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A Short Review on Preparation and Characterization of Iraqi Porcelanite Aggregate Concrete

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Abstract

Conventional concrete is recognized for its high density, which leads to a higher cost of building foundations and columns. Recently, many efforts have been made to produce lower density concrete with acceptable and applicable mechanical properties. One option can reduce the density of the conventional concrete by using partial or total replacement of porcelanite instead of natural gravel. Porcelanite aggregate concrete can be prepared by adding different ratios of porcelanite and several other additives to the mortar, depending on the required density of the prepared porcelanite concrete. This study aims to assess porcelanite aggregate concrete components, manufacturing methods, and features of porcelanite aggregate concrete. Furthermore, this literature review aims to appraise and provide a complete vision of the testing program, including compressive strength, density, porosity, splitting tensile strength, and water absorption of porcelanite aggregate concrete. Also, this paper focuses on studying the development and applications of the porcelanite aggregate concrete, which will be presented in detail through this study.

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1. Introduction

The utilization of lightweight aggregate in concrete is primarily to lower the self-weight of the concrete, which leads to a reduction in foundation dimension and cost savings [1]. It is considered lightweight concrete when the density is no more than 1920 kg/m^3. The normal weight for concrete with a usual density from 2240 to 2480 kg /m^3 [2]. The minimum compressive strength of 28 days for lightweight concrete is about 17.0 MPa, which is defined as Low Strength Concrete (LSC); when the compressive strength ranges from 17 to 27 MPa, it is classified as medium strength (MSC), while if it is greater than 41 MPa it is classified as high strength concrete (HSC) [3]. However, the water absorbed by lightweight aggregates (LWAs) reduces concrete shrinkage [4], acting as reservoirs that compensate for moisture loss due to drying. Internal curing of lightweight aggregate concrete (LWAC) can greatly reduce shrinkage [5]. Furthermore, the strong bond between LWA and the cement matrix decreases length variations, which are caused by moisture or heat influences [6]. The shrinkage behaviour of LWAC differs from that of standard normal weight concrete due to a combination of these characteristics and the vast diversity of LWA [6, 7]. Typical ranges of concrete densities made with different LWA are classified by the American Concrete Institute (ACI) [4]. Recent studies [8, 9] have revealed that there is a plentiful supply of lightweight rocks that might be used to make concrete with a lower density then the present practice in this country. Lightweight concrete can be produced using different lightweight aggregates. Lightweight aggregate arises from either natural material or as a by-product of thermal treatment for natural raw materials. Volcanic pumice, clay, slate, shale, fly ash, palm oil shell ash, biscuits ceramics, under-ash oscillation, and others can manufacture different lightweight concrete collections [10, 11]. There are also issues with the LWAC's positioning. LWAC is sensitive to aggregate segregation during mixing because of its components' varying densities [12]. The segregation in LWAC causes a lot of variation in the concrete properties, which has a negative effect on the mechanical properties and the durability of the concrete [13]. It can be noticed that superplasticiser was increasing the compressive strength and tensile for the concrete and protect it [14]. Nanotechnology is more useful for many fields like civil, energy, drugs and solar cells [15-17]. This review aims to provide information and guideline for using lightweight concrete by different mix ratio of (cement: sand: porcelanite aggregate), additives, and mechanical properties for building material. Figure 1 shows a simplified idea of the mixing concrete material.

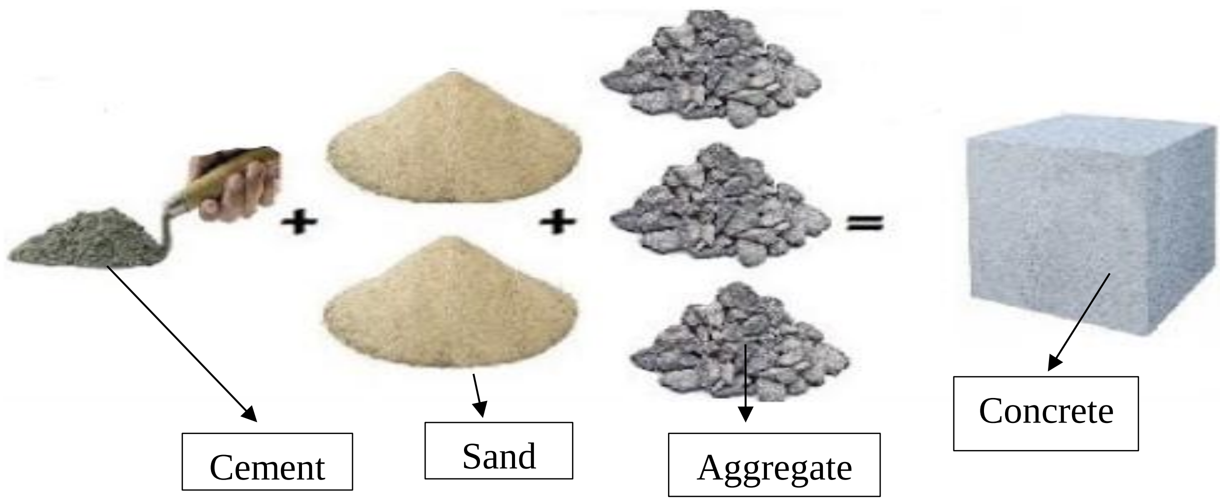

Figure 1: Traditional concrete material mix.

2. Research Significance

This paper focuses on the use of porcelanite aggregate concrete, preparation and characterization. Self-weight accounts for a significant fraction of the total load on the structure, and the substantial benefits of lowering the concrete density. An attempt has been made to improve the mechanical properties of lightweight porcelanite concrete using different additives such as chopped carbon fibres, metakaolin, silica fume, west material, and fly ash.

3. Porcelainte

Porcelanite is an important industrial, sedimentary rock. It is categorized under more than 20 different names and many brands (e.g., diatomite, diatomaceous earth, kieselguhr, cellite, filtac, etc.) [18]. The mineral and chemical composition of porcelanite rocks reflect their unique properties, making them suitable for industry. The term porcelanite is known by many authors [19]. Kastner et al. [20] were the first to restrict porcelanite to rocks composed primarily of opal-CT (cristobalite -tridymite). These rocks were discovered in Iraq's Western Desert, near Rutba, by the State Company of Geological Survey and Mining in the year of 1986 [18]. The mineral compositions were determined for porcelanite aggregate as shown in table 1.

Table 1: The mineral compositions of porcelanite aggregates.

No.	Compounds	%by weight
1	Opal-CT	64.28
2	Quartz	10.42
3	Clay	7.72
4	Dolomite	7.12
5	Calcite	6.30
6	Apatite	1.83
7	Halite	0.63
8	Gypsum	0.61

4. Method

Porcelanite aggregate concrete was searched on several databases such as Web of Science, Scopus, and Google Scholar. The primary database searched was Web of Science, where papers are most accessible and widely used for research. The research classified relevant keywords, including superplasticizer, additives, concrete, and lightweight porcelanite concrete. The search only covered articles published in Iraq. Initially, based on keywords search, more than 15 papers over the last decade were obtained. As the initial search results include all porcelanite aggregate concrete-related papers, it was necessary to exclude irrelevant studies. Only studies related to porcelanite aggregate concrete, where the applicable keywords' titles were reviewed in more than 15 papers, were used. A selection and screening procedure followed this process. The abstract was examined to determine its relevance to the research, porcelanite aggregate concrete produced by the mixing method was selected, and reliable contents with valuable findings were then carefully read from papers that fit this study's objective. Based on the total number of articles chosen for this review, the analysis and review were made considering the types of additives that were used in porcelanite aggregate concrete was replaced cement ratio in each of the metakaolin, waste material, chopped carbon fibres, and fly ash or by reinforced concrete deep beam. Main objectives to be achieved in the in-depth discussion include summarizing the ongoing research topics within lightweight concrete incorporated poreclanite aggregate and analysing the advantages and limitations.

5. Porcelanite Lightweight Aggregate Concrete

5.1. Porcelanite as Coarse Aggregate

Porcelanite lightweight aggregate stone was found locally. On the No.4 (4.75mm) sieve, aggregate is primarily retained. H. M. Saleh in 2012, studied the possibility of using porcelanite as coarse aggregate to produce lightweight concrete [21]. The 1:2:4 mix proportioning ratio (cement: sand: aggregate) was used to keep the concrete mix ratio constant for all types of concrete. A set of samples with 0; 0.25; 0.5; 0.75; 100 percentages of porcelanite were prepared, and their characteristics were measured. The measured properties were compressive strength, splitting tensile strength, fresh and hardened density. The measurements have shown that the density and compressive strength of the porcelanite concrete are decreasing with increasing the procelanite percentage; because porcelanite aggregate has a lower density than gravel [21]. D. M. Al Saffar and Q. A. Al Quraishy in 2018, have studied the effect of high temperature (200 to 700 ˚C) on the residual mechanical properties [22]. Six samples were prepared; the first three mixes were used as reference mixes, and they included cement, porcelanite as coarse aggregate, and fine porcelanite as a partial and total replacement for sand. To make Lightweight Aggregate Foamed Concrete, 2% foam agent by weight of water was added (LWAFC) [22].

5.2. Porcelanite as Fine Aggregate

Procelanite was replaced with some ratios of fine aggregate. A. A. Salih and Z. M. Abed in 2014, investigated the effect of different curing methods (air curing, emulsified asphalt (flan coat) curing, curing seven days, and permanently water curing) [23]. Furthermore, a local material, procelanite, was used as an internal curing agent material; replacement percentages (volumetric replacement) of fine aggregate on specific Roller Compacted Concrete (RCC) features. This study would lead to exploring the possibility of introducing more practical methods for the pavement with minimal curing processing requirements. Compressive strength of RCC was improving by internal curing (IC) with the replacement of 5% porcelanite, and for the highest value compared to other mixtures ranges between (25.5-45 MPa) for RCC reference ranging from (23-41 MPa) and for others (14.5-38 MPa). This concrete is mainly applied in Dam construction, fast laying of single layer paving for highways, runways, and laying a multi-layer foundation [23]. Z. M. Abed and A. A. Salih in 2016, studied porcelanite as a partial replacement of fine aggregate [24]. The primary purpose of this research is to investigate the effect of various curing methods (air curing, seven days water curing, and permanent water curing) and porcelanite (local material used as an Internal Curing agent). In addition to the Roller Compacted Concrete reference mixture, various proportions of the saturated porcelanite content were added (5, 8, 12, 16, 20) % and used by volumetric substitution of fine, kiln dried aggregates, and different proportions of moisture content are used to determine the relationships of moisture content, dry density, and (14%) of the cement content by weight of dry aggregate in air. Porcelanite positively affects Roller Compacted Concrete properties, such as improving the elastic compatibility with cement paste, reducing micro-cracking, and improving the Intermediate Transfer Zone (ITZ) between porcelanite and cement paste matrix that affects permeability, elimination, or reduction of cracks due to self-shrinkage [24].

5.3. Porcelanite Aggregate Replacement of Gravel

River gravels are irregular, rounded shapes, having smooth surface texture. N. A. Al-Bayati *et al.* in 2013, studied lightweight concrete by using different percentages of porcelanite as coarse aggregate [25]. The type of concrete depends on the size fractions, for concrete containing fine normal weight (sand) aggregate and mixture of lightweight (100%, 75%, 50%, 25% and 0%) graded porcelanite and ordinary coarse aggregate (0%, 25%, 50%, 75%, 100% graded gravel) according to ACI 318M-11. There are many structural advantages of using lightweight concrete (LWC) as a building material. It reduces dead load due to lower density and allows for smaller and lighter structural parts. Reductions in poles and beam dimensions' result in more space savings and reductions in subjective weight, improving the seismic resistance ability to build structures [25]. N. Al-Bayati in 2016, researched the non-destructive ultrasonic pulse velocity method and the rebound hammer method and were used to determine the compression strength and modulus of elasticity of structural normal and lightweight aggregate concrete mixes [26]. For any strength level, the combined rebound and pulse velocity test methods provide good results. The use of a non-destructive ultrasonic pulse velocity test to predict the concrete's compression strength; also to estimate a simplified expression based on the dependence of ultrasonic pulse velocity on concrete density and elasticity is obtained using nonlinear regression of power fit with R2 = 1.0, correlation coefficient (0.9999), and Standard Error (0.0196) [26]. Kaiss F. Sarsam *et al.* in 2017, used a nonlinear finite element analysis to investigate the behavior of simply supported reinforced concrete deep beams after they were strengthened with externally bonded carbon fiber composite materials to research their shear behavior carbon fiber reinforcement polymer (CFRP) [27]. Seven identical porcelanite lightweight aggregate concrete with deep beams were numerically analyzed using the ANSYS computer program; two of them were left un-strengthened to act as reference beams, while the other five were strengthened with carbon fiber strips in various orientations (vertical, horizontal, and inclined) and layers (one and two layers). A structural lightweight aggregate concrete was made using locally available natural porcelanite aggregate [27]. K. F. Sarsam *et al.* in that same year, 2017, have experimentally tested the structural behavior of carbon fiber reinforcement polymer (CFRP) concrete reinforced with deep beams [27]. Nine identical porcelanite lightweight aggregate reinforced deep concrete beams were fabricated, cast, and tested as part of the experimental program. Three of the deep beams that have been examined were left unstrengthen to act as reference beams, while the other three were strengthened. Then several trial mixes were created to meet these two requirements and achieve an optimal concrete compressive strength of (26.34 MPa) at (28 days) with an oven dry density of around (1950 kg/m3). In this study, GLENIUM51 was used as a high-performance superplasticizer admixture [28]. A. S. Mohammad *et al*. in 2018, researched manufacturing structural lightweight aggregate concrete and explored it using locally available natural porcelanite rocks [29]. The beams were intended to meet the ACI 318M-14 building code criteria. Compared to the unstrengthen control, the CFRP strips increased the load carrying capability of the strengthened deep beams by 50%. Aramid (AFRP), carbon (CFRP), basalt, and glass (GFRP) are the four primary forms of FRP utilized in the building sector. There are a variety of performance qualities available within these fiber categories. As demonstrated in figure 2, the fibers have a linear elastic response up to ultimate load—comparing a few different FRP composites. In general, the reinforcement supplied by externally bonded carbon fiber strips limited the widening of the diagonal cracks. As a result, the thickness of the strip and its normal orientation has a considerable impact on the structural performance of the strengthening lightweight deep beams [29].

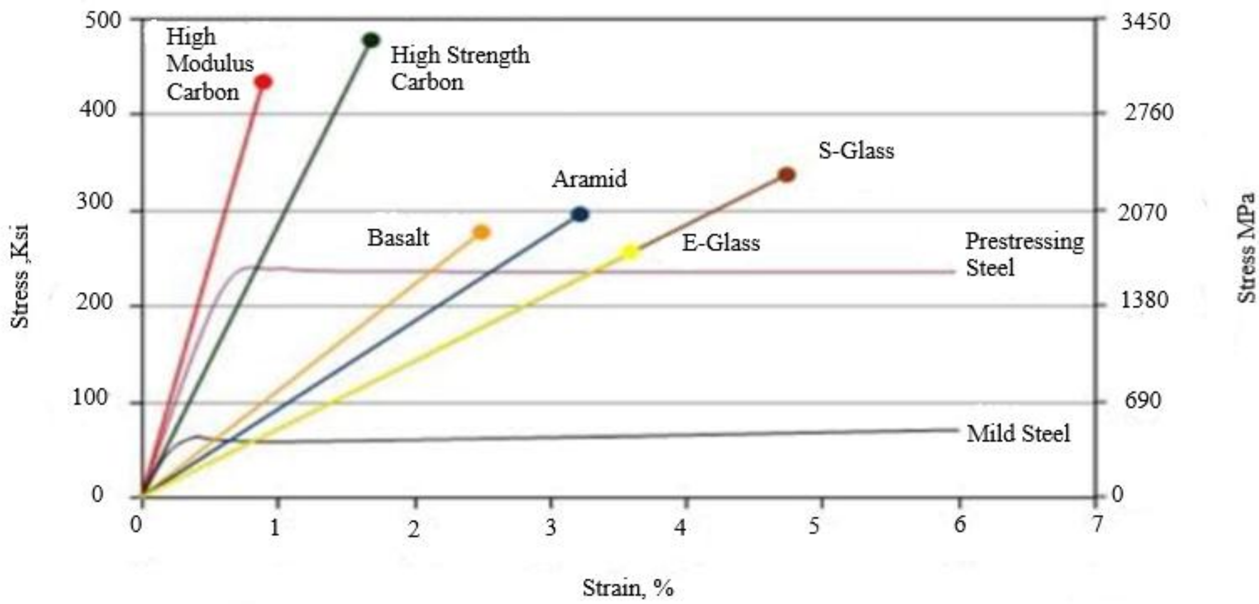

Figure 2: comparison of stress-strain relationships between FRP composites and reinforcing steel [29].

6. Partial Replacement of Cement

6.1. Metakaolin

Metakaolin was a partial replacement for cement. N. M. Fawzi *et al.* in 2013, presented a structural lightweight porcelanite aggregate concrete [30]. Several experiments were performed by replacing the cement with different proportions of metakaolin. Metakaolin which was replaced by 5%, 10%, 15%, and 20%. A Control reference mixture without metakaolin was prepared for comparison. It shows that compressive strength, flexural strength, and others properties. Lightweight structural Aggregate concrete is important, and it is a versatile substance in modern Construction. The 15 % metakaolin had the highest compressive, splitting tensile, flexure, and modulus of elasticity. It has a varieties of applications, such as multistory applications, Building frames, floors, bridges, offshore oil platforms, and pre-stressed or precast elements of all kinds [30].

6.2. Waste Material

Waste materials such as wood sawdust, cork granules, coconut pith, and rice husks are classified as organic wastes, whereas wastes such as broken brick aggregate, silica gel, iron splinters, silica fume, minced rubber, and chopped worn-out tires are classified as inorganic wastes [31]. S. M. Hama in2017, used Porcelanite aggregate as a lightweight aggregate; at first plastic bottles were cut as slices and used as fibers with percentages of 0.0%, 0.5%, 0.75%, 1.0%, 1.25% and 1.5% by volume [32]. The results show that compressive and tensile stress for mixing 1% plastic fibers (PF) gave the best results than the reference mixture without PF. Eggshell (rich in CaO) and glass residues (rich in silica) were crushed and powdered to the required size and used as a partial substitute for cement, with 0%, 5%, 10%, 15%, and 20%. Compressive strength, bending strength, density, absorption, and modulus of elasticity were measured. According to the compressive strength tests, confusion with Glass Powder were increasing with increasing Glass Powder Content (see Figure 3) [32].

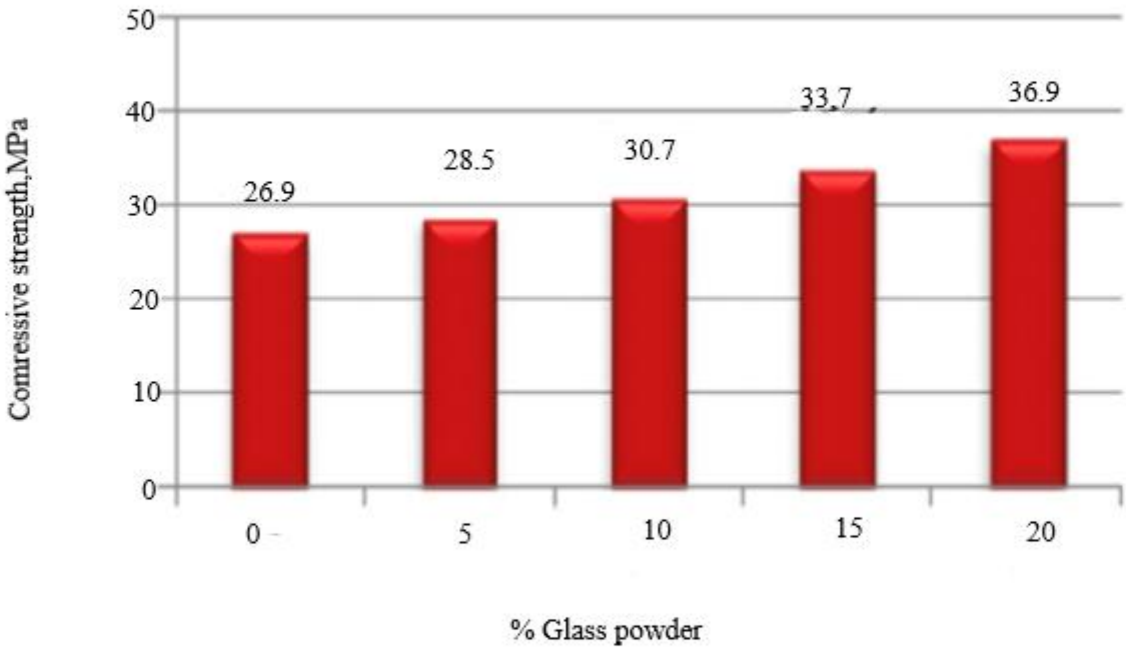

Figure 3: Variation of compressive strength with% Glass Powder [32].

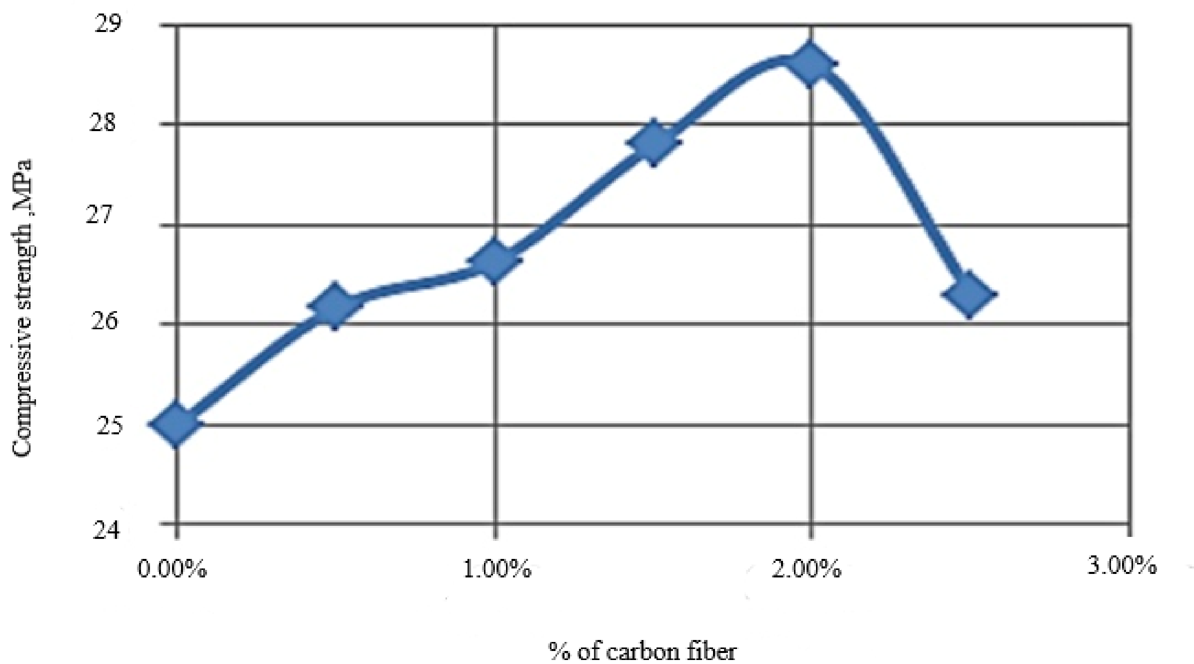

Figure 4: Variation of compressive strength with% Carbon Fiber [34].

6.3. Chopped Carbon Fiber

Carbon fibers are usually combined with other materials to form a composite [33]. S. M. Hama *et al.* in 2018, used chopped carbon fiber to improve the tensile strength of porcelanite aggregate concrete [34]. Fume silica was added in order to improve compressive strength mixtures. Silica fume increases the water demand, and the use of carbon fibers reduces workability, so superplasticizers were used to reduce the demand for adding a high percentage of water. The results show that compressive strength, splitting tensile strength, modulus of elasticity of carbon fiber porcelanite, lightweight aggregate concrete increased up to 2% compared with samples without fibers. Compressive strength of Carbon fiber porcelanite concrete samples is observed and compared to carbon-free control samples fibers. Mixtures have been shown, with carbon fibers higher compressive strength compared to reference blend without fiber at 4.68%, 6.52%, 11.20%, 14.40%and 5.20% for 0.5, 1.0, 1.5, 2.0 and 2.5% increase compressive strength with increased volume fraction up to 2.0% (see Figure 4) [34].

6.4. Fly Ash

Fly ash is a fine and glassy powder that is recovered as a byproduct of coal combustion when energy is generated at a power station. It's regarded as a waste product of coal combustion. Fly ash composition is determined by the source. The majority of fly ash particles are spherical in shape and range in size from 0.5 to 100 micrometers [35]. Tareq S. al-Attar1 *et al.* in 2019, studied lightweight concrete's water absorption [36]. The mixture's ingredients were combined in a mechanical mixer with a capacity of 20 liters. In the mixer, natural sand and porcelanite aggregate were mixed for 2 minutes, then a mixture of cementations materials (FA+C) was added and mixed continuously for 2 minutes, then half of the mixing water was added while the mixing began, and the other half of the water was mixed with admixture and poured into a mixer, it proceeded to mix for 2 more minutes. The water absorption that resulted at 28 days revealed that fly ash FA50 and FA60 are better lightweight's concretes than FA70. Therefore, it is reasonable to recommend that the approval age should be increased from 28 days to a higher age or that the concrete be strengthened with fiber reinforcement [36]. Suhad M. Abd and D. K. Ismail in 2019, studied the effects of different aggregates on the mechanical properties, which included, compressive strength, fresh and hardened density, and also elasticity modulus and they were tested in this study [37]. The shape of the failure depends mainly on the bond between the mortar and the aggregate. The type of aggregate had a noticeable effect on compressive strength and modulus of elasticity by increasing the percentage of fine aggregate (fly ash). The design ratio in compressive strength to the mixture (LE-4 1: 1:0.4) comparison with porcelanite in the same ratio (P-1: 1: 0.4) is about 26% show the Leca (LE)aggregate significantly better than porcelanite (P) [37].

6.5. Silica Fume

Lightweight porous concrete [38]. W. I. Khalil *et al* in 2016, produced paving bricks using high-strength lightweight aggregate concrete (HSLWAC) [39]. The proportion was 1: 1.35: 0.87 (cement: sand: porcelanite coarse aggregate). The cement weight was 520 kg/m^3, the weight of other components was calculated accordingly. The size of porcelanite coarse aggregate is 9.5 mm, and silica fume is 5% partially. Weight of the cement superplasticizer is 1%, and the weight of the water to the weight of cement (w / c ratio) is 0.29. Fibers were used including macro hooked steel fiber 50 mm long and 0.5 mm diameter (aspect ratio, l/d = 100), micro polypropylene fiber (pp), and micro carbon fiber (CF). They prepared three different high-strength lightweight aggregate concrete HSLWAC mixes. The produced HSLWAC paving bricks indicated that its classified as medium loading to Iraqi Specification No. 1606-2009. (Compressive strength, oven dry density, splitting tensile strength, and modulus of rupture) [39].

7. Advantages and Disadvantages of Porcelanite Concrete

Advantages:

Increased strength due to internal treatment, durability improved, reduced crack shrinkage due to more excellent moisture retention, reducing weight on structure elements, thermal insulation is improved over conventional concrete, handling costs are reduced, Fire resistance is superior, reducing labor cost and transportation is easier [2, 40].

Disadvantages:

The compressive and flexural strength of porcelanite aggregate concrete is less when compared to standard concrete. The structure has low abrasion resistance, nature makes it permeable, and steel undergoes corrosion. This concrete is sensitive to the amount of water in the mix. Placing and finishing cement mixtures is difficult to achieve proper mixing. The mixing time is longer than with traditional concrete [41-43].

8. Conclusions

In terms of material and applications, lightweight concrete differs from conventional concrete. When compared to conventional concrete, lightweight concrete has a higher strength-to-weight ratio. Structural Lightweight Aggregate Concrete (SLWAC) produced from locally available porcelanite aggregate complies with SLC Lightweight Structural Concrete requirements according to ACI 213R-03 “Guide to Classifications for Lightweight Structural Concrete” and ASTM 330-05 “Standard Specification for Lightweight Aggregate for Structural Concrete. Porcelanite aggregate is a broad group that includes many types of chemical and mineral composition and physical properties. Porcelanite as aggregate leads to the following changes in the properties of cement paste, mortar, and concrete: increases the water cement ratio, decreases the compressive strength with increasing porcelanite, decreases the splitting tensile strength with increasing porcelanite, reduces the density with increasing the porcelanite, workability of mixtures increased with porcelanite aggregate, adding 2% foaming agent was beneficial in aiding in enhancing workability, deflections are reduced by around 50% when CFRP strips are used to reinforce lightweight aggregate deep beams. Some additives such as metakaolin (MC), plastic fiber (PF), or isolated carbon fiber raise the compressive and splitting forces, tensile power, rupture modulus, and elasticity modulus. The compressive strength has seen the most improvement.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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