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# Effect of (LECA) as a Partial Replacement of Coarse Aggregate on Some Properties of Glass Fiber Reinforced Self-Compacting Concrete

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## ABSTRACT

This study investigates fresh and hardened self-compacting concrete properties. LECA will be used in place of coarse aggregate in (0, 20, 40, and 60) % proportions in a partial replacement. First, four SCC mixes were made based on LECA volume fraction and then the second group was made by adding 1% glass fiber by volume to group one's mixes. Hardened concrete after 7, 28, and 56 days was tested for density, water absorption, and (compressive, splitting tensile, and flexural) strengths. Results suggest that LECA increases workability. Rising LECA percentage decreases compressive strength; for 60% LECA, the decrease was (51.90, 45.34, and 41.26) % for 7, 28, and 56 days, respectively. With 60% LECA replacement, flexural strength decreased by (54.38, 33.80, and 32.78) % for 7, 28, and 56 days, respectively. Density drops significantly with LECA, reaching its lower density at (60) % of LECA. Water absorption rises with the increase of LECA. After adding glass fiber workability dropped significantly, and hardened characteristics improved. Compressive strength increased slightly compared to the same mixtures without glass fibers. At20% of LECA the compressive strength increased by (5.58%) at 28 days compared to (60%) LECA at which the compressive strength increased by (3.82%). Glass fiber addition increased flexural strength significantly compared to the same mixes without glass fibers. The mixture with (20%) LECA had the greatest increase (24.46%) in 28 days, compared to the mix with (60%) LECA (18.22%). Density increased slightly with glass fibers. Glass fibers increase water absorption compared to the same mixes without glass fiber.

**Keywords:** Self-compacting concrete, LECA, Partial replacement, Glass fiber.

## 1. INTRODUCTION

Concrete is often compacted using traditional techniques like manual rodding and mechanical vibration/spinning of high-pressure shock. These techniques might not work in constructions with crowded reinforcement. Additionally, they need more time and effort during construction **(Okamura, 1997).** SCC is an obvious example of high-performance

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concrete that does not need mechanical vibration to fit in formwork in a compact way. In locations where concrete placement and compaction are complicated, self-compacted concrete is preferable compared to traditional concrete **(Fawzi and Al-Awadi, 2017)**. Professor Okamura and his students in the late 1980s created the early SCC **(Li et al., 2022)**. SCC exceeded traditional concrete in terms of characteristics including filling ability, ease of passage, and segregation resistance when it is still fresh **(Hachim and Fawzi, 2012; Al-Obaidy, 2017)**. When in its plastic condition, SCC takes the form of a formwork. When it is hardened, it produces dense, homogenous concrete that has better engineering features and is more durable than conventional vibrated concrete **(Al-Obaidey, 2017; Al-Kabi and Awad, 2024)**. The qualities of the prepared SSC combination are examined in accordance with EFNARC recommendations **(Russell, 1997).** Self-compacted concrete's workability is affected by a number of variables, including the type of structure, the placement and consolidation techniques selected, the formwork's shape, and the type of reinforcement**(Khayat et al., 1997).**

LECA is a lightweight aggregate that is produced using a rotary kiln method. It has three typical particle sizes (4 – 12) mm**(Mahdy, 2016)**. LECA is made from an exceptional plastic clay that contains little to no lime. Rotating kilns are used to dry, heat, and burn the clay at temperatures between 1100 and 1300 °C **(Abbas, 2022)**. During firing the organic chemicals in the clay burn off which causes the clay pellets to expand and become honeycombed but the exterior of each granule melts and sintered. The resulting porous, lightweight ceramic pellets have a high crushing resistance **(Selman and Abbas, 2023)**. LECA is a natural product with no hazardous ingredients. It has good acoustic and thermal insulation qualities, is noncombustible, nonbiodegradable, inert, resistant to chemicals and frost, and won't degrade in water, It's inactive with a neutral pH **(Boudaghpour and Hashemi, 2008).**

There are various natural and Artificial fibers are added to concrete to enhance its characteristics such as steel, glass, and carbon fibers **(Anas et al., 2022)**. Adding glass fiber enhances the behavior of SCC. Glass fiber percentage is contingent on the glass fiber type, shape, volume, and weight content **(Mohamed et al., 2022)**. **(Kumar et al., 2022)** investigated the characteristics of SCC at which LECA will be used as a coarse aggregate replacement by (0, 10, 20, 30, 40, and 50) %. According to nondestructive test data, values are continuously reducing as the proportion of LECA increases. Results of hardened tests show a significant range beyond 30% of LECA substitution in SCC. **(Ayswarya et al., 2020)** studied a replacement of coarse aggregate by LECA by (20, 40, 60, and 80) % in SCC. According to the compressive strength test results on the third and seventh days, 20% is the ideal replacement, indicating that 80% of the reference mix's target strength was achieved. **(Ameer et al., 2020)** studied the effect of using (25, 50, 75, or 100) % LECA as a coarse aggregate replacement in self-compacting concrete (SCC). The compressive strength dropped with an increase in LECA percentage which was (15.83,25.96,35.0,44.72) % at 28 days. There was a decrease in splitting tensile strength of about (22.9, 31.2, 36.9, 44.4) % at 28 days, also the flexural strength dropped by (10, 18.7, 36.3, and 41.9) % at 28 days. **(Babu et al., 2008)** discovered that adding glass fibers in SCC mix resulted in a little increase in the final strength.

**(Hake et al., 2020)** investigated the impact of glass fibers on SCC. The results indicate that when (0.25 and 0.50) % of glass fibers were added, GFRSCC compressive, split tensile, and flexural) strengths raised by (2.80 and 12.42) %, (4.47 and 25.12) %, and (6.57 and 14.34) % respectively, in comparison to the traditional SCC. **(Yew et al., 2020)** used high-content LECA as a partial replacement at content percentages of (50, 60, 70, 80, and 90) %. The

results indicate that the best results of (compressive, splitting tensile, and flexural) strengths, density, and workability, were obtained when crushed LECA was used at 70% of replacement. **(Ahmad et al., 2017)** found that Glass fiber significantly improves (splitting tensile and flexural) strengths while having a negligible impact on the modulus of elasticity and compressive strength in SCC. **(Harle, 2014)** discovered that, when compared to concrete without fibers, (compressive, flexural, and splitting tensile) strengths of conventional concrete with glass fibers at 3, 7, and 28 days increased by (20 - 30) %, (25 - 30) %, and (25 - 30) %, respectively.
The purpose of this study is to examine the behavior SCC before and after adding glass fiber with varied quantities (0, 20, 40, and 60) % of coarse aggregate substituted by LECA. The mechanical properties (compressive and flexural) strengths in addition to dry density and water absorption are used to assess the behavior of SCC.

## 2. MATERIALS AND METHOD

### 2.1 Materials

2.1.1 Cement

For all concrete mixes, ordinary Portland Cement (OPC) (CEM I-42.5 R) was used. **Tables 1** and **2** present a description of the properties of the cement used, which complies with **(IQS No. 5, 2019)** specifications.

**Table 1.** Chemical composition and main compounds of OPC

| Chemical composition | Result | Limits of (IQS No. 5, 2019) |
|---|---|---|
| Lime (CaO) | 63.2 | ----- |
| Silica ($SiO_2$) | 20.44 | ----- |
| Alumina ($Al_2O_3$) | 5.35 | ----- |
| Iron Oxide ($Fe_2O_3$) | 3.45 | ----- |
| Magnesia (MgO) | 2.95 | 5.0 (max) |
| Sulfate ($SO_3$) | 2.40 | ≤ 2.8 If $C_3A$ > 3.5 |
| Insoluble residue (I.R) | 0.76 | 1.5 (max) |
| Loss on Ignition (L.O.I) | 1.90 | 4.0 (max) |
| Main compound of OPC | | |
| Tri Calcium Silicate ($C_3S$) | 50.85 | ----- |
| Di Calcium Silicate ($C_2S$) | 20.64 | ----- |
| Tri Calcium Aluminate ($C_3A$) | 9.15 | ----- |
| Tera Calcium Aluminate Ferrite ($C_4AF$) | 10.90 | ----- |

**Table 2.** Physical properties of OPC

| Physical Properties | Result | Limits of (IQS No.5, 2019) |
|---|---|---|
| Specific surface area $m^2/kg$ (Blaine method) | 378 | ≥ 280 |
| Initial setting time, (min) | 162 | ≥ 45 |
| Final setting time, (hr : min) | 4:30 | ≤ 10 |
| Compressive strength, (MPa)<br>@ 2 day<br>@ 28 day | <br>23<br>43.9 | <br>≥ 20<br>≥ 42.5 |

*Tested in the consulting Engineering Bureau at the University of Baghdad

### 2.1.2 Fine Aggregate (Sand)

In this research, all of the concrete mixes included natural sand. sand's characteristics and grading conform to **(IQS No. 45, 1984)**. **Table 3** shows the characteristics of the sand used. The sand graduation is shown in **Table 4**.

**Table 3.** Chemical and physical properties of fine aggregate

| Property | Specification | Result | Limits of (IQS No.45, 1984) |
|---|---|---|---|
| Specific gravity | **(ASTM C128, 2007)** | 2.58 | -------- |
| Absorption % | **(ASTM C128, 2007)** | 0.94 | -------- |
| Dry rodded density (kg/m$^3$) | **(ASTM C29/C29M, 2007)** | 1647 | -------- |
| Sulfate content % ($SO_3$) | **(Iraqi Reference Guide No.500/3, 2018)** | 0.26 | 0.5%(max) |
| Fine particles passing from sieve 75 μm, % | **(Iraqi Reference Guide No.500/4, 2018)** | 2.73 | 5.0%(max) |

**Table 4.** Grading of fine aggregate

| Sieve size (mm) | Passing % | Limits of (IQS No.45, 1984), zone (2) |
|---|---|---|
| 10 | 100 | 100 |
| 4.75 | 93 | 90-100 |
| 2.36 | 79 | 75-100 |
| 1.18 | 71 | 55-90 |
| 0.6 | 53 | 35-59 |
| 0.3 | 26 | 8-30 |
| 0.15 | 4 | 0-10 |
| Fineness Modulus | 2.740 | |

### 2.1.3 Coarse Aggregate (gravel)

Natural gravel with a nominal size of 10mm from the Al-Nibaee area was used. **Tables 5** and **6** demonstrate that the aggregate utilized satisfies Iraq's **(IQS No. 45, 1984)** requirements.

**Table 5.** Grading of coarse aggregate.

| Sieve size (mm) | Passing % | Limits of (IQS No. 45, 1984) (10) mm |
|---|---|---|
| 20 | 100 | 100 |
| 14 | 100 | 100 |
| 10 | 96 | 85-100 |
| 5 | 18 | 0-25 |
| 2.36 | 4 | 0-5 |

**Table 6.** Chemical and physical properties of coarse aggregate.

| Property | Test result | Limits of (IQS No. 45, 1984) |
|---|---|---|
| Specific gravity | 2.654 | ------ |
| Absorption | 0.6% | ------ |
| $SO_3$ | 0.05% | ≤0.1% |
| Dry rodded density | 1642 kg/m$^3$ | ------ |

2.1.4 Light Weight Expanded Clay Aggregate (LECA)

LECA with a nominal size of 9.5 mm was used in this research, as shown in **Fig. 1**. **Tables 7** and **8** describe the grading and characteristics of LECA, respectively.

**Table 7.** Grading of (LECA).

| Sieve size (mm) | Passing % | (ASTM C330, 2017) Nominal size 2.36mm-9.5mm |
|---|---|---|
| 12.5 | 100 | 100 |
| 9.5 | 97 | 80-100 |
| 4.75 | 18 | 5-40 |
| 2.36 | 3 | 0-20 |

**Table 8.** Properties of (LECA).

| Property | Result | Specification | Limits of (IQS No.45/1984) |
|---|---|---|---|
| Specific gravity | 0.55 | **(ASTM C128, 2007)** | ------ |
| Absorption % | 19 | **(ASTM C128, 2007)** | ------ |
| Bulk density (loos), kg/m$^3$ | 320 | **(ASTM C29/C29M, 2007)** | ------ |
| Sulphate content $SO_3$, % | 0.05 | **(Iraqi Reference Guide. No.500/3, 2018)** | ≤ 0.1 |

*Tested in the consulting Engineering Bureau at the University of Baghdad

(a) (b)

**Figure 1.** (a) Light Weight Expanded Clay Aggregate (LECA), (b) Magnification image of LECA.

2.1.5 Silica Fume (SF)

Silica fume is a very fine pozzolanic material. In this research, the weight of cement was partially replaced with silica fume. **Tables 9** and **10** illustrate the chemical analysis and physical description of silica fume. The results indicate that silica fume complies with **(ASTM C1240, 2014).**

**Table 9.** Physical properties of silica fume.

| Property | Test result | (ASTM C1240, 2014) |
|---|---|---|
| Percent retained on 45-µm (No. 325) sieve, % | 8 | ≤ 10 |
| Accelerated pozzolanic Strength activity index @ 7 days, % | 120 | ≥ 105 |
| Specific surface area, m$^2$/g | 17 | ≥ 15 |

*Tested in the laboratories of the Building Research Center

**Table 10.** Chemical analysis of silica fume.

| Oxide composition | Oxide content % | (ASTM C1240, 2014) |
|---|---|---|
| $SiO_2$ | 90 | ≥ 85.0 |
| L.O.I | 2.8 | ≤ 6.0 |
| Moisture content | 0.37 | ≤ 3.0 |

### 2.1.6 Chemical Admixture (Super-Plasticizer)

In this investigation, the super-plasticizer (SP) with a dose range of (0.15-1) liter was added for every 100 kg of cementitious materials. It is used to achieve high early strength, high flow ability, and low water content. It satisfies **(ASTM C494, 2013)**, type F, and it does not contain chlorides. **Table 11** illustrates this admixture's characteristics.

**Table 11.** Technical properties of super-plasticizer (given by manufacturer).

| Appearance | Transparent or Light Brown Liquid |
|---|---|
| Calcium Chloride | Nil |
| Density | 1.10 ± 0.02 gm/ml |
| Viscosity | 450 cPs @ 20°C |
| Setting time | Initial and final setting time depends on temperature, cement quantity, and dosage used |

### 2.1.7 Glass Fiber (GF)

The glass fibers that were employed had an aspect ratio of 80 and a circular cross-section, as shown in **Fig. 2**. It is 12 mm in length. Its diameter is 0.15 mm, and it is alkali resistant. **Table 12** lists the characteristics that were provided by the supplier.

**Figure 2.** Glass fiber.

**Table 12.** Properties of glass fibers.

| Nature | Alkali Resistant Glass |
|---|---|
| Appearance | Opaque |
| Specific Gravity | 2.68 |
| Fiber Length | 12 mm |
| Absorption | Nil |
| Chemical Resistance | Very High |
| Modulus of Elasticity | 72 GPa |
| Tensile Strength | 1.700 MPa |
| Softening Point | 860°C |

2.1.8 Mixing Water

In this study, the concrete mixtures were mixed and cured using tap water and it complies with **(IQS. No. 1703, 1992)**.

## 2.2 SCC Mixes

Two groups of mixes were conducted based on **(EFNARC, 2005)**, the first group consisted of Four SCC mixes depending on coarse aggregate volume fraction replacement by (0, 20, 40, and 60) % LECA. The second group consists of adding (1% glass fiber) by volume for the same mixes as group one. For all mixes, the water-cement ratio (w/p) was 0.32, the fine aggregate was 866 kg/m$^3$, and the superplasticizer was 1 % for each 100 kg of cementitious material. Details of concrete mixes are shown in **Table 13**.

**Table 13.** Details of SCC mixes.

| Mixes | Cement kg/m$^3$ | Silica Fume kg/m$^3$ | Water kg/m$^3$ | Coarse aggregate kg/m$^3$ | LECA Kg/m$^3$ | Glass Fiber % |
|---|---|---|---|---|---|---|
| MR | 540 | 54 | 188 | 750 | 0 | 0 |
| $ML_{20}$ | 540 | 54 | 188 | 600 | 28.7 | 0 |
| $ML_{40}$ | 540 | 54 | 188 | 450 | 57.5 | 0 |
| $ML_{60}$ | 540 | 54 | 188 | 300 | 86 | 0 |
| $MLG_{20}$ | 540 | 54 | 188 | 600 | 28.7 | 1 |
| $MLG_{40}$ | 540 | 54 | 188 | 450 | 57.5 | 1 |
| $MLG_{60}$ | 540 | 54 | 188 | 300 | 86 | 1 |

## 2.3 Mixing Procedure

Coarse aggregate and LECA were first immersed in water for 24 hours and then spread in the laboratory for enough time to remove excess water to get an SSD state to prevent them from absorbing mixing water. In this investigation the method of **(Doukakis, 2013; Abbas et al., 2016)** was used to make SCC, the fine materials which include cement and silica fume were thoroughly mixed, coarse aggregate was mixed with the fine aggregate in the mixing bowl, and then the mixture of fine materials added to them and ensure well dry mixing. LECA was mixed with (1/3) of the amount of mixing water for one minute then poured with the mixture in the mixing bowl and mixed well, superplasticizer was poured into the pail's remaining water and stirred and added to the mixing bowl and mixed them for three minutes. As seen in **Fig. 3**, glass fibers were added eventually and slowly to achieve a homogenous distribution. Three more minutes were spent on the mixing process. After that, the mixture is allowed to rest for two minutes before the fresh state tests are carried out and the concrete mixture is poured into the molds.

## 2.4 Preparation, Casting, and Curing of Specimens

After finishing the mixing procedure, the steel molds were prepared, cleaned, and lubricated with oil. Subsequently, the concrete was cast into the molds without any vibration. Cube (100×100×100) mm specimens were used to evaluate the compressive strength of each concrete mix, (100 × 200) mm cylinder was used for the splitting tensile strength test. The prism for flexural strength was (80x80x380) mm. After that, nylon sheets were placed over the specimens. The molds were removed after a 24-hour period. Following that, the specimens were cured for (7, 28, and 56) days in the water tank.

**Figure 3.** Glass fiber addition.

## 2.5 Fresh Concrete Testing

To evaluate the properties of SCC in a fresh state, five tests were conducted (at the material laboratory, college of enginering, university of baghdad): to evaluate flowability, a slump flow test was used. To evaluate flowability and viscosity, $T_{500mm}$ and V-funnel tests were used. To evaluate passing ability, L-box tests were used. To evaluate segregation resistance, sieve segregation tests were used. Before the concrete is poured into the molds, these tests are conducted following the finish of the mixing procedure based on **(EFNARC, 2005).**

## 2.6 Hardened Concrete Testing

### 2.6.1 Compressive Strength Test

According to **(BS EN 12390-3, 2019)**, the compressive strength test for SCC was conducted utilizing a cube of 10×10×10 cm (at the material laboratory, college of enginering, university of baghdad) as seen in **Fig. 4**. SCC cubes were used in this research at ages 7, 28, and 56 days. By averaging the three specimens at each age the compressive strength was determined.

**Figure 4.** Compressive strength test.

### 2.6.2 Flexural Strength Test

The flexural strength was measured using (80×80×380) mm prism specimens supported simply under center point loading (at the material laboratory, college of Enginering, university of Baghdad) as shown in **Fig. 5**, in accordance with **(ASTM C293, 2008).** SCC specimens were used in this test at ages 7, 28, and 56 days. The flexural strength was determined by averaging the three specimens at each age.

**Figure 5.** Flexural strength test

2.6.3 Oven Dry Density

SCC dry density was calculated (at the material laboratory, college of Engineering, University of Baghdad) using **(ASTM C642, 2013).** The oven dry density was measured by using (100×100) mm cubes after drying them at (100±2 0C) for 24 hours. They were weighed ($W_0$).

2.6.4 Water Absorption

SCC water absorption was measured (at the material laboratory, college of Engineering, University of Baghdad) using (**ASTM C642, 2013)**. Initially, the samples were placed in an oven set to between 100 and 110 ˚C for 24 hours of drying. Specimens were taken out of the oven and let to cool to room temperature before their masses were calculated. The specimen was measured for its dry mass (A). Then, specimens were submerged for 24 hours in water. Any remaining water was then wiped off with a piece of cloth, and the specimen's weight (saturated surface dry) was calculated (B).

## 3. RESULTS AND DISCUSSION

### 3.1 Fresh Concrete Properties

The results of fresh concrete tests (slump flow, $T_{500mm}$, V-funnel, L-box, and sieve segregation) tests are shown in **Table 14**. It can be seen that the workability increased with the increase of LECA percentage by (0, 20, 40, and 60) % due to its rounded appearance, low specific gravity, and high water absorption as seen in a previous study by **(Kumar et al., 2022)**. At (60%) LECA the SCC reached its highest slump flow value with a rising percentage of (8.42) % compared with the reference mixture. After adding glass fiber, the workability decreased significantly compared with the same mixes without glass fiber due to the increase in internal friction.

**Table 14.** Results of fresh concrete tests.

| Mixes | Slump flow(mm) | $T_{500mm}$ (sec) | V-funnel (sec) | L-box | Segregation index, % |
|---|---|---|---|---|---|
| MR | 700 | 4.1 | 10.5 | 0.82 | 11.1 |
| $ML_{20}$ | 715 | 3.9 | 10.1 | 0.87 | 11.5 |
| $ML_{40}$ | 738 | 3.7 | 9.7 | 0.93 | 12.2 |
| $ML_{60}$ | 759 | 3.5 | 9.2 | 0.96 | 12.9 |
| $MLG_{20}$ | 695 | 4.3 | 11.3 | 0.84 | 10.6 |
| $MLG_{40}$ | 707 | 4.1 | 10.5 | 0.89 | 11.7 |
| $MLG_{60}$ | 715 | 3.9 | 9.6 | 0.93 | 11.1 |
| **(EFNARC, 2005) Limits** | SF1 550 - 650<br>SF2 660 - 750<br>SF3 760 - 850 | $T_{500}$ > 2, V-funnel (9 to 25) | | ≥ 0.8 with 3 bars | SR1 ≤ 15<br>SR2 ≤ 20 |

## 3.2 Hardened Concrete Properties

### 3.2.1 Compressive Strength

Compressive strength probably is the most essential property used, several other mechanical characteristics of SCC are related to this property. The findings of the compressive strength test conducted on the cubes of the mixes of SCC at 7, 28, and 56 days are shown in **Table 15** and **Fig. 6**, by increasing the proportion of LECA by (0, 20, 40, and 60)% in the unreinforced SCC it was noticed a significant decrease in compressive strength, for 20% of LECA the decrease was (35.10, 16.74, and 16)% for 7, 28, 56 days, respectively, and for 40% of LECA the decrease was (46.62, 34.65, and 21.47)% for 7, 28, and 56 days, respectively, and for 60% of LECA the decrease was (51.90, 45.34, and 41.26) for 7, 28, and 56 days, respectively. The compressive strength reduction contributed to the high porosity and low specific weight of LECA. Although increasing LECA percentage lead to decrease in the strength but also it leads to decrease the weight of concrete, high thermal and acoustic isolation, and better behavior in fire which is compatible with (Abdullah and Mohammed, 2023). Adding (1%) by volume of glass fibers to the same mixes that contain (20, 40, and 60) % of LECA caused the compressive strength to improve slightly compared with mixes without glass fibers. For 20% LECA the compressive strength enhancement after adding glass fibers was the best which was (4.07, 5.58, and 9.52) % for 7,28, and 56 respectively.

**Table 15.** Results of compressive strength test.

| Mixes | Compressive Strength, MPa | | |
|---|---|---|---|
| | **7 days** | **28 days** | **56 days** |
| MR | 34.1 | 43 | 47.5 |
| $ML_{20}$ | 22.1 | 35.8 | 39.9 |
| $ML_{40}$ | 18.2 | 28.1 | 37.3 |
| $ML_{60}$ | 16.4 | 23.5 | 27.9 |
| $MLG_{20}$ | 23 | 37.8 | 43.7 |
| $MLG_{40}$ | 18.9 | 29.3 | 40.5 |
| $MLG_{60}$ | 17 | 24.4 | 30.1 |

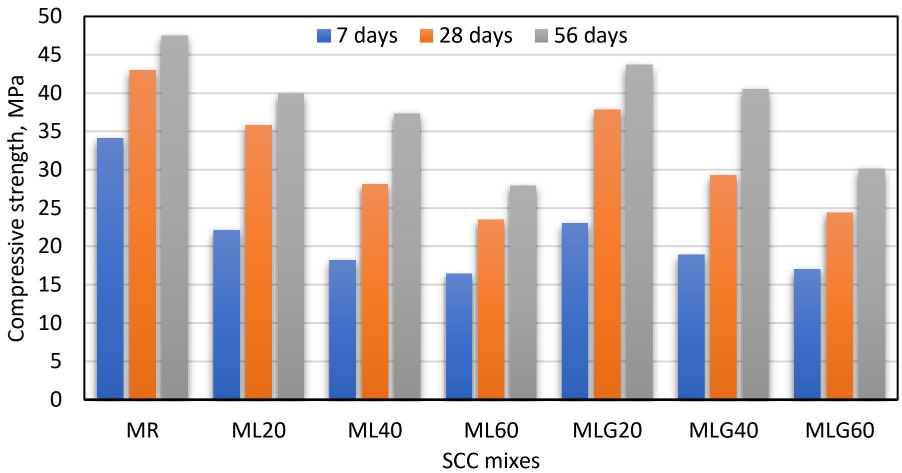


**Figure 6**. Effect of LECA on compressive strength of SCC.

3.2.2 Flexural Strength

Flexural strength testing assesses how materials react to typical beam loads. For the test, prisms of (80 x 80 x 380) mm were used at three curing ages (7, 28, and 56) days. The results of flexural strength are shown in **Table 16** and **Fig. 7**. By increasing the proportion of LECA by (0, 20, 40, and 60)% in the unreinforced SCC it was noticed a significant decrease in flexural strength, for 20% of LECA the decrease was (41.4, 22.38, and 15.44)% for 7, 28, 56 days, respectively, and for 40% of LECA the decrease was (48.07, 24.60, and 23.54)% for 7, 28, and 56 days, respectively, and for 60% of LECA the decrease was (54.38, 33.80, and 32.78) % for 7, 28, and 56 days, respectively. This reduction in flexural strength is due to the round shape of LECA which weakens the connection with the cement paste. After adding (1%) by volume glass fibers to the same mixes the flexural strength improved significantly compared with mixes without glass fibers, but the increase in flexural strength decreased with the increase of LECA. For 20% LECA the increase in flexural strength after adding glass fibers were the best which was (40.41, 24.46, and 17.51) % for 7,28, and 56 respectively.

**Table 16.** Results of flexural strength test.

| **Mixes** | **Flexural Strength, MPa** | | |
|---|---|---|---|
| | **7 days** | **28 days** | **56 days** |
| MR | 5.7 | 6.3 | 7.9 |
| $ML_{20}$ | 3.34 | 4.89 | 6.68 |
| $ML_{40}$ | 2.96 | 4.75 | 6.04 |
| $ML_{60}$ | 2.6 | 4.17 | 5.31 |
| $MLG_{20}$ | 4.69 | 6.25 | 7.85 |
| $MLG_{40}$ | 4.13 | 5.76 | 7.03 |
| $MLG_{60}$ | 3.58 | 4.93 | 6.1 |

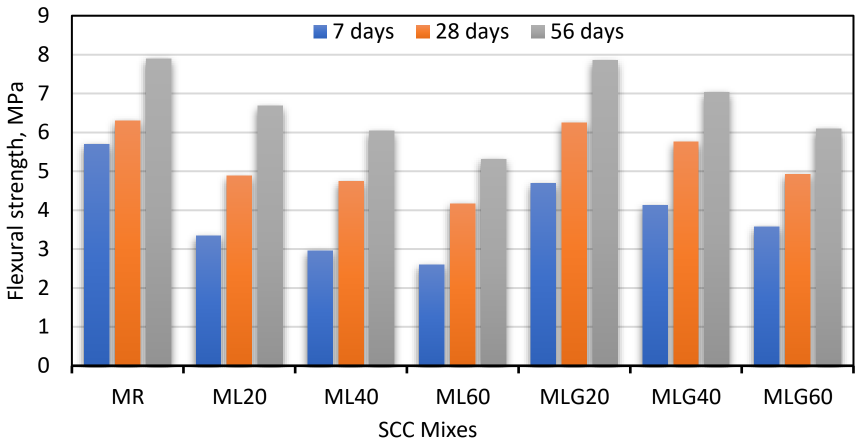


**Figure 7**. Effect of LECA on flexural strength of SCC.

3.2.3 Oven Dry Density

The dry density of each mix was established, **Table 17** and **Fig. 8** show the test findings for the SCC specimens' oven dry density at 28 days. The results show that the density decreases gradually with the increase of LECA percentage (20, 40, and 60%) and the maximum increase was at LECA percentage (60%) which was (18.01%), this decrease in density is due to the low weight of LECA compared with natural coarse aggregate. After the addition of (1%) volume fraction of glass fiber, there was a slight increase in density.

**Table 16.** Results of density test.

| Mixes | Density, Kg/m³ at 28 days |
|---|---|
| MR | 2420 |
| $ML_{20}$ | 2289 |
| $ML_{40}$ | 2195 |
| $ML_{60}$ | 1984 |
| $MLG_{20}$ | 2310 |
| $MLG_{40}$ | 2219 |
| $MLG_{60}$ | 2025 |

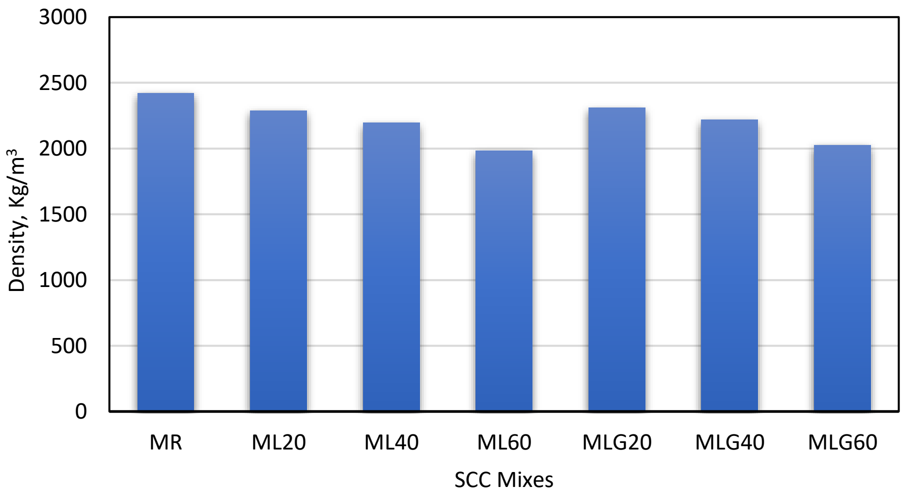


**Figure 8**. Effect of LECA on the density of SCC.

3.2.4 Water Absorption

At 28 days, the water absorption values for the SCC specimens are shown in **Table 17** and **Fig. 9**. The findings show that water absorption increases significantly as the percentage of LECA increases by (20,40, and 60) % to reach its maximum increase at (60) % of LECA which was (17.03) % because LECA has a high porosity compared with normal coarse aggregate. After the addition of (1%) glass fiber water absorption also increases compared with mixtures without glass fibers.

**Table 16.** Results of water absorption test.

| Mixes | Water absorption, % at 28 days |
|---|---|
| MR | 2.7 |
| $ML_{20}$ | 2.85 |
| $ML_{40}$ | 2.94 |
| $ML_{60}$ | 3.26 |
| $MLG_{20}$ | 2.93 |
| $MLG_{40}$ | 3.16 |
| $MLG_{60}$ | 3.35 |

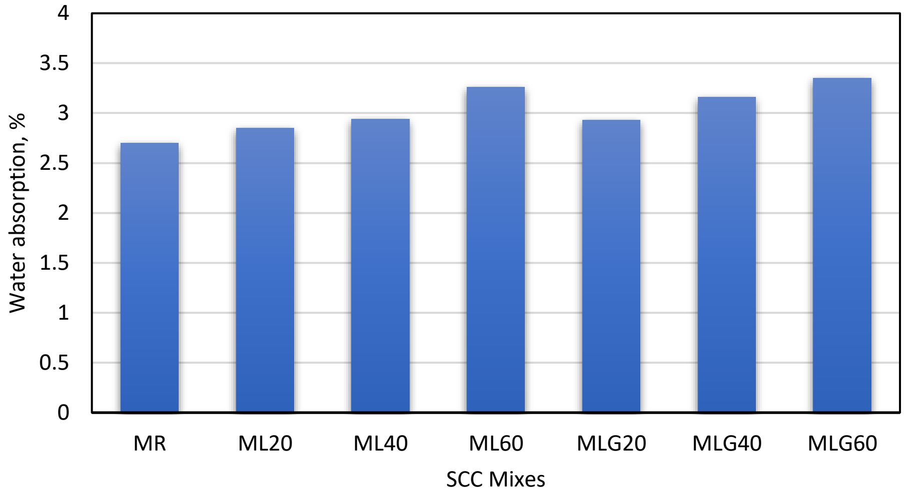


**Figure 9**. Effect of LECA on the absorption of SCC.

## 4. CONCLUSIONS

The effect of the partial replacement of lightweight expanded clay (LECA) from the coarse aggregate and the addition of (1%) by volume of glass fibers on SCC properties in its fresh and hardened state can be summarized below:

1. The partial replacement of LECA with coarse aggregate by (20, 40, and 60) % caused an increasing workability gradually. However, after the addition of glass fibers, the workability decreased significantly.
2. The increase in LECA replacement percentage caused a significant decrease in compressive strength of SCC and this decrease was found to be very high at (60%) of LECA which was 45.34 % at 28 days comparing with the reference mix. But glass fiber addition enhanced the compressive strength slightly and the highest effect was in the mix with (20%) of LECA and the increase was 5.58 % at 28 days comparing with the same mix without fiber.
3. The increase in LECA percentage caused a gradual decrease in flexural strength and the maximum decrease was at (60%) of LECA which was 33.8 % at 28 days comparing with the

reference mix. But this strength improved significantly after the addition of glass fibers and the best effect was in the mixture with (20%) of LECA and the increase was 24.46 % at 28 days compared with the same mix without fiber.
4. Density decreased gradually with the increase of LECA percentage and the lowest density was achieved at (60%) of LECA which was 1984 kg/m$^3$ at 28 days. The addition of fiber affects slightly on the density.
5. The increase in LECA percentage affected largely the water absorption to reach its maximum increase at (60%) of LECA which was 20.74 % at 28 days compared with the reference mix, the addition of glass fibers caused a higher increase in water absorption.

## NOMENCLATURE

| Symbol | Description |
|---|---|
| SCC | Self-compacting concrete |
| LECA | Lightweight expanded clay aggregate |
| SF | Silica fume |
| GF | Glass fiber |
| SP | Superplasticizer |

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## Credit Authorship Contribution Statement

Hiba Hassan Ghanem: Experimental work, writing, and editing. Asist. Proof. Hadeel Khalid Awad: Supervision, reviewing, evaluation, and editing.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have evidence to affect the work reported in this paper.

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# تأثير استخدام (LECA) كبديل جزئي للركام الخشن على بعض خواص الخرسانة ذاتية الرص والمسلحة بألياف الزجاج

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## الخلاصة

تركز هذه الدراسة على خواص الخرسانة ذاتية الرص في الحالة الطرية والمتصلبة. تم استخدام (*LECA*) كبديل جزئي للركام الخشن. أولا تم انتاج أربع خلطات بنسب ليكا (٠، ٢٠، ٤٠، و٦٠) ٪، المجموعة الثانية تتكون من إضافة (١٪) من الألياف الزجاجية حجمياً لنفس خلطات المجموعة الأولى. تم اجراء اختبارات مقاومة الانضغاط، مقاومة الانحناء، الكثافة، والامتصاص لتقييم خصائص الخرسانة الصلبة بعد معالجة العينات لمدة ٧ و٢٨ و٥٦يومًا. أظهرت النتائج أن قابلية التشغيل زادت مع زيادة *LECA*. بزيادة النسبة المئوية لــ *LECA* تنخفض مقاومة الانضغاط، بشكل ملحوظ، لــنسبة استبدال ٦٠٪ من *LECA* كان الانخفاض (٥١,٩، ٤٥,٣٤، و٤١,٢٦) ٪ عند ٧ و٢٨ و٥٦ يومًا على التوالي. تتناقص مقاومة الانحناء أيضًا مع زيادة *LECA*، بالنسبة لـ ٦٠٪ من *LECA* كان الانخفاض (٥٤,٣٨، ٣٣,٨٠، و٣٢،٧٨) ٪ عند ٧ و٢٨ و٥٦ يومًا على التوالي. كما تتناقص الكثافة بشكل ملحوظ مع زيادة *LECA* لتصل إلى قيمتها الأقل عند (٦٠٪) من *LECA*. يزيد امتصاص الماء مع زيادة *LECA*. بعد إضافة (١٪) من حجم الألياف الزجاجية انخفضت قابلية التشغيل بشكل ملحوظ وتحسنت خواصها الصلبة، حيث تحسنت مقاومة الانضغاط قليلاً مقارنة مع نفس الخلطات التي لا تحتوي على ألياف زجاجية. للخليط الذي يحتوي على (٢٠٪) من *LECA* كانت الزيادة (٥,٥٨٪) عند ٢٨ يوم مقارنة مع الخلطات التي تحتوي على (٦٠٪) من *LECA* والتي كانت (٣,٨٢٪) عند ٢٨ يوم. أدت إضافة الألياف الزجاجية إلى الخلطات إلى تحسين مقاومة الانحناء بشكل ملحوظ مقارنة بالخلطات التي لا تحتوي على ألياف زجاجية، وكان أفضل تأثير للخليط الذي يحتوي على (٢٠٪) من *LECA* وكانت الزيادة (٢٤,٤٦٪) مقارنة مع الخلطات التي تحتوي على (٦٠٪) من *LECA* والتي كانت (١٨,٢٢٪). بعد اضافة ألياف الزجاج كانت هناك زيادة خفيفة جداً في الكثافة. يزداد امتصاص الماء أيضًا مقارنة بالخلطات التي لا تحتوي على ألياف زجاجية.

**الكلمات المفتاحية:** الخرسانة ذاتية الرص، الليكا، الاستبدال الجزئي، الياف الزجاج.