Article

Effect of Nano-Clay on Lightweight Self-Compacting Concrete Behavior

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Abstract

In recent years, researchers have also been interested in the production of lightweight self-compacting concrete (LWSCC). Using light weight aggregates to find an alternative to the usual heavy weight concrete. In this study, an experiment was conducted to produce and develop LWSCC to improve some of its properties. Whereas, Expanded Polystyrene (EPS), which is considered a waste polluting the environment, was used as a partial substitute for coarse aggregate to produce lightweight concrete, and Nano-clay (NC) material with microscopic properties in different proportions was used to improve its mechanical properties. The fresh, hardened and mechanical properties of this type of concrete were studied, as a reference mixture of self-compacting concrete and six mixtures of lightweight self-compacting concrete (LWSCC) were prepared, where the coarse aggregate was partially replaced by the lightweight EPS aggregate and part of the cement weight was replaced in different proportions. In this experiment, the fresh properties of LWSCC concrete containing EPS and the effect of adding NC in different proportions, represented by slump flow, T500 and V-funnel, were studied. The hardening properties of this type of concrete, such as density, water absorption, voids, electron microscopy and Ultrasonic Pulse Velocity (UPV), were studied. Where the results showed that the best replacement ratio was NC 2%, which improved the density and within the range of lightweight concrete by 22% after adding NC and replacing part of the coarse aggregate with EPS granules, and reduced the water absorption and voids by 50%, and the concrete moved from doubtful to good. The UPV assay has improved the microstructure of concrete. The mechanical properties, compressive strength (CS) and flexural strength, were studied, which showed that the NC 2% substitution ratio showed the best results. Finally, the study showed that LWSCC concrete produced from EPS waste and NC had reduced density due to the incorporation of EPS particles. The increase in NC material led to segregation in the compression zone due to its entry into microscopic voids and the buoyancy of lightweight materials to the top. While the replacement of 60% from coarse aggregate with EPS granules and replacing 2% of the weight of cement with NC, it showed the best results for hardened concrete.

Keywords: Concrete; Nano-clay; lightweight; mechanical properties.

1. Introduction

1.1 Research background

The use of admixtures on a smaller scale to reinforce concrete components is a well–known concept, it has been used since ancient times, with admixtures blended into smaller scale estimate fine and coarse aggregate [1]. In any case, in our cutting-edge day development hones we have overlooked the antiquated hones smaller scale admixtures in concrete [2]. Portland cement concrete is a fairly brittle substance that is prone to cracking in both the plastic and hardened stages. When the water evaporated from the concrete surface is greater than the water absorbed, plastic shrinkage occurs. A volume change causes the surface to crack because concrete is frail in tension in its plastic stage [3]. The water within the pores of concrete begins to evaporate as it hardens. This causes the concrete to shrink due to the volume alter, which is controlled by addition of Nano admixtures. This results in a tensile stress being developed in hardened concrete, once more causing the concrete to crack [4].

Although the look of cracks conveys a bad impression of durability, quality, and serviceability, but these cracks often have only aesthetic problem. Cracks also lead to disagreements between the owner, design engineer, and contractor, resulting in construction delays and fetched increases as a result of work stoppages and assessments, which are more problematic than the actual effects of cracks. One of the solutions to this issue is the addition of Nano admixtures (Nano size fine aggregate) to concrete [5].

Self-compacting concrete (SCC) has several issues with pumping and lateral pressure on the formwork, as well as a high fluidity, which limits its broad application [6], [7]. Formwork pressure is related the material fresh state performance. Rheological properties, as yield stress (dynamic and static), viscosity and thixotropy, are fundamental properties of new SCC and can alter its shape of spreading. In this way, controlling these properties is essential to overcome SCC cast in put issues. According to a few thinks about, Nano clays can alter SCC rheological properties [8], [9]. Besides, Nano clays combined with a high range water reducing admixture (HRWRA) can increase static yield stress and reduce dynamic yield stress, upgrading the effective thixotropy [10].

Okamura in Japan proposed self-compacting concrete in 1986. It was built at the workshop in 1988 and produced satisfactory results in terms of concrete physical and mechanical properties. The first workshop for the purpose of examining self- compacting concrete and the materials used in it was published in "August 1998 in Japan at the University of Kochi" and many articles were presented in the world in relation to the development of self-compacting concrete (K. Ozawa, University of technology). Also, self-compacting concrete is used in many projects and the most important application of that is in the developing world in the longest cable bridge (1998 m), Akashi Kiaky Bridge [11].

The most critical fundamental rule for streaming and cohesive concretes SCC is the utilize of superplasticizer combined with a moderately high content of powder materials in terms of Portland cement, mineral additions, ground filler and/or exceptionally fine sand. A fractional substitution of Portland cement with fly ash was quickly discovered to be the best compromise in terms of rheological properties, isolation resistance, quality level, and crack-freedom, especially in mass concrete structures subjected to restrained thermal stresses caused by the cement's hydration heat [12].

1.2 Literature Review

Investigation was conducted around the effect of nano-clay (NC) dispersion on concrete properties by [13]. This was extensively studied by using various percentages of NC (5, 7.5, and 10%) as cement partial replacements by two ways; added as-received, added after being dispersed in water by using bath sonicator. In fact, the properties of self-compacting concrete (SCC) can be manipulated by the addition of nano montmorillonite (NMMT) clays. Therefore, Hosseini et. al. [14] conducted study to present the results of an experimental investigation on incorporating small dosages of NMMT clays (0.25, 0.50, 0.75 and 1.00% addition by mass of total cementitious material) into SCC. The results showed that the addition of .5% NMMT resulted in the highest compressive strength; however, a mixture with .75% NMMT had the highest splitting tensile strength among mixtures at curing ages of 7, 28 and 56 days.

In 2021, Mehrabi et. al. [15] investigated employing recycled concrete aggregate (RCA) and pozzolanic additives as a partial replacement (PR) of natural coarse aggregate (NCA) and Portland cement, respectively. For this purpose, the NCA was replaced with 10%, 25%, 50% and 100% RCA and the Portland cement was replaced with 10%, 25% and 50% pumice used in combination with 1–3% NC (NC). The compressive and flexural strengths, void content, density, and permeability of concrete were evaluated. The authors found that using RCA decreased density, CS (up to 58%) and flexural strength (FS) (up to 64%) and increased the void content and permeability (up to 15%) of concrete.

The effects of NC addition on fresh state, mechanical, and durability properties of plain and blended cement self-consolidating concrete (SCC) incorporating mineral admixtures as supplementary cementitious materials were investigated by [16]. Mineral admixtures such as silica fume (SF), class F fly ash (FA), rice husk ash (RHA), and ground granulated blast furnace slag (GGBFS) were used as partial replacement of cement. The results indicated that by incorporating 3% NC in blended cement SCC, satisfactory workability and mechanical properties can be achieved.

The durability of concrete to freeze and thaw (F-T) cycles is one of the most important challenges of reinforced concrete structures in regions with cold climate [17]. Thus, Langaroudi and Mohammadi [18] studied the effect of this phenomenon on concrete properties to evaluate the vulnerability rate of these structures during frequent F-T cycles seems necessary. The properties of specimens including the mass, electrical resistivity, dynamic modulus of elasticity and CS were measured during the F-T cycles. Results showed that using 3% NC considerably improves the F-T resistance of SCC, as compared to the control mix.

The study of Mohamed [19] investigated the effect of nano particles on the mechanical properties at different ages of concrete. Different mixtures have been studied including nano-silica (NS), NC or both NS and NC together with different percentages. Mechanical properties have been investigated such as compressive and flexure strength through testing concrete prisms 40, 40 and 160 mm at 7, 28 and 90 days to explore the influence of these nano particles on the mechanical properties of concrete. Results of this study showed that nano particles can be very effective in improving mechanical properties of concrete, nano-silica is more effective than nano clay in mechanical properties and wet mix gives higher efficiency than dry mix.

Morsy et. al. [20] used several nanomaterials in cementitious matrices: multi wall carbon nanotubes (MWCNTs) and NCs. The physico-mechanical behavior of these nanomaterials and ordinary Portland cement (OPC) was studied. The NC used in this investigation was nano-kaolin. The OPC was substituted by 6 wt.% of cement by nano metakaolin (NMK) and the carbon nanotube was added by ratios of 0.005, 0.02, 0.05 and 0.1

wt.% of cement. The results showed that, the replacement of OPC by 6 wt.% NMK increases the CS of blended mortar by 18% compared to control mix and the combination of 6 wt.% NMK and 0.02 wt.% CNTs increased the CS by 29% than control.

The aim study of Shahrajabian and Behfarnia [21] was to investigate the effect of nanoparticles including nano-silica, nano-alumina, and NC on the resistance of Alkali-activated slag (AAS) concrete against freeze and thaw cycles. The results showed that nano-silica and NC, respectively, performed better than the nano-alumina in improving the strength and durability of alkali-activated slag concrete subjected to freeze and thaw cycles.

A nano-silica (5% to 50%) water-based solution and silane/ NC (5% to 50%) composite were used as superficial treatments for concrete [22]. The coatings were applied on concretes with different water-to-binder ratios (0.35 to 0.6). The transport properties of treated concrete were evaluated by the rapid chloride penetrability test and absorption and desorption percentages. The results showed that increasing the concentration of nano-silica in the colloid led to improved performance of concrete, with 50% dosage leading to the least penetration depth, absorption and desorption percentages, and mass loss, whereas for the silane/nano-clay composite, a low percentage (5%) of NC was adequate to mitigate the damage of concrete under aggravated conditions.

1.3 Definition of Lightweight Concrete (LWC)

There are many definitions of lightweight concrete, which often leads to inaccuracies in referring to lightweight concrete. Deviations exist for strength, density and the type of lightweight concrete. ACI 213R-14 “Guide for Structural Lightweight Concrete”. The minimum strength is 17 MPa and the equilibrium density is between 1440- 1840 kg / m^3. Lightweight, high-strength concrete is rated at a CS of about 27 MPa with a 28-day life. The mix design of LWC (lightweight concrete) is completely different from NC (normal concrete) due to the dominating effect of LWA Used [23], [24]. Proportioning of LWC must consider the boundary conditions like strength, density and durability. Structural LWC gives better fire resistance due to the voids in this type of concrete, as these voids lead to dispersion and dissipation of heat inside the concrete and thus it is a good heat insulating material and a soundproofing material compared to normal concrete. Also, this type of concrete is better earthquake resistance because the voids allow the seismic wave to be absorbed and allow greater deformation in the concrete before the failure occurs [25] [26].

1.4 Expanded Polystyrene (EPS) Beads

EPS foam is the correct term for any form of expanded polystyrene. Expanded Polystyrene insulation is a lightweight, rigid cell insulation. EPS is available in several compressive strengths to withstand load and back-fill forces. Commonly used as insulation for walls, foundations and roofing, it can also be used as a lightweight material in concrete. there are many benefits to selecting EPS products:

- Constant thermal resistance
- Strength Sustainability
- No growth of bacteria, nor will it decay over time
- Dimensional stability
- Chemical inertness
- Low cost

Expanded Polystyrene has never contained any CFCs. EPS is a manufacturing facility that is conscious of the environment. Our EPS trim is recycled in-house, and we accept recyclable EPS from customers and the general public, minimizing the number of EPS that would otherwise wind up in landfills. All of these acts contribute to keeping our planet's air cleaner and reducing the impact of landfills on the environment [27].

Nano clay can be used in design, construction and many fields since nanotechnology generated products have many unique characteristics. These features can, again, broadly repair problems in existing construction, and may alter the needs and arrangement of the construction process. These include products intended: (i) Good properties of cementitious materials, (ii) Strong and sustainable structural compounds [28], [29].

1.5 Significance of the Study

An attempt was made in this study to demonstrate the advantages and benefits of using Nano materials additive in concrete for a variety of applications. The use of Nano additives helps in modifying the properties of concrete in both the fresh and the hardened phase, thus results in more durable concrete, high early strength, strong microstructure, etc. Given the urgent need to use LWSCC in concrete structures to reduce the cost in material terms by reducing the dead load and thus reducing the steel reinforcement, an attempt will be made to know the behavior of this type of concrete using Nano additives to improve its performance and study its properties.

1.6 Research objectives

The research objectives of the current research are (i) to present an experimental study on inclusion in LWSCC for small doses of NC as a replacement of cement weight according to previous studies, where the replacement percentage starts from 2% and then the proportions are increased until the replacement rate is reached 10% of the cement weight, (ii) to assess the fresh, hardened, and mechanical properties of the LWSCC mixtures that have been produced.

2. Methods and Materials

2.1. Experimental Program

Experimental tests were conducted on the effect of EPS and NC on the following concrete properties:

> Fresh properties: which included testing of T500 and V-funnel to ensure specifications that meet this type of concrete.

> Hardening properties: which included testing water absorption, air voids, dry density and ultrasonic pulse velocity (UPV).

> Mechanical properties: which included testing for flexural strength, CS and flexural behavior of lightweight self- compacting concrete beams made of Nano clay and EPS. Figure 1 shows the flow diagram for the experimental program for this study.

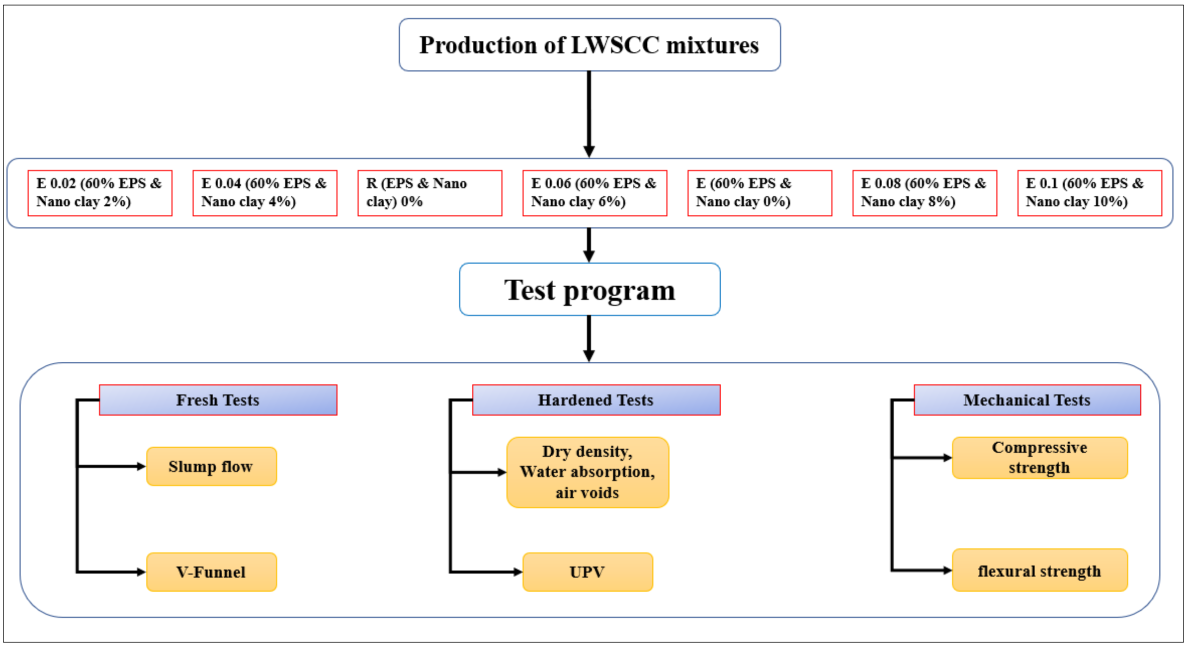

Figure 1. Flow chart of the experimental program.

2.2. The materials used in the experiment

i. Cement

Al-Mass cement (Ordinary Portland Cement) OPC was used which is commonly used in Iraq. Table 1 show the chemical and physical composition of the cement used.

Table 1. Physical and chemical properties for used cement.

Physical Properties	**Limits of Iraqi Specification No.5/2019** [30]	**Test Results**
Specific surface area (m^2 /kg)	≥ 230	314
Initial setting Final setting	Not less than 45 min Not more than 600 min	126 228

Compressive strength MPa for 2-day for 28-day	10 MPa lower limit 32.5 MPa lower limit	12.6 45
Oxides composition	Limits of Iraqi Specification No.5/2019 [30]	Test Results %
CaO	-	67
SiO_2	-	16.25
$Al2O_3$	≤ 3.5	3.42
$Fe2O_3$	-	-
MgO	5 % Max	2.38
SO_3	-	3.75
Main Compounds (Bogue's Equation)		Oxide % by Weight
C3S	-	51.9
C2S	-	31
C3A	-	8.96
C4AF	-	7.98

ii. Water

Tap water was used in the mixing and treating processes.

iii. Coarse Aggregate

The round natural aggregate was used in this study, where it is washed with water several times and left to air dry to be used in the concrete mix. Table 2 and Figure 2 is an explanation of the physical properties of coarse aggregates according to the Iraqi standard [31], and the dry density used is 1650 kg/m^3.

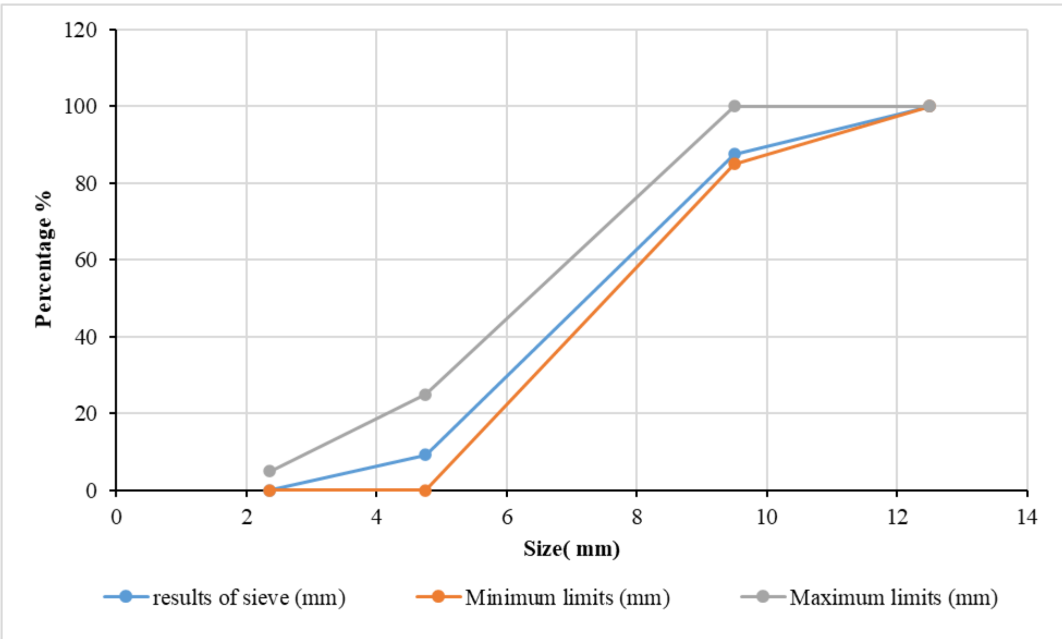

Figure 2. Coarse aggregate sieve analysis.

Table 2. The Gradient and physical properties of used coarse aggregate.

Sieve size (mm)	Passing %	
	Results of sieve analysis	**Limits of Iraqi No.45 (10mm)**
12.5 mm	100	100
9.5 mm	87.5	85-100
4.75 mm	9.2	0-25
2.36 mm	0	0-5
Physical properties	**Tests results**	**Limits of Iraqi specification No.45**
Absorption	0.6 %	-
Specific gravity	2.62	-
Sulfate content SO_3	0.08 %	0.1 % max

iv. Fine Aggregate

Local fine aggregates were used in this study. And a sieve analysis was made for it, and it was in conformity with the Iraqi standard [32] in terms of gradient as well as physical properties. Table 3 and Figure 3 is an illustration of fine aggregate, sieve analysis, and physical properties of it. Its dry density was 1750 kg / m^3.

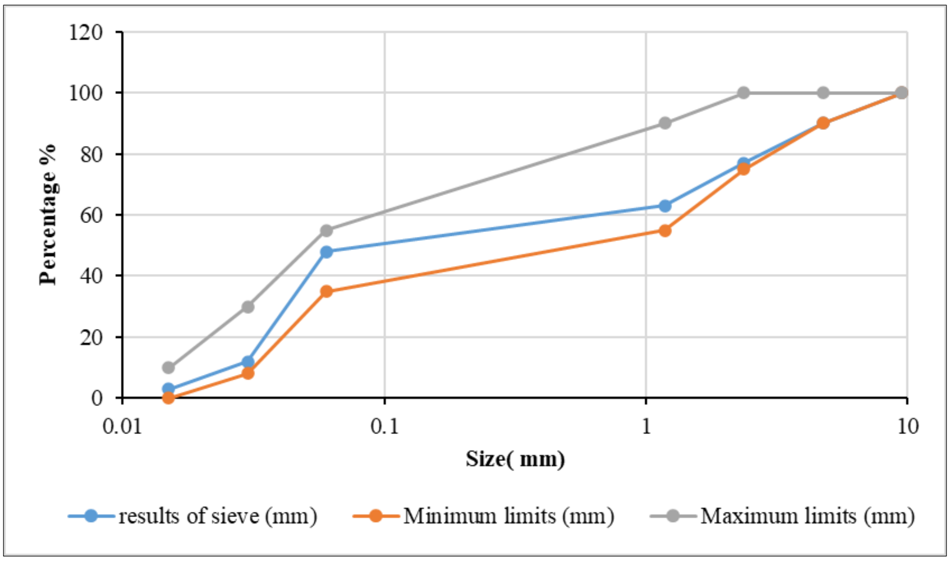

Figure 3. Fine aggregate (sand) sieve analysis.

Table 3. Sieve analysis and physical properties of fine aggregate (sand).

Sieve size (mm)	**Passing %**	
	Results of sieve analysis	**Limits of Iraqi No.45 (zone 2)**
9.5 mm	100	100
4.75 mm	90	90-100
2.36 mm	77	75-100
1.18 mm	63	55-90
600 µm	48	35-55
300 µm	12	8-30

150 µm	3	0-10
Physical properties		
	Tests results	**Limits of Iraqi specification No.45**
Absorption	0.8 %	-
Specific gravity	2.71	-
Sulfate content SO^3	0.27 %	0.5 % max

v. Expanded Polystyrene Beads (EPS)

It was used Expanded Polystyrene Beads (EPS) spherical cork beads with a single size of 10 mm are generally used and have the specifications as shown in Table 4 and Figure 4.

Figure 4. Expanded polystyrene beads (EPS) used in the experiment.

Table 4. Physical Properties of expanded polystyrene beads (EPS) [33].

Particle size	**Bulk Density**	**Specific gravity**
Spherical (8-9 mm dia)	6.86 kg/m^3	0.011

vi. Silica Fume (SF)

UAE commercial silica fume (SF) was used in this study Which has the following characteristics shown in Table 5.

Table 5. Properties of used silica fume [34].

Physical properties	**Content %**	**ASTM C1240-05 limits**
Strength Activity Index with cement at 7 days, min % of control	120	Max 105 %
Bulk density (kg/ m^3)	300 kg /m^3	-
Appearance	Grey powder	-
Specific surface area	20	Min 15 m^2/g
Oxide composition	**Tests Results**	**ASTM C1240-05 limits**
SiO_2	94.4	Min 85 %
Al_2O_3	0.3	-
Fe_2O_3	0.81	-

Na_2O	0.08	-
K_2O	0.43	-
CaO	0.26	-
MgO	0.14	-
SO_3	0.87	-
Tio_2	< 0.02	-
Loss of ignition L.O.I.	3.36	Max 6 %
Moisture Content	2.2	Max 3 %

vii. Superplasticizer (SP)

A superior plasticizer (Sika ViscoCrete 5930) was used in this study for the purpose of reducing the water to cement ratio and obtaining high workability. Table 6 is an explanation of the properties of the superior plasticizer.

Table 6. Properties of superplasticizer Sika ViscoCrete 5930 [35].

Turbid liquid	**Appearance**
kg\liter 1.1	Density
8	PH

viii. Nano clay

Nano clays are pozzolanic clays like kaolin and bentonite, kaolinite, montmorillonite, hectorite, halloysite, etc. By grinding these clays to the nanoscale degree, these clays become what is called Nano clays. Where nanoparticles have a size of a millionth of a millimeter, that is of a billionth of a meter [36]. Nanotechnology deals with measurements between 1 to 100 nanometers and a surface area of ∼750 m^2/g).

2.3. Procedure for Mix Design

i. Mixing

Experimental mixtures were made to obtain lightweight, self-compacting concrete based on EFNARC (2005) specifications as follows:

- Based on previous studies, experimental mixtures were made to obtain self-compacting concrete. Where three mixtures were made in fixed proportions of the materials with a change in the water percentage, as shown in Table 7. Whereas the optimum mixture for self-compacting concrete that met EFNARC (2005) specifications was the mixture named R^2.

Table 7. The ratio of the reference concrete mixture.

Comp. MPa	**Seg %**	**v-funnel**	**slump**	**T500**	**N.C (kg/m³)**	**EPS (kg/m³)**	**S (kg/m³)**	**G (kg/m³)**	**W (kg/m³)**	**S.P (kg/m³)**	**S.F (kg/m³)**	**Cemet (kg/m³)**	**Mix Code**
R1	400	100	12	165	865	865	0	0	2.8	750	8.5	13	60.2
R2	400	100	12	175	865	865	0	0	2.2	780	8.2	14.2	56.3
R3	400	100	12	185	865	865	0	0	1.5	810	6.9	21	48.8

- Nine experimental mixtures were made to obtain lightweight-self-compacting concrete (LWSCC) with a density ranging between (1440 – 1840) Kg/m3 where the reference mix ratios were used and the volumetric replacement ratios between coarse aggregate and EPS were carried out at rates ranging between (20%, 40% and 60%) from EPS in place of coarse aggregate. Also, different proportions of water were used. Where the best mixture was with a replacement rate of 60% of EPS, 40% of coarse aggregate and a water percentage of 175 kg /m^3 as shown in Table 8.
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Table 8. The ratios of the mixing of lightweight self-compacting concrete.

Mix Code	Cemet (kg/m³)	S.F (kg/m³)	S.P (kg/m³)	W (kg/m³)	G (kg/m³)	S (kg/m³)	EPS (kg/m³)	N.C (kg/m³)	T500	Slump	V-Funnel	Seg %	Comp. MPa
R.L.E 20%	400	100	12	165	692	865	1.086	0	7	612	11.1	12.1	25.7
R.L.E 40%	400	100	12	165	519	865	2.176	0	10.2	606	14.8	11.4	22
R.L.E 60%	400	100	12	165	346	865	3.259	0	11.5	600	16	11	19.8
R.L.E 20%	400	100	12	175	692	865	1.086	0	6.3	630	10.5	13.2	24.2
R.L.E 40%	400	100	12	175	519	865	2.176	0	6.8	628	11.7	12.1	20.2
R.L.E 60%	400	100	12	175	346	865	3.259	0	7	620	13	11.4	18.3
R.L.E 20%	400	100	12	185	692	865	1.086	0	2	780	8.3	2.4	22.3
R.L.E 40%	400	100	12	185	519	865	2.176	0	2.3	762	8.7	19.5	17.4
R.L.E 60%	400	100	12	185	346	865	3.259	0	2.5	750	8.8	19.1	12.1

After obtaining the reference mixture for lightweight self-compacting concrete (LWSCC). Mixtures were made for the purpose of studying the effect of the nano clay on the fresh, hardened and mechanical properties of concrete and choosing the best replacement ratio. Where the substitution between cement and nano clay was Replace by weight. Substitution ratios were (2%, 4%, 6%, 8%, 10%) .as shown in Table 9.

Table 9. The ratios mixing of lightweight self-compacting concrete with nano clay.

Mix Code	Cement (kg/m³)	S.F (kg/m³)	S.P (kg/m³)	W (kg/m³)	G (kg/m³)	S (kg/m³)	EPS (kg/m³)	N.C (kg/m³)
N.C 2%	392	100	12	175	519	865	2.176	8
N.C 4%	384	100	12	175	519	865	2.176	16
N.C 6%	376	100	12	175	519	865	2.176	24
N.C 8%	368	100	12	175	519	865	2.176	32
N.C 10%	360	100	12	175	519	865	2.176	40

R1 = Ordinary Self Compacting Concrete
R.L.E 20% = lightweight Self-Compacting concrete. (20%EPS+80%Coarse aggregate)
R.L.E 40% = lightweight Self-Compacting concrete. (40%EPS+60%Coarse aggregate)
R.L.E 60% = lightweight Self-Compacting concrete. (60%EPS+40%Coarse aggregate)
N.C 2% = lightweight Self-Compacting concrete with 2% nonoclay.
N.C 4% = lightweight Self-Compacting concrete with 4% NC.
N.C 6% = lightweight Self-Compacting concrete with 6% NC.
N.C 8% = lightweight Self-Compacting concrete with 8% NC.
N.C 10% = lightweight Self-Compacting concrete with 10 % NC.

ii. Casting

The molds required for casting were prepared for the purpose of studying hardening and mechanical properties. Which includes cubes, prisms and cylinders, and the following steps were worked out:

- First, make sure that the molds are well-tightened to ensure that the mixture does not leak following the recommended specification.
- The molds are lubricated with a brush for easy removal of the concrete molds when dry.

- The raw materials of the mixture are placed in the rotary mixer and make sure the materials are mixed well, then water is added to the mixer and continue mixing for 3-4 minutes to get a good mixture.
- Concrete is poured into the molds without vibration, as the mixture has achieved the specifications of compacted concrete according to the EFNARC (2005) standard.
- After completing the pouring, wait 10-15 minutes, then the surface of the mold is adjusted by a hand trowel.
- The molds are covered with polyethylene sheets to prevent evaporation and wait for a period of no less than 24 hours or more to dry and then open the mold for the purpose of curing.

iii. Curing

After completing the casting process into the molds. Samples were left to dry for 24 hours at 25 ° C. Then the samples are disassembled and placed in a water treatment bath at a temperature of 25 °C until the specified testing time is reached. Processing was done according to ASTM C192 / C192M-18 [37].

2.4. Determination of the workability of LWSCC Mixtures

i. Slump Flow and T-500 mm Test

A slump flow test was performed for all concrete mixtures in this study, which is considered an important test for evaluating the workability and viscosity at work and in the laboratory for self-compacting and lightweight self-compacting concrete because there are risks of segregation and bleeding.

ii. Funnel Test

This test evaluates the fresh properties of self-compacting concrete in a manner that differs from the precipitation flow test, where although this test is designed to measure the capacity of filling concrete with a maximum size of 20 mm, it measures its ability to flow through narrow spaces without obstruction. During this test, the necessary time was measured from the moment the funnel gate was opened to the moment all the concrete exited the funnel, which is the moment the light was seen through the gate opening.

It is expressed as T5 min. The concrete is considered to have self-compaction properties if this time is within 6-12 seconds.

2.5 Hardened Properties of LWSCC Mixtures

i. Dry Density

In accordance with the requirements of ASTM C642-6 [12]. The density values for concrete specimens with dimensions (100 * 100 *100) mm were determined at a 28-day age according to the following steps. a) The dry mass (A) is calculated by drying samples at 80 ° C for a period of 24 hours. Then, it is taken out and left to cool at room temperature, b) The saturated mass (B) is calculated by extracting water-saturated samples, drying the surface with a cloth, and then calculating its weight, c) The dry mass (C) is calculated by drying samples at 80 ° C for a period of 24 hours. Then it is taken out and left to cool at room temperature, d) After immersion and drying, the sample is placed bucket of filled with water connected to a wire tied to a scale for the purpose of measuring its weight in water and it is called the apparent mass (D). Then the density of the specimens is calculated using equation (1).

$$Dry\ Density\ \% = \frac{A}{C - D} \times 100 \qquad (1)$$

where A = mass of oven-dried sample in air, B = mass of surface-dry sample in air after immersion, C = mass of surface-dry sample in air after immersion and drying, D = apparent mass of sample in water after immersion and drying.

ii. Water Absorption

The water absorption was calculated for concrete cubes with dimensions (100 * 100 * 100) mm using the formula number (2) depending on ASTM C642-6.

$$Water\ Absorption\ \% = \frac{C - A}{A} \times 100 \quad (2)$$

iii. Voids

The voids test was performed on concrete samples with dimensions (100 * 100 * 100) mm depending on ASTM C642-13 [38] and according to equation no (3).

$$\text{Voids}\ \% = \frac{C - A}{C - D} \times 100 \quad (3)$$

iv. Ultrasonic Pulse Velocity (UPV)

Accordance with the standards ASTM C597-16. Ultrasonic pulse velocity test was performed on (100 *100*100) mm cubes. Pulse velocity was determined by dividing the pulse time to length of path as shown in the equation no (4).

$$V = L/T \quad (4)$$

where V is the velocity of ultrasonic pulse (km/sec), L is the length of the sample (km) and T is the transit time (seconds). The Ultrasonic Pulse Velocity Tester is supplied complete with:

- Two 54 KHz transducers (Transmitter and Receiver) with 3 meters' cable
- Calibration rod
- Coupling agent (250 mm)
- Carrying case.

2.6 Mechanical Properties of LWSCC Mixtures

i. Compressive Strength

The CS test is one of the most important mechanical tests for concrete. As it is believed that this test is the guide and reference for the rest of the properties of concrete (Flexural, modulus of bending, etc.). The CS of the lightweight self-compacting concrete was tested for all reference mixtures and mixtures containing nano clay materials using cubes at ages of 7 days, 28 days and 56 days according to BS EN 12390-3 standard [39]. This variation in ages is due to the fact that compression resistance develops over time, as it is possible to notice changes in results at these ages.

ii. Flexural Strength

The flexural strength of the seven mixtures was tested using the flexural device. Flexural strength test was based on ASTM C293-02, at age was 28 days. The dimensions of the prism are (100 mm by 100 mm by 400 mm), which is subject to a one-point load, where the prism is loaded until failure. The modulus of rupture was computed using the equation below.

$$F_R = 3/2\,\frac{PL}{bd^2} \quad (5)$$

where *FR*: is modulus of rupture in MPa. *P*: is ultimate applied load in N. *b*: is average width of prism in mm. *d*: is average depth of prism in mm. *L* : is span length between supports in mm.

3. Results and Discussion

In this section, the experimental results of fresh, hardened and mechanical properties will be presented and discussed. The effect of adding nano clay on LWSCC lightweight self-compacting concrete will be studied. And compared to lightweight, self-compacting concrete without adding nano clay. Additionally, the results on the flexural behavior of LWSCC beams were presented. The description of the performance was based on load-deflection response, while first crack load, crack width, and crack patterns development were discussed as well.

3.1. Fresh Properties

A test was performed for fresh concrete (slump flow, T500 and V-Funnel tests for all concrete mixtures (R, R.L, NC 2%, NC 4%, NC 6%, NC 8%, NC 10%) (Table 10).

Table 10. Fresh properties of LWSCC mixtures.

Mix Code	Slump Flow		V-funnel (Sec)	J – Ring(mm)	SR%
	Flow (mm)	Time (sec)			
R	780	2.2	8.2	10	14.2
R. L. E60%	620	7	13	11.5	11.4
N.C 2%	750	4.2	10.1	10	8.2
N.C 4%	765	3.8	8.3	5	9.5
N.C 6%	780	2.8	8	5	15.3
N.C 8%	800	2.6	7.5	8	15.75
N.C 10 %	805	1.2	7	4	19.43
Limit of EFNARC (2005)	550-850	≤2 >2	≤8 9 to 25	10-15	0-20%

i. Slump Flow and T-500 mm Test

This test was used to determine the workability of the concrete and assess its viscosity. As the higher the slump flow value, the greater the ability of concrete to fill the formwork by its weight. Previous studies indicated that the use of soft materials increases workability because they help the mixture slip [40]. Table 11 and Figure 5 shows the values of slump flow for the mixtures used in the study.

Table 11. Test results of slump flow and T-500 tests for all mixtures.

Mix code	Slump flow(mm)	T500(sec.)
R	780	2.2
R. L. E60%	620	7
N.C 2%	750	4.2
N.C 4%	765	3.8
N.C 6%	780	2.8
N.C 8%	800	2.6
N.C 10%	805	1.2

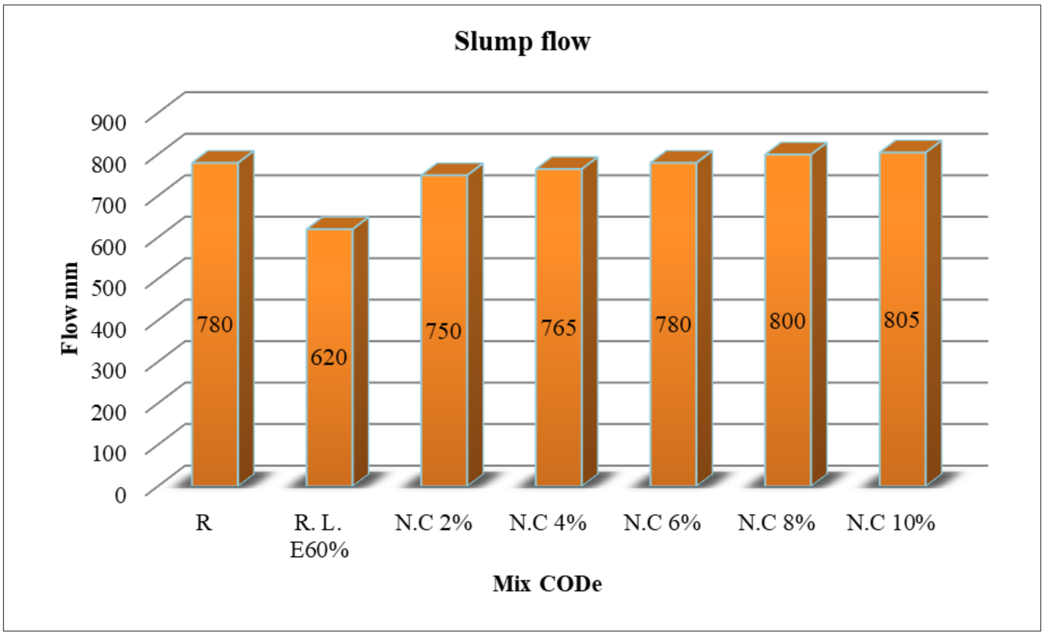

Figure 5. Test results of slump flow and T-500 tests for all mixtures.

As the diameter of the concrete flow increases with the increase in the proportion of NC, there is a decrease in the time required to reach the diameter of 500 mm, which represents the T500 test. It is noted that the reference mixture (R), which represents the self-compacting concrete, has obtained a slump flow equal to 780 mm, which falls within the classification of SF 3 according to the EFNARC (2005) standard, MAY (2005). Which is used for vertical applications in particularly congested structures, constructions with complex geometries, or for filling beneath formwork, as specified in the specification. The surface finish of SF3 is frequently superior to that of SF 2. The reference mixture (R. L. E 60%), which represents lightweight, self-compacting concrete with 60% replacement of EPS in place of coarse aggregate (volumetric replacement) in which slump flow is reduced to 620 mm.

The reason for this is due to the use of EPS granules, which in turn reduce the operability due to its lightweight that reduces its mobility as well as its high ability to absorb water, which leads to a reduction in stagnation flow as well as an increase in T500 time. The mixture NC 2%, which represents a lightweight, self-compacting concrete with a replacement ratio of 2% of the cement weight with the NC material, the slump flow increased and the time T500 decreased due to the use of very fine nanomaterials and their It penetrates into tiny voids, which led to the improvement of workability. The mixture NC 4% increased slump flow to 765 mm and also decreased T500, which indicates that this ratio improved the characteristics of fresh concrete. The percentages NC (6- 8-10) %. We notice an increase in the slump flow and a decrease in T500 significantly, but in these ratios due to the increase of the NC and its penetration into the tiny voids, it pushed the mixing water up. And because the mixture contains lightweight aggregate, which is EPS, it pushed it to the top because of its low density, which caused the non-homogeneous mixture, the rise of lightweight aggregates to the top, and the formation of a weak layer on top of the concrete, which is a weak point in the hardened concrete as shown in Figure 6.

Figure 6. Clarifies concrete cubes with a ratio of 8% NC.

For what has been mentioned above, the best replacement ratio for nano clay, which gives the best results in fresh concrete, is the mixture NC 4%.

ii. V-Funnel Test

This test was performed to find out the ability of concrete to pass through narrow openings and its ability to fill molds. Table 12 and Figure 7 shows the values of V-funnel for the mixtures used in the study.

Table 12. Test results of V-Funnel tests for all mixtures.

Mix code	**$t_{v-funnel}$ (Seconds)**
R	8.2
R. L. E60%	13
N.C 2%	10.1

N.C 4%	8.3
N.C 6%	8
N.C 8%	7.5
N.C 10%	7

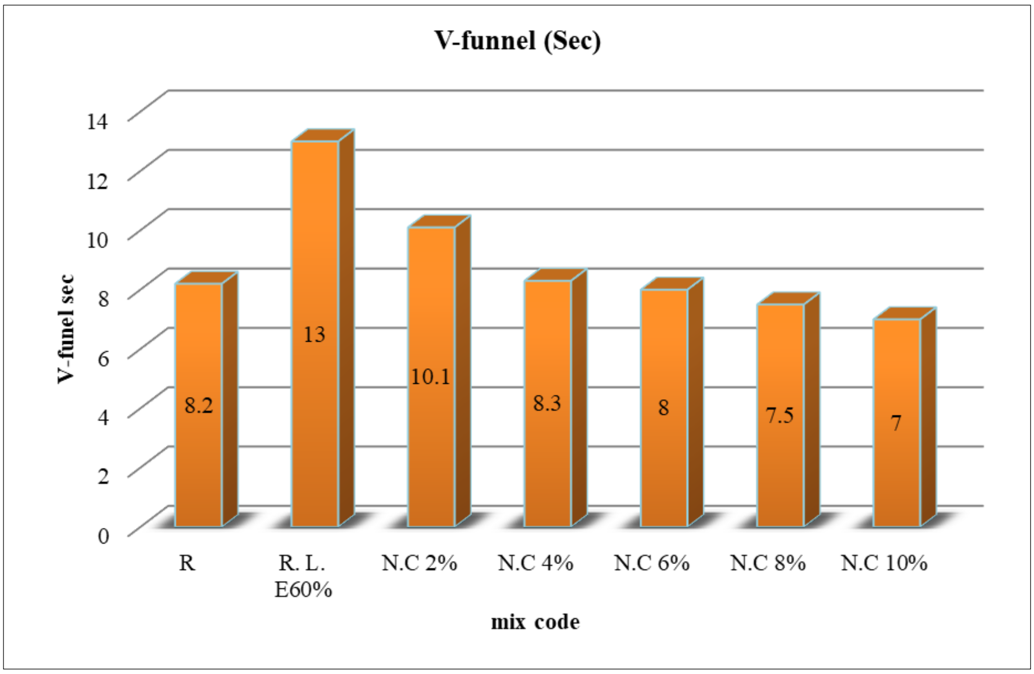

Figure 7. Test results of V-funnel tests for all mixtures.

Where we note that the values of the reference mixture (R) have a lower value over time than the reference mixture of lightweight self-compacting concrete R. L. E60% for the same reason that was mentioned in the slump flow test due to the decrease in workability due to EPS granules.

While the results showed that with increasing the percentage of replacing the NC material, the passage time was reduced. The reason for this can be attributed to the very fine nanoparticles in the NC material that cause the mixture to slip, causing an increase in workability and thus reducing the time required for the mixture to pass.

3.2. Hardened Properties

Hardened tests were carried out for all concrete mixtures which includes (Dry Density, Water absorption, Voids) as shown below

i. Dry Density, Water Absorption, and Voids

Table 13 shows the density, Water absorption and voids values of the mixtures that were used in the experiment. according to ASTM C642-13. Figure 8 shows the EPS distribution pattern in concrete specimen. The lightweight concrete ranges between (1440-1840) Kg /m^3.

Table 13. Dry density, water absorption, and voids test results for all mixtures.

Mix code	Density % (kg/m^3)	Water Absorption %	Voids %
R	2312	0.6	1.57
R. L. E60%	1718	2.08	3.71
N.C 2%	1800	0.98	2
N.C 4%	1757	1	1.77

N.C 6%	1758	1.01	1.77
N.C 8%	1840	1.28	2.29
N.C 10%	2100	0.97	2.05

Figure 8. EPS distribution pattern in concrete specimen.

The results as shown in Figure 9 showed that the R mixture was of the density of normal-weight concrete. The mixture R. L. E60% was dense for lightweight concrete because it contained 60% volumetric replacement of EPS in place of coarse aggregate. The results showed that the addition of NC material gradually increased the density according to the replacement percentage. Where the mixture N.C 2% had a density of 1718 Kg / m3 until the density reached 2100 kg / m3 in the mixture N.C 10%, where the density here became as normal concrete and not lightweight concrete. The reason for this is that the NC is a very soft material that goes into the microscopic spaces and interacts to cut the tiny pores and pushes the water to the top, which in turn rises the lightweight EPS materials to the top, where the higher the proportion of the nanoparticles the density increases due to what we mentioned previously.

This is in relation to high replacement ratios. As for the replacement ratios from (2-6) %, their interpretation differs, as these ratios do not cause isolation in the components of the concrete, but rather work to enter into the micro-microscopic spaces to interact with the anxious compound $Ca(OH)_2$ to create a new gel that cuts Capillary pores and fills the voids, thus increasing the density and durability.

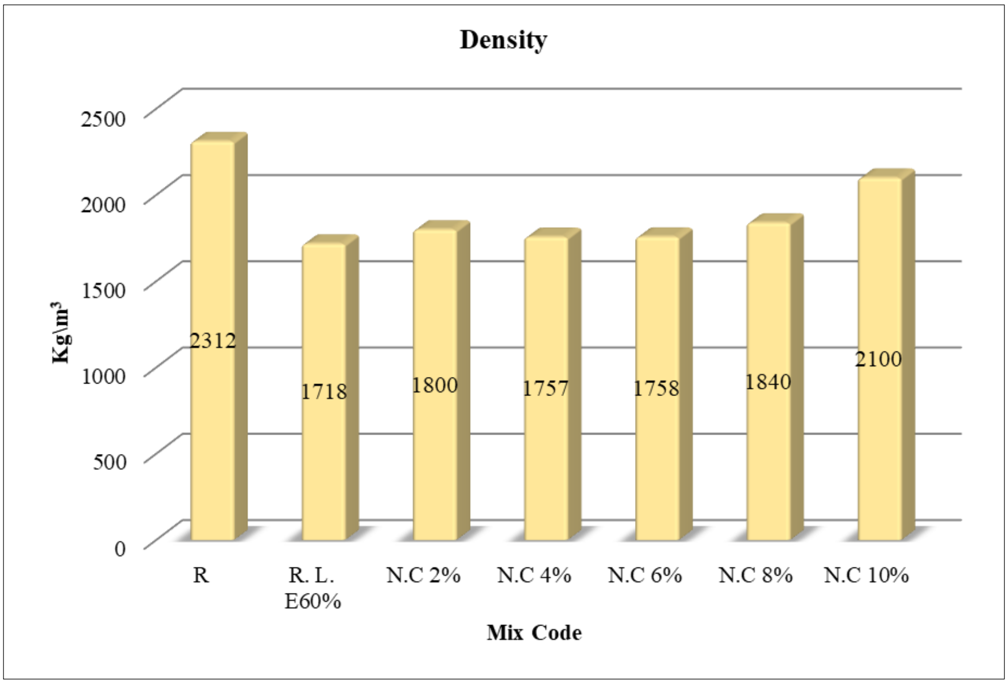

Figure 9. Density results for all mixtures.

From the Figure 10, it is noticed that the R mixture had a good absorption rate, which gives the concrete better durability. The mixture RL E60% has increased the absorption rate due to the presence of Eps that create air voids, after adding the NC, the absorption rate is reduced by almost half as indicated in the ratios (2-4-6) % as the nanoparticles work to cut the capillary pores and thus reduce Absorption ratio. Then the absorption rate begins to increase as the proportion of nanoparticles increases due to the formation of larger voids in the high replacement ratios of the mixture inhomogeneity and the occurrence of segregation.

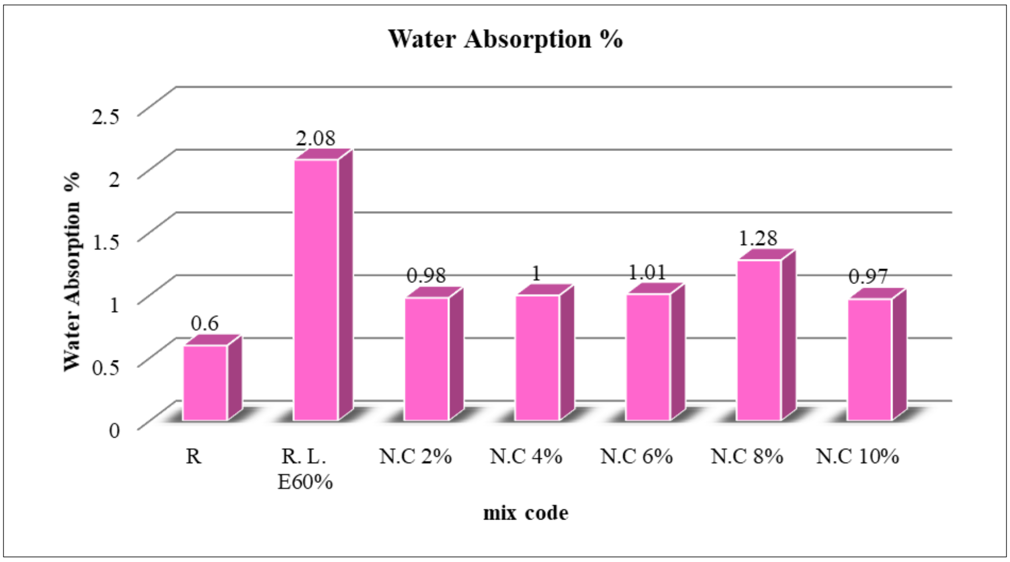

Figure 10. Percentage of water absorption values for all mixtures.

It is noticed from Figure 11 that the mixture R. L. E60% had a higher void ratio than the R mixture due to its light weight. It is noted that LWSCC concrete, when adding NC, reduces the percentage of voids and exhibits the behavior of water absorption almost for the same reasons that were mentioned previously in the same paragraph.

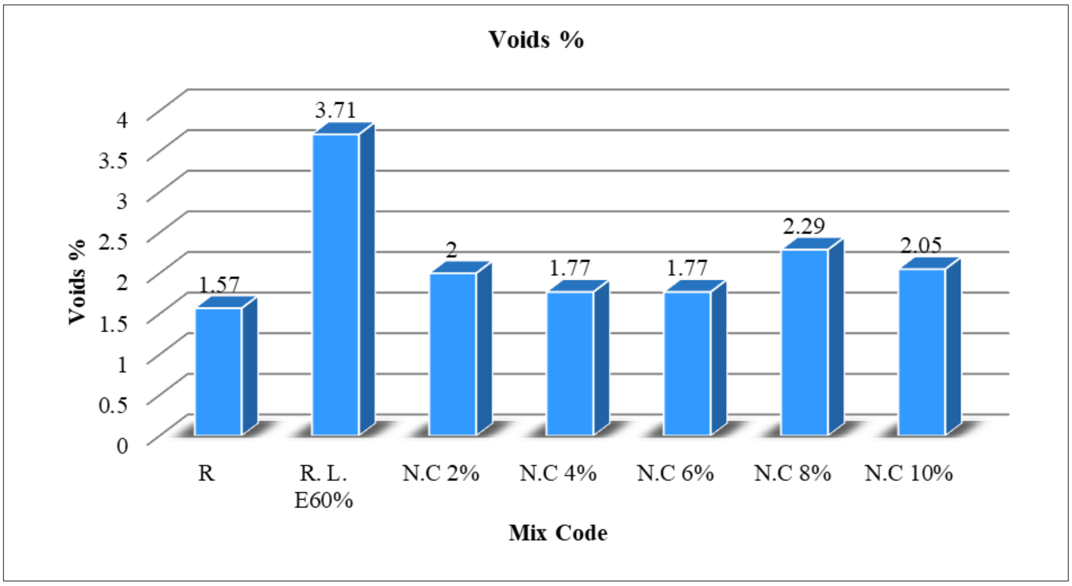

Figure 11. Percentage of voids values for all mixtures.

ii. Ultrasonic Pulse Velocity (UPV)

Ultrasonic pulse velocity is a non-destructive measure of concrete quality. Table 14 shows the values of UPV for the mixtures used in the study.

Table 14. Ultrasonic pulse velocity (UPV) test results for all mixtures.

Mix code	UPV (km/sec.)	Mark
R	4.05	Good
R. L. E60%	3.14	Doubtful
N.C 2%	3.77	Good
N.C 4%	3.6	Good
N.C 6%	3.69	Good
N.C 8%	2.7	poor
N.C 10%	2.44	poor

Figure 12 shows that the reference mixture R gave good results for UPV assay. While the mixture R. L. E60% gave Doubtful results, the reason is due to the presence of EPS granules. This leads to the formation of air spaces, which in turn scatter the ultrasound, which gives fewer results. After adding the NC to the mixture, good results were given for this test as shown in the mixture N.C 2%, N.C 2%, and N.C 6%. The reason for this is that the NC contributed to filling the voids, which gave more cohesion to the concrete. It is noticed that when the percentage of NC was increased, it gave weak results due to the segregation that occurs and the lack of homogeneity of the mixture by using larger quantities of NC in lightweight concrete.

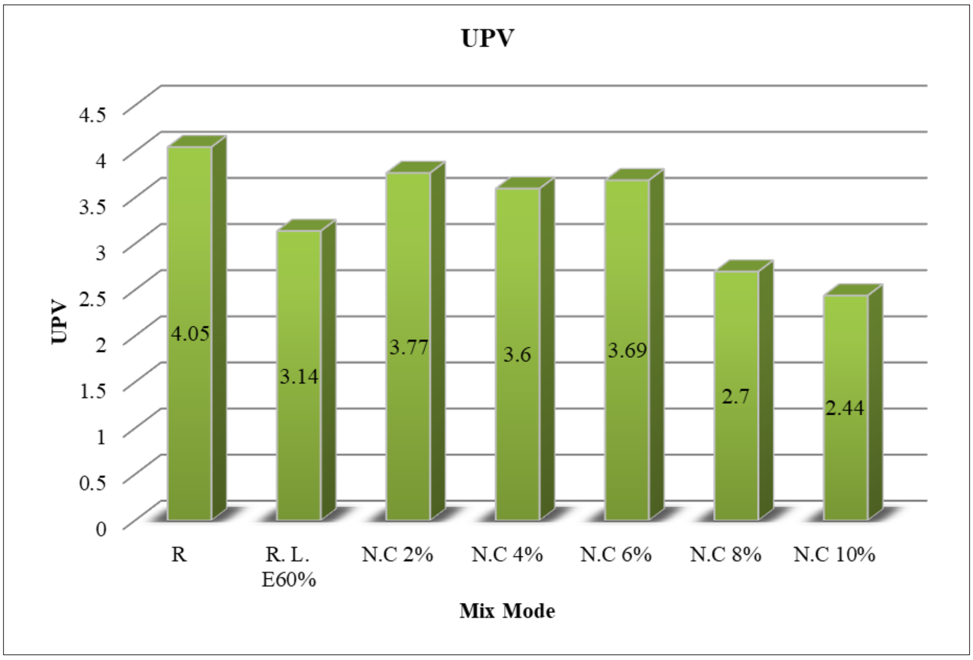

Figure 12. Ultrasonic pulse velocity (UPV) test results for all mixture.

3.3. Mechanical Properties

i. Compressive Strength

A CS test was performed for all concrete mixtures at the age of 7 days, 28 days and 56 days with curing as shown in Table 15 and Figure 13.

Table 15. CS test results of all mixtures for 7, 28, and 56 days.

Mix code	**Compressive Strength (MPa)**		
	7 days	28 days	56 days
R	38.9	56.3	64.1
R. L. E60%	9.3	18.3	21.5
N.C 2%	10	20	23.3
N.C 4%	9.63	21.8	25.2
N.C 6%	9.8	22.6	25.4
N.C 8%	13	22.8	25.7
N.C 10%	15.9	29.1	31.9

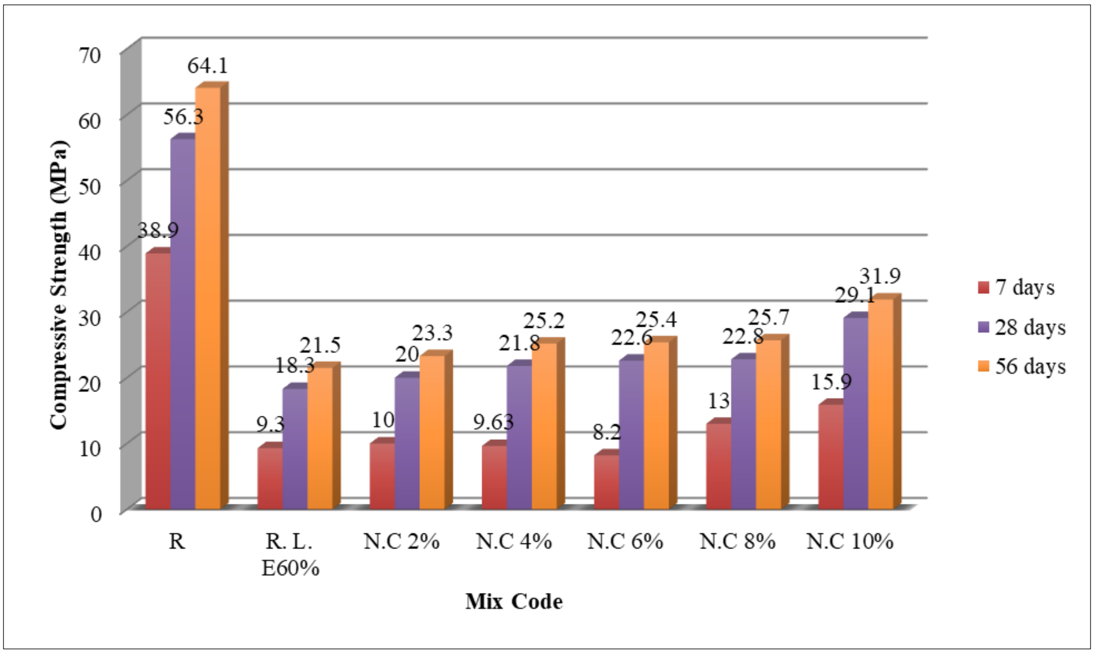

Figure 13. CS test results of all mixtures for 7, 28, and 56.

The reference mixture R had good resistance 56.3 MPa at 28 days of age due to the homogeneity of the mixture and the use of complementary materials for cement and additives that improved the properties of the concrete and through which self-compacting concrete was obtained. Mixture R. L. E60%, which is a lightweight self-compacting concrete. We notice a decrease in the CS to reach 18.3 MPa due to the use of EPS granules that have a smooth surface, which reduces the adhesion with the cement paste, as well as its resistance, which is low compared to the coarse aggregate. Whereas, ultra-lightweight concrete resistant concrete has a CS of 27 MPa. It was noticed that when adding the NC material, the CS improved at a substitution ratio of (2-4) % to reach 21.8 MPa with a lifetime of 28 days, which is good resistance and can be used constructively. When the ratio of NC substitution is increased, the results show an increase in compressive strength, but in reality, what happens is segregation, which leads to the rise of lightweight materials to the top, causing the heterogeneity and segregation of the mixture and the buoyancy of the EPS granules upwards, and this leads to not to obtain lightweight, self-compacting concrete because its density is higher, and the resistance becomes higher.

ii. Flexural Strength (Fr)

Flexural Strength values were calculated for all mixtures and the values were as shown in Table 16.

Table 16. Flexural Strength test results of all mixtures for 7, 28, and 56-day.

Mix code	**Flexural Strength (MPa)**		
	7 days	28 days	56 days
R	18.98	31.31	35.1
R. L. E60%	10.3	16.2	19.9
N.C 2%	13.26	18.72	22.2
N.C 4%	13.1	18.2	22
N.C 6%	12.48	16.6	20.1
N.C 8%	12.13	18.92	22.5
N.C 10%	14.8	19.56	23

From Figure 14 it is evident that for the same previous reasons that were mentioned above that the mixture LWSCC was FS 10.3 MPa. After adding the NC, the FS improved to a replacement ratio of 2% and 4% positively due to the pozzolanic NC material that enters into the microscopic voids to interact and cut the micro-voids and a new gel fills these gaps, leading to the improvement of concrete properties. When the substitution ratio increases, this leads to segregation of lightweight materials to float on top, producing denser concrete, and it appears that FS has increased due to the aforementioned cause.

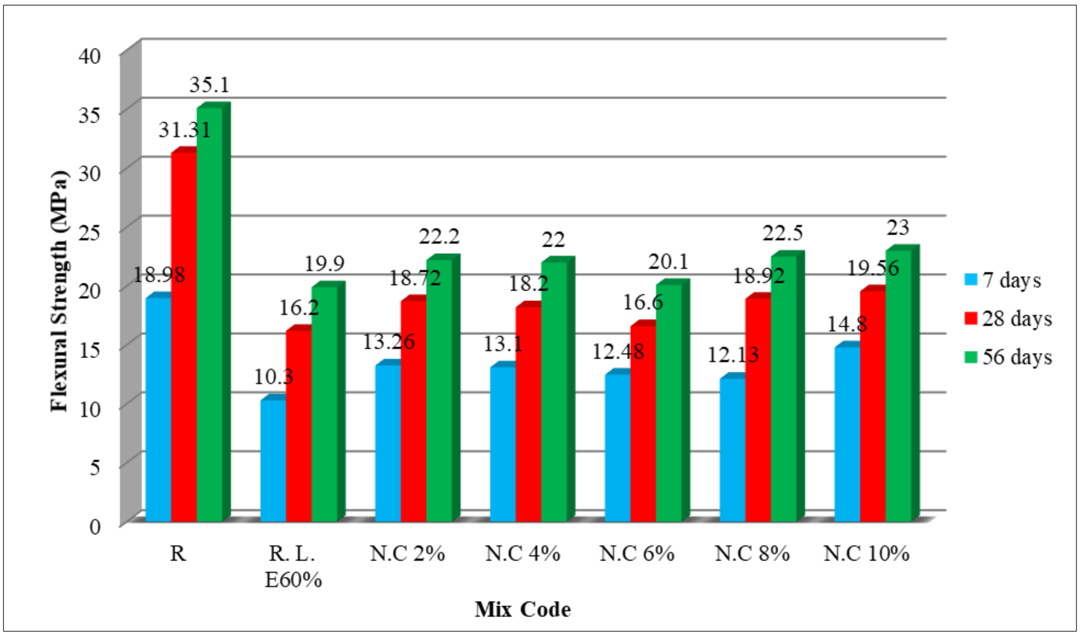

Figure 14. Flexural Strength test results of all mixtures for 7, 28, and 56-day.

4. Conclusions

The conclusions were drawn from this experimental research as shown below:

i. Various proportions of NC were used, estimated at (2-10) % of the weight of cement, and these proportions were mixed with LWSCC concrete made of EPS as a partial replacement of coarse aggregate. These proportions showed varying values in the fresh properties of concrete and the optimal proportions It is between (2 and 4%) of NC, which gave the best workability and preserved the properties of concrete in terms of homogeneity and density.

ii. When the percentages increased by more than 4%, it showed an increase in the density of concrete and led to segregation in the concrete components, where the soft materials became at the bottom and the lightweight materials floated at the top, this leads to weakness in the compression zone, but without the use of NC, the mixture was not homogeneous and contained many voids.

iii. For the production of LWSCC concrete, the focus should be on the density and homogeneity clause, whereby increasing the percentage of NC, it gave a good density, but when it exceeded the upper limit, i.e. more than 4%, it gave a very high density and went out of the range of lightweight concrete, where the density reached 2100 kg / m3 for the ratio 10% of NC.

iv. In LWSCC concrete, when using NC, the UPV values improved from doubtful to good, and when the proportion of NC was increased from the upper limit, it gave weak UPV values.

v. The mechanical properties analysis showed that there is an improvement in the CS when adding a Nano-material by 2%, where the CS has improved than the reference mix of LWSCC concrete (RL E60%) without NC by (9.3, 18.3, 21.5). MPa at the age of 7, 28 and 56 days, respectively, to (10, 20 and 23.3) MPa after adding (NC 2%), which showed that it was the best replacement ratio that reduced the failure line in concrete and improved the new and mechanical properties of concrete.

Conflict of interest: The authors declare no conflict of interest.

References

[1] M. T. Souza, I. M. Ferreira, E. G. de Moraes, L. Senff, and A. P. N. de Oliveira, “3D printed concrete for large-scale buildings: An overview of rheology, printing parameters, chemical admixtures, reinforcements, and economic

and environmental prospects," *J. Build. Eng.*, p. 101833, 2020.

[2] L. Kanamarlapudi, K. B. Jonalagadda, D. C. K. Jagarapu, and A. Eluru, "Different mineral admixtures in concrete: a review," *SN Appl. Sci.*, vol. 2, no. 4, pp. 1–10, 2020.

[3] A. A. Shubbar, M. Sadique, M. S. Nasr, Z. S. Al-Khafaji, and K. S. Hashim, "The impact of grinding time on properties of cement mortar incorporated high volume waste paper sludge ash," *Karbala Int. J. Mod. Sci.*, vol. 6, no. 4, 2020.

[4] F. Curcio, D. Galeota, A. Gallo, and M. M. Giammatteo, "High-performance lightweight concrete for the precast prestressed concrete industry," in *American Concrete Institute, ACI Special Publication*, 1998, vol. SP179.

[5] J. C. Lim and T. Ozbakkaloglu, "Stress-strain model for normal- and light-weight concretes under uniaxial and triaxial compression," *Constr. Build. Mater.*, 2014.

[6] G. Barluenga, M. Giménez, A. Rodríguez, and O. Rio, "Quality Control Parameters for on-site evaluation of pumped Self-Compacting Concrete," *Constr. Build. Mater.*, vol. 154, 2017.

[7] G. R. Lomboy, X. Wang, and K. Wang, "Rheological behavior and formwork pressure of SCC, SFSCC, and NC mixtures," *Cem. Concr. Compos.*, vol. 54, 2014.

[8] N. A. Tregger, M. E. Pakula, and S. P. Shah, "Influence of clays on the rheology of cement pastes," *Cem. Concr. Res.*, vol. 40, no. 3, 2010.

[9] Z. Quanji, G. R. Lomboy, and K. Wang, "Influence of nano-sized highly purified magnesium alumino silicate clay on thixotropic behavior of fresh cement pastes," *Constr. Build. Mater.*, vol. 69, 2014.

[10] Y. Qian and G. De Schutter, "Enhancing thixotropy of fresh cement pastes with nanoclay in presence of polycarboxylate ether superplasticizer (PCE)," *Cem. Concr. Res.*, vol. 111, 2018.

[11] A. Gerritse, "Design considerations for reinforced lightweight concrete," *Int. J. Cem. Compos. Light. Concr.*, vol. 3, no. 1, 1981.

[12] H. J. H. Brouwers and H. J. Radix, "Self-compacting concrete: Theoretical and experimental study," *Cem. Concr. Res.*, vol. 35, no. 11, 2005.

[13] N. Hamed, M. S. El-Feky, M. Kohail, and E. S. A. R. Nasr, "Effect of nano-clay de-agglomeration on mechanical properties of concrete," *Constr. Build. Mater.*, vol. 205, 2019.

[14] P. Hosseini, A. Afshar, B. Vafaei, A. Booshehrian, E. M. Raisi, and A. Esrafili, "Effects of nano-clay particles on the short-term properties of self-compacting concrete," *http://dx.doi.org/10.1080/19648189.2015.1096308*, vol. 21, no. 2, pp. 127–147, Feb. 2015.

[15] P. Mehrabi *et al.*, "Effect of pumice powder and nano-clay on the strength and permeability of fiber-reinforced pervious concrete incorporating recycled concrete aggregate," *Constr. Build. Mater.*, vol. 287, 2021.

[16] M. A. Mirgozar Langaroudi and Y. Mohammadi, "Effect of nano-clay on workability, mechanical, and durability properties of self-consolidating concrete containing mineral admixtures," *Constr. Build. Mater.*, vol. 191, 2018.

[17] Z. S. Al-khafaji, N. S. Radhi, and S. A. Mohson, "Preparation and modelling of composite materials (polyester-alumina) as implant in human body," *Int. J. Mech. Eng. Technol.*, vol. 9, no. 4, 2018.

[18] M. A. Mirgozar Langaroudi and Y. Mohammadi, "Effect of nano-clay on the freeze–thaw resistance of self-compacting concrete containing mineral admixtures," *Eur. J. Environ. Civ. Eng.*, 2019.

[19] A. M. Mohamed, "Influence of nano materials on flexural behavior and compressive strength of concrete," *https://doi.org/10.1016/j.hbrcj.2014.11.006*, vol. 12, no. 2, pp. 212–225, Aug. 2019.

[20] M. S. Morsy, S. H. Alsayed, and M. Aqel, "Hybrid effect of carbon nanotube and nano-clay on physico-mechanical properties of cement mortar," *Constr. Build. Mater.*, vol. 25, no. 1, pp. 145–149, Jan. 2011.

[21] F. Shahrajabian and K. Behfarnia, "The effects of nano particles on freeze and thaw resistance of alkali-activated slag concrete," *Constr. Build. Mater.*, vol. 176, pp. 172–178, Jul. 2018.

[22] M. R. Sakr and M. T. Bassuoni, "Effect of Nano-Based Coatings on Concrete under Aggravated Exposures," *J. Mater. Civ. Eng.*, vol. 32, no. 10, 2020.

[23] M. A. Elrahman, S. Y. Chung, and D. Stephan, "Effect of different expanded aggregates on the properties of lightweight concrete," *Mag. Concr. Res.*, vol. 71, no. 2, 2019.

[24] K. Dhir, R. G. C. Mays, and H. C. Chua, "Lightweight structural concrete with Aglite aggregate: mix design and properties," *Int. J. Cem. Compos. Light. Concr.*, vol. 6, no. 4, 1984.

[25] Y. Ke, A. L. Beaucour, S. Ortola, H. Dumontet, and R. Cabrillac, "Influence of volume fraction and characteristics of lightweight aggregates on the mechanical properties of concrete," *Constr. Build. Mater.*, vol. 23, no. 8, 2009.

[26] P. L. Domone, "Self-compacting concrete: An analysis of 11 years of case studies," *Cem. Concr. Compos.*, vol. 28, no. 2, 2006.

[27] S. G. Barton *et al.*, "Standard Practice for Selecting Proportions for Structural Lightweight Concrete (ACI 211 . 2-98) Reported by ACI Committee 211," *Aci 211.2-98*, vol. 98, no. Reapproved, 1998.

[28] A. M. Rashad, "A synopsis about the effect of nano-Al2O3, nano-Fe2O3, nano-Fe3O4 and nano-clay on some properties of cementitious materials - A short guide for Civil Engineer," *Materials and Design*, vol. 52. 2013.

[29] W. Zhu, P. J. M. Bartos, and A. Porro, "Application of nanotechnology in construction Summary of a state-of-the-art report," *Mater. Struct. Constr.*, vol. 37, no. 273, 2004.

[30] I. Specifications, "Properties of Portland Cement," 2019. .
[31] S. Hedjazi, "Compressive Strength of Lightweight Concrete," in *Compressive Strength of Concrete*, 2020.
[32] "Iraqi Specification," *Baghdad*, 1984. .
[33] T. Tamut, R. Prabhu, K. V. of research in LastName, and undefined LastNameLastName2014, "Partial replacement of coarse aggregates by expanded polystyrene beads in concrete," *kresttechnology.com*, 2014.
[34] A. C1240-15, "Standard Specification for Silica Fume Used in Cementitious Mixtures, West Conshohocken," *PA*, 2015. .
[35] S. E. for C. Chemicals, "High Performance Superplasticiser Concrete Admixture," *Sika ViscoCrete® -5930*, 2015. .
[36] K. Heiza, F. Eid, and T. Masoud, "Behavior of Reinforced Concrete Slabs Cast with Light Weight Self Compacting Concrete," *J. Eng. Sci. Mil. Technol.*, vol. 17, no. 17, pp. 1–12, Apr. 2017.
[37] "ASTM C192 / C192M - 18 Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory." .
[38] ASTM C642-13, "Standard test method for density, absorption, and voids in hardened concrete, ASTM International," *ASTM Int.*, no. 3, 2013.
[39] B. BS EN 12390-3:2009, "Testing Hardened Concrete Part 3: Compressive Strength of Test Specimens," *Bs En*, 2009.
[40] H. E. Elyamany, A. E. M. Abd Elmoaty, and B. Mohamed, "Effect of filler types on physical, mechanical and microstructure of self compacting concrete and Flow-able concrete," *Alexandria Eng. J.*, vol. 53, no. 2, 2014.