Improving Concrete Quality on Structural using Lightweight Aggregates (LWA): A Comprehensive Review

L.Oksri Nelfia[1], Candra Supriyatna[2], Agung Sumarno[3]
[1]Lecturer, [2]Student, Researcher[3]
[1,2] Civil Engineering Department, Universitas Trisakti, Jakarta, Indonesia
[3]Research Center for Biomaterials – Indonesian Institute of Sciences

Correspondent Author: lisa@trisakti.ac.id

Abstract

This paper reviews and analyses the use of LWA (light-weight aggregates) and precursor materials as cement substitutions from unused waste materials that partially cause environmental pollution. The purpose of this research is to find out, identify and analyse efforts to improve the quality of environmentally friendly structural lightweight concrete through a review of mechanical characteristics, workability, permeability, durability and lightweight concrete microstructure. Basically, the use of LWA as a concrete building material lowers the quality of concrete, but some precursor materials with certain compositions are able to improve the quality of concrete, in addition to the material. Method and composition of the mixture also affect the quality of concrete. Research showed the substitution of cement with nano silica, increases quality regarding the percentage of nano silica in the mixture, in addition to the pozzolan reaction between cement particles and nanoparticles, depending on the concrete ages. The microstructure of lightweight concrete can be repaired and refined. It is hoped that through this writing it is able to improve and innovate prospective researches and the industrial sector in the development of environmentally friendly structural lightweight concrete in the future.

Keywords: Structural Lightweight Concrete, Lightweight Aggregate (LWA), Precursor Material, Mechanical Characteristic and Density

1. Introduction

Concrete is one of the most widely used building materials due to the rapid increase of construction. The use of normal concrete is considered less effective, because the weight of the contents of concrete is quite large, especially in Indonesia, often hit by earthquakes, that needs to be considered and get special treatment in the context of the use of concrete as an effort to design earthquake-resistant buildings. The use of cement in the concrete production process produces a lot of carbon dioxide gas (CO2) which is one of the factors that cause the greenhouse effect. In addition, the number of materials produced both natural and artificial that do not have added value, unused and some potentially cause pollution. Because of this problem, there has been a lot of researches on environmentally friendly lightweight concrete.

According to (SNI 03-2847-2002, 2002) Lightweight concrete has a density of less than 1900 kg / m3. There are several ways to make lightweight concrete including using light aggregates, not using sand and making air cavities. According to research (Wongkvanklom et al., 2018) generally light concrete composed of light aggregates including pumice stone, scoria, volcanic "cinder," diatomite, expanded or the result of clay burning, shale, slate, perlite, vermiculite, slag or coal and the results of combustion residue. (Lee et al., 2019) through the use of Oil Palm Boiler Clinker (OPBC) and Lightweight Expanded Clay Aggregates (LECA) with superplasticizers capable of producing lightweight concrete with high quality above 40 MPa. The same thing is shown (Huda et al., 2018) through the use of palm waste in the form of Oil Palm Shell (OPS) and Palm Oil Clinker (POC) with superplasticizer and w / c of 0.35 capable of producing lightweight concrete with a quality of 30-50 Mpa. (Dolatabad et al., 2020) use LWA in the form of perlite, scoria, and LECA in the manufacture of lightweight concrete using superplasticizers capable of producing concrete with a quality of 20-35 MPa. The following material is an aggregate that has a light density, which dominates the composition of concrete as a light concrete production effort. In addition, the use of cement substitution uses cementitious material as an effort to improve quality and also the production of environmentally friendly lightweight concrete. (Mortazavi & Majlessi, 2013) performs cement substitution with silica fume of 0-25% with superplasticizer, able to produce lightweight concrete with compressive strength of 30-50 MPa at the age of 28 days. (Iqbal et al., 2017) use fly ash as a cement substitution in self compacting high strength lightweight concrete using a superplasticizer capable of producing compressive strength of 60-70 MPa at the age of 28 days. (Rokiah et al., 2019) using Processed Spent Bleaching Earth (PSBE) as cement substitution in foam concrete, able to produce concrete with compressive strength close to 30 MPa and density ranging from 1500-2000 kg.m3. Given the large amount of wasted material that can be used both as aggregates and cement substitution in the manufacture of structural lightweight concrete.

As known, basically the value of the strength and durability of concrete is directly proportional to its density so it is found that in fact the strength of light concrete is much smaller than normal concrete this can be seen in some studies through outstanding journals. This is an encouragement for authors to evaluate and analyse efforts to improve the quality of structural lightweight concrete through the use of light aggregates in this writing with literature study methods.

1.1 Objectives.

In this writing, the author aims to conduct evaluation and analysis from various sources related to improving the quality of structural lightweight concrete both in terms of material and composition and methods. So that in order to achieve the above goals, the goal needs to be described to be more specific which includes, knowing the mechanical characteristics of lightweight structural concrete, density, permeability, and microstructure and knowing the material and its optimum composition and effectively used in improving the quality of structural lightweight concrete, it would be nice to be environmentally friendly.

2. Literature Review

In this writing literature review contains a review of the materials of lightweight concrete used in several sources. Lightweight concrete building materials used include aggregates, cement, water, and added materials. The aggregates used include Lightweight Aaggregates (LWA) as both coarse aggregates and fine aggregates, also used materials and cement substitutes. Below the author describes some of these materials.

2.1 Aggregates

One of the efforts in the manufacture of lightweight concrete through the use of Lightweight Aggregates (LWA). According to (SNI 03-3449-2002, 2002) lightweight aggregates are aggregates that have a maximum loose dry content weight of 1100 kg / m3 which is divided into two, namely natural and artificial light aggregates. There are different types and variants of lightweight aggregates. Below the authors review some light aggregates based on the literature used.

Natural aggregates include:

- Perlite is a volcanic rock that has an acidic and rhyolitic composition and is formed in moist and aqueous environments. These aggregates are available in a wide variety of generally white colors. (Dolatabad et al., 2020)
- Scoria is a lightweight aggregate formed by volcanic meltwater that enters water reservoirs such as rivers and lakes and cools lava, and its color is dark grayish brown.
- Pumice is one of the lightweight aggregates formed from supercooled lava liquid, which contains SiO2 from volcanic eruptions, and has a low density due to the formation of gas bubbles.

Artificial aggregates include:

- OPS &OPBC (Oil Palm Shell & Oil Palm Boiled Clinker) is a waste product produced through the extraction process during the palm oil process which can used as aggregates in the processed of lightweight concrete.
- LECA (Lightweight Expanded Clay Aggregates) are lightweight aggregates of clay. LECA is produced by heating a clay of fine particle shapes or pallets with a low content of lime heated at a temperature of 1100 to 1200 o C (Bin Othman et al., 2020)
- Polyefins Aggregates are aggregates recycled plastic materials (Colangelo & Farina, 2019)

Table 1 Physical Characteristic of LWA

Materials	SG (g/cm^2)	Bulk Density (kg/m^3)	References
NCA	2.67	1491	(Lee et al., 2019)
OPS	1.17	590	(Huda et al., 2018)
OPBC	1.83	781	(Huda et al., 2018)
LECA	0.66	810	(Lee et al., 2019)

Polyefins	-	300	(Elrahman et al., 2019)
Pumice	0.92	1200	(Chambua et al., 2021)
Scoria	1.32	-	(Dolatabad et al., 2020)
Perlite	0.54	-	(Dolatabad et al., 2020)

A. OPS
Source: (Shafigh et al., 2011)

B. OPBC
Source: (Shafigh et al., 2011)

C. LECA
Source: (Yang et al., 2018)

D. Perlite
Source: (Dolatabad et al., 2020)

E. Polyefins Aggregates
Source: (Elrahman et al., 2019)

F. Pumice
Source: (Elrahman et al., 2019)

G. Scoria
Source: (Dolatabad et al., 2020)

Figure 1. LWA

It can be seen in table 1 and figure 1 where each LWA has its own characteristics, namely its different shapes, colors and characteristics, where some of the material is unused waste material.

2.1 Cementitious Materials

Cementitious materials are materials that are used as adhesives or unifying concrete materials that cause pozzolanic reactions in concrete. One of the cementitious ingredients is cement. But the process of cement production and the use of cement in concrete produces a lot of CO2 gas which is one of the causes of the greenhouse effect. So that in the writing with the topic of improving structural lightweight concrete, analysis and assessment of the use of cementitious material aimed at improving the quality of structural lightweight concrete, it is better to be environmentally friendly. For example, waste materials such as fly ash and slag are used. The following authors describe the cementitious material used in the research reviewed as a reference including:

- GGBFS (Ground Granulated Blast Furnace Slag) is a waste production of iron smelting consisting of calcium silicates and aluminosilicates (Palash S. Dongre 1s et al., 2016)
- NSP (Nickel Slag Powder) is a waste formed during the nickel ore smelting process. through the use of nickel slag as a cement substitution material can reduce pollution resulting from the use of cement
- SBE (Spent Bleaching Earth) is a solid waste or residue resulting from cooking oil from palm oil that requires several methods, especially bleaching methods (Rokiah et al., 2019)
- Silica Fume is one of the cement substitutions pozzolan materials that has rich of silica composition (SiO2) produced during the process of making silica or ferrosilica with a temperature of 2000ºC (Mortazavi & Majlessi, 2013).
- Fly ash is waste produced through the process of burning coal in a steam power plant furnace. The dominant fly ash composition will be silica content (SiO_2).
- RHA (Rice Husk Ash) is a waste produced during the process of burning rice skin. About 20% of RHA can be produced from 100% burning of rice skin.

A.GGBFS
Source: Reasercher Document

B.NSP
Source:(Wu et al., 2018)

C.SBE
Source: Rokiah et al., 2019)

D.Silica Fume
Source: (Mortazavi & Majlessi, 2013)

E.Fly Ash
Source: (Ibrahim et al., 2020)

F.RHA
Source: (Foong et al., 2015)

Figure 2 Cementitous Materials

Figure 2 shows that each cementitious material has its own shape, colour and characteristics, but visually has one thing in common, namely powder or powder resembling cement.

3. Methods

The method used in this writing is the study of literature through a review of the topic of improving the quality of structural lightweight concrete. According to the author, there are several factors that can affect the quality of lightweight concrete including mix design composition, material selection, method of implementation to treatment of lightweight concrete. Below the author describes these factors based on reference sources relevant to improving the quality of structural lightweight concrete in accordance with several points of purpose of this writing.

3.1 Effect of Cementitious Materials on Mechanical Characteristics and Density

(Foong et al., 2015) on Enhancement of the mechanical properties of lightweight oil palm shell concrete using

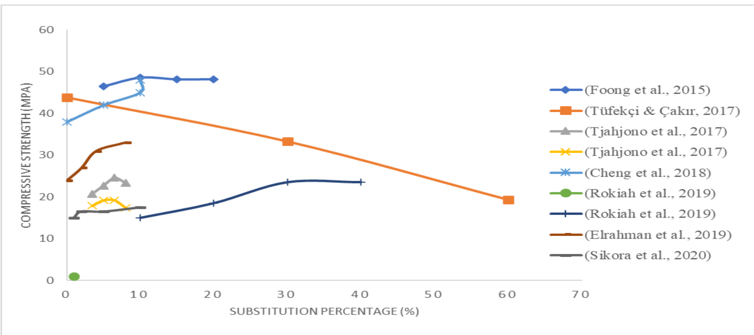

Figure 3 Effect of Cementitious Materials on Compressive Strength

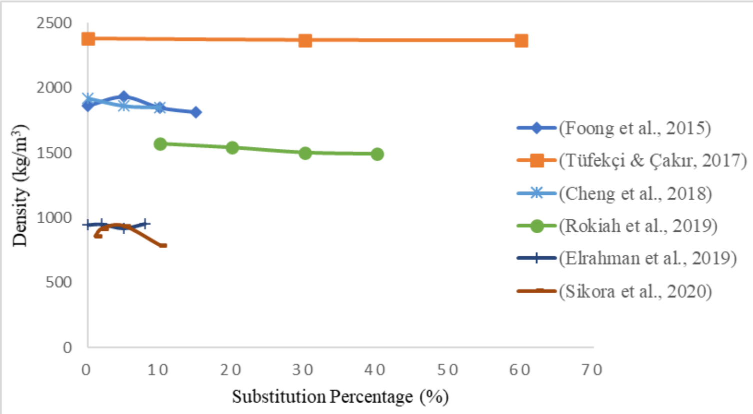

Figure 4 Effect of Cementitious Materials on Density

rice husk ash and manufactured sand through a review of the use of rice husk ash and manufactured sand as cement substitution with variations of 5-20% and fine aggregates. The results showed that as the percentage of rice husk ash increased directly to the compressive strength and splitting tensile strength inversely to the density of concrete, as for the maximum slump value at the composition of 90% OPC with 10% RHA of 156 mm. Tjahjono et al., 2017) on the use of silica fume and fly ash and superplasticizers on lightweight concrete using OPS. The results showed that the greater the percentage of silica fume and fly ash directly proportional to the strong value of the compressive strength, the optimal percentage was obtained by 6.5% SF and 6.5% FA and through the use of OPS using Silica fume was able to produce concrete with a compressive strength of 24.8 MPa. (Cheng et al., 2018) on the use of seawater and cement substitution through the use of metakaolin and GGBFS on lightweight concrete. The results showed that the use of a combination of cement using metakaolin and GGBFS with sequential variations of 10% and 10% against binders using seawater was able to produce a strong compress value exceeding 50 MPa at 28 days of concrete age. (Elrahman et al., 2019) on the effect of using nano silica on lightweight concrete with variations of 0-20%. The results show that as nano silica increases, the compressive strength and flexural strength increases (Sikora et al., 2020) on the effect of using nano silica with variations of 0-10% against binders on lightweight concrete and ultra-lightweight concrete. The results showed in the lightweight category concrete the optimum nano silica composition was 2% against binders, while in ultra-lightweight concrete by 5% against binders it was reviewed against the compressive strength and splitting tensile strength.

3.2 Effect of Lightweight Aggregates (LWA) on Mechanical Characteristics and Density

(Shafigh et al., 2017) on the aggregate use of the palm oil industry. Aggregates used include OPS (Oil Palm Shell) and OPBC (Oil Palm Boiled Clinker). In the study, 2 variations of the sample were made, namely fully OPS and the combination of OPS and OPBC with superplasticizer by 1%. The study produced sequential compressive strength of no less than 38 MPa and 53 MPa at 28 days of age. Judging from the value of density and slump obtained sequential values of below 1950 kg / m3 and below 60 mm. The overall combination of OPS and OPBC produces better quality than full-fledged OPS. (Tüfekçi & Çakır, 2017) on the use of RCA (Recycled Coarsed Aggregates) and GGBFS (Ground Granulated Blast Furnace Slag) on lightweight concrete. Aggregate substitutions of 0-100% and GGBFS of 0-60% with w/b of 0.5. The results showed positive results where the s increase in the percentage of RCA is directly proportional to the compressive strength and splitting tensile strength, while the value of the increase in GGBFS is inversely proportional to its characteristics and obtained a slump value with a range of 15-20 mm, but the use of RCA has not produced lightweight concrete where the density is produced above 1900 kg / m3. (Shivashankar & Chetan, 2018) on the use of LECA as a crude aggregate substitute on lightweight concrete. Gross aggregate substitution of 0-50% with w/c of 0.50. The results showed that as the percentage of LECA slump values increased, compressive strength and density decreased. (Huda et al., 2018) on the use of palm waste namely OPS and POC (Palm Oil Clinker) on lightweight concrete conducted several variants of sample substitution with a value of w / c of 0.35 with a superplasticizer of 2% against w / c. The results showed that concrete uses POC stronger than OPS and optimum compounding is 50% OPS and 50% POC with a compressive strength value of 46.47 MPa and a slump of 50 mm but this composition has a density above 1900 kg / m3 and the composition that falls into the category of light concrete is 100% OPS where the compressive strength value is 36 MPa with a density below 1900 kg / m3. (Colangelo & Farina, 2019) on the use of PA (Polyefins Aggregates) with substitutions of 0-30% of lightweight concrete. The results of the study through the use of artificial aggregates type PA (Polyolefins Aggregates). The results showed that the increase in pa percentage was inversely proportional to the strong value of its press and density.

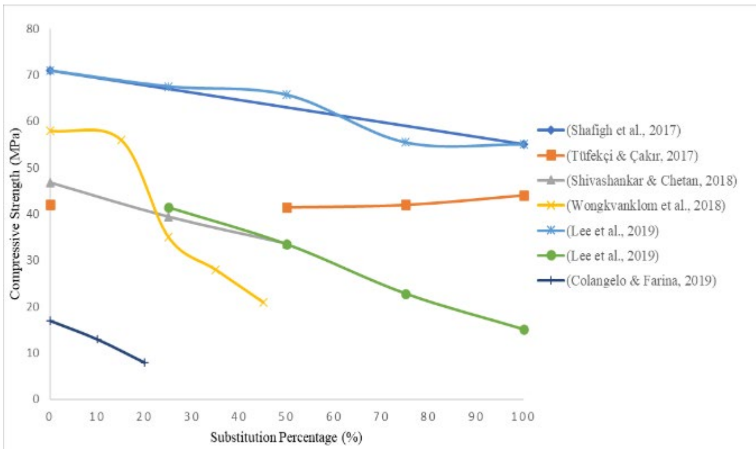

Figure 5 Effect of LWA on Compressive Strength

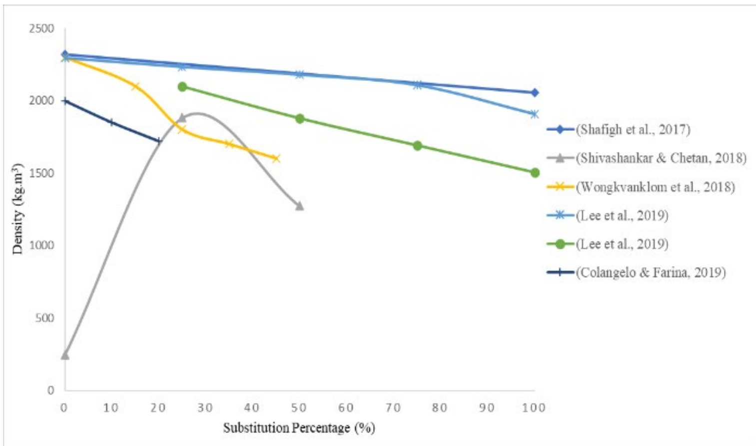

Figure 6 Effect of LWA on Compressive Strength

3.3 Effects of Cementitous Material, LWA on Water Absorbtion and Porosity

(Elrahman et al., 2019) on the effect of using Nano silica with substitution variations of 0-4% against binders with superplasticizers on lightweight concrete. The results showed that the greater the percentage of nano silica against binders, the value of water absorption, porosity decreased, while the compressive strength increased (Sikora et al., 2020) about the effect of using nano silica with substitution variations of 0-10% against binders with superplasticizers in lightweight and ultralightweight concrete The results showed on lightweight categories of concrete the composition of nano silica optimum by 2% against binders, while in ultra-lightweight concrete of 5% against binders is shown through the value of water absorption, porosity and compressive strength of lightweight concrete are optimum. (Ibrahim et al., 2020) through the expansion of Expanded Perlite Aggregates (EPA) as a substitution of fine aggregates and substitution of cement with GGBFS and silica fume. In the study, cement substitution with GGBS and Silica fume was conducted respectively by 50% and 7% against binders. Based on the results of the study, as the percentage of perlite increases, the compressive strength value decreases, conversely when viewed against water absorption directly proportional to perlite percentage against aggregates.

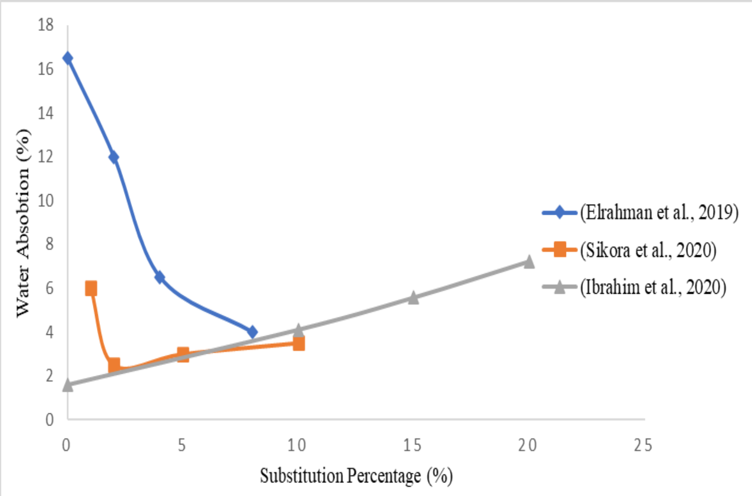

Figure 7 Effect of Cementitious Materials and LWA on Water Absorption

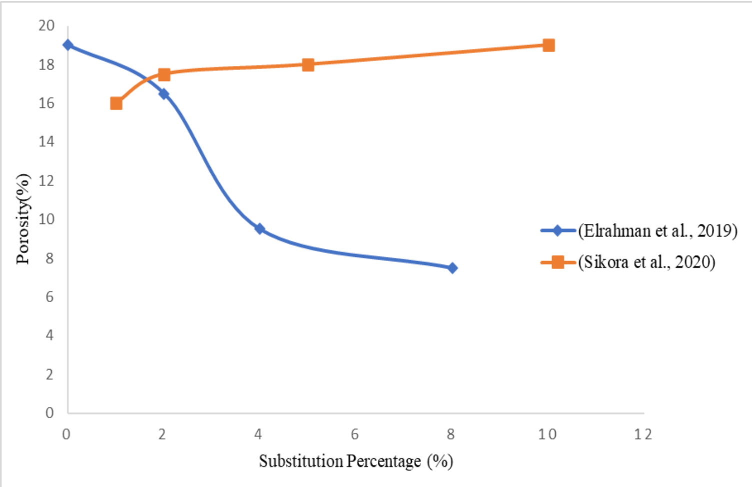

Figure 8 Effect of Cementitious Materials on Porosity

3.4 Effect of Cementitious Materials and LWA on Microstructure of Lightweight Concrete

The review of structural lightweight concrete microstructures through SEM-EDX and XRF aims to find out and review the characteristics and properties of each material and the constituent components of concrete, while the components reviewed include, shape, size, sticking power, chemical composition of a material to evaluate as an effort to improve the quality and performance of structural lightweight concrete. Below the author will show pictures of material microstructure, analysis of some of the references used. (Elrahman et al., 2019) on the use of LWA and the substitution of cement with nano silica on structural lightweight concrete. In the study, cement substitution was carried out using nano silica with sequential variations of 0-4% against binders where LWA material is used in the form of expanded glass (Liaver) with a fraction of 0.5-4 mm as a coarse aggregate and a fine aggregate in the form of quartz sand with a fraction of 0.1-0.3 mm. SEM results showed that the greater the percentage of nano silica, the percentage of cavities in the composition of light concrete the less or less in other words the use of silica was able to reduce the cavity in the sample, in addition to the use of larger doses resulting in the formation and collection of particles, normally called particle agglomeration. This has a significant effect on the characteristic values of mechanical, porosity, permeability and durability of lightweight concrete, where a 4% variation of nano silica to binders has a better effect on almost all aspects.

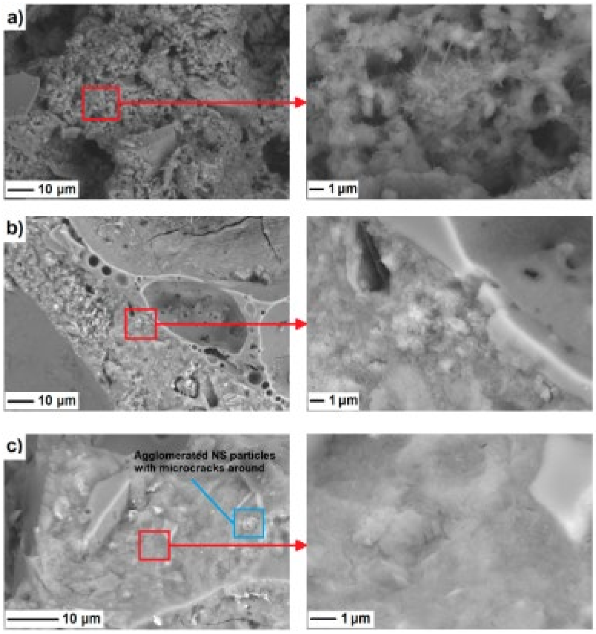

Figure 9 SEM of LWC using nanosilica
Source: (Elrahman et al., 2019)

Descriptions:
• Figure a. showing the composition of nanosilica use by 2% against binders
• Figure b. showing the composition of nanosilica use by 4% against binders
• Figure c. shows the composition of nanosilica use by 8% against binders.

(Sikora et al., 2020) on the effect of nano silica on lightweight and ultra-lightweight concretes. In the study, cement substitution using silica fume with variations of 10% and nano silica with variations of 0-10%, expanded glass (Liaver) with different fractions as coarse aggregates and fine aggregates and also superplasticizers. The results showed that in terms of aggregate porosity Ultra Lightweight Concrete (ULWC) is greater than Lightweight Concrete (LWC), where the cavity is characterized by white parts in addition, each variant also has a different size and volume porosity, of course this has an impact or influence on concrete both in terms of mechanical characteristics and durability.

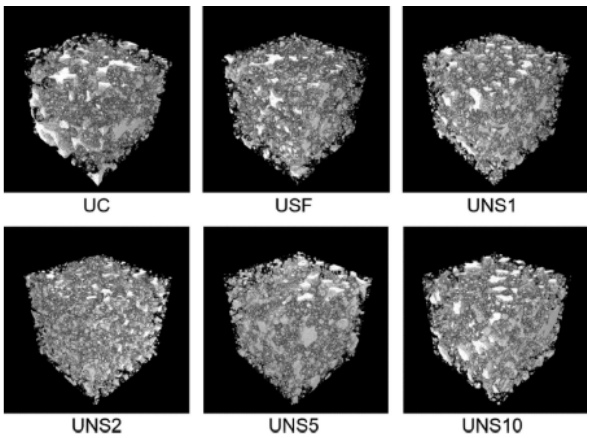

Figure 11 3D SEM ULWC
Source : (Sikora et al., 2020)

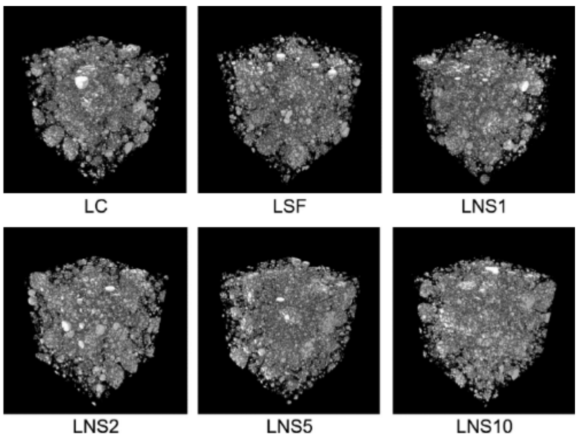

Figure 10 3D SEM LWC
Source : (Sikora et al., 2020)

Descriptions:
- Code U : Ultra Lightweight Concrete (ULWC)
- Code L : Lightweight Concrete (LWC)
- SF : Silica fume composition 10%

- NS1 : Nanosilica composition by 1% against binders

4. Conclusions

Based on the analysis and review of various research references related to efforts to improve the quality of structural lightweight concrete conducted on a review basis, it can be concluded in this writing that:

1. In an effort to improve the quality of structural lightweight concrete needs to be used cementitious materials including silica fume, metakaolin, micro silica, rice husk ash, fly ash and GGBFS. The results of analysis from previous research showed that the use of the material was able to increase the mechanical characteristics of concrete and lower the density of structural lightweight concrete except with GGBFS. The increase in the percentage of GGBFS shows a less satisfactory result where compressive strength, and splitting tensile strength decreases, but the density of concrete can be reduced, this is evidenced by the specific gravity that is smaller than cement. According to the authors of cementitious the most optimal material in terms of improving the quality of lightweight concrete is nano silica with a percentage of substitution below 10% against binders.
2. The use of Lightweight Aggregates (LWA) both natural and artificial lightweight aggregates including LECA, EPA, EPS, PA, OPC, OPBC significantly determines the mechanical characteristics, workability and density of structural lightweight concrete. Broadly speaking, the use of light aggregates (LWA) shows the result of the percentage of LWA substitution against fine aggregates, as well as coarse aggregates inversely proportional to the compressive strength, flexural strength, splitting tensile strength, density and slump of structural lightweight concrete. According to the authors, the most optimal material for use as a structural lightweight concrete constituent is OPS or palm shell shown through research (Aslam et al., 2017) with a composition of 100% OPS able to reach a compressive strength of 53 MPa with a density of 1790 kg / m^3
3. Through the concrete microstructure from relevant references, it can be seen that the use of lightweight aggregates makes the composition of concrete more porous than normal concrete, while the use of precursor materials gives a significant influence along with the age of concrete where the pores, sticking power becomes better, which affects the mechanical characteristics of lightweight concrete, porosity, permeability and durability of lightweight concrete.

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