

Performance of Zero Cement Concrete Synthesized from Fly Ash: A Critical Review

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Abstract. Since the invention of the reinforced concrete (RC) technique, RC buildings have comprised the majority of extant building systems. The shift from traditional materials to green or low/zero carbon designed materials that are energy efficient, such as fly ash (FA), is recognized as one of the desirable approaches to reduce CO_2 emissions and the climate change crisis. This review aims to summarize the performance of fly ash based Zero Cement Concrete (FA – ZCC) according to the main parameters: Fly ash types (ASTM FA Class F and Class C), precursor activator, molarity (Sodium Hydroxide concentration), modulus ratio (SiO_2/Na_2O), mixture design, mixing approach, compressive strength (f'_c), modulus of elasticity (MOE), splitting tensile (f_t), curing time, and curing technique. The findings of this critical review show that the compressive strength of FA-ZCC Class C is higher in comparison with Class F FA – ZCC. Ambient curing for ZCC made from FA Class C was more suitable compared with Class F, which needed high-temperature curing. Increasing molarity up to 14 led to better ZCC regardless the type of FA. Modulus of elasticity and tensile strength of FA – ZCC was found to be similar to or lesser than those for normal cement concrete. Besides, standard approaches should be provided to enhance the mixture design technique, mixing procedure approach, mechanical properties of ZCC synthesized by FA.

1 Introduction

With a global yearly production of 20 billion tonnes, concrete is currently the most commonly utilized construction material [1,2]. J. Aspdin's invention in 1824 proved that ordinary Portland cement (OPC) is a superior binder for concrete production [3]. Since that, OPC has become one of the main global sources of energy used in combustion and chemical processes. The emissions of Carbon dioxide (CO_2) represent about 7% to 8% from global CO_2 production, which is annually reach to 1.5 Giga-tons [4,5]. Construction containing OPC has some limitations as a result of increasing environmental pollution and corrosion than blended with natural and/or by-product materials e.g. silica fumes, fly ash (FA), slag, etc. [6]. Nowadays, concrete industry is shifting towards a green and sustainable infrastructure, and this can be done by employing natural resources or by-products that are now substituted for

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cement in the construction industry [4]. Currently, a partial or a total replacement of Portland cement by natural Pozzolana or by-product materials is a promising choice to produce a concrete similar to *OPC* concrete. Zero Cement Concrete (*ZCC*) is a new generation material recently used in construction industry. When compared to *OPC*, the CO_2 emissions from *ZCC* are between 50 and 80 percent lower [7]. Although some intriguing and promising sustainable concrete solutions have been developed, research on cementless concrete is still in its early phases [8].

A literature survey has been conducted on the overall performance of *FA – ZCC* including structural behaviour, mechanical properties, mix design, reviews, stress strain relationship, economic and environmental effects (Table 1). Limited studies are available on the development and application of *ZCC*. Fig. 1 shows the number of published articles on *ZCC* over the years, for example, SCOPUS databases showed limited publications starting from early the year 2000, to reaching their maximum in 2021 with a slow growth rate during 20 years. According to SCOPUS database [8], published documents on *ZCC* between 1951 and 2021 have just increased by less than 35%. Also, a very limited number of publications on the chosen topic ranging from 2 to 11 journals.

Table 1. Literature survey on *FA – ZCC*

Reference	Subject focus
[9,10,19–22,11–18]	Structural performance of <i>ZCC</i>
[23,24,33,25–32]	Mix design procedure
[28,34–36]	Comprehensive review of the mixture design proportion and procedure
[7,37,46–49,38–45]	Stress-strain characteristics
[3,7,54–63,8,64–70,28,34,36,50–53]	Overall characteristics review
[56,71–75]	Environmental effect, economical assessment, and carbon dioxide emission

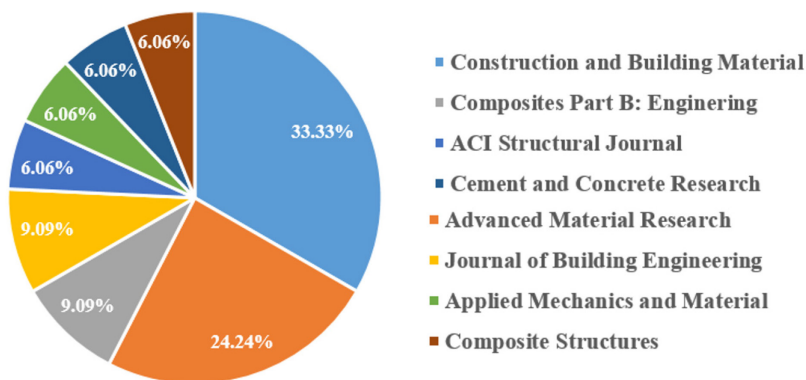


Fig. 1. Selected journals that published articles on *ZCC* as per SCOPUS (modified and redrawn from Wasim et al. [8])

In 2013, The Global Change Institute (GCI) at the University of Queensland was the first worldwide workplace to effectively deploy *ZCC* for structural objectives [76]. Other application includes bridge deck, boat ramp, water tank, retaining wall and pavement [77]. The starting material is combined with an activating solution that provides the necessary alkalinity to release *Si* and *Al*. The alkaline solution is often represented by the mixture of Sodium Hydroxide *NaOH* (SH) with Sodium Silicate Na_2SiO_3 (SS) (also known as water-

glass) or the conjunction of Potassium Silicate K_2SiO_3 (*KS*) with Potassium Hydroxide *KOH* (*KH*) [36]. In Alkali Activated Materials (*AAMs*), the precursor is activated by the alkaline solution to generate a calcium silicate hydrate (*C – S – H*) gel, which is chemically related to that formed by the hydration of *OPC* [77].

Among the literature, the geopolymer (*GP*) term and alkali-activated (*AAM*) materials terms appeared as synonyms or as binder without *OPC* [74], or somewhat interchangeably [68], despite the fact that the chemical reactions involved in the matrix synthesis in both *GP* and *AAM* are fundamentally different [74]. According to Ahmad et al. (2019) [66], *ZCC* is an improved version of *GPC* in which the heating activation of the precursors, such as *GGBFS* or *FA*, is achieved by using an alkaline solution namely *NaOH* and Na_2SiO_3 . Provis et al. (2013) [64] differentiated between geopolymer and alkali-activated materials (*AAMs*); when it contains a lot amount of calcium materials, it is an alkali-activated material, but activated *FA* with low calcium content will give geopolymer. However, Davidovits et al. (1999) [78] remarked that using the term "alkali-activated" could cause major misunderstanding and lead to incorrect assumptions regarding *GPC*. To sum up, there is no confusion in terminology since the objective is unified toward cleaner and greener production of *ZCC*.

2 Components of *ZCC*

ZCC is a revolutionary and environmentally friendly building material that is utilized as an alternative to *OPC* concrete (Fig. 2). Basically, the main constitutes of *ZCC* are namely, as shown in Fig. 3, precursor/binder material (rich aluminosilicate binder (e.g., *FA*), alkaline activators (e.g., a combination of *NaOH* with Na_2SiO_3 or *KOH* with K_2SiO_3), Aggregates (coarse and fine), extra water (potable or distilled or deionized) and admixture (e.g., superplasticizer) if needed. It was reported that the best commonly suitable aluminosilicate materials for producing the *ZCC* are *FA* and *GGBFS*, which both have been shown to offer affirmative effects [50]. The main binder materials are natural or by-products, which are rich in alumina-silicate minerals [23]. The raw materials used to make geopolymer are determined by criteria such as availability, pricing, application type and end-user demand. Alkaline liquids are made from soluble alkali metals, commonly Sodium or Potassium. Sometimes, superplasticizers (SP_s) may be used as a constitute of *ZCC* [51]. According to the testing results, the *SP* dosage was effective for binder content levels ranging from 0.8 to 1.5 percent [26].

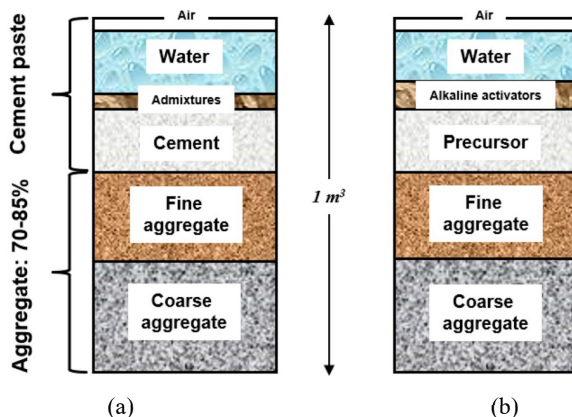


Fig. 2. Comparison between [35]: (a) Conventional cement concrete and (b) Zero cement concrete

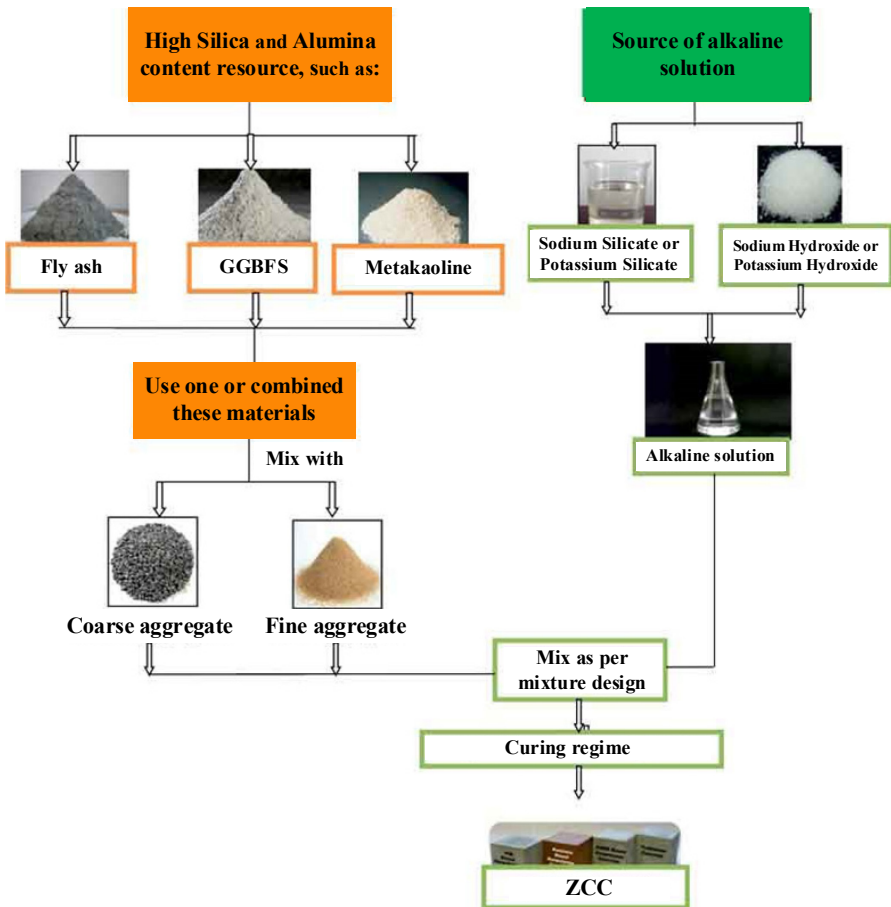


Fig. 3. Example of ZCC's components (modified from Ouyang et al. [87])

2.1 Precursors

Precursors are a wide range of aluminosilicate materials (*GGBFS*, *FA*, calcined clays, metakaolin, silica fume, volcano ash, boiler ash, other Pozzolana, etc.), with varying availability, responsiveness, cost and price around the world [65]. *FA* and *GGBFS* are found to be the most common aluminosilicate appropriate precursor resources for the production of *ZCC*, which have been demonstrated to give good results [50]. For each precursor material, there have been benefits and drawbacks. Metakaolin has a white colour. The high dissolvability of metakaolin in the reactant solution results in a controlled Si/Al ratio in the *ZCC* [79]. Metakaolin is costly to generate a large quantity since it needs a high temperature (500 °C–700 °C) for several hours for its calcination. In comparison, using waste materials such as *FA* is economically cost effective [80].

2.2 Fly Ash (FA)

FA is classified into two classes (*C* and *F*), which can be measured by *X – ray* fluorescence (*XRF*) results [81], based on *ASTM C618* and *AASHTO M295* [82] (Fig. 4). When compared

to FA Class F, FA Class C has a higher calcium content (more than 20%) [3]. This quantity of CaO is lower than OPC content (Fig. 5) [83]. In general, FA is regarded as dangerous to individuals and the environment since it contains acidic and poisonous materials, making it a pollutant [59]. Aquatic life may suffer if FA is improperly disposed of in the ocean, rivers, or ponds. Annually, FA production is about 900 Mt: 500 Mt for China, 140 Mt for India, 115 for USA and the EU and 14.5 Mt for Australia. Soon, FA production is expected to reach 2000 Mt [1].

Depending on the amount of unburned carbon in the ash, the colour of FA can range from tan (low CaO content) to gray (mid CaO content) to black (high CaO content) (Fig. 6) [84]. The physical properties of FA consist of tiny spherical particles, hollow or solid and primarily glassy in composition. Angular particles make up the carbonaceous material in the FA. Most bituminous coal's FA particle size distribution is often comparable to that of silt. (\leq sieve No. 200). Bituminous coal FA is slightly finer than sub-bituminous FA in spite of that sub-bituminous coal FA is silt-sized as well. FA has a specific gravity of (2.1-3.0) and a specific surface area ranging from 170 to 1000 m^2/kg [83].

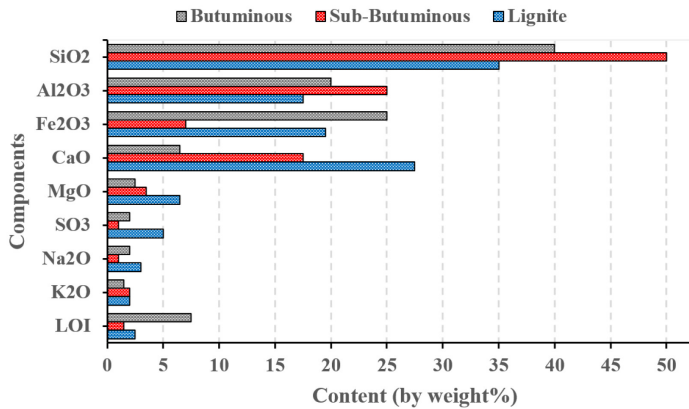


Fig. 4. Traditional average range of FA chemical composition generated from various coal categories (modified and redrawn from Nuaklong et al. [103])

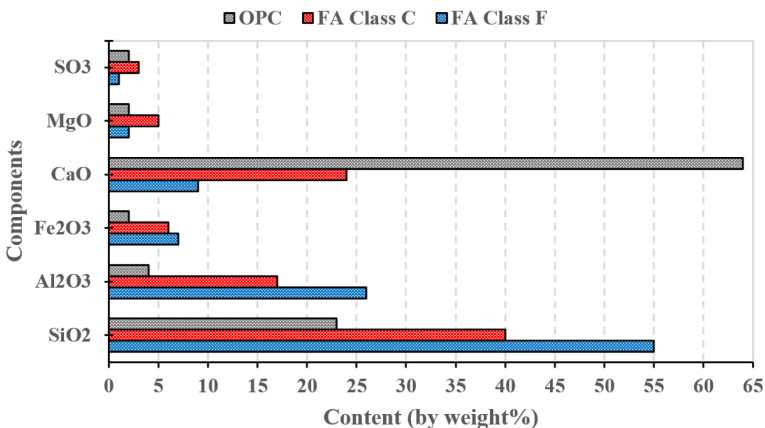


Fig. 5. Comparison between typical components of FA (Class C and F) and OPC (modified and redrawn from [83])



Fig. 6. Various colours of FA, which collected from different regions, based on *CaO* content (modified and redrawn from Gomaa et al. [84])

2.3 Activators

From the literature, the most commonly used alkaline liquid is a mixture of Na_2SiO_3 with $NaOH$ or K_2SiO_3 with KOH [85]. These activators: $NaOH$, Na_2SiO_3 , KOH and K_2SiO_3 are abbreviated as *SH*, *SS*, *KH* and *KS*, respectively. As potential activator chemicals, few classifications of alkali activation comprise $Ca(OH)_2$, MgO and CaO [65]. Palomo et. al., (1999) [86] examined the *FA – ZCC* that activated by either *SS* with *SH* or by *KS* with *KH*. It was discovered that the alkaline liquid type has a considerable impact on strength, with the combination of *SH* and *SS* providing the highest $f'c$ [86]. Ouyang et al. (2020) [87] conducted an experimental work to investigate the best modulus of Sodium Silicate, which is called molar ratio (modulus ratio= SiO_2/Na_2O). They concluded that the molar ratio higher than 1.5 to 2 resulted in strength reduction and prevent the reaction process and hence, the optimum molar ratio is 1.5. Moreover, the ratio of alkaline solution to *FA* (Alk/FA) plays a huge role in the properties of *FA – ZCC* and hence lower Alk/FA led to high strength and good permeability values [59].

2.4 Molarity

Sodium Hydroxide is marketed as pellets (granules) or flakes with a purity range of 96% to 98.6%; the price of the product is based on the material's purity [17]. Sodium silicate (*SS*) also known as water glass is available in the market in gel form. The strength of *ZCC* mortar is significantly influenced by the proportion of SiO_2 and Na_2O in *SS* gel. Typically, a ratio between 1 and 1.5 produces results that are adequate [17]. It has been advised to make the alkaline activator solution (*SH* and *SS*) one day (24 hours) in advance of use to ensure adequate solution mixing [38], Since during the mixing $NaOH$ solution, a great heat is produced and the polymerization occurs by reacting with one another, acting as a binder in the geopolymer mortar. It is recommended that after combining the *SS* and *SH* solution, the solution should be utilized within 36 hours because after that it becomes semi-solid [17].

It was found that the strength characteristics produced better and higher outcomes when increased the molarity dosage of the $NaOH$ solution utilized in the *ZCC* mix design [88]. Higher molarity causes higher $f'c$ and less workable materials. According to the literature, high strength in *ZCC* can be attained when the molarity of the $NaOH$ solution is between 10M and 16M and the ratio of *SS/SH* is between 0.5 and 2.5 [51]. It was concluded that the workability was decreased by raising the *SS/SH* ratio from 0.67 to 3.0 and the *SH* molarity from 10M to 20M. The *SS/SH* ratio of 0.67 to 1.0 produced the significant $f'c$ [84]. Geopolymer with relatively high strengths of 60–70 MPa was obtained when 10M and 15M $NaOH$; *SS/SH* of 1.0 [89]. It was also found that The forerunner of *FA* class *F* with the maximum $f'c$ was *SH* with a molarity of 15M and *SS/SH* of 1.0 and 2.0. Additionally, for

mixes with an SS/SH ratio of 1.0, the setting time and workability shrank as the molarity increased [84]. Nevertheless, the $f'c$ of the GPC is unaffected by the mass ratio of alkaline solution to FA (Alk/FA) [88].

3 Mixture Proportion Design

For decades, unlike ZCC , the standard guideline for designing mixture proportions of the conventional OPC concrete is available such as ACI 111.1 [90]. Because of the narrow investigation on ZCC mix design, there appears to be no precise technique that takes into account all of the important parameters.

Li et al. [35] reviewed many papers concerning various mix design procedures of zero cement concrete/mortar based on trials and errors attempts. They concluded that there are three major methods: (1) Target strength method, which involves fixing the content of either water or binder (2) Performance-based method and (3) Statistical factorial model method, which involves Taguchi methods and multivariate regression model. Among these methods, the target strength procedure is the most popular and proper method. They also recommended that the optimal design procedure should be selected based on the situation, demand and required specification of the ZCC production [35].

4 Mixing procedure

There is currently no standard mix design procedure for ZCC [29]. From the literature review, many researchers have used various procedures for a mix design methodology to manufacture the $ZCCs$ by trial and error to determine the optimal mix process as shown in Table 2. The parameters were varied around mixing time and which material was mixed first. Gomaa et al. (2018) [84] utilized 4 and 8 mixing procedures to produce 215 mortar mixtures (using one type of FA class C) and 80 different mixtures of $ZCCs$ (employing four types of FA class FA with different CaO percentages) respectively. The mixing procedures are illustrated in Table 3. They concluded that the best mixing steps were procedure number 4 and 8 for FA mortar and FA , respectively, taking into account that mixing dry materials before adding the FA was significant to produce good performance mixture including setting time, workability and compressive strength. Besides, increase the mixer speed (from 136 rpm to 281 rpm) and mixing the activator solution prior adding them to the mixture gradually for 5 minutes instead of 1 minute during mixing enhance also the compressive strength, setting time and workability.

Table 2. Mixing mechanism steps available in the literature for ZZC and ZC mortar

Precursors	Step 1	Mix. time (min)	Step 2	Mix. time (min)	Step 3	Mix. time (min) or until a homogeneous mixture was obtained
FA Class F [91][92] FA Class C [93] GGBFS [94] FA Class F and GGBFS [95,96]	CA Sand FA and/or slag	1-3	SS and SH	1-5	Water and SP (if needed)	5
FA Class F [89,97,98]	FA and SH	5	Aggregate	5	SS	5
FA Class F [99] FA (Class F and Class C) [99]	FA and SH	0.5-5	SS	1	Aggregate	1-3
FA Class F [47,100,101] FA Class C [95]	All dry ingredients	2-4 Or till the mixture was consistent	SS and SH, Water, SP (if needed)	2-8		
FA Class F with additives (e.g., rice husk, Nano alumina and Nano silica) [101]	All dry ingredients	1 Or till the mixture was consistent	SH	till the mixture was consistent	SS	5
FA Class C [102]	All dry ingredients	1 Or till the mixture was consistent	SS	2	SH (solid state)	10
FA Class F [66]	FA and aggregate	3	Fluid segment (SH and SS)	4		
FA Class F and GGBFS [38]	CA Sand	3	FA GGBFS	3	Fluid segment (SH, SS and SP if any)	4
FA Class F [23]	Solid constitutes	3	Liquid constitutes	3	Additive (SP)	4
FA Class F [25]	FA with Aggregates	2	Alkaline liquids, Water, SP	3-5	-	-

	FA with SH	2	SS	2	Aggregates	3 min., then, add extra water with SP for 2 min.
	FA with Aggregates	2	SS	3	SH	2 min., then, add extra water with SP for 2 min.

Table 3. Different mixing procedures using various FA class C for ZCCs and ZC mortars adopted by Gomaa et al. (2018) [84]

ZCC																			
Trail mix	Step 1	Mixing time (min)	Step 2	Mix. time (min)	Step 3	Mix. time (min)	Step 4	Mix. time (min)	Extra time (min)	Step 5	Mix. time (min)	Extra time (min)	Step 6	Mix. time (min)	Final Mix. time (min)				
1	C A Sand	1	FA	1	AAS	1	Wt	1							3				
2			FA		Wt		AAS	1							3				
3			FA		W		SH	2	-	SS	1							3	
4			FA		1/4 W		AAS	1	-	3/4 W	1							3	
5			FA		1/2 W		1/2 AA	1	2	1/2 Wt	1	-	1/2 AA	1					3
6			1/2 W		FA		1/2 Wt	1	-	1/2 AA	1	1	1/2 AA	1					3
7			FA		Wt		1/2 AA	1	1	1/2 AA	1							3	
8			FA		Wt		AAS	5							5				
ZC mortar																			
Trail mix	Step 1	Mixing time (min)	Step 2	Mix. time (min)	Step 3	Mix. time (min)	Mixer speed (rpm)							Final Mix. time (min)					
1	FA Sand	1	AAS	1	W	1	136							2					
2			Wt		AAS	1	136							4					
3			Wt		AAS	1	281							4					
4			Wt		AAS	5	281							5					

5 Curing Conditions

Curing conditions include curing type and period. Curing period is one of many factors (including properties of raw constituents, activator solution, molarity, temperature and CSH stage) that affect the concrete properties (fresh and hardened states), durability, acid resistance and behaviour of ZCCs [103]. The experimental outcomes showed that as the curing age increases, the compressive strength of ZCCs increases (e.g., 7 to 28 d and 28 to

90 d) [103]. This action is similar to conventional concrete, especially beyond 90 d of curing, the development of *Ca*-rich gel phases can also lead to significant improvement in later age strength [104].

Gomaa et al. (2018) [84] used different regimes of curing: The first regimen involved a high-heat curing process lasting 24 hours in an electric oven set to 70 °C. The second regime included 7 days of ambient temperature (23 ± 2) °C. For both curing types, two methods were used to store the specimens after demoulding them: (1) Samples were kept in the lab at room temperature until the testing age as per *ASTM C39/2016*. (2) To stop moisture loss, specimens were placed in plastic bags as per *ASTM C39-2016*. Wallah et al. (2006) [80] used two curing approaches for low calcium *FA* based *GPC*, heat curing either, dry curing (24 hr for 60°C oven-curing) or curing in steam chamber and ambient curing of the laboratory conditions without any heat-curing. Although the curing regime has been affected by mixture design and chemical and/or physical properties of *FA – ZCCs*, it is well concluded that heat (oven) curing and ambient curing (or moisture curing) were appropriated for *ZCCs* synthesized by *FA* type F and type C, respectively [84]. It should be noted that samples with dry curing produced an *f'c* greater than samples cured in steam hall.

For concrete made with *FA*, moisture curing with tap water or lime-saturated water hydrated lime (*CA(OH)₂*) creates a saturated solution when less than 0.2 percent of the material has melted. This only amounts to (0.9 pounds/55 gallons) or (2 grams/litre) [105]. To stop leaching of calcium carbonate (*CaCO₃*) from the concrete, lime is added to the water. The specifications can be found in the edition of *ASTM C511-2013* [106]. Many researchers have used several types of curing regimes for *FA – ZCCs* including an oven or heat curing (with/without steam), curing at ambient laboratory/room temperature and moist curing (using tap water or lime saturated water. For appropriate *FA – ZCCs* curing, they recommended the following:

- Each specimen rested for two hours at room temperature of (23 ± 2) °C after the concrete had been cast in the plastic cylinders.
- The recommended curing time is 6 -6 hrs, but it has also been said that curing times of more than 48 hours are insignificant.
- Longer curing times result in concrete with advanced ultimate strength and enhanced durability.
- Under low temperatures (< ambient of 21 to 23 °C), *FA – ZCCs* needs higher than 24hrs to set because the rate of reaction is slower.
- Although it is practically hard to perform in situ, an oven curing regime at high temperatures of between (600-900 °C) improves the polymerization progression and leads to well gel development, which improves *f'c* and durability characteristics.
- Longer curing times result in concrete with higher ultimate strength and durability.
- To stop the water from evaporating after demoulding, for oven and ambient curing, the *FA – ZCCs* samples should be wrapped in plastic bags because it stops moisture from evaporating while curing.
- To develop *FA – ZCC* strength, it is advantageous to apply curing at room temperature for a longer period of time.

6 Mechanical Characteristics of FA – ZCC

The quality of ZCC can be significantly indicated by the compressive strength ($f'c$). Many parameters and factors of ZCC effects, regardless of the factors related to aggregate (coarse and fine), the ZCC compressive strength including [28]: molarity, SS to SH ratio, molar ratio (modulus ratio or Silica modulus= SiO_2/Na_2O) of SS, binder types, Alkali solution/binder ratio, water/binder ratio, binder/aggregate ratio, mixture proportion, mixing procedure, resting time, curing regime and superplasticizer/binder ratio, etc. It is documented that the $f'c_{FA-ZCC}$ increased when the ratio of alkali activation solution (AAS) to solid mass decreased [28], which has the same trend effect of water cement ratio on conventional concrete. alkali activation solution (AAS) (including water in SS and SH), whereas, solid mass includes FA, solid mass of SS and SH. Further positive factors including [28]: Curing temperature from 30-90 °C, higher ratio of AAS to solid mass, higher molarity of SH up to 10 or 14, Higher SS/SH up to 2.5 and longer curing time.

On the other hands, further strength characteristics of FA – ZCC like elasticity modulus (MOE), tensile strength (f_t) and rupture modulus (f_r) were investigated and studied in the literature. These mechanical properties are also affected by the same mentioned parameters that affected compressive strength. Numerous researchers were studied the modulus of elasticity with stress strain relationship [48]. MOE of lightweight and normal concrete, which can be formulated using well known code of practice (e.g., ACI code 318), in general affected by the content nature including aggregate and MOE of the paste. However, overall evaluation of the scientific literatures showed that MOE_{ZCC} of FA – ZCC is slightly lower than [47] or similar [7] to MOE for conventional concrete [45]. Eq. 1 and Eq. 2 show the relationship between MOE , $f'c$ and density (ρ) [107]. Fernández et al. (2006) [47] ranged the MOE between 20 to 40 GPa, whereas for the related NC ranged between 25 to 35 GPa. While Joseph et al. [108] found it to be between 40 to 60 GPa, which was also higher than the corresponding MOE_{NC} . Eq. 3 and Eq. 4 formulated by Thomas et al. (2015) [42] also predicted the MOE_{FA-ZCC} with correlation factors of 0.58 and 0.6, respectively. These various outcomes of MOE_{FA-ZCC} between the literatures are mainly due to different cementitious material (*ASTM FA Class F* and *Class C*), dosages, mixture design, mixing procedure, etc. It was observed that the tensile strength of the FA – ZCC synthesized by FA and activated by the combination of SS and SH is similar to that formulated by ACI 318 and higher than suggested by Eurocode 2 [94].

$$E_{FA-ZCC} = 0.037 \times \rho^{1.5} \times \sqrt{f'c} \quad (1)$$

$$E_{FA-ZCC} = 0.015 \times \rho^{1.43} \times f'c^{0.84} \quad (2)$$

$$E_{FA-ZCC} = 2900 \times (f'c)^{3/5} \quad (3)$$

$$E_{FA-ZCC} = 4400 \times \sqrt{f'c} \quad (4)$$

7 Conclusion and Future Research Need

The performance evaluation of cementless concrete synthesized from the combination of FA, alkali activator (Na_2SiO_3 with $NaOH$), aggregate (fine and coarse), superplasticizer (optional) and extra water (if needed) are reviewed, compared and studied. The following conclusion may be drawn from the current evaluation:

- Utilizing fly ash as a partial substitute for Portland cement would significantly serve in the development of concrete-based construction products.

- *FA – ZCC* and conventional concrete are approximately similar or lesser in mechanical properties such as modulus of elasticity, compressive and tensile strengths,
- *ZCC* synthesized by *FA Class C* has higher strength than *ZCC* made from *Class F*.
- Precursors for ambient-cured and thermal-cured (high temperature), have been used in class *C* and class *F*, respectively.
- High calcium content of *FA class C*, gives an extra hydration reaction that affects strength development.
- High temperature curing (30-90) °C for *FA – ZCC Class F* is more convenient than Class *F*, which preferred an ambient curing temperature.
- Compressive strength, modulus of elasticity and splitting tensile strength obtained from *FA – ZCC* can be similar to that of normal cement concrete.
- Long curing period led to better strength of *FA – ZCC* regardless of the type of *FA*.
- Modulus ratio (molar ratio= SiO_2/Na_2O) equal to 1.5 resulted in optimum strength for *FA – ZCC*
- Higher ratio of *SS/SH* up to 2.5 led to higher strength.
- Higher Molarity up to 14 headed to better strength.

Despite the fact that many experimental data are presented by various authors to understand the *FA – ZCC*, the lack of codes of practice is impeding its widespread adoption. Thus, there is a necessity to provide a standard method to support the design procedure and principles of mixture design, stress-strain relationship, mechanical properties, etc. of *FA – ZCC*.

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