


Figure 1. SEM, XRD, and PSD results of the raw materials.

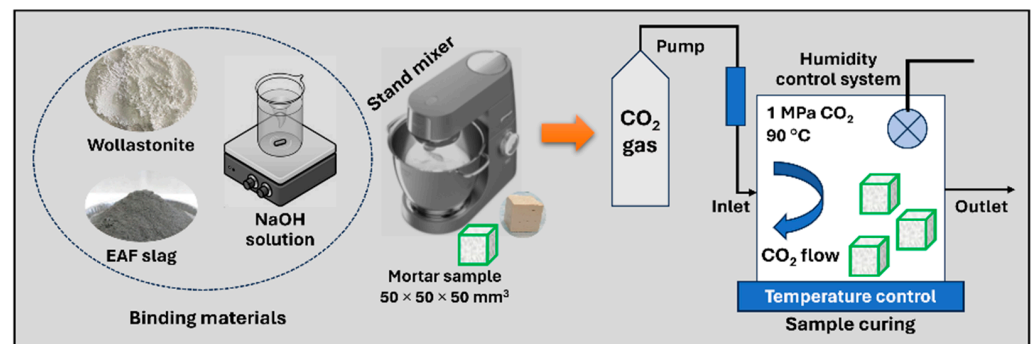


Figure 2. Scheme illustrating the curing conditions of mortar samples.

2.2. Test Methods

To assess workability, a fresh mortar sample was filled into the truncated cone and placed in the center of the flow table apparatus according to ASTM C1437 [34]. The cone was removed leaving the fresh sample, which was dropped continuously for 15 times. Fresh mixture flow is the resulting increase in the average base diameter of the mortar mass, measured in at least four diameters in equivalently spaced intervals expressed as a percentage of the original base diameter. The compressive and flexural strengths of the mortar samples were determined at the end of 7 days. A sample of dimensions $40 \times 40 \times 40 \text{ mm}^3$ was tested according to ASTM C109 [35] using an electromagnetic testing machine with a capacity of 3000 kN. The loading rate was maintained at 0.3 kN/s. The load at failure divided by the cross-sectional area of the sample gives the compressive strength. To determine the flexural strength according to ASTM C348 [36], a mortar sample of $40 \times 40 \times 160 \text{ mm}^3$ size was used. The load was disposed of in the middle of the sample using a rigid semi-cylinder with a constant displacement of 0.5 mm per min. The samples were supported by two rigid semi-cylinders spaced 120 mm apart, and the whole system was fixed to a rigid steel profile to eliminate sample deformation during loading. The flexural strength was calculated in the center of the sample using Equation (1), where P is the applied load, l is the length between the roller supports, and b and h are the width and height of the sample. A mean of four replicates was calculated.

$$\text{Flexural strength (MPa)} = \frac{3Pl}{2bh^2} \quad (1)$$

2.3. Characterization Studies

Small pieces were obtained from mortar samples destroyed on a compression testing machine. They were dried in a vacuum condition at 30 °C for 48 h and studied using Pascal-140/440 MIP (Thermo Scientific, Waltham, MA, USA) to obtain information on the microstructure. These measurements were made with an Hg intrusion pressure of up to 400 MPa. The diameter of the pores was calculated using the Washburn equation following

the properties of Hg: density 13.53 g/cm³, surface tension 0.485 N/m, and contact angle 130°. Sufficient care was taken to discard the tested fragments. Vacuum-dried samples were also scanned using SEM (JEOL, Tokyo, Japan) to obtain secondary electron images. Before this scan, the samples were coated with gold for 80 s on a sputter coating machine. This was done to reduce the charging effect that frequently occurs when imaging mortar samples under SEM. To obtain information on mineralogical changes, the dried samples were ground to a size of less than 45 µm and scanned using the XRD at a rate of 0.02° 2θ for a total range of 5–60°. The powdered samples were tested on a TGA analyzer (PerkinElmer, Hopkinton, MA, USA), during which the sample was heated from 35–900 °C at a rate of 10 °C/min, under a nitrogen-purged environment.

3. Results and Discussion

3.1. Sample Properties

Figure 3 shows the results of the flow table and compressive and flexural strength tests. The average flow diameter of WS60 was 24% smaller than that of WS0, indicating that the addition of a higher volume of slag could affect the fluidity of fresh wollastonite mortar mixes by adsorbing more free water onto their angular surfaces. However, the flow of wollastonite improved in the presence of 20% slag, which may be due to the higher presence of wollastonite that used free water available in the fresh matrix. This finding recommends the use of superplasticizers during the increasing use of slag in wollastonite mixtures to avoid workability issues. Dong, et al. [37] found volume expansion problems in cement mixes containing EAF slag due to free CaO and a decrease in workability due to water absorption. In this study, the NaOH solution was used in the preparation of fresh mortar samples. This alkaline solution breaks the weak bonds of SiO₂ in EAF slag, thus releasing metasilicate anions. These silicate anions are easily involved in the reaction with CaO of raw materials under normal conditions [15]. The average compressive strength of the WS0, WS20, WS40, and WS60 samples was determined to be 18, 19, 21, and 16 MPa, while their flexural strength was 11.2, 12.3, 10.8, and 7.7 MPa, respectively. The compressive and flexural strengths of WS20 were found to be 6% and 10% greater than those of WS0 (i.e., reference sample). There is a decrease in these strengths of mortar samples by up to 11% and 31% due to the greater replacement of wollastonite with EAF slag. There is no significant change in the development of the strength of the wollastonite mixes when the addition of EAF slag was limited to 50%. In particular, the wollastonite matrices mixed with 20% EAF slag exhibited the highest mechanical performance. Coarse EAF slag particles were used as an aggregate [25], and the proposed reason for the observed increase in strength is that slag particles are porous, allowing the cement paste to penetrate the slag particles, resulting in an interlocked system that can lead to higher strength.

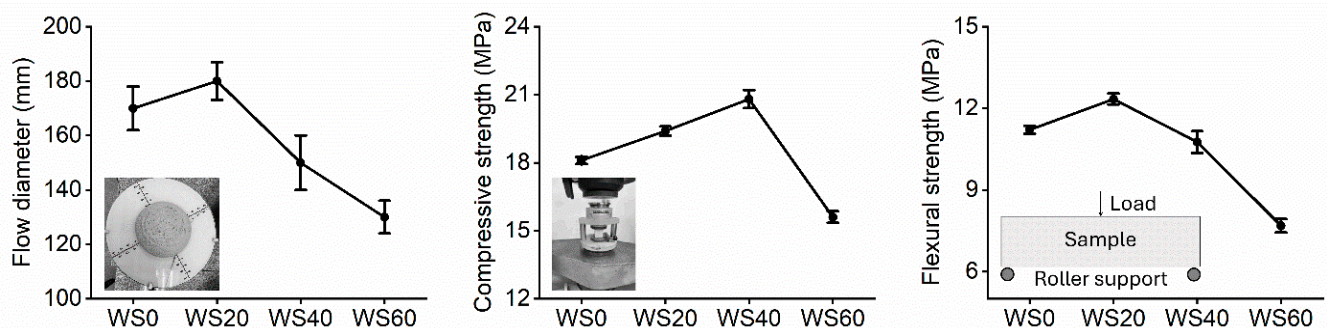


Figure 3. Results of the flow table and compressive and flexural strength tests.

In this study, the drop in compressive strength of WS60 was attributed to multiple reasons. First, if the interlocking effect of combining wollastonite and slag as binders can contribute to an increase in compressive strength, it is possible that a mortar mix containing significantly less wollastonite than EAF slag will not be able to bind effectively, leading

to a drastic decrease in strength. A study suggests that smaller particle sizes, including the EAF slag size, may be associated with more efficient carbonation, potentially affecting the formation of CSH and CaCO_3 with crystalline morphologies [22]. It is also observed that cement mixes containing EAF slag tend to be more susceptible to water permeation, suggesting that they have a higher volume of spaces, which is associated with a decrease in strength [11]. The WS60 mix was largely composed of EAF slag and is therefore much more porous and less dense than other mixes due to the coarser texture and larger particle size of the binder material used. Although the WS40 mix appears to have an ideal ratio of EAF slag to wollastonite to allow optimal interlocking and minimal void space, the WS60 mix lacks homogeneity and, therefore, does not have enough wollastonite to interlock and is significantly more porous. The high Fe_2O_3 content in EAF slag has also been found to be associated with a decrease in strength when used as a binder [28]. However, when the Fe_2O_3 content is reduced, it is observed that the compressive strength tends to perform better [22]. Therefore, it is possible that the WS40 mix has a lower Fe_2O_3 content compared with WS60, which contains less wollastonite, more EAF slag, and therefore more Fe_2O_3 . Finally, as observed in this study, the hydration reaction that takes place during the curing process of concrete is affected by the content of EAF slag present in the matrix. Water demand increased as the EAF slag increased in this study; however, after 40% replacement of the EAF slag, water bleeding was also observed. Other studies of EAF slag as a partial replacement binder have observed notable delays in the hydration reaction compared with cement and GGBFS blends, as well as a decrease in compressive strength at all hydration ages up to 90 days [28]. Therefore, it is possible that there is an optimized condition for the partial replacement of wollastonite with EAF slag, and the WS60 mix contained too much slag, affecting the hydration reaction to a degree severe enough to have a significant impact on the mechanical performance.

3.2. Microstructure

Clay containing water with a turbidity of around 800 NTU was passed through the concrete samples for ten repeat cycles. The SEM images in Figure 4 revealed the microstructure of the carbonated samples based on wollastonite and EAF slag. Dense formation of aragonite and calcite was observed with needle and rhombohedral morphologies in their microstructure. Tobermorite, a crystalline form of CSH, was observed in WS0 together with such carbonates, indicating the generation of CSH in wollastonite matrices made with an NaOH solution. Calcite formation was observed to be dense in WS40, which could be mainly due to CO_2 interactions with EAF slag. The XRD and TGA results shown in Figures 5 and 6 confirmed the presence of these carbonates in the sample matrices based on wollastonite and EAF slag. The main XRD peaks at 8.9° , 17.8° , 26.1° , 26.6° , and 29.5° 2θ positions attribute to tobermorite, wollastonite, aragonite, quartz, and calcite crystals. Carbonation of EAF slag systems results in the major formation of tobermorite and calcite [38]. Aragonite is a form of CaCO_3 that can also be seen in such systems when it is allowed to dry [39]. The presence of quartz in cement-based materials containing EAF slag has been associated with greater stability and improved characteristics, including acceleration of early-age hydration and increased compressive strength [40]. Calcium aluminum oxide was detected at 35.9° 2θ in the carbonated samples in this study and, when hydrated, it can result in the formation of ettringite, monosulfate, and calcium aluminum hydrate. However, ettringite is formed when there is enough gypsum, and ettringite is converted to monosulfate when all gypsum has been consumed in the synthesis of ettringite [41]. There is a notable increase in the amount of tobermorite formed in WS40. A similar study investigated the potential of using alkali activation to produce high-performance materials that use EAF slag. The high Al_2O_3 and SiO_2 content in the EAF slag itself was found to respond optimally to the alkali activation process, and the samples demonstrated acceptable levels of bending and compressive strength [42]. The NaOH solution was used in the sample casting process of this study, which may have served as an alkali activator and interacted with Al_2O_3 and SiO_2 compounds of the binders, thus contributing to the increased strength

observed up to the 40% replacement level. It is also suggested that the SiO_2 content in the samples, as well as alkali activation, propagated the formation of an amorphous CSH, leading to a denser microstructure and, therefore, to greater strength development [42]. The EAF slag used in their study contained higher amounts of Al_2O_3 and SiO_2 than the EAF slag used here, but it is possible that the wollastonite content in WS40 also contributed to the formation degree of crystalline CSH. On the contrary, studies in which alkali activation was not used observed decreases in CSH formation and compressive strength with partial replacement of cement with EAF slag at all levels of replacement, despite the addition of silica particles [43]. At higher replacement levels, such as the WS60, homogeneity cannot be achieved within the samples, as there is not enough wollastonite present to account for the relatively low amounts of silicon in the EAF slag used here and to supplement the amount of crystalline CSH products formed. Therefore, segregation and bleeding can result in decreased mechanical performance. The content of crystalline CSH has been repeatedly linked to an increase in compressive strength [43] and is supported by the observation that the WS40 has the greatest compressive strength and the highest crystalline CSH content compared with the other samples. However, the presence of CaCO_3 increases with the content of EAF slag and does not correlate with the strength patterns. This is supported by previous studies that also did not observe any significant or sufficient strength gain in cement and EAF slag blends, despite CaCO_3 formation due to carbonation [44]. However, it is suggested that EAF slag still helps maintain sufficient CO_2 sequestration during the carbonation process so that it can serve as a supplementary cementitious material, both for environmental reasons and to promote pozzolanic reactions in subsequent hydration [44]. This, once again, supports the idea that EAF slag is optimally used as a supplementary material in cement manufacturing and that excess slag can lead to a decrease in strength.

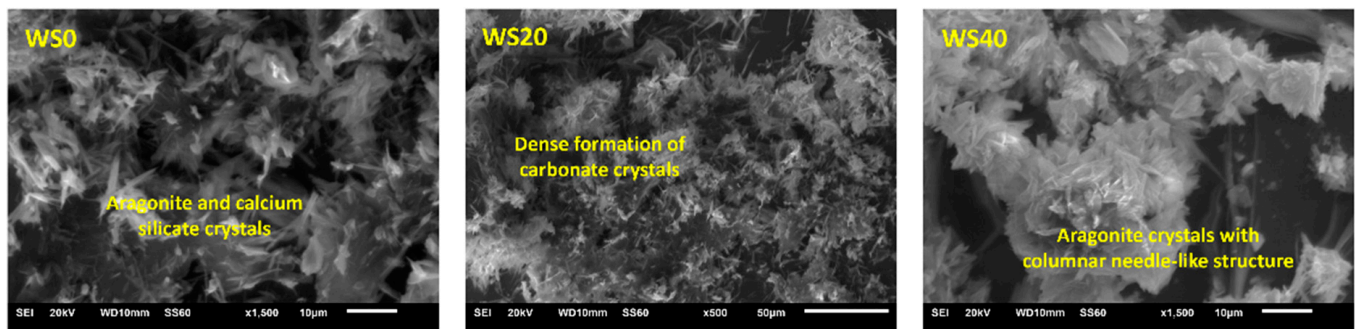


Figure 4. SEM images revealing the microstructure of mortar samples.

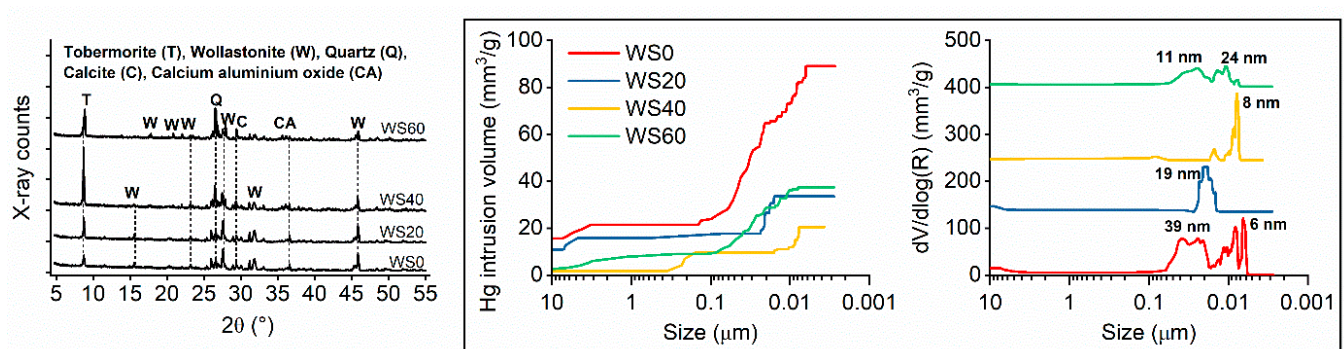


Figure 5. Results of the XRD and MIP investigations.

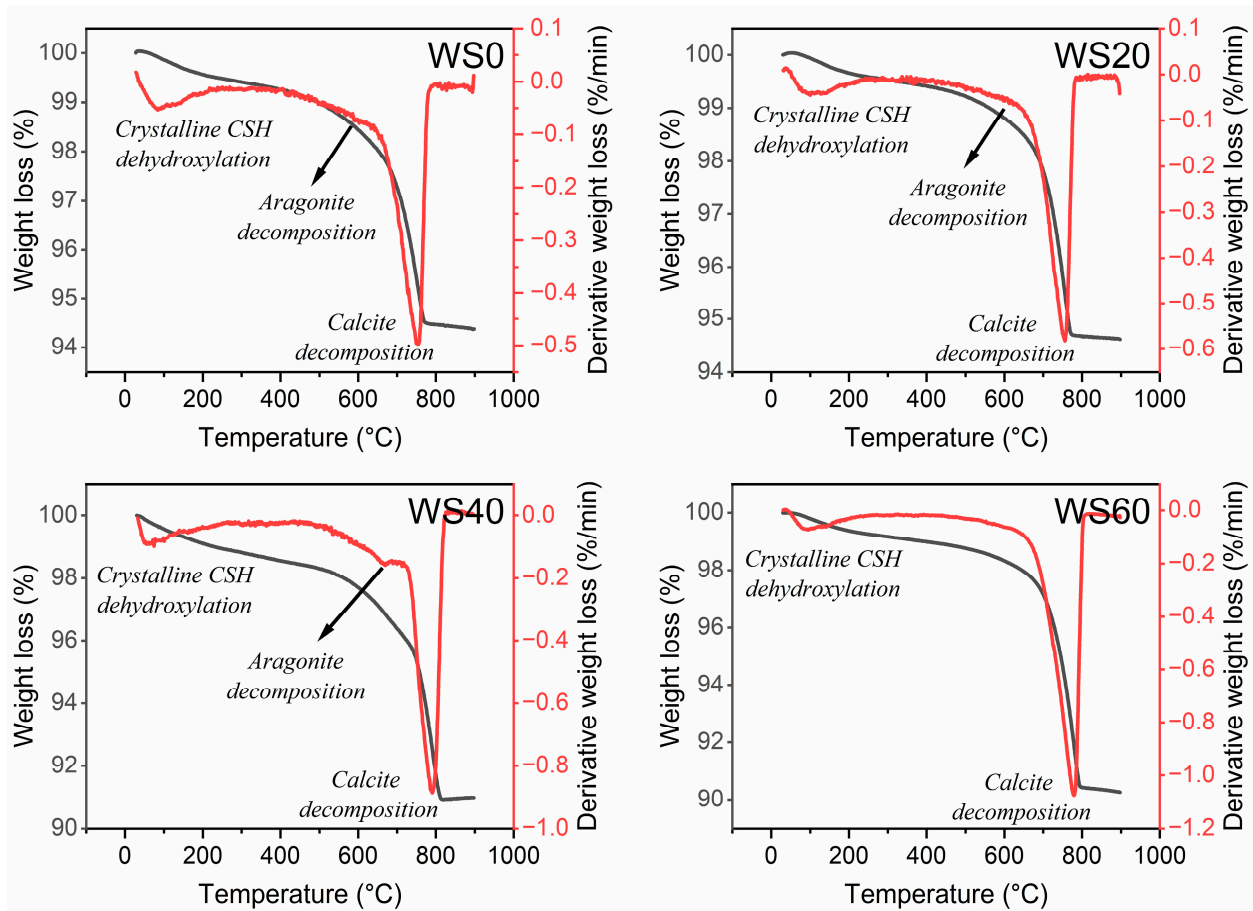


Figure 6. Results of the thermogravimetric analyses.

It was noticed from the TGA results that weight losses due to the decomposition of the main binder products in the samples based on wollastonite and EAF slag were found to fall within the temperature range of 30–800 °C. This weight loss region indicates the formation of calcite and aragonite in all mixtures. WS40 and WS60 demonstrate a significant weight loss in these regions, indicating that a higher level of CO₂ capture can be achieved using EAF slag due to the observed increase in CaCO₃ production. This could be attributed to the high amount of CaO present in the EAF slag, which can then form calcite and aragonite when exposed to CO₂ under pressure. Calcite and aragonite are both polymorphs of CaCO₃, where calcite has a trigonal crystal structure and aragonite has an orthorhombic crystal structure. Table 2 lists the weight losses due to the decomposition of CSH, calcite, and aragonite formed in carbonated samples. The total weight loss due to the decomposition of the binder products in WS60 was calculated to be 73% greater than in WS0. Weight loss due to the decomposition of aragonite and calcite was greater in WS60 compared with the remaining samples. The formation of calcite and aragonite in WS60 was 4.3 and 1.3 times higher than that of WS0. The dehydroxylation of CSH was found to be lower in WS0 and WS20, but the use of EAF slag greater than 20% increased this phase alteration in mortar samples. Weight losses in WS40 and WS60 samples indicated the decomposition of aragonite regions as early as 470 °C. Similar research with EAF slag and carbonated cement-based materials has shown that aragonite is observed to form when the system is allowed to dry [39]. The main binder product of the EAF slag is still calcite, but traces of aragonite were also observed [17]. The molecular bonds of aragonite tend to be weaker than those of calcite, and aragonite is observed to dissolve more easily than calcite. It is suggested that various reaction conditions, such as the water-to-solids ratio, relative humidity, and partial pressure of CO₂, affect the hydration reaction and that there are optimal conditions for the formation of each silicate [34]. The reaction conditions here

were kept as constant as possible, so the variation in CaCO_3 formation is likely due to the different contents of EAF slag and, therefore, the variation in mineral contents. There is also a slight loss of structural water that can be observed within the range of 70–100 °C for the WS40 mix. The tobermorite mineral is formed during prolonged hydrothermal reactions of silica and calcium compounds at specific starting ratios. A study identified that reactions with a starting calcium-to-silica ratio of 1.5 resulted in tobermorite [45]. This same study confirmed that tobermorite dehydroxylation occurs when water is lost at 90 °C [45].

Table 2. Microstructural properties of the wollastonite matrices interpreted from the TGA and MIP information.

Sample	WS0	WS20	WS40	WS60
Total weight loss (%)	5.6	5.4	9	9.7
Weight loss due to CSH dehydroxylation 30–260 °C (%)	0.5	0.4	1.1	0.8
Weight loss due to aragonite decomposition 650–750 °C (%)	2.6	2.6	1.7	3.3
Weight loss due to calcite decomposition 750–1000 °C (%)	1	1.2	4.3	4.3
Gel pore volume <10 nm (%)	18	0	42	4
Capillary pore volume ~10–100 nm (%)	56	48	11	71
Macropore volume >100 nm (%)	26	52	47	25

Figure 5 also shows the results of the MIP test, representing the pore entry size distributions rather than the pore size distributions. The Hg intrusion pressure achievable by the equipment is limited to a maximum pressure of up to 400 MPa, which corresponds to a minimal pore radius of 2 nm following a cylindrical pore model [46]. The volume of Hg that penetrated WS0, WS20, WS40, and WS60 was determined to be 89, 34, 20, and 37 mm³/g, indicating that the volume of interconnected pores within the wollastonite matrices was lower due to the addition of EAF slag of up to 60%. In particular, Hg intrusion in WS40 was 76% lower than in WS0. Pore sizes between 10 and 10 µm are described as capillary pores, while pores below 10 nm are classified as gel pores [47]. Table 2 also listed the pore-related properties of the mortar samples interpreted from the MIP data. The volume of capillary pores within the wollastonite matrix was greater compared with macropores (i.e., pore size greater than 10 µm) which usually form as a result of air trapping during sample preparation. The volume of capillary pores in WS40 was 84% lower than that of WS0, indicating that the slag particles effectively filled the capillary pores. The largest peak in the differential Hg intrusion curve is identified as the most likely diameter [48]. The pore diameters of WS0, WS20, WS40, and WS60 were determined to be 39, 19, 8, and 24 nm. The diameter of the pores in WS0 was almost 5 times greater than that of WS40, indicating that the relatively higher strength of WS40 was obtained due to the dense formation of crystalline products, including CSH and CaCO_3 .

4. Conclusions

This study compared the performance of wollastonite-based mortar mixes containing 0–60% EAF slag. NaOH solution was used in their preparation, and the hydroxyl species broke the weak bonds of SiO_2 in the EAF slag, thus releasing metasilicate anions. These silicate anions are involved in the reaction with the CaO of wollastonite under normal conditions. It was observed that the wollastonite-based mortar sample containing 40% slag had the highest compressive strength, while the mixture containing 60% slag had the lowest compressive strength. This disparity in strength levels may be attributed to the formation of a high crystalline CSH content in the WS40, a severe lack of homogeneity in the WS60, and the interactions between EAF slag and wollastonite as binders. Despite having the lowest compressive strength, the mix containing 60% slag had the highest amount of CaCO_3 present, suggesting that CaCO_3 does not play a significant role in the development of the strength of EAF slag cements when sample homogeneity cannot be achieved. The level of compressive strength observed in the WS40 is a very promising sign for the use of EAF slag as a supplementary binder in the manufacturing of commercial cement. The use

of this slag in the wollastonite matrix reduced the formation of pores by up to 76%. The use of EAF slag would be environmentally and economically sustainable; when used in combination with alkali activation and wollastonite, EAF slag appears to be usable even when untreated. This is likely related to the presence of crystalline CSH in wollastonite and slag blends because crystalline CSH is associated with increased stability in cementitious materials. The use of EAF slag in this context promotes the sequestration of CO₂, as well as the diversion of industrial waste from landfills.

Author Contributions: Conceptualization, methodology, validation, formal analysis, investigation, data curation, and writing—original draft preparation—M.M. and S.K.; resources—A.C.; supervision, writing—review and editing—L.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Narodowa Agencja Wymiany Akademickiej (NAWA), grant number BPN/ULM/2021/1/00120.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

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