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Engineering Properties of Alkali-Activated Mortar Incorporating Electric Arc Furnace Slag: A Case Study of Misurata City, Libya

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Abstract This study investigates the engineering properties of alkali-activated mortar produced with Electric Arc Furnace Slag (EAFS) sourced from a steel factory in Misurata City, Libya, as a sustainable alternative to ordinary Portland cement. EAFS was used as the sole binder at replacement ratios of 0%, 5%, 10%, 15%, 30%, 60%, 80%, and 100%. The alkaline activator consisted of sodium hydroxide (NaOH) at concentrations of 2, 4, 6, and 8 M, combined with sodium silicate (Na_2SiO_3) at a fixed ratio ($R = Na_2SiO_3/NaOH$) of 0.5, while the binder-to-total liquid ratio was maintained at 0.44. Key engineering properties, including flowability, density, compressive strength, and flexural strength, were evaluated after 28 days of curing at 30 °C. The results indicate that an EAFS replacement ratio of 15% yields optimal performance. Increasing NaOH concentration from 2 M to 8 M improves fluidity but reduces density and compressive strength, which is attributed to the formation of portlandite and limited production of calcium silicate hydrate (C-S-H) or calcium-sodium aluminosilicate hydrate (C-(N)-A-S-H) gels due to the reduced availability of Ca^{2+} and Na^{+} ions in EAFS. The cementitious behavior of the slag is also influenced by the presence of tricalcium silicate (C_3S), tricalcium aluminate (C_3A), and calcium aluminate ferrite (C_4AF). This case study demonstrates that locally sourced EAFS from Misurata City can be effectively utilized in alkali-activated mortars, though its engineering properties are highly dependent on activator concentration and replacement level.

Keywords: Electric Arc Furnace Slag; Alkali-Activated Mortar; Engineering Properties; Misurata City

1. Introduction

Today, all industrial slags find highly specific applications [1,2]. The carbon dioxide (CO_2) emissions associated with one ton of ordinary Portland cement (OPC) range from 0.82 to 1.0 metric tons, attributable to the substantial embodied energy consumed during its manufacturing process. In light of the large annual consumption of OPC and the high associated embodied energy, researchers have initiated investigations into novel, more environmentally friendly materials to mitigate CO_2 emissions [3,4].

Steel slag contains calcium, silicon, and phosphorus (Ca, Si, and P) [5], along with other constituents that are conducive to plant growth [6, 7]. Owing to its high content of calcium oxide (CaO)-based alkaline metal oxides, steel slag exhibits significant potential for CO_2 sequestration [8]. Given its high and amorphous quantities of Ca, Si, and Al, it is frequently employed as a binder, partially substituting Portland cement. The cementation properties of electric arc furnace (EAF) slag render it a viable alternative to clinker. Moreover, as EAF slag reduces the firing temperature, it may potentially lower the energy consumption in the production of Portland cement [10]. Electric arc furnace (EAF) slag is a type of steel-making slag (SMS). The chemical composition of electric arc furnace slag (EAFS), which is rich in aluminosilicate, makes it a potential substitute for cement in concrete. In the construction industry, EAF slag can be utilized as aggregates or as a pozzolanic material, a practice that has gained increasing popularity in recent times. Studies have demonstrated that when EAFS is used to replace coarse and/or fine aggregates, it can significantly enhance the mechanical strength [11]. In terms of slag composition, there is no significant difference in the chemical compositions between water-cooled blast furnace slag (BFS) and air-cooled blast furnace slag (ACBFS) used as an aggregate. The chemical compositions of cement clinker and electric arc furnace slag (EAFS) are more similar. EAF slag, a by-product generated during the steel-making process in an EAF, encompasses a variety of materials, including recycled steel scraps and certain metal oxides [12]. During the steel-making process, steel slag accounts for 15 – 20% of the total production and is the primary waste material. In 2019, the global steel production reached 1868.8 million tons, with electric arc furnaces contributing nearly 40% of the world's steel output [13]. Although the EAF method is estimated to be used in 29% of global steel-making, it accounts for 70% of crude steel production in the United States [14]. Currently, researchers are conducting in-depth investigations into the feasibility of using EAFS as a cement substitute, primarily due to its high content of calcium oxide (free-CaO) and ferric oxide (FeO).

The EAF has evolved into an efficient melting device, with designs emphasizing increased capacity. Melting is achieved by supplying energy to the interior of the furnace. In the initial oxidation stage within the furnace, flows of steel components and incompatible non-metallic slag are mixed to form EAFS. [15, 16] posited that slag is formed when impurities such as carbon, silicon, phosphorus, aluminum, sulfur, and some iron are oxidized and mixed with lime or dolomite. After tapping, the steel and liquid slags are stored in separate ladles. Since EAF slag has a lower density than steel, it is hypothesized to float on the molten metal in its liquid state. EAF slag is removed and typically air-cooled gradually to form crystal structures.At the beginning of the electric arc furnace (EAF) process, waste recycled steel and fluxing agents are charged in a cold state. An electric current is applied to graphite electrodes, generating an arc that melts the charge. Impurities are removed by injecting oxygen, and the steel chemistry is refined by adding additional metals or alloyants. The majority of substances to be removed during the refining process have a greater affinity for oxygen than for carbon. Consequently, when oxygen preferentially combines with these elements to form oxides, they float out of the steel and through the slag. While the molten slag is tapped and removed, the molten crude steel is tapped into a ladle.The EAF slag contains metallic oxides formed from various components, such as silicon, sulfur, manganese, phosphorus, iron, aluminum, and carbon. These components are commonly removed from steel during purification processes in electric arc furnaces; the phosphorus content is reduced by 20% to 50% in the EAF process. Desulphurization is carried out during ladle furnace operations and tapping, resulting in the production of calcium aluminate slag. The carbon content is reduced to the appropriate level for tapping in the presence of oxygen during flat-bath operation. Subsequently, the slag is poured out of the furnace through the slag door when the furnace is tilted rearward. By removing the slag at this stage, phosphorus reversion is completely eliminated. The slag can be foamed by injecting carbon, which converts FeO to metallic iron and generates carbon monoxide in the process.

Lee et al. [18] have been classified the iron and steel slag as indicated in Figure 1. They concluded that in the manufacturing process, EAF slags can be acquired independently. By reducing slag process or oxidizing slag process. Depending on the components added during the steelmaking process, EAF slag can be separated into EAF-C slag from carbon steel and EAF-S slag from stainless steel. The addition of ferrochrome and nickel, which are necessary for the manufacturing of stainless steel, causes a notable difference in the composition of carbon steel EAFS compared to stainless steel slag [19].

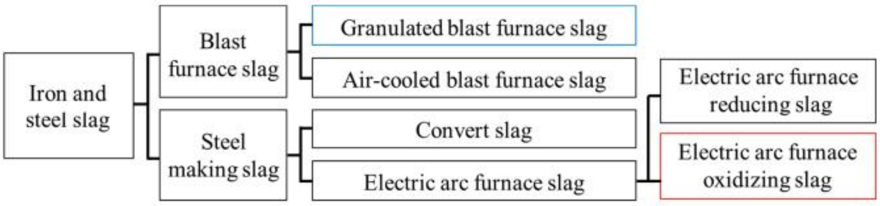


Figure 1. Varieties of iron slag and steel depending on [18].

The volumetric instability of EAF slag is caused by the carbonation that occurs after the hydroxylation of free-CaO. The long-term oxidation of Fe_2O_3 to Fe_3O_4 is associated with its volumetric expansion, and [18] has clarified that a high concentration of Fe oxide reduces the chemical activity in concrete throughout the hydration process. Moisture of hydrates lime (CaO) and periclase (MgO) over several months prevents it from expanding later [15], and the cooling stage of the steel slag must be regulated in order to lower the CaO level. Electric arc furnace slag is a coarse, porous, blackish-gray aggregate that contains small particles of metallic iron as shown in Fig. 3. The appropriate pre-treatment, EAF slag works best in bituminous mixtures of all types when the coarse aggregate is partially substituted. The mixes' mechanical performance, durability, and long-term sustainability are all improved by use of EAF slag [20].

The EAF slag's strong surface friction and crushing resistance allowed it to perform remarkably well in terms of compressive and flexural strengths. Then, they suggested that the main applications of EAF slag are in the addition of cements, road layers, and road bases and subbases, and that these problems are the reason it hasn't been employed as a cementing element. However, a number of studies use EAF powder (see Figure 2) as a binder material because it is an alkali activator that, when combined with a small amount of cement in alkaline conditions, forms a solid binder. The expression "partial replacement" refers to the fact that EAF slag can be combined with other C3S-containing source materials to create the required Portland cement mixture, [19]. Furthermore, even though EAF slag is produced in significant quantities, its low CaO content and low reactivity and high Fe content, along with metal-Fe and Cr, make it an unattractive choice. It should be noted that the pozzolanic activity of EAFS is limited due to its high ferric oxide level and low amorphous silica content, [17].

Figure 2. A steel making slag, EAF slag lumps (right), EAF slag powder (left).

EAF slag can be utilized in geopolymer concretes as a binder that has been activated with alkali solutions [21]. One of the numerous advantages of geopolymer concrete, which is made from waste materials, is its strength and longevity. As a sustainable substitute for conventional binders made of ordinary Portland cement (OPC), geopolymer is gaining popularity in concrete [22]. The EAF slag can be used as aggregates in geopolymer composites or as a pozzolanic material. It provides both financial and environmental advantages because fly ash, silica fume, and slag are the primary industrial solid waste products utilized as binding agents in geopolymer [23]. These industrial solid waste products have the potential to address the problem of waste disposal in landfills by reducing the requirement for OPC in the production of concrete [24]. And alkali-activated binders have already been seen to sometimes even surpass the quality of cement-based building materials, [25]. EAF powder is used as a binder material in several studies because it is an alkali activator that solidifies as a binder when mixed with a tiny amount of cement in alkaline circumstances. Flexural and compressive strengths of slag geopolymer concretes increased as the slag content increased. [26] Steel slag has been used to produce construction materials [27], such as cementitious pastes, bricks and concrete. In a study on materials for combined-alkali-activated slag pastes, neither fine nor coarse particles were used [28]. They found that compared to sodium carbonate, sodium hydroxide activates more strongly in the early stages. The behavior of hardened slag paste materials were demonstrated to be positively impacted by a few appropriate additions and curing procedures.

The ratio of CaO to SiO_2 content is one of the most important slag compositional factors for use in binders [29]. The formation of aluminoslilicate oligomers and Al and Si structural units also contribute to the formation of a poorly structured but very mechanically strong structure when combined with calcium. For usage in binders, the ratio of CaO to SiO_2 content is one of the most crucial aspects of slag composition, [29]. The primary reaction product of the alkali activation of slag is calcium (alumino) silicate hydrate C-(A)-S-H gel [30] which is comparable to the calcium silicate hydrate (C-S-H) gel, which is the reaction result of the cement hydration process. Sajedi et al. [31] clarified that $Ca(OH)_2$ is first released when clinker minerals are hydrated to create calcium silicate hydrate C–S–H gel and ettringite (C6AS3H32(6CaO•Al2O3•3SO3•32H2O). Slags can be divided into two categories based on their basicity index from a chemical perspective. The most basic is the C/S ratio; some criteria must be met for slag to be reactive. Portland cement was partially substituted with EAF slag in concrete by Roslan et al. (2020) [32]. According to their research, concrete with up to 10% EAF slag substituted will have greater strength than control concrete. This is because the void between $Ca(OH)_2$, ettringite, and the hard phase can be filled by the fine grains of EAF slag. Shi (2004) [33], they indicated that components like C3S ($3CaO.SiO_2$), C2S ($2CaO.SiO_2$), C4AF ($4CaO.Al_2O_3.FeO$), and C2F (2CaO.FeO) were discovered to have an impact on the cementitious properties of the slag. Because of this, EAF slag can be used in place of traditional clinkers like calcium aluminoferrite C4AF, belite C2S, and alite C3S. However, because the C3S content of the slag is lower than that of ordinary clinker, complete replacement is not possible. Nikoli´c et al. [34] discussed the dissolution of Si and Al from the EAFS is significantly impacted by alkali concentrations and alkali type at molarity concentrations of 5, 7, and 10M. They demonstrated that the initial concentrations of the alkali solution had a major impact on the effectiveness of EAFS dissolution, that the highest release of Si and Al happened during the first few minutes of the slag dissolve process, and that the solid ions to liquid ratio decreased as the temperature increased. The amount of slag dissolving has decreased since then. Si and Al dissolved with activation energies of 90.68 kJ/mol and 33.62 kJ/mol in KOH solution and 55.27 kJ/mol and 48.05 kJ/mol in NaOH solution, respectively.

The high temperature resistance of Portland cement mortars and alkali activated slag mortars is obviously different from one another, according to test results. Regardless of the applied cured conditions, alkali activated slag mortars may not exhibit spectacular mechanical and high temperature resistance, which is contrary to expectations. Furthermore, the chemical components, microstructural were significantly impacted by the applied curing regime and exposed temperature level up to 60 °C. Comparing specimens cured at room temperature (21

◦C) to a similar sample cured at 60 ◦C for 6 hours, the compressive strength of the former was reported to be 25.6 MPa, a 59% increase, [35]. However, ground granulated blast furnace slag (GGBFS) can be cured at ambient temperature, whereas EAFS and FA need a higher curing temperature. Amin et al. [36] shown that with regard to the age of hydration of the mix (OPC+ EAFS), they have calculated the amounts of free lime and chemically mixed water. The results demonstrated the highest strength values for the paste made of Mix (94% OPC + 6% EAFS). By substituting 10% or 15% EAFS for the OPC, the compressive strength values at all hydration ages are significantly lower than those of the normal OPC paste. The reduction in OPC content could be the cause of the decline in the amount of hydration products, mainly CSH, that are formed. Up to 28 days, the cumulative water values for all hardened cement pastes rise with the hydration age. The production of hydration products, primarily CSH, and their subsequent accumulation are responsible for this rise. Additionally, the data show that from the moment of mixing until one day of hydration, a rapid hydration reaction occurs. A slight decrease in the combined water content values was observed after 90 days of hydration; this decrease is explained by the hydration products' phase transformation from high-water-content hydrates to low-water-content hydrates, which indicates that silica fume's higher pozzolanic activity with the free lime released from OPC hydration leads to the formation of large quantities of CSH with increased water contents. According to the study's findings, sodium hydroxide and sodium silicate solutions were used to activate EAFS. The findings of the tests also showed that increasing the relative humidity, the curing temperature, and the curing time improved the strength by reducing microcracks and changing hydration processes. With the current study, the usage of EAFS is regarded as having been successfully discontinued [37]. The study found that 30% clinker–EAFS substitution may produce a compressive strength of 50 MPa, 20% replacement can produce 58 MPa, and 100% cement can produce 58.6 MPa for the reference specimen [38]. Zhao et al. [39] examined the impact of partially substituting EAFS for cement, with particular attention to the particle distribution of EAFS. The results showed that, as compared to the reference blast furnace slag blended cement specimens, concrete specimens with properly ground EAFS exhibited better microstructure, better durability performance, lower porosity, and higher compressive strength. Additionally, increasing the fineness of EAFS particles and adding early thermal curing into the curing phases improved the hydration performance and accelerated early-age hydration. [35]. $CaO{\bullet}Al_2O_3$ (CA) and $3CaO{\bullet}Al_2O_3$ (C3A) are two calcium aluminate phases that are rapidly hydrated as a result of the EAF slag cooling process. Jain, [40] described the interplay between slag and Portland cement clinker hydration. Monosulfate (C4ASH12 ($4CaO{\bullet}\ Al_2O_3{\bullet}SO_3{\bullet}12H_2O$)), ettringite (C6AS3H32 ($6CaO{\bullet}Al_2O_3{\bullet}3SO_3{\bullet}32H_2O$)), hydrogarnet, C-S-H, CH, and C4AH13 are the main hydration products of Portland cement. Three reaction models were investigated for the slag-blended cement based on stoichiometric calculations [41]. Consequently, the production of ettringite from C3A is taken into account. The CH and the available C3A combine to form C4AH13. It should be noted that there is little variation in OPC chemistry between sources. Moreover, Roslan et al. [42] revealed that the compressive, tensile, and flexural strengths improved over time with a 20% cement–EAFS replacement. When combined with lime and water called pozzolans. Pozzolana was defined as siliceous/aluminous materials, whichever natural or artificial, that chemically react with calcium hydroxide (CH) that can release calcium hydroxide (Portland cement clinker) when water is present. An excellent illustrations of pozzolanic materials include fly ash (FA), silica fume (SF), slag, and metakaolin (MK). According to the findings, the compressive strength is unaffected even when 40 weight percent of OPC is substituted with pozzolanic elements. This is explained by the fact that pozzolana and the pozzolanic material both function as fillers, enhances the C-S-H phase's development [43]. In contrast to the OPC results, the slump decreased with a lower air concentration in the combinations that used EAF oxidizing slag in place of cement. The concrete mixture may become less fluid if fine EAF slag is added because it lowers the air content. Measurements of the compressive with oxidizing slag from EAF were taken at 3, 7, and 28 days. The EAF slag concrete gained strength more slowly than OPC in the beginning, but after 28 days, the strength did not drastically decrease with the addition of 15% cement [18]. The untreated EAFS compressive strength of 2 MPa was significantly less than the pozzolanic material's minimum required compressive strength. In contrast, the treated EAFS exhibited a compressive strength of 8.5 MPa, which was significantly higher than the necessary minimum. The SiO_2 found in untreated EAFS in the form of a modified monticellite phase does not readily react with lime. Since the SiO_2 in the treated EAFS is mostly in the merwinite phase, it reacts strongly with lime when water is present to generate Ca-silicates [38]. Muhmood et al. [38] also they explained that in comparison to the slag as received, this slag becomes more hydraulic after treatment, including remelting and water quenching, which lowers the Fe-oxide content and raises the basicity index. Electric arc furnace slag can be used to replace 30% of the clinker in the cement mix, however the strength of the mixture is significantly reduced (53.4 MPa). As a result of remelting, the slag's pozzolanic strength increased from 2.0 MPa for the as-received slag to 8.0 MPa for the treated slag. They appeared that the cement comprising of 20% untreated slag achieves 58 MPa after 28 days, as opposed to the control's 58.6 MPa. Conversely, the strength of the treated EAFS mixed cement is equivalent to the control for the first 7 days, and after 28 days, rises to 61 MPa. Alkali-activation of steelworks slags as EAFS is also possible due to their silicate and lime percentages, [25]. Slag activators, like Portland cement, can be made up of several activators, such as sodium hydroxide (NaOH) (NH) and sodium silicate (Na_2SiO_3) (NS) [44]. KOH, K_2SiO_3, NaOH (NH), and Na_2SiO_3 (NS) make up the most often used alkaline solution. However, researchers usually select sodium-based alkaline solutions when alkaline reagent costs are taken into account. The use of sodium hydroxide and sodium silicate has been verified by [45]. The impact of the concentrations of KOH and NaOH, solid to liquid, was examined by Nikolic et al. [34] on the kinetics of Si and Al dissolution in EAFS by temperature and ratio. Si and Al of EAFS dissolved more readily in the study when alkaline solution concentrations (NaOH or KOH) increased. Around the slag grains, a gel-like layer developed that contained more silica and was denser than the cement hydration products [46]. Slag cements usually take longer to hydrate than Portland cement clinker. As with OPC cement mortar, adding water to the mortar causes the flow of AAS to increase. The slag was entirely crystalline upon receipt, with monticellite predominating [36]. Sodium hydroxide is quite effective in activating aluminosilicate binders that contain both high and low calcium. The concentration of (OH^-) hydroxyl ions and silica monomers controls the NH molarity, which then affects workability. When mixing mortar, it is preferable to use NH (1–8); the ratio (R = NS/NH) of (1-3) is based on a number of earlier studies [47]. Compared to sodium silicate (NS), workability can be improved when sodium hydroxide (NH) is the sole alkaline activator. Moreover, it is challenging to assess the effects of changing the ratios and amounts of the constituents in the alkaline solution on the fresh-state performance of EAFS or other binders. These issues arise because each binder has a different molecular makeup that allows for different interactions with the alkaline solution, making direct comparisons challenging [48]. Several studies on alkali-activated EAFS, sodium hydroxide and sodium silicate were used by [35, 37] to achieve 40.7 MPa, 22.0 MPa, and 16.0 MPa compressive strength values, respectively. According to Abdollahnejad et al. [49], 27.0 MPa was recorded using only sodium hydroxide. Sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) were utilized in alkali-activated electric arc furnace slag mortars. The mechanical performance was increased by Na_2O/binder concentration (4%, 6%, 8%, 10%, and 12%) and the SiO_2/Na_2O ratio (0, 0.5, 1.0, 1.5, 2.0, and 2.5). For two hours, the samples were subjected to 100% CO_2 at a pressure of five bars. The results indicated that EAFS, FA, and cement had a 12% CO_2 uptake. However, the maximal compressive strength (i.e., 31 MPa as opposed to 3.9 MPa in uncarbonated mixtures) was reached after an extra 28 days of accelerated carbonation [11]. The mixed concentrations of NH 10% and 12%, sodium silicate (Na_2SiO_3) of zero were specimens with insufficient stability and showed values near zero due to an excess of sodium hydroxide and a need for sodium silicate. After increasing the strength to a certain percentage with additional Na_2O, the performance actually starts to deteriorate. The particles may, however, considerably reduce OH- across the Ca^{2+} ion contact from the EAFS surface. Consequently, it is possible to conclude that the reduced strength is caused by insufficient C-(A-)S-H gels, which are created when Ca^{2+} combines with Si^{4+} [11].

Electric arc slag (EAFS), a relatively less-known material, was utilized to substitute cement in chemical mortar at different weight percentages (0%, 5%, 10%, 15%, 30%, 60%, 80%, and 100%). The objective of this study is to assess the effectiveness of EAFS, an environmentally-friendly waste binder material obtained from the steel-making slag of Misurata City, in alkaline-activated slag mortar. To attain optimal mechanical performance, diverse combinations of sodium hydroxide (NaOH) or (NH) and sodium silicate (Na_2SiO_3) or (NS) were applied. This was accomplished by adjusting the SiO_2/Na_2O ratio (0, 0.5) and the molarity of NH (2M, 4M, 6M, and 8M). To guarantee that all mixtures had a consistent temperature, the alkaline solutions were prepared 24 hours prior to mixing. When the alkaline-activated solution (AAS)/Binder ratio is 0.4, the NH/Binder ratio is 0.27%. The presence of NH concentration enhances the amorphousness of the mortar, which in turn increases the reactivity of Ca^{++} ions during the formation of the C-S-H phases. It has been demonstrated that the R = Na_2SiO_3 /NaOH ratio influences the strength and fresh-state behavior of EAF slag alkaline-activated mortar. The results indicated that the optimal percentage of EAF slag for improving the mechanical and physical properties is 15%. With sodium hydroxide at 2M, 4M, 6M, and 8M, the compressive strength increases as the Na_2O/Binder ratio rises with EAF replacement ratios of 5%, 10%, and 15%. Consequently, the compressive strength decreases for all percentages of EAFS cement replacement as the ratio of total Na_2O to EAFS increases. When compared to the reference mortar (C0S) composed of cement, sand, water, and superplasticizer (SP), the flexural and compressive strengths of the waste slag mortar were not significantly affected by the EAF or alkaline concentration.

2. Materials

2.1 Cement

Zliten cement, type CEM II-4-1 A-L 42.5 N, Al-Burj Factory, Al-Ittihad. The chemical composition as described by [50]; cement's mechanical and physical characteristics is shown in Table 1, 2 and 3. The study's conclusions indicate that Zliten cement is the best type of cement available locally, in accordance with Libyan criteria.

Table 1. The Main oxide components (%) of cement as given by [50].

Chemical element	SiO_2	Al_2O_3	CaO	Fe_2O_3	MgO	SO_3	L.O.i	CaOF	Na_2O	TiO_2	M_nO
Composition	19.50	5.41	64.04	2.76	2.82	1.80	0.38	0.82	0.25	8.94	2.277

Table 2. Mineral composition (%) of clinker as given by [50].

C_2S	C_3S	C_3A	C_4AF
21.21	63.43	14.13	21.11

Table 3. Physical and mechanical properties of cement as given by [51].

Testing	Results	Libyan Specifications Limits No. 430 of 1997	BS12:1996
Initial setting time (min)	218	> 45 min	> 45 min
Final setting time (min)	250	< 10 h	< 10 h
Fineness	3201	> 2500	> 2500
Expansion (mm)	0.90	< 10 mm	< 10 mm
Compression strength at 3 days (MPa)	37.20	> 21	> 21
Compression strength at 28 days (MPa)	58.33	> 39	> 39

2.2 Natural sand

Natural river sand from the Gulf of Bomba near of Derna City was brought for use in this research, as shown in Figure 3. Its basic properties ASTM C33 specification, fineness modulus, FM of 1.89, and from ASTM C128 [52] was determine the specification coefficient of absorption 1%, Bulk specific gravity (SSD) and Bulk density (2.75 kg/m^3).

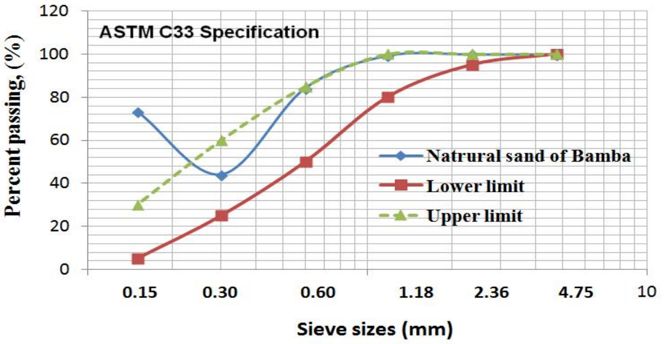


Figure 3. Sieve analysis results of river sand of Libya.

2.3 Electric arc furnace

The main producer of the steel and iron in Libya is in Misurata City. It is the primary source of slag waste [53]. It was massive aggregates in a solid condition, ranging in size from 3 to 7 cm and having a grayish black color. EAF slag was crushed using a Los Anglese machine with 12 rolled steel during a 2hr period, and it passed through a 0.75µm sieve. The EAF slag size < 0.75µm has been preserved, and the crushing process is repeated for sizes greater than 0.75µm. Physical properties and chemical composition is shown in Table 4, 5 and 6.

Table 4. Physical properties of Libyan steel slag (factory of Misurata) [53].

Scrap iron (%)	Density (ton/m^3)	Granular size(mm)
2-4	1.6	1-300

Table 5. The Main oxide components (%) of Libyan steel slag, (factory of Misurata) [53].

Zn	Cl	CaO	MgO	Na_2O	SO_3	SiO_2	K_2O	Al_2O_3	MnO	TiO_2	Fe_2O_3
12	0.085	33.0	7.11	0.25	0.35	17.54	0.13	5.45	2.277	0.94	25.9

Table 6. Mineral composition (%) of Libyan steel slag (factory of Misurata) [53].

C_2S	C_3S	C_3A	C_4AF
105.0	72.62	29.32	78.73

2.4 Alkali activators

List of abbreviations and notations

AAS	Alkaline activated solution (NS+NH)	L	Litter
AAS_{total}	NS+NH+FW	M	Concentration molarity
B	Binder	MM	Molar mass
C_0	Reference mortar without EAFS	Na_2O	Sodium oxide solid mass
C_{0S}	Reference mortar with superplasticizer and no EAFS	$Na_2O_{,total}$	Total Sodium solid from NS+NH
C_{EAF5s}	Reference mortar with superplasticizer and with EAFS (5%)	NH	Sodium hydroxide (NaOH)
FW	Free Water	NS	Sodium silicate ((Na_2SiO_3)
H_2O_b	Bonding water	R	Molarity ratio = Na_2SiO_3/ NaOH
H_2O_{ub}	Unbonding water	TL/B	Total liquid/ binder ratio
K	Mole of Na_2O divides by mole of NaOH	W	Mass

- Calculate the mass of the solid Na_2O in a sodium hydroxide(NH) solution

NH flakes (~99% purity), and (M) is: 0M, 2M, 4M, 6M and 8M was diluted in (1L) of distilled water. Eq. (1) gives an example of calculating NH molar of 4M (g), more detailed in [54]:

$$4M = \frac{N.of\ Moles}{1L} \tag{1}$$

According to Law of conservation of mass, the MM NaOH is 40:

$$2NaOH\ (2\ \text{x}40\ \text{g/mol}) \rightarrow Na_2O\ (62\ \text{g/mol}) + H_2O\ (18\ \text{g/mol}) \tag{2}$$

$$NH\ flakes\ (\text{g})\ in\ 1L = MMNH\ (\text{g}) * (100\ /\ NH\ purity\ (\%)) * M\ of\ NH \tag{3}$$

$NH\ flakes\ (\text{g})\ in\ 1L = 4 * \frac{100}{99} * 40 = 161.62\text{g} \approx 160\ \text{g}$ → *thus 1L contained 160g of NaOH flakes.*

In 4M, the percentage of NaOH flakes in 1L of solution= 100/1000* 160 = 16%

Total distilled H_2O = 100% -16% =84%

$$2NaOH \rightarrow Na_2O + H_2O_b + H_2O_{ub} \tag{4}$$

For 4M NaOH of (y) gram mass of NaOH pellets is approximately 16% of (y). The moles of Na_2O solid of NaOH is:

$$k = \frac{40}{80} = \frac{1}{2} \tag{5}$$

Assumed, AAS/B = 0.4 → AAS = 0.4* B = 0.4* 580 = 232 kg/m^3

$$AAS = NH + NS \tag{6}$$

Assumed, (R) = 0.5

$$Mass\ of\ NH = \frac{AAS}{1+R} = \frac{AAS}{1+0.5} \tag{7}$$

$AAS = NH + 0.5\ NH = 1.5\ NH$

$Mass\ of\ NH = 154.67\ kg;\ mass\ of\ NS = 0.5 * 154.67 = 77.34$ kg

$Solid\ flaks\ of\ NaOH = NHtotal\ in\ solution * Concentration\ of\ NH\ in\ solution = 154.67*16/100 = 24.74\ kg$

Correction of water

$WH_2O_{,\ total} = 154.67 * 0.84 = 129.923$ kg

Weight of Na_2O solid from NaOH was calculated as:

$$Na_2O_{solid} = k * W_{NHtotal\ in\ solution\ includ\ flaks} * NH_{Concnetration\ in\ 100g} * \frac{MM\ Na2O}{MMNaOH} \tag{8}$$

$$Na_2O_{solid} = \frac{1}{2} * 154.67 * \frac{16}{100} * \frac{62}{40} = 19.179 \text{ kg}$$

$$WH_2O_{,b} = WNaOH\ flaks - W_{Na2O}$$
$$= 24.75 - 19.179 = 5.571 \text{ kg}$$

- **Find the mass of SiO_2 solid in a solution of Sodium silicate (NS)**

The company of Misurata City us was Fournier by NS, the following composition: Na_2O = 8.8%, H_2O = 62 %, and SiO_2= 29.2%, as previous assumed, ratio (R) = 0.5.

$$\text{The mass of } Na_2O \text{ in } NS = (8.8/100) * 77.34 = 6.805 \text{ kg} \tag{9}$$

$$\text{The mass of } H_2O \text{ in } NS = (62/100) * 77.34 = 47.951\ kg \tag{10}$$

$$\text{The mass of } SiO_2 \text{ contained } in\ NS = (29.2/100) * 77.34 = 22.583 \text{ kg} \tag{11}$$

Determine the total mass of Na_2O

$$Na_2O, \text{ total} = Na_2O \text{ from } NH + Na_2O \text{ from } NS \tag{12}$$

$$Na_2O, \text{ total} = 19.179\ kg + 6.805\ kg = 25.984 \text{ kg} \tag{13}$$

Determine the overall quantity of FW

Distilled water was used as (FW) in the binder synthesis since it is required to facilitate the polymeric reaction, it was calculated as following:

$W\ H_2O_b$ = 5.571 kg
$W\ H_2O_{ub}$ = 129.923 kg
The mass of H_2O in NS = 47.951 kg

Total H_2O = 255.2 kg

FW = 255.2-5.571-129.923-47.951 =71.755 kg

It proved difficult to handle after mixing for several reasons, including: the cement's fineness was significantly lower (less than 20% passing through a sieve of 75 µm); the sand was extremely fine, as per ASTM C33 [55], with 0.75 µm <EAFS size <1 µm). All the information required to compute free water is shown in Table 7.

Table 7. Determine free water, AAS/binder of NaOH concentration (2M, 4M, 6M and 8M).

Molarity (M)	2M	4M	6M	8M
H_2O/B	= 255.2/ 580 = 0.44			
FW	62.18	71.755	81.355	90.944
$AAS_{(NH+NS)}$	=154.6+ 77.34 =232			
% of increasing water as wt of cement	62.18/580 = 10.72	71.755/580 =12.37	81.355/580 =14.03	90.944/580 =15.68
AAS_{total}	232+62.18 = 294.18	=232+71.755 =303.77	=232+81.355=313.35	=232+90.944=322.94
AAS_{total}/B	0.507	0.524	0.540	0.557

3 . Mortar Design

3.1 Casting

Composition of the reference mortar

C_0 mix with a W/C ratio of 0.55 is made up of 1:2 cement, sand, and water. In this case, W is the sum of the water from AAS plus free water. The water content was lowered to 20% by using superplasticizer (1% of cement weight) in the chemical admixture reference mortar, C0S. This resulted in W/C = 0.44, the mixed composition shown in Table. 8.

Composition of AAS slag mortars

NaOH molarity 2M, 4M, 6M, and 8M was prepared 24h before casting. When we mixed each one molar of NH a heat temperature from dissolution of solids in alkaline solutions was observed. And mortar mixed prepared according to ASTM C305-06 [56] as following: Add NH, NS and free water in the bowl of mixer; switch the mixer to the low speed; mix during 30 sec after insert cement and selected EAFS ratio, introduce entire sand slowly continue in mixing for an additional 60 sec; stop the mixer for 90 sec; during the first 15 sec remove by means of a rubber scraper all the mortar adhering to the wall and bottom part in middle bowel and to allow AAS reaction at rest; finishing by mixing for 60 sec at high speed until obtain a homogenous mixed; total mix shall be not exceed 4 min. Unlike OPC, EAF slag mortar will have a blackish-gray color after curing. Especially when using a mortar that has 100% EAFS (0% cement).

3.2 Specimens sizes

Specimens of 50×50×50 mm^3 cubes were used for testing the compressive strength of alkali activation of EAF slag mortar according to ASTM standard specification C 109/C 109M – 08 [57]. There are three specimens for every molarity and seven different EAFS percentages. There are three specimens for each of the reference mortars (C_0 and C_{0S}) and 90 specimens overall for the compression test. Furthermore, 20 specimens that met ASTM C348-21 [58] conformance standards and measured 4 x 4 x 16 cm were used for the flexural strength test.

3.3 Curing Method

The cube and flexural specimens were kept in the molds for a 24 hr at 30°C±5. Before being tested, reference specimens (C0 and C0S), after the mold was removed, the reference sample was immersed in a water tank for the last 28 days of curing. For the test age of 28 days, alkali activation of EAF slag mortar specimens were demolded and placed to cure in plastic sacs. The saturated surface dry test was conducted in compliance with BS 1881: Part 114 [59].

Table 8. EAF slag alkaline activated mortar mix proportion, (NH concentration example: 2M).

EAF_{100s}	C_{EAF80s}	C_{EAF60s}	C_{EAF30s}	C_{EAF15s}	C_{EAF10s}	C_{EAF5s}	C_{0s}	C_0	Mix
0	116	232	406	493	522	551	580	580	C (Zliten)
580	464	348	174	87	58	29			EAFS(< 75µm)
1157	1157	1157	1157	1157	1157	1157	1157	1157	S (Bamba)
5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8		SP
4	4	4	4	4	4	4			Molar
0.4	0.4	0.4	0.4	0.4	0.4	0.4			AAS/Binder
232	232	232	232	232	232	232			AAS (Total)
154.67	154.67	154.67	154.67	154.67	154.67	154.67			NH
77.33	77.33	77.33	77.33	77.33	77.33	77.33			NS
71.77	71.765	71.765	71.765	71.765	71.77	71.77			FW
303.77	303.77	303.77	303.77	303.77	303.77	303.77			Liquid (total)
19.18	19.18	19.18	19.18	19.18	19.18	19.18			Na_2O from NH
6.81	6.81	6.81	6.81	6.81	6.81	6.81			Na_2O from NS
22.58	22.58	22.58	22.58	22.58	22.58	22.58			SiO_2 from NS
25.98	25.98	25.98	25.984	25.98	25.984	25.98			Na_2O Total
4.48	5.6	7.47	14.93	29.87	44.8	89.6			Na_2O / EAFS %
0.87	0.87	0.87	0.87	0.87	0.87	0.87			SiO_2 /Na_2O
5.568	5.57	5.57	5.57	5.57	5.57	5.57			H_2Ob from NH
129.92	129.92	129.92	129.92	129.92	129.92	129.92			H_2Oub from NH
47.95	47.95	47.95	47.95	47.95	47.95	47.95			$H_2O$from NS
255.2	255.2	255.20	255.20	255.20	255.20	255.20	255.20	319	Total Water
0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.55	TL/B

Symbols: C_0 for reference mortar, C_{0S} for reference mortar with 1% superplasiticer (SP (1% wt of cement); 20% reduction in water of C_0), CBFS5s for mortar with 5% EAF slag-cement replacement; CEAF10s: 10% EAF slag-cement replacement… ect. And EAF100s: 100% EAF slag and 0% cement.

4. Physical and Mechanical Properties

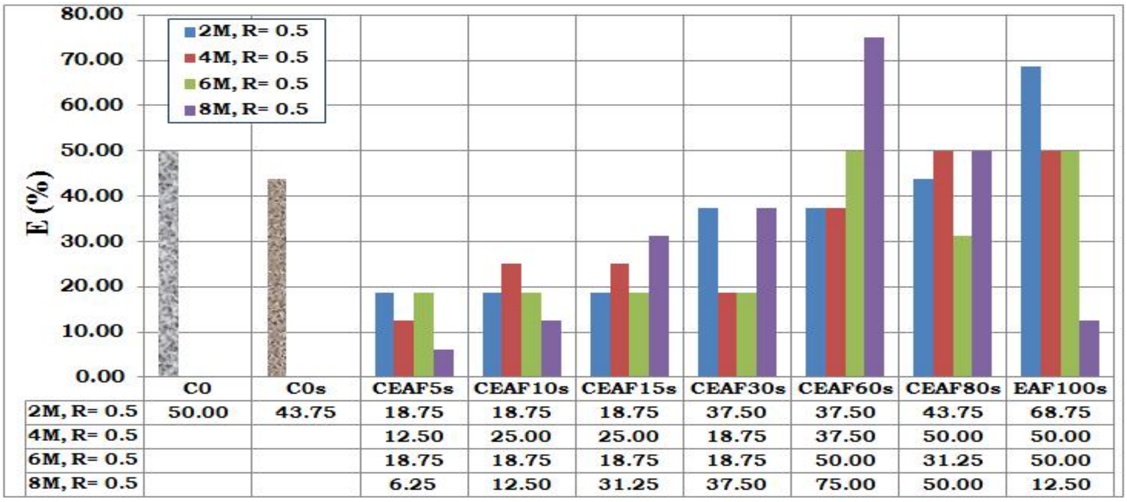
4.1 Spread flow properties

Reference mortar (C_{0S}), a workable paste with a fluidity of at least 115 mm, serves as a standard for all mixes. The flow test was conducted using ASTM C230/C230M-20 [60]. Flow of AAS mortar is as an indication of its workability, the results give indication of the ease of placing and compacting mortar without segregation [61]. After the mortar is placed into in two layers and taken out of a cone-shaped mold. The flow diameter D_f is then computed using the average, as per ISO 9812, alternatively we adopt the form of the (cone). The flow is provided using the formula, Eq (14):

$$E\ (\%) = (D_f\text{-}D_i)\ /Di*100 \tag{14}$$

Where D_f is the mortar's average diameter, D_i is cone's basic diameter.

The pastes containing slag cements exhibited different rheological properties from pastes comprised only of Portland cements, when water-reducing admixtures were not utilized, the pastes and mortars performed better in terms of particle dispersion and fluidity. The workability of reference mortar (C_0) is higher than that of reference mortar (C_{0S}). There are certain percentages that the mortar's workability drops by 5%, 10%, 15%, and 30% of EAFS. It is suggested that during early mixing, the slag cement particles absorb less water than Portland cement. However, there is a noticeable gain in workability when extra EAFS cement is added at a ratio of 60%, 80%, or 100%. In terms of molarity, it demonstrates that the workability of mortar containing EAFS replacement cement rises as NH molar increases. According to Figure 4, mortar workability appears to be unsteady for 2M to 8M with EAFS up to 30%. The partial reaction of the mixture's alkali activator could be the cause. Furthermore, the mortar becomes more fluid when the EAFS proportion is greater than 60%. Consequently, as the amount of sodium hydroxide (NH) and total solid mass of Na_2O in sodium hydroxide and sodium silicate grows, the AAEAFS mortar becomes more workable. However, the workability of molarity of 6M tends to stabilize at lower percentages of EAFS (5%, 10%, 15%, and 30%), while it continues to rise at larger percentages of EAFS (80%, 100%, and 60%). Unless 100% of EAFS, or no cement, is employed, the sample has an 8M molarity indicating approximately lower fluidity.



	C0	C0s	CEAF5s	CEAF10s	CEAF15s	CEAF30s	CEAF60s	CEAF80s	EAF100s
2M, R= 0.5	50.00	43.75	18.75	18.75	18.75	37.50	37.50	43.75	68.75
4M, R= 0.5			12.50	25.00	25.00	18.75	37.50	50.00	50.00
6M, R= 0.5			18.75	18.75	18.75	18.75	50.00	31.25	50.00
8M, R= 0.5			6.25	12.50	31.25	37.50	75.00	50.00	12.50

Figure 4. Variations in workability of mortar of reference mortar without EAFS (C_0), reference mortar without EAFS and with SP (C_{0S}); for percentages of weight-based cement substitution utilizing EAFS at quantities of 0%, 5%, 10%, 15%, 30%, 60, 80, and 100% in relation to molarity of 2M, 4M, 6M, and 8M, (R = NS/NH) = 0.5.

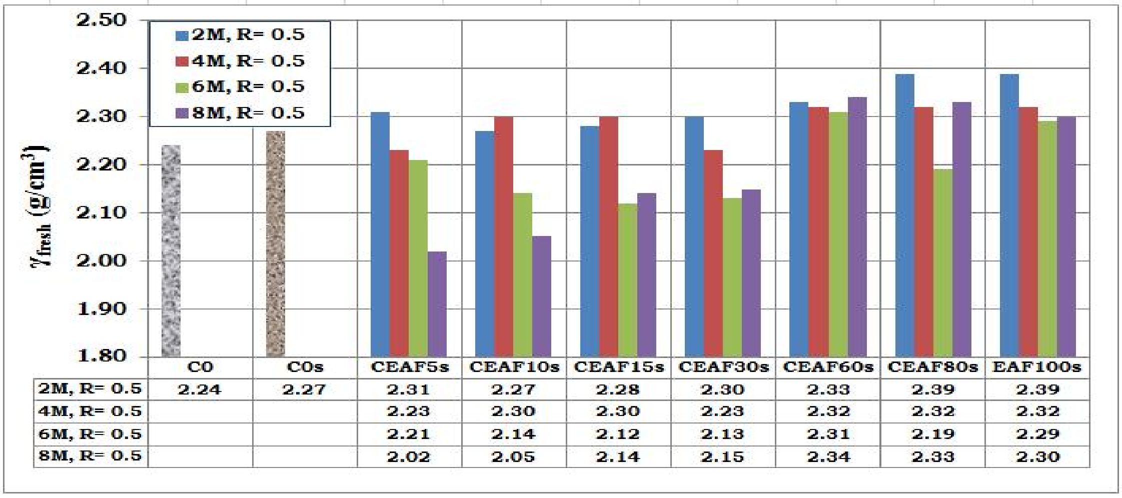
4.2 Density of mortar

- **Density of fresh mortar**

According to ASTM C 138, 2001 [62], density measurements were taken. It is evident that when the NH concentration rises from 2M to 8M, the fresh density diminishes; however, at 6M, the density values are roughly constant. Figure 5 illustrates how the density of the mortar grows in relation to the reference mortar with SP when the EAFS exceeds 60%.

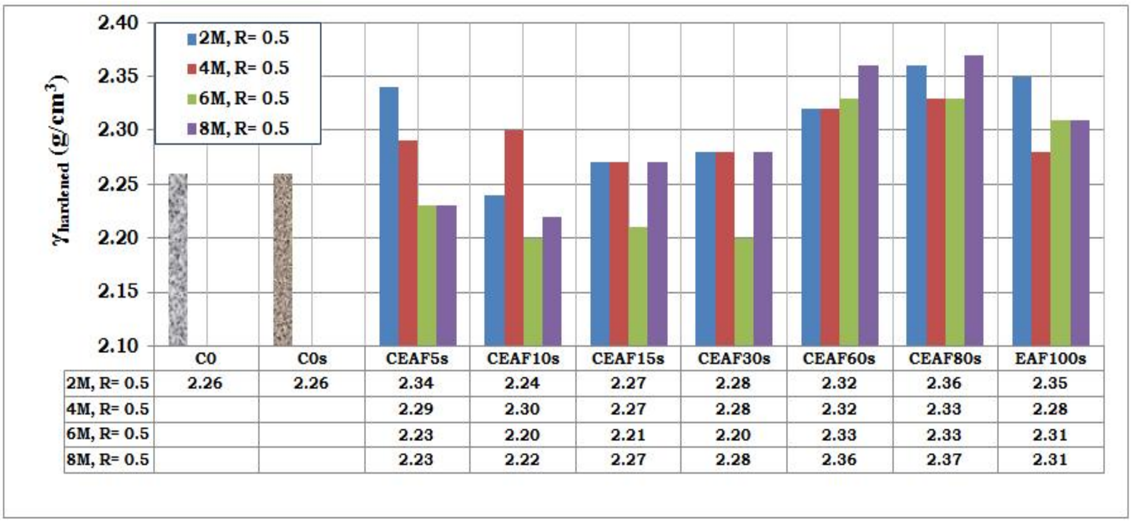
- **Density of hardened mortar**

Slag dissolves more slowly than it does in its fresh condition, causing C-S to agglomerate. Furthermore, the Na2O solid ratio in NH is high with respect to molarity. After 28 days of curing. The density increases when EAFS increases relative to C_{0S}, and the Na_2O mass solid doesn't significantly affect in hardened density than fresh density. Figure.7 showed that 2M produced poly condensation and gel solidification of density in the majority of slag mortar. The reference mortar's density (C_{0S}) was 2.26 g/cm^3, while the AAS slag mortar's density ranged from 2.24-2.34 g/cm^3. EAFS and alkaline activated solution were added to each mix to enhance the density at the hardened stage, as described in EN 1015-10:1999 [63].



	C0	C0s	CEAF5s	CEAF10s	CEAF15s	CEAF30s	CEAF60s	CEAF80s	EAF100s
2M, R= 0.5	2.24	2.27	2.31	2.27	2.28	2.30	2.33	2.39	2.39
4M, R= 0.5			2.23	2.30	2.30	2.23	2.32	2.32	2.32
6M, R= 0.5			2.21	2.14	2.12	2.13	2.31	2.19	2.29
8M, R= 0.5			2.02	2.05	2.14	2.15	2.34	2.33	2.30

Figure 5. The fresh mortar density of reference mortar without EAFS (C_0), reference mortar without EAFS and with SP (C_{0S}); for various weight-based cement substitution percentages using EAFS at 0%, 5%, 10%, 15%, 30%, 60%, 80%, and 100% in relation to 2M, 4M, 6M, and 8M mo-larity, (R = NS/NH) = 0.5.



	C0	C0s	CEAF5s	CEAF10s	CEAF15s	CEAF30s	CEAF60s	CEAF80s	EAF100s
2M, R= 0.5	2.26	2.26	2.34	2.24	2.27	2.28	2.32	2.36	2.35
4M, R= 0.5			2.29	2.30	2.27	2.28	2.32	2.33	2.28
6M, R= 0.5			2.23	2.20	2.21	2.20	2.33	2.33	2.31
8M, R= 0.5			2.23	2.22	2.27	2.28	2.36	2.37	2.31

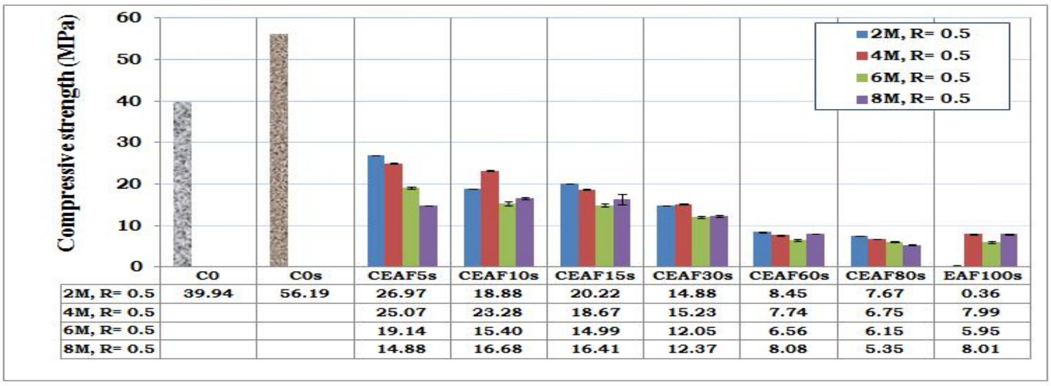
Figure 6. Density of hardened mortar of reference mortar without EAFS (C_0), reference mortar without EAFS and with SP (C_{0S}); in proportion to morality of 2M, 4M, 6M, and 8M, (R = NS/NH) = 0.5 for percentages of weight-based cement replacement using EAFS at amounts of 0%, 5%, 10%, 15%, 30%, 60%, 80%, and 100%.

4.3 Compression properties

The reference mortar (C_{0S}) has a compressive strength of 56.91 MPa, whereas the reference mortar (C_0) has a lower compressive strength of 39.94 MPa. It is well-known that the chemical composition of superplasticizers and other factors, such as cement fineness and the manner in which it is introduced to the combination, affect how effectively superplasticizers function in cementitious structures. The W/C ratio determines the amount of water-filled space in the fresh cement pastes; for a W/C of 0.5 this is about 60%. For R values of 0.5 a compression test was performed. The compressive strength of AAEAFS decreases as NH molar increases up to 4M. Moreover, compressive strength reduces as more EAFS is utilized in place of cement. Figure 7 demonstrates that the compressive strength drops by more than 15% when the EAFS ratio increases.

The following percentages were higher than those of reference mortar (C_{0S}), which had a maximum compressive strength of 56.19 MPa: 48.00, 33.60, 35.99, and 26.48%, EAFS of (5%, 10%,15%, and 30%) of 2M; 44.62, 41.43, 33.23, and 27.10%, EAFS of (5%, 10%,15%, and 30%) of 4M; 34.06, 27.41, 26.68, and 21.45%, EAFS of (5%, 10%,15%, and 30%) of 6M; 26.47, 29.68, 29.20, and 22.01%, EAFS of (5%, 10%,15%,15%,15%, and 30%) of 8M respectively. Therefore, the compressive strength improved more when the percentage of EAFS cement substitute was smaller (5%) than when it was higher. The strength, however, tends to decrease at 15% of EAFS. This suggests that the strength of mortar is primarily affected by EAFS particles larger than 45 μm, since the

EAFS fineness was passing through a sieve of 75 µm. Under most standard standards, particles larger than 45 µm are frequently restricted. In order to provide concrete with adequate strength development, the EAF slag's Blaine surface area must be between 4000-6000 cm^2/g. Because of its interaction with water, granulated slag, a cementitious material, experiences a unique type of hydration when mixed with lime or PC, as shown in [30]. According to Türker et al., [35] under laboratory conditions, cement mortars activated with cured alkaline did not develop microcracks.



	C0	C0s	CEAF5s	CEAF10s	CEAF15s	CEAF30s	CEAF60s	CEAF80s	EAF100s
2M, R= 0.5	39.94	56.19	26.97	18.88	20.22	14.88	8.45	7.67	0.36
4M, R= 0.5			25.07	23.28	18.67	15.23	7.74	6.75	7.99
6M, R= 0.5			19.14	15.40	14.99	12.05	6.56	6.15	5.95
8M, R= 0.5			14.88	16.68	16.41	12.37	8.08	5.35	8.01

Figure 7. Variations in compressive strength of reference mortar without EAFS (C_0), reference mortar without EAFS and with SP (C_{0S}); for percentages of weight-based cement substitution utilizing EAFS at quantities of 0%, 5%, 10%, 15%, 30%, 60, 80, and 100% in relation to molarity of 2M, 4M, 6M, and 8M, (R = NS/NH) = 0.5.

4.4 Flexural properties

Flexural strength tests for reference mortar and AAS of EAF slag mortar were conducted at three points. For every percentage of EAFS and NH concentration, tests were performed on a flexural test machine after 28 days. Two supports that were 100 mm apart held up the specimen. As seen in Figure 8, the loading actuator increased the specimen's center of stress until it ruptured with loading speed of 50 N/s.

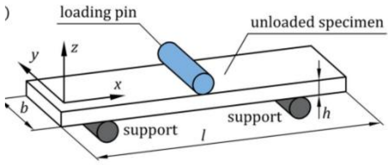


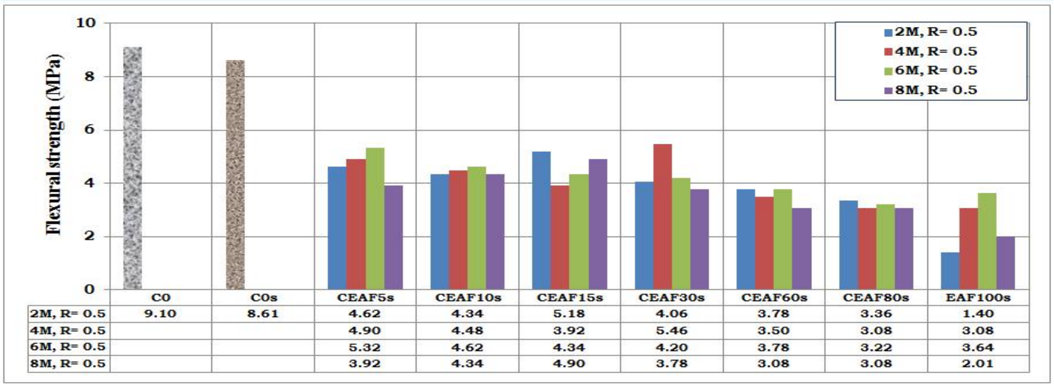
Figure 8. Three-points bending test of EAFS mortar.

Using the elementary theory of beams, the flexural strength's σ_f was calculated from the equation:

$$Flexural\ strength\ (\sigma_f)(MPa) = \frac{3PL}{2b*h^2} \tag{15}$$

Where:
P: the maximum applied load;
L: the distance between supports (100 mm);
b: the width of specimens (40 mm);
h: the thickness of beam (40 mm).

The strength of C_{0S} specimens is typically higher 8.61 MPa but lower than OPC mortar of 9.1 MPa at 28 days. The bending strengths of reference mortar (C_0) and (C_{0S}) were higher approximately the half than AAS slag waste mortar except for EAFS 5%, 6M and EAFS 15%, 2M, which ≈ 60% of C_{0S}, see Figure 9. Lower flexural strength recorded of EAFS 100%, 2M which ≈ 16% of C_{0S}. This shows that resistance decreased with EAFS up to 30% cement replacement; nevertheless, there is no apparent impact of raising NH concentration on flexural strength when compared to raising the EAFS ratio; however, it is evident that strength decreases with % EAFS.



	C0	C0s	CEAF5s	CEAF10s	CEAF15s	CEAF30s	CEAF60s	CEAF80s	EAF100s
2M, R= 0.5	9.10	8.61	4.62	4.34	5.18	4.06	3.78	3.36	1.40
4M, R= 0.5			4.90	4.48	3.92	5.46	3.50	3.08	3.08
6M, R= 0.5			5.32	4.62	4.34	4.20	3.78	3.22	3.64
8M, R= 0.5			3.92	4.34	4.90	3.78	3.08	3.08	2.01

Figure 9. Flexural strength evolution of reference mortar without EAFS (C_0), reference mortar without EAFS and with SP (C_{0S}); for percentages of weight-based cement substitution utilizing EAFS at quantities of 0%, 5%, 10%, 15%, 30%, 60%, 80%, and 100% in relation to molarity of 2M, 4M, 6M, and 8M, (R = NS/NH) = 0.5.

5. Results Discussion

EAFS exhibits hydraulic binding characteristics. Flow results depending on the main factor, that affects the rheology of the AAS alkali activated slag, the concentration of the activator, amount of water, cement of Zliten (C3S of 63.43; C3A of 14.13%); EAFS of Misruata (C3S of 72.62%; C3A of 29.32%), effect of SP. The effects of these factors are explained as follows:

5.1 Effect of the type and concentration of activators (NS, NH)

The use of sodium silicate (NS) has been linked to a high loss of fluidity of the AAS; therefore, we used a ratio of R = 0.5 instead of R = 2.5 (because of the rapid formation of reaction products and the high amount of alkali NS+NH in the mortar), which made handling the slag mortar extremely challenging. Na_2O total in solution is activated using sodium hydroxide decrease oxide. High fluidity loss has been linked to reduced flowability of AAS activated with sodium silicate, which leads to poor workability. Fig. 5 illustrated how an increase in activator concentration results in a increase in AAS slag mortar flow, while increasing Na_2O from NH+NS solution with molarity of NH showed in Figure 10.

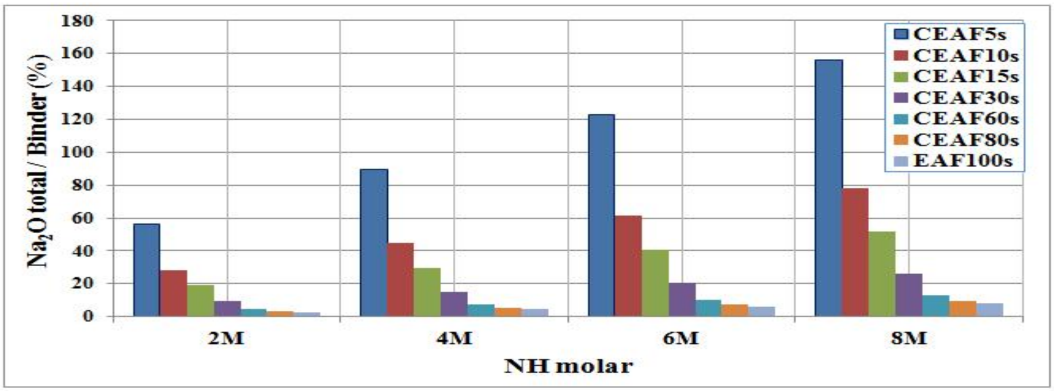


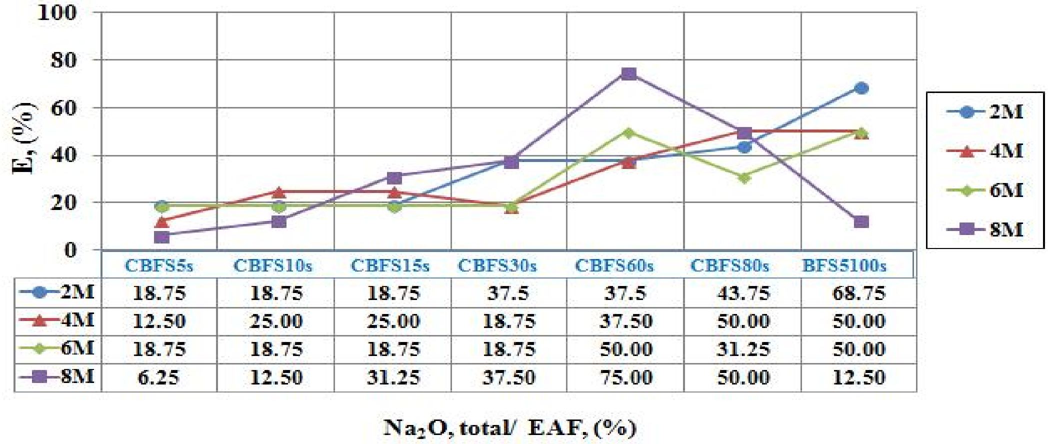
Figure 10. $Na_2O_{,\ total}$ to binder ratio vs molarity of NH.

5.2 Effect of water and superplasticizer

The workability of Portlandite cement reference mortar (C_0) was more fluidity. The workability of reference mortar (C_{0S}) shows similar results of the flow of AAS increases (4M, 6M and 8M) with increase in the amount of water introduced into the slag mortar. When compared to pastes of reference mortar (C_{0S}), we concluded that pastes incorporating slag cements showed distinct rheological characteristics, the pastes and mortars performed better in terms of particle dispersion.

5.3 Effect of Na_2O/EAFS on workability

The fluidity of AAEAFS mortar increases with EAFS%. Molarity ratio of R = 0.5 is lowered since the mortar is more fluid and an increase in NH allows for greater fluidity in the mixture. As illustrated in Figure 11, the workability was more closely associated with Na_2O than with the ratio of EAFS cement substitute. Workability tends to increase with rising NH molarity concentrations (2–8 M) in all approximately mixtures, and appears to increase with EAFS after up to 30%. Particle dispersion was improved by the presence of superplasticizer in the mix mortar, which also displayed distinctive rheological properties. The size and shape of the slag's particles have a major effect on its activation, flow, and workability with the alkaline solution. This resulted from the addition of a solid substance, which increased the alkaline solution's viscosity.



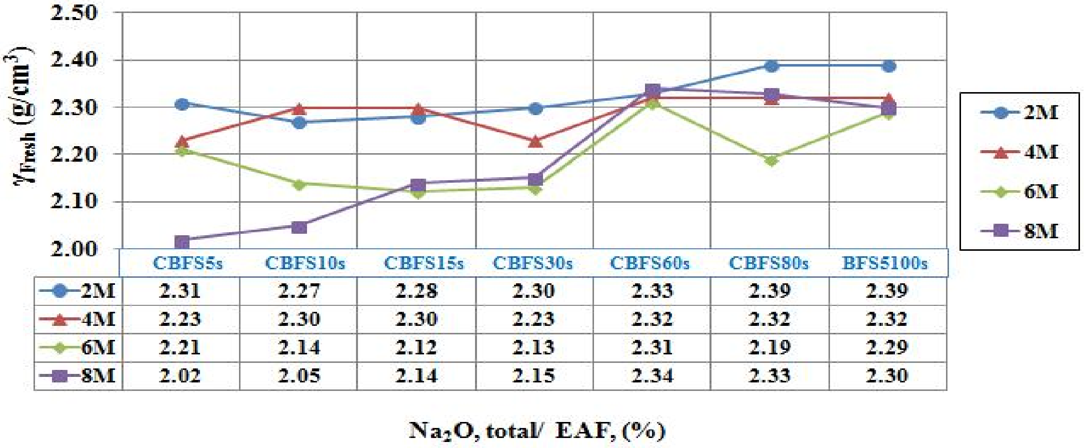
	CBFS5s	CBFS10s	CBFS15s	CBFS30s	CBFS60s	CBFS80s	BFS5100s
2M	18.75	18.75	18.75	37.5	37.5	43.75	68.75
4M	12.50	25.00	25.00	18.75	37.50	50.00	50.00
6M	18.75	18.75	18.75	18.75	50.00	31.25	50.00
8M	6.25	12.50	31.25	37.50	75.00	50.00	12.50

Figure 11. The workability of alkaline activated mortar vs the percentage of Na_2O/EAFS.

5.4 Effect of Na_2O/EAF percentage on density

- **Fresh density**

The fresh density of AAEAFS mortar increases with Na_2O/EAFS cement replacement. Furthermore, fresh density tends to approach with the percentage of EAFS reaches 60%, after which it tends to increase, with rate of increscent lightly. Figure 12 indicated that influence of NH molarity concentrations (2–8M) is lowered.



	CBFS5s	CBFS10s	CBFS15s	CBFS30s	CBFS60s	CBFS80s	BFS5100s
2M	2.31	2.27	2.28	2.30	2.33	2.39	2.39
4M	2.23	2.30	2.30	2.23	2.32	2.32	2.32
6M	2.21	2.14	2.12	2.13	2.31	2.19	2.29
8M	2.02	2.05	2.14	2.15	2.34	2.33	2.30

Figure 12. Fresh density of alkaline activated mortar vs the percentage of Na_2O/EAFS.

- **Hardened density**

The bulk density of AAEAFS mortar at 28 days is showed in Figure 13. With the Na_2O/EAFS replacement of cement, approach density values were obtained with R values of 0.5. Additionally, it seems that density with NH molarity exhibits no greater influence of alkali activators. It can be linked to fluctuating C-N-S-H gel formation is poor and restricted Na_2O levels.

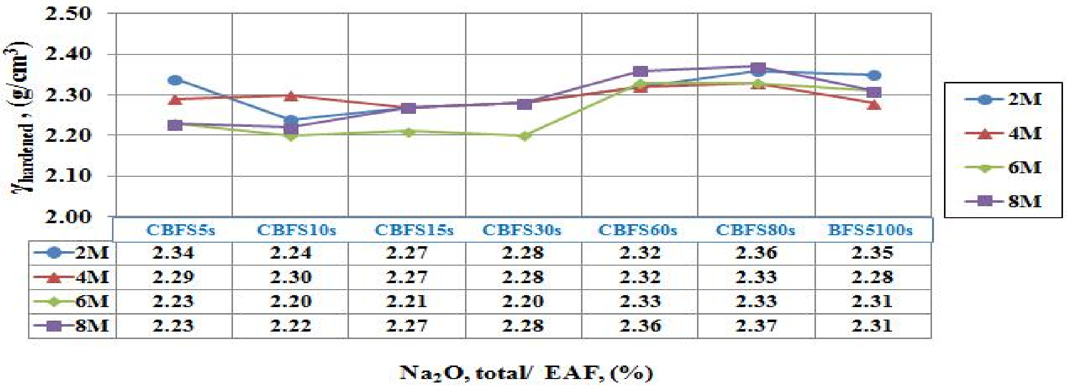


Figure 13. Hardened of alkaline activated mortar vs the percentage of Na_2O/EAFS.

5.5 Effect of alkali activators on compressive strength

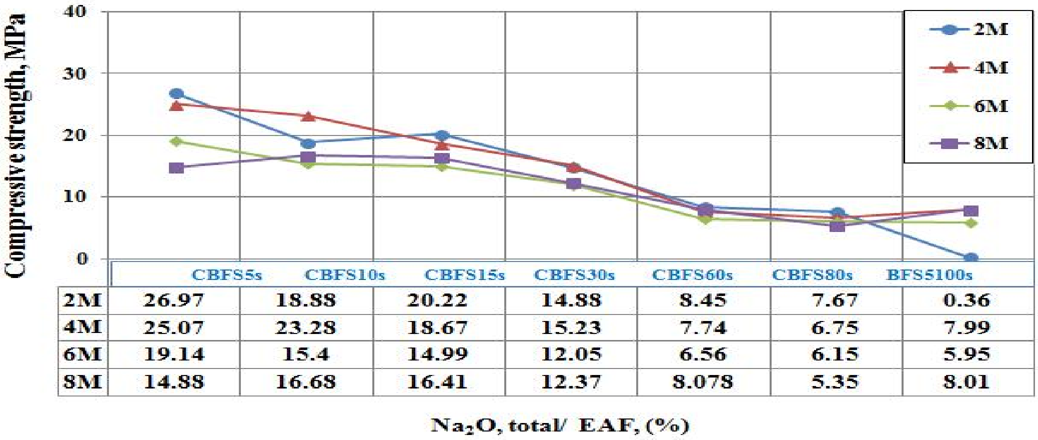
Decrease the compressive strength in NH concentration at 6M, 8M enables lower formation of C-S-H and decrease the formation of crystalline compounds as alite (C3S) and belite (C2S) [64]. Increase in the strength of AAS mortar when the activator dosage was increased from 8% to 16%. Increase in the strength of the AAS could be attributed to lower content of Na_2O in the mixture, which also affects the alkali content of the slag mortar. Slag cement improves the percentage of strength gain relative to C_{0S}. Since EAFS are poorly soluble in water, they are known to solidify extremely slowly. Figure 14 shows a minor addition of EAFS, up to 15 weight percent, was found to improve compressive strength, while a higher addition was lead to reduce compressive strength. EAFS of Misurata City contain Na_2O (0.25%), SiO_2 (17.54%), Al_2O_3 (5.45%) and Fe_2O_3 (25.9%). While the high Fe oxide Fe_2O_3 concentration lowers the chemical activity in concrete during the hydration process [18]. Thus the propability to produce $Na(OH)_2$ plus $Ca(OH)_2$, which increase pH of AAEAFS mix.

The primary reaction product of the alkali activation of slag is calcium (alumino) silicate hydrate C-(A)-S-H gel [30]. $Ca(OH)_2$ is first released when clinker minerals are hydrated to create C–S–H gel and ettringite [31]. The reactions between Ca^{2+} ions of EAFS and OH- ions of alkali activator might be produce of $Ca(OH)_2$. As explained by [65] the reaction of Portlandite and the formation of $CaCO_3$ may be the reason for strength gaining because the produced $CaCO_3$ could fill the micro voids in the AAEAFS structure [37]. A high concentration of OH^- in the mixture caused more Si^{4+} and Al^{3+} ions from EAFS to dissolve. However, an excess of OH^- in the mixture reduced Ca^{2+} ions, Na^+ ions of EAFS, which would result in insufficient calcium silicate hydrate (C-S-H) or calcium-sodium aluminosilicate hydrate (C-N-S-H) gels. This effect has a significant effect on the strength and structure of the mortars. Thus the large size of the cement particles and the BSF aggregate, which were hardly blending to 45µm, prevented the alkali from becoming more concentrated and prevented the formation of a more densified interfacial transition zone, which would haven't increased strength. As the quantity of slag waste mortar rises, the percentage of total Na_2O decreases, as seen in Figure 14. It's been demonstrated that replacing more EAFS in OPC lowers the overall amount of heat realized when cement hydrates and increasing compressive strength.

The solid weight of Na_2O from (NH+NS) solution to binder ratio is shown in Table 9. When the mixture's Na_2O content is raised to 6M, the compressive strength decreases by 5–15% EAFS. As a result, an undesirable structure was seen when the Na concentration was raised over a fixed value [37]. For 2M of EAFS 5% and 15%, the ideal sodium molarity is 56.53, 18.84; for 4M of EAFS 5% and 10%, it is 89.60, 44.80, which enhanced the compressive strength by 25.07, 23.28 MPa. Strength values increased when the concentration of Na^+ in the mixtures was increased to a constant proportion.

Table 9. Values of Na_2O, total of (NH+NS) to EAFS ratio of cement replacement.

Molarity	CEAF5s	CEAF10s	CEAF15s	CEAF30s	CEAF60s	CEAF80s	EAF100s
2M	56.53	28.27	18.84	9.42	4.71	3.53	2.83
4M	89.60	44.80	29.87	14.93	7.47	5.60	4.48
6M	122.67	61.33	40.89	20.44	10.22	7.67	6.13
8M	155.73	77.87	51.91	25.96	12.98	9.73	7.79

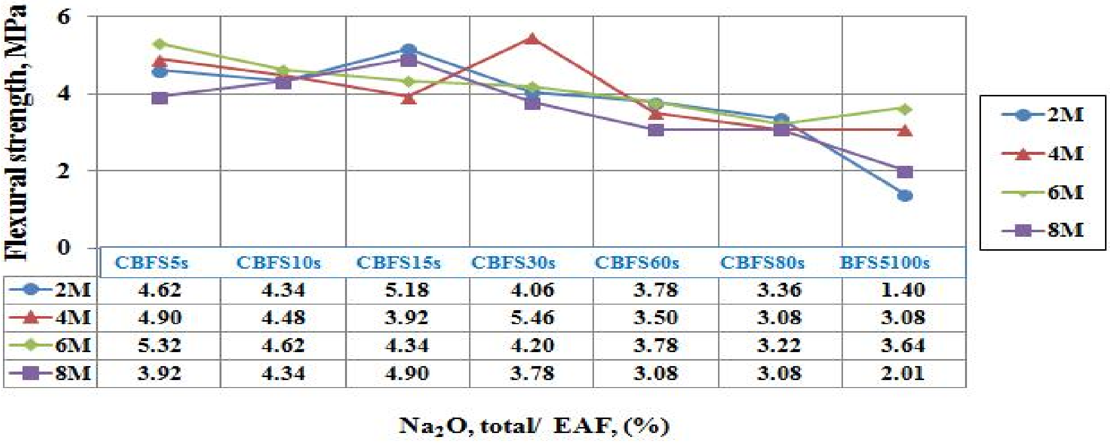


	CBFS5s	CBFS10s	CBFS15s	CBFS30s	CBFS60s	CBFS80s	BFS5100s
2M	26.97	18.88	20.22	14.88	8.45	7.67	0.36
4M	25.07	23.28	18.67	15.23	7.74	6.75	7.99
6M	19.14	15.4	14.99	12.05	6.56	6.15	5.95
8M	14.88	16.68	16.41	12.37	8.078	5.35	8.01

Figure 14. Compressive strength of alkaline activated slag mortar (values indicated in table below the curve) vs. Na_2O, $_{total}$/BFS (values is shown in Table 9).

5.6 Effect of alkali activator on flexural strength

Flexural strength of 5%, 10%, 15%, 30%, 60%, and 80% of the slag additive material was shown in Figure 15. Maximum flexural strength has measured of 4M, EAFS 30%. No significant influence of NH molarity was observed. Adding more Na_2O can strengthen mortar's ability to bend.



	CBFS5s	CBFS10s	CBFS15s	CBFS30s	CBFS60s	CBFS80s	BFS5100s
2M	4.62	4.34	5.18	4.06	3.78	3.36	1.40
4M	4.90	4.48	3.92	5.46	3.50	3.08	3.08
6M	5.32	4.62	4.34	4.20	3.78	3.22	3.64
8M	3.92	4.34	4.90	3.78	3.08	3.08	2.01

Figure 15. Flexural strength of alkaline activated slag mortar (values indicated in table below the curve) vs. Na_2O, $_{total}$/BFS (values is shown in Table 9).

5.7 Potential using options of EAF slag and environmental benefits in construction

One way to reduce waste and carbon emissions is to use waste materials to replace cementitious binders. The SABINE project looks for ways to prepare, manage, and activate steelworks slags as EAFS so that they can be used as a replacement binder in building materials [66]. As part of the project, research institutions and Sabine MC are searching for methods to incorporate them as secondary raw materials into cement and other building products. The possibility of using steelworks slag to bind materials used in geotechnical construction is also being investigated. As a result, many unique products have emerged, such as cement-free EFC concrete and cement-free annular gap grouting mortar.

EAF is now a sustainable steel production technology since it makes use of recovered steel scraps and alloys. However, in order to prevent environmental contamination, waste industrial slag generated during the production of EAF steel must be appropriately repurposed. The heavy toxic components found in EAF slag, such as zinc (Zn), manganese (Mn), nickel (Ni), cadmium (Cd), chromium (Cr), and aluminum (Al), can harm soil and water when disposed of in landfills. Additionally, incineration is costly and energy-intensive. Recycling EAF slag in geopolymer composites reduces greenhouse gas emissions and promotes environmental sustainability [22].

EAFS is adequate with lower strength in several geotechnical applications, including sealing wall masses for subterranean sealing walls, liquid soil for pipeline trench backfill, and annular gap masses for automated tunnel excavations [25]. If EAF slag is appropriately recovered and treated to reduce its hazardous qualities, it can be utilized in eco-friendly construction materials like geopolymer concrete [22]. One of the many benefits of the steel industry's byproduct, EAF slag, is its high silica content, which makes it a good substitute material for geopolymer concrete [67].

6. Conclusion

Research has indicated the advantages of incorporating steel slag into building materials, which are manifested in the enhancement of mechanical properties and environmental benefits. This study validates the efficacy of utilizing Misurata City slag in building construction. Nevertheless, the government transports this slag to neighboring regions as Libya gains minimal or no benefits from it. The addition of Electric Arc Furnace Slag (EAFS) to cement mortar can improve its mechanical and physical properties by up to 15%. In this research, the ratio of NS/NH was investigated to comprehend the influence of Na_2O content on the hydration of slag cement paste. When the ratio R = NS/NH exceeds 0.5, its implementation becomes more challenging. A higher R value leads to a reduction in the workability of the mortar. Compared with pastes composed solely of Portland cement or chemical admixture (SP), the workability and density of Alkali-Activated Slag (AAS) pastes exhibit distinct rheological characteristics. Consequently, the optimal sodium molarity is determined to be 2M and 4M. By using NH + NS activated slag as a binder to enhance strength, the issue of low early strength can be resolved.

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