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THE EFFECT OF NANO ALUMINA ON SOME PROPERTIES OF LECA LIGHTEIGHT SELS COMPACTING CONCRETE

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Abstract:

Lightweight concrete (LWC) was recently applied effectively in the construction of buildings for a long time as a result of its physical qualities, which include its light weight, high thermal insulation, and durability. In this study, three different percentages of nano alumina (0.5, 1, and 2%) were used to replace a portion of the cement. The LWSCC mixtures were tested utilizing slump flow, L-box, and segregation tests to determine these values of fresh characteristics. The tests on freshly poured concrete showed that the addition of finer materials resulted in less workable concrete in the mixtures containing nano alumina. The impact of nano alumina has improved the hardened characteristics of (LWSCC), such as splitting tensile strength, compressive strength, flexural strength, and scanning electron microscopy. The test results revealed that, in terms of compressive strength, flexural strength, and splitting tensile strength, respectively, the mixtures that included nano alumina significantly outperformed the reference mixture at 28 days by 13.67%, 4.8% and 4.5%.

Keywords: lightweight self-compacting, Leca, Nano alumina, compressive strength, splitting tensile strength, SEM

1. Introduction

Due to its excellent chemical and physical characteristics, such as strength, durability, and resistance to environmental factors, concrete has been a fundamental building material since ancient times. As a result of the development of scientific technology, various types of concrete have been developed recently in order to be used in a variety of applications (Mohammed and Hamad) [1]. The need for a unique type of lightweight, strong, and durable concrete has recently increased due to the development of tall buildings and structures with long parts (Elshahawi et al., 2021) [2]. Lightweight concrete, which has a density between 1400 and 2000 kg as opposed to traditional concrete's up to 2400 kg, started to be used. Therefore, using less dense concrete could result in significant benefits such as smaller cross-sectional load-bearing elements and a consequent reduction in foundation size (Hachim and Fawzi, 2012) [3]. The using of lightweight concrete has the advantage of reducing both the cross-sectional area and overall weight of the structure (Mahdy, 2016) [4]. Lightweight expanded clay aggregate is one of the synthetic lightweight aggregates with a range of applications. In the production of light aggregates, clay is used.The environment benefits from recycling clay from large infrastructure development projects into lightweight aggregates (Abbas, 2022) [5]. Without any mechanical consolidation or compaction, self-compacted concrete (SCC) can be poured into the structural framework of a building and can penetrate the reinforcing (Gaimster and Dixon, 2003) [6]. Self-compacting concrete is an innovative kind of concrete that can be poured and compacted without the use of vibration. It can move under its own weight while completely filling the forms and reaching full

مجلة دجلة • المجلد ٦ ،العدد ٤ (٢٠٢٣)، ص: ٨٦ ـ ١٠٠
ISSN: 2222-6583

compacting, even when heavily reinforced with additional material (Al-Anbori 2013) [7]. In the research community, lightweight aggregates—both natural and synthetic—are used more and more frequently in lightweight self-compacting concrete (LWSCC). In addition, there a lot of research conducted on the application of lightweight aggregates (LWA) in self-compacting concrete (SCC) over the past ten years on a global scale. LWSCC, that employs green aggregates, has a lot of possibilities to take the place of conventional concrete (Ting et al., 2019)[8].

Clay is heated to 1200°C in a rotating kiln to produce Light Expanded Clay Aggregate (LECA) (John Clarke, 1993) [9]. The spherical LECA organism has an unbroken network of pores. Thermally insulating tiles, thermally conductive plaster, lightweight blocks, concrete, divider panels, and concrete aggregates can all be made using LECA. Concrete that is used for structural lightweight construction must have a minimum compressive strength of 17 MPa and a density of less than 1850 kg/m3.

There are many advantages to using LECA in concrete, but there are also some disadvantages that can be reduced by using particular secondary components (Mithra, 2021) [10]. Self-compacting lightweight concrete combines the beneficial properties of self-compacting lightweight concrete, which emphasizes low weight while maintaining high strength, with those of lightweight concrete, which emphasizes self-deairing and maximum flow ability. Since it is a pumpable concrete with the qualities of a fair-faced concrete, it may be used both on site and in a factory that produces precast elements (Muller and Haist, 2004) [11].last times, there has been a lot of curiosity in the use of nanomaterials to enhance the characteristics of conventional concrete. Concrete will become stronger and more resilient when nanomaterials are added. Concrete can be nano-engineered to change the way it behaves and add new properties by adding nanoscale parts and elements (like nanoparticles and nanotubes) (Norhasri et al. 2017) [12]. (Li et al., 2006) [13] investigated how nano-alumina affected cementitious composites' elastic modulus and compressive strength, and they found that on day 28 the elastic modulus increased by 143%. The researchers found that by incorporating nano-alumina into mortars, the interfacial transition zone became more compact and the cement's porosity decreased, increasing the mortars' elastic modulus and compressive strength (Jahangir and Kazemi 2014) [14].

In this study, three different cement replacement ratios (0.5, 1, and 2%) will be assessed by combining a nanomaterial known as nano alumina with lightweight self-compacting concrete. Tests will be done to see how the replacement affects the physical changes and to compare it to the reference mixture.

2. Materials

2.1 Cement

This study employs ordinary Portland cement (type I) satisfied with Iraqi Specification No. 5/2019 (IQS No. 5/2019) [15].

2.2 Fine Aggregate

Sand used in this study complies with Iraqi specification No. 45/1984 (IQS No. 45/1984) [16], as do the fine aggregate sieve analysis and fine aggregate properties.

مجلة دجلة • المجلد ٦ ،العدد ٤ (٢٠٢٣)، ص: ٨٦ ـ ١٠٠
ISSN: 2222-6583

2.3 Light Expanded Clay Aggregate (LECA)

Lightweight expanded clay aggregate (LECA) was used in place of natural coarse aggregate. The max size of LECA is 10 mm. Table 1 displays the characteristics of light-expanded clay aggregate.[17,18]

Table1. The properties of light expanded clay aggregate

Properties	***Experimental value***	***Specification***	***Limits of IQS No.45/1984***
Bulk density (kg/m$^{3)}$	320	ASTM C29/C29M	….
Sulphate content SO_3	0.03	IQS No.45/1984	≤0.1
Specific gravity	2.6	ASTM C127	….
Water absorption%	21.6	ASTM C127	….

2.4 Silica Fume

is a pozzolanic, very fine mineral replacement that is ready for use and complies with ASTM C1240-20 [19 It functions chemically as a highly reactive pozzolan and physically to optimize the distribution of particles in the concrete or mortar mixture. The properties of silica fume are listed in Table 2.

Table 2. The properties of silica fume

Property	*Value*
Color	Grey to medium grey powder
State	Sub-micron powder
Specific gravity	2.10 to 2.40
Bulk density	500 to 700 kg/m^3
Chemical Requirements	
Silicon Dioxide (SiO_2)	Minimum 85%
Moisture Content (H_2O)	Maximum 3%
Loss on Ignition (LOl)	Maximum 6%
Physical Requirements	
Specific Surface Area	Minimum 15 m^2/g

مجلة دجلة • المجلد ٦ ،العدد ٤ (٢٠٢٣)، ص: ٨٦ ـ ١٠٠
ISSN: 2222-6583

Pozzolanic Activity Index, 7 days	Maximum 105% of control
Over size particles retained on 45 micron sieve	Maximum 10%

2.5 Limestone Powder

In this study limestone powder was used. To increase the segregation resistance, it was used as an inert mineral filler. Table 3 shows the chemical properties of limestone powder.

Table 3. The chemical properties of limestone powder

Oxide Composition	*Content %*
CaO	51.6
SiO_2	1.3
Al_2O_3	0.62
MgO	0.48
Fe_2O_3	0.15
SO_3	0.06
L.O.I	41.6

2.6 Superplasticizer

Superplasticizer is designed to produce highly practical concrete and is an excellent high-efficiency plasticizer that also helps in the production of self-compacting concrete.Very high workability without particle separation. It added at a dosage range of 0.6-2 liters per 100 kg of the cementitious materials. It's satisfied the requirements of ASTM C494-13, type F [20].

2.7 Nano Alumina

This substance, also referred to as aluminum oxide or alumina and made by Changsha Santech Co., is a highly abrasive substance. Both a liquid and a solid form of aluminum oxide nanoparticles exist as a white powder. They can be created using a variety of manufacturing techniques to produce excellent qualities that are very useful for a variety of global industries. The characteristics of nano alumina are shown in Table 4.

Table 4.The characteristics of nano alumina

Property	*Value*
Size	50 nm

Appearance	White powder
Al_2O_3	≥ 99.5%
NaO_2	≤ 0.02 %
Fe_2O_3	≤ 0.02 %
LOI	≤ 2%
Density	(0.5-0.7) %
Water content	≤1.0 %
PH	6 - 7.5

2.8 Water

In this study, both the mixing and curing of the concrete mixtures were done with tap water. It also complies with Iraqi specification (No. 1703/2018) [21].

3. Mixing Proportion

The mix design method of (EFNARC, 2005) [22] for LWSCC was used in this study. To satisfy the requirements of structural LWC and self-compactability, multi-trail mixes have been used with the proportions of the materials changed. In this study, four mixes—the reference mix and three mixes containing nano alumina—were used. Three partial replacements (0.5, 1, and 2%) are added to nano alumina. For each mixture, the amount of powder, SP dosages, amount of coarse aggregate, amount of fine aggregate, and W/p ratio were all the same. 150 kg of Leca, 800 kg of sand, 194.7 kg of water, 80 kg of silica fume, 30 kg of limestone powder, and 1.7% of S.P. Table.5 provides details on the mixtures used in this study.

Table 5. The details of mixes by weight (kg/m^3).

Mix	*Cement kg/m^3*	*Nano percent%*	*Nano Alumina(kg/m^3)*
M0	480	-	……
MA1	477.6	0.5	2.4
MA2	475.2	1	4.8
MA3	470.4	2	9.6

4. Results and Discussion

4.1 Fresh Tests

4.1.1 Slump Flow Test

By using the nano alumina as a partial replacement of the cement, it was observed a decrease in the slump flow diameter as shown in Table 6 and figures 1 all results according to **EFNARC2002 [23]**. As shown in Table 6 and Figure 1 the slump flow decreases by 2.67%, 6.67%, and 12 % when using nano-alumina material at 0.5%, 1%, and 2% replacement. This is because high-surface-area Nanomaterials absorbing some of the mixed water caused flow values to decrease. (Younus et al., 2023)[24].

Table 6. Results of slump flow test

Mix	*Slump flow (mm)*
MO	750
MA1	720
MA2	700
MA3	660

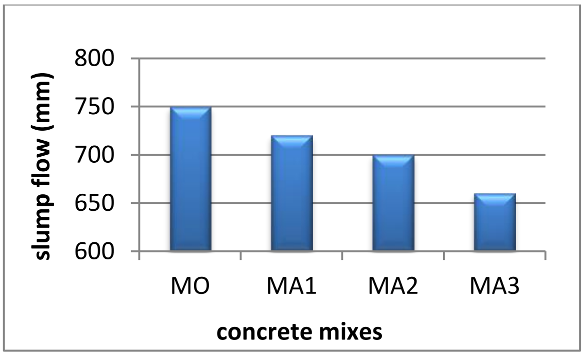

Figure 1.Slump flow test results

4.1.2 Segregation Test

A segregation test was used to assess the LWSCC mixture's resistance. If the paste's viscosity is high enough, the aggregate particles will be supported, keeping them from separating from the mixture. Table 7 and Figure 2 demonstrate that, in comparison to the reference mixture, segregation decreases when nano alumina is added. this is due to the fact that nano alumina has a very large surface area, is extremely fine, reacts quickly, and raises the density of freshly laid concrete. The segregation value for mixes with nano alumina, it ranged from 15.5% to 7.1%. The findings showed that the segregation was allowed according to (**EFNARC, 2005**) [22].

Table 7.Segregation test results

Mix	*Segregation %*
M0	17.9

MA1	15.4
MA2	12.4
MA3	7.1

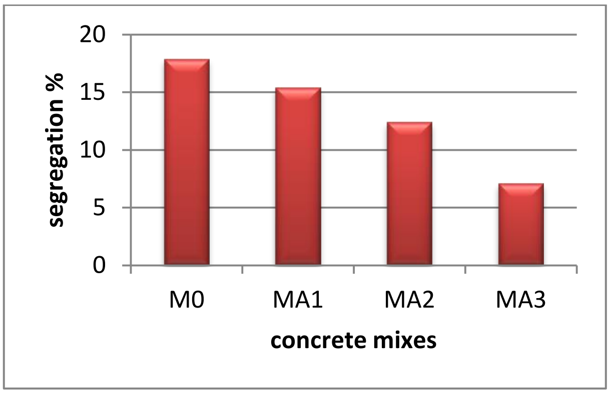

Figure 2.Segregation test results

4.1.3 L-Box Test

It was necessary to calculate the L-box height ratio using H2/H1 in order to determine the SCC mixtures' passing capacity. Utilized three-bar L-box to evaluate H2/H1.Table 8 and Figure 3 present the test results. To be certified, the SCC requires an L-box height ratio of at least 0.8.According to EFNARC 2002 [23], the ratio exhibits perfect fluid behavior in the concrete when it reaches 1.0. When Nanomaterials are used to partially replace cement, the mixture becomes denser and moves more slowly through the L-Box device. As a result, the H2/H1 value decreases. Replacing cement with nano-alumina reduces the percentage by 1.1%, 3.3%, and 7.8%. The decrease varies with the replacement ratios of 0.5%, 1%, and 2%, respectively.

Table 8.L-Box test results

Mix	*H2/H1*
M0	0.9
MA1	0.89
MA2	0.87
MA3	0.83

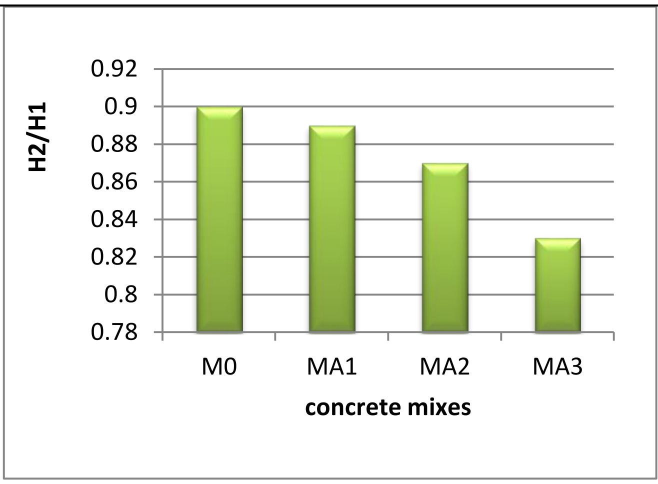

Figure 3.L-box test results

4.2 Hardened Test

4.2.1 Compressive Strength Test

According to (BS EN 12390-3, 2019) [25], this test was performed on 100 mm cubes. The tests were performed on the samples at 28 days, with the average of the three specimens used to calculate the results. All mixtures had strengths greater than 17 MPa after 28 days, per (ACI 213R-03) [26]. Table.9 and Figure.4 display the results. The mixes with nano alumina had higher compressive strength compared to the reference mix. The increase was about 5.19%, 13.67%, and 26.67% for (0.5, 1 and 2) % replacement percentage respectively. The increase may be caused by how aluminum nanoparticles react with Portland cement during hydration. Aluminum nanoparticles react fast with calcium hydroxide to make silicate-hydrate gel (C-S-H). They have a high surface area. The cement gel became stronger and its holes were filled, while $Ca(OH)_2$ crystals decrease (Heidarzad Moghaddam, H., et al. 2021) [27].

Table 9. Compressive strength for mixes

Mix	*Compressive Strength Mpa at 28 days*
MO	26.18
MA1	27.54
MA2	29.76
MA3	33.21

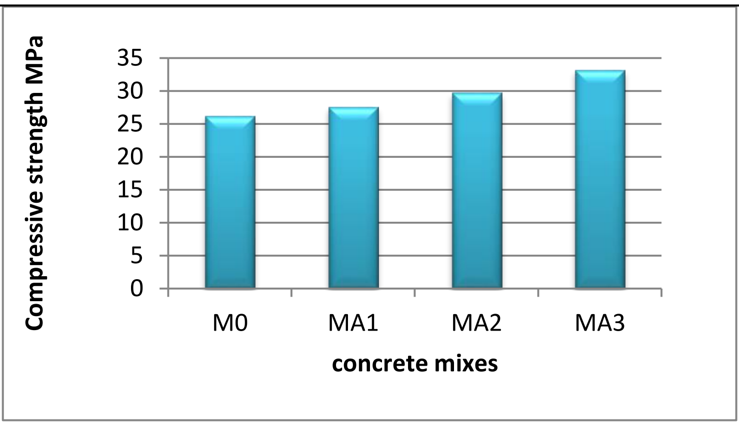

Figure 4.Compressive strength for mixes

4.2.2 Flexural Strength Test

Using the center point method, flexural strength was measured in accordance with (ASTM C293/C293M-16)[28].The 80x80x380mm prism test samples were aged at 28 days. Only a 300mm span of support was provided for them. For each mix, an average of three prisms were obtained. Figure 5 and Table 10 shows the result of replacing part of the cement with nano-alumina. The three mixes showed an improvement in flexural strength compared to the reference mixture with 0.5%, 1%, and 2% replacement ratios. The percentages of improvement for these percentages were 2.4%, 4.8%, and 9.1 %, respectively. The results of the flexural strength test indicated that the addition of alumina as a partial replacement of cement particles increased the strength of concrete through the conversion of calcium hydroxide to C-S-H. While maintaining the strength of the concrete, Nano alumina particles were added to increase the pozzolanic reactivity (Sadrmomtazi and Barzegar, 2010) [29].

Table 10.Flexural strength for mixes

Mix	*Flexural Strength Mpa at 28 days*
MO	3.7
MA1	3.79
MA2	3.88
MA3	4.04

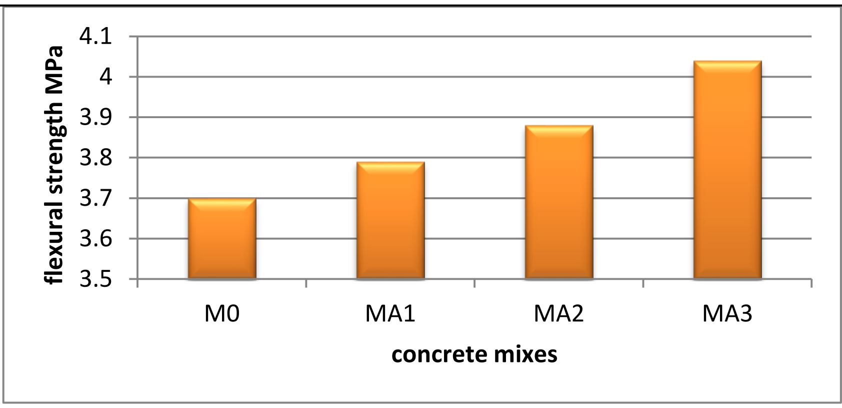

Figure 5. Flexural strength for mixes

4.2.3 Splitting Tensile Strength

The compressive machine at Civil Engineering Department laboratories was used to assess the splitting tensile strength of concrete cylindrical specimens of (150*300) mm according to ASTM C 496-17 [30]. The cylinders were examined at 28 days and the average of three cylinders was obtained. As shown in Table.11 and Figure.6 using nano-alumina as a partial replacement of the cement, the tensile strength of the concrete improved. This improvement was seen in all three replacement ratios (0.5%, 1%, and 2%), with an increases rate of 1.5%, 4.5%, and 10.9% respectively. Adding nano alumina as partial replacement of cement to the concrete increases the strength by making it denser and creating more C-S-H gel (Ashok, K., et al., 2021) [31].

Table 11.Splitting tensile strength for mixes

Mix	*Splitting Tensile Strength Mpa at 28 days*
MO	2.65
MA1	2.69
MA2	2.77
MA3	2.94

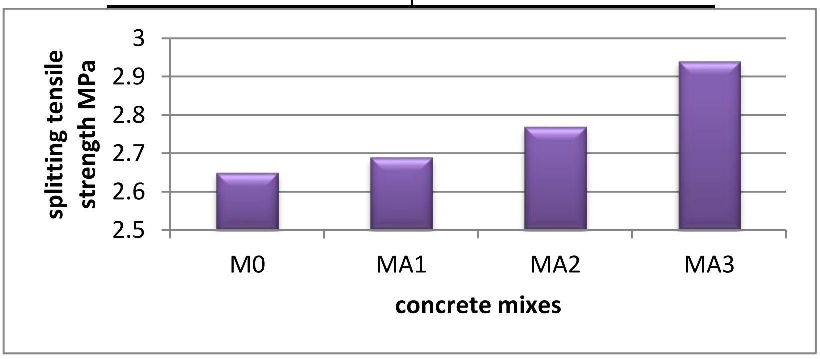

Figure 6.Splitting tensile strength for mixes

مجلة دجلة • المجلد ٦ ،العدد ٤ (٢٠٢٣)، ص: ٨٦ ـ ١٠٠
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4.2.4 Scanning Electron Microscopy

The scientists performed a microscopic analysis of the concrete using scanning electron microscopy. SEM makes it possible to examine a variety of aspects of the device's microstructure. The texture of the sample's fractured surface was examined using a scanning electron microscope with a tungsten source at voltages up to 30 kV and a working distance of 1–12 mm (TESCANVEGA system), both before and after nanomaterials were added as a partial replacement for cement. Nano alumina was added to concrete in place of some of the cement to improve the interfacial transition zone between the cement and aggregate, as shown in Figures 7 and 8. The additional nano-alumina primarily filled the ITZ of cement and sand, with some capillaries in the matrix acting as ultrafine aggregates. As a result, the concrete's compressive strength increases (Barbhuiya et al., 2014) [32].

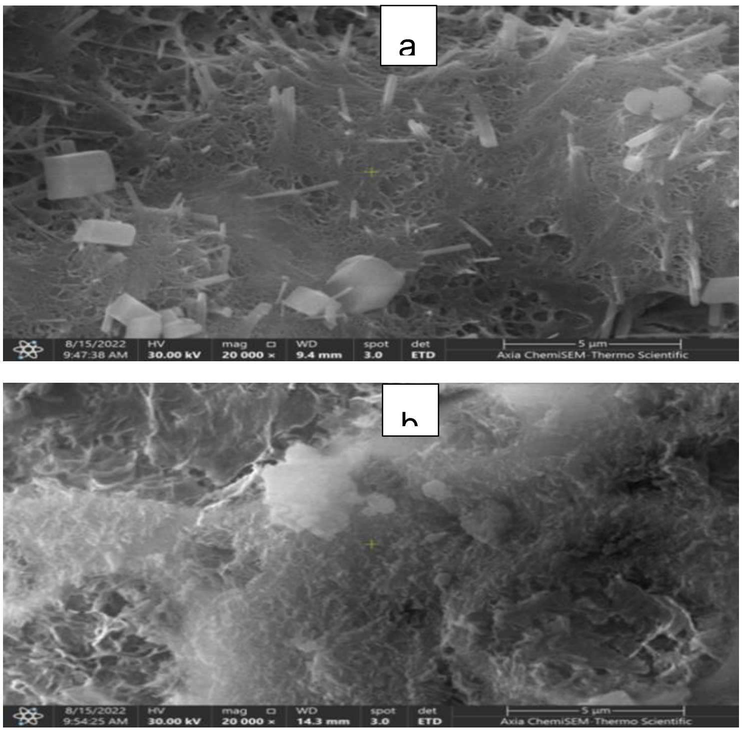
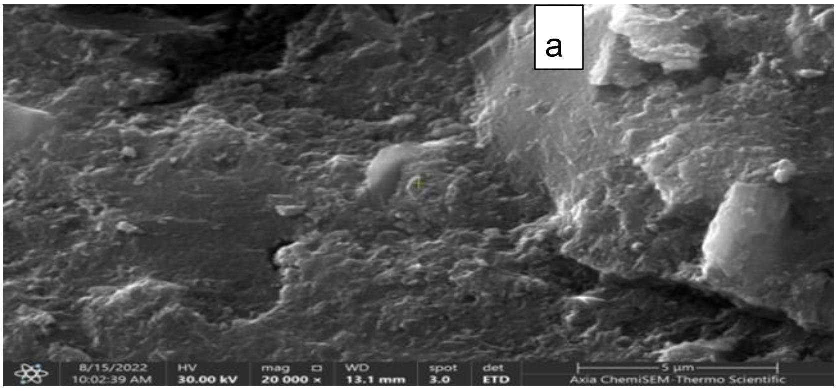


Figure7. a) SEM image for reference mix, b) SEM image for mix with 0.5% nano alumina at 90 days



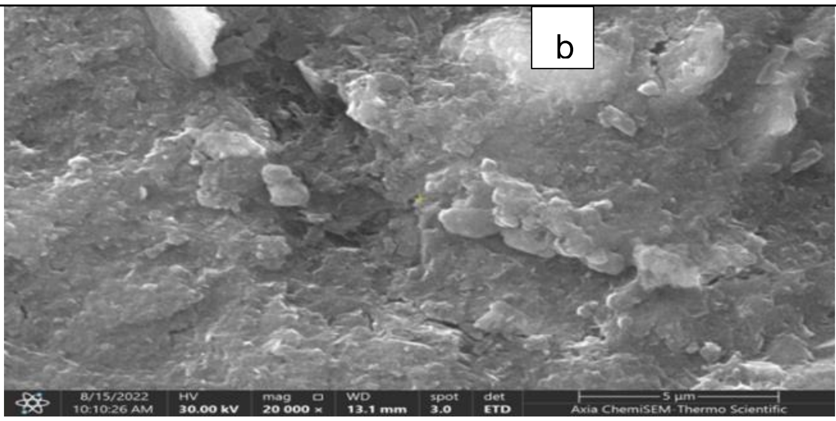


Figure8.a) SEM image for mix with 1% nano alumina at 90 days, b) SEM image for mix with 2% nano alumina at 90 days.

5. Conclusions

This study assessed the effect of using nano alumina as a partial replacement of cement on the fresh and hardened properties of LWSCC mixes, the results showed that:

- The results of the slump flow test showed that the addition of nano alumina as a partial replacement of cement to LWSCC mixes reduces the flow by a small percentage.
- The segregation index decreased with addition nano alumina to LWSCC mixes as a partial replacement of cement. Segregation index for mixes with nano alumina the decreasing ranged between (15.4-7.1).
- The (H2/H1) ratio decreased when adding nano materials to LWSCC mixes as a partial replacement of cement. (H2/H1) ratio for mixes with nano alumina the decreasing ranged between (0.89-0.83).
- The compressive strength of the specimens containing nano alumina increased by about (5.19, 13.67 and 26.67) % for replacement percentages of (0.5, 1, and 2) % respectively compared to reference mix.
- Flexural strength increased for mixes with nano alumina by about (2.4, 4.8, and 9.1)% for the replacement ratio (0.5, 1 and 2) % respectively compared to reference mix.
- Splitting tensile strength increased for mixes with nano alumina by about (1.5, 4.5, and 10.9) % for the replacement ratio (0.5, 1 and 2) %respectively compared to reference mix.
- SEM figures for mixes with nano alumina that the structure is compressed, with CH needles no appearing, fewer non-hydrated crystals filling in any gaps, and the mixture is more homogeneous. The increased strength may be the result of high nano-Al_2O_3 activity, which stimulates the pozzolanic reaction and produces more calcium silicate hydrate (C-S-H) gel.

Abbreviations

LECA	*Light expanded clay aggregate*

LWA	Lightweight aggregate
LWC	Lightweight concrete
LWSCC	Lightweight self-compacting concrete
M0	Reference mix
MA1	Mix with 0.5% nano alumina
MA2	Mix with 1% nano alumina
MA3	Mix with 2% nano alumina
SCC	Self-compacting concrete

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مجلة دجلة • المجلد ٦ ،العدد ٤ (٢٠٢٣)، ص: ٨٦ - ١٠٠
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مجلة دجلة • المجلد ٦ ،العدد ٤ (٢٠٢٣)، ص: ٨٦ - ١٠٠
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