Flexural Strength of Fibrous Light-Weight Self-Compacted Concrete beams

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Abstract: In this research, the effect of using steel fiber and polypropylene on the behavior of the lightweight self-compacting concrete (LWSCC) beams have been studied. Seven beams have been cast with different parameters and compared. Two ratios of coarse aggregate replacement with lightweight aggregate expanded clay (LECA) have been considered partially and full replacement (50% and 100%) in this study based on previous study. Also, a 1% volumetric ratio fiber reinforcement has been added to investigate its effect on the flexural performance of LWSCC. A reduction in the ultimate load capacity and stiffness have been observed for LWSCC beams compared with the control beam by about 19% and 24.8% for partial and full LECA replacement, respectively. The steel fiber enhanced the performance of LWSCC beams in terms of cracking formation, crack width, ultimate capacity and allow the beams to have more ductile behavior. The ultimate load for fibrous LWSCC has been increased by about 11% and 12% for partial and full LECA replacement compared to beams without fibers. Beams with polypropylene and steel fibers exhibit similar behavior to the beams with steel fiber only in term of load-vertical displacement curves. However, the difference in the ultimate load capacity were 4% and 5% for the partial and full LECA replacement, respectively.

Keywords. Hybrid concrete, light weight concrete, polypropylene fiber, self-compacting concrete, steel fiber.

1. Introduction

Self-compacting concrete (SCC) has been first introduced in 1988 in Japan. Since that time, many researches have been done to examine the different parameters that may have influence on the mechanical properties of this concrete type [1]. The SCC is defined as concrete that has high fluidity and can flow under its weight to fill the spacing between reinforcing bars and any gab or corner without any afford of vibration [2]. The main cause of using SCC is durability which can be achieved by enhancing the quality of construction work [3].

When the self-weight has an important action on the total capacity of the structure, there will be a need to produce lightweight self-compacting concrete (LWSCC) by using the light-weight aggregate for achieving the fresh and hardened properties of concrete [4]. The LWSCC is a special concrete type that contains lightweight aggregate or large voids which decrease the density of the concrete. Many types of lightweight aggregate (LWA) can be used such as expanded clay, volcanic, pumice, slate, and shale, etc. [5,6,7,8]. The expanded clay has a density lower than normal aggregate [9]. The concrete produced...
from expanded clay have more compressive strength than the other types of aggregate. Expanded clay can be produced by heating the raw material in a rotary kiln at a temperature of (1000-2000)°C where the density of this material is around (610-900)kg/m³ [10]. Kumar and Prakash [11] showed that the average strength of lightweight concrete with cinder and light expanded clay aggregates (LECA) was 39.2 MPa with a density that varied in range of (1800-1950) kg/mm³.

Different types of fibers can be added to concrete to enhance the structural behavior of the structural members. The most common type is the copper coated wire which is called steel fiber. Adding the steel fiber leads to decrease the shrinkage and cracks width and increase the bond between the reinforcing and concrete [12]. Steel fiber improves the mechanical properties of the concrete such as limiting the crack width, increase load-bearing capacity and enhance concrete durability and ductility [13]. Another type of fiber that can be used is polypropylene fiber. This type can work to improve the compressive and tensile strength, thermal conductivity, and ductility of the concrete [14]. The hybrid fiber reinforcement can be employed by using a different kind of fibers with different properties. Hybrid fiber works to control drying shrinkage and cracking [14].

Heiza et al. [15] studied the effect of lightweight aggregate expanded clay (LECA) on the self-compacting concrete slab and it has been found the LWSCC with low density can be produced using expanded clay. LECA tends to increase the workability, passing ability, and stability for the fresh behavior of concrete. The first crack, and ultimate loads increase with the increasing in the reinforcement ratio. Wan et al. [16] studied the LWSCC by using perlite, scoria, and polystyrene (BST) as a lightweight aggregate and they found that the density, compressive strength, elastic modulus, and stress-strain curve have been reduced while segregation resistance and stability increased by increasing the binder content. For 10% BST replacement the compressive strength increased to 33.3%, and for 25% perlite, the compressive strength decreased by 21%, and for 25% scoria replacement, the compressive strength decreased 5%. Al-Shaar [17] studied the flexural behavior of filled steel tube beams with both LWC and SCC. The experimental showed that the lightweight filled steel tube and self-compacting filled steel tube had the same failure mode and similar to the normal concrete filled steel tube. The filled steel tube filled with SCC and LWC showed an enhancement in the ductility, flexural strength and moment capacity compared to normal concrete filled steel tube.

Mazaheripour et al. [14] found that when adding 0.3% polypropylene fiber, a decrease in the workability and slump flow from 720 to 430 mm without affecting the compressive strength and elastic modulus with an increase in the splitting tensile strength and flexural strength has been observed. Iqbal et al. [18] found that adding the steel fiber to LWSCC reinforced concrete beams enhanced the peak load and improved the bending moment. Cai et al. [19] found that when adding 1% of steel fiber increased the compressive strength and high splitting tensile strength by more than 1%. It also has been found that the adding of 0.5% steel fiber had little effect on the splitting strength. However, the flexural strength and ductility, and toughness have been increased by increasing the volume of steel fiber.

Ismael [20] found that the effect of steel fiber on the normal and high strength SCC slab resulted in an improvement in its flexural behavior, first crack, and ultimate load, and central deflection. While adding steel fiber to the high strength concrete had less effect than the normal strength that because the high strength concrete is more brittle than the normal concrete. However, increasing the steel fiber ratio led to a decrease central deflection of the slab.

Liu et al. [21] studied the effect of hybrid fibers on lightweight self-compacting concrete and found that the fly ash and silica fume had a good influence on the mechanical properties. Adding the steel and polypropylene fiber led to an improvement in the compressive, splitting, and flexural strength. Whereas, when adding more ratio of polypropylene led to decreasing the compressive strength. Al-Sibahi and Mashshay [22] performed an experimental program to study the behavior of reinforced column made with engineering cementitious composites (ECC) under concentric and eccentric load. Two steel fibers
ratios were employed (0.5% and 1%). The polypropylene ratio was kept to be 0.5%. The results showed that columns with only 1% steel fibers had a higher load-carrying capacity compared to columns with both steel and polypropylene fibers.

Adding fibers to the LWSCC had little attention from the researchers. In this study, the effect of employing both the steel and polypropylene fibers on the flexural strength of LWSCC beams has been investigated. Two ratios of coarse aggregate replacement with LECA have been considered partially and full replacement (50% and 100%). Two groups of fibers were employed with 1% as volumetric ratio.

2. Experimental Program

Seven simply supported beams have been cast in the experimental program with dimensions of (150 X 250 X 1650) mm to study different factors that can affect the structural behavior. The first beam has been considered as a control beam that has been prepared with only self-compacted concrete. Two lightweight RC beams have been prepared using expanded clay as a replacement for the coarse aggregate. Partial and full replacement of aggregate (50% and 100%) were employed in this study (based on the results of previous study [5]). The first beam has been cast with 50% replacement of coarse aggregate and the other has been prepared with 100% replacement. Then each type of LWSCC has been cast by adding steel fibers and hybrid fibers. The percentage of used fiber was 1% as a volumetric percentage based on the outcomes of previous study [22]. For the case of the hybrid fiber, the percentage has been 0.75% for the steel fiber and 0.25% for the polypropylene fiber. The properties of fibers used in this research are shown in Table 1. Other materials that used in this research have been Portland cement that follows the Iraqi specifications (IS No. 5:1984), coarse aggregate with a max size of 10 mm and sulfate content SO₃ of 0.08, fine aggregate with Sulfate content SO₃ (0.34), limestone powder (LP) with a specific gravity of (1.07) kg/m³, superplasticizer from (Sika ViscoCrete 5930-L), expanded clay (LECA) with a max size of 10 mm and bulk density of 260 kg/m³. The water-cement ratio (w/c) has been 0.35. The details and mix proportions of all used material are listed in Table 2. The specimen nomenclature uses S to refer to Specimen. The numbers following the letter S refer to coarse aggregate replacement percentage 00 for 0% replacement, 50 for partial replacement, and 100 for full replacement. The following letter F refers to Fiber. The numbers 0, 1, and 2 that follow the letter F refer to the use of fibers; 0 for the absence of fibers, 1 for the use of steel fibers only, and 2 for the use of hybrid fibers (steel and polypropylene fibers). The properties of fibers used in this experimental is listed in Table 1, while the mix properties for all specimen is listed in Table 2.

All beams have been reinforced with 2Φ16 steel bars as main tensile reinforcement and 2Φ10 as compressive reinforcement for practical consideration. The shear reinforcement has been provided using closed Φ10 at 100 mm c/c to ensure the flexural failure. The cross-section and steel reinforcement are shown in Error! Reference source not found.. Prior to beam casting, slump flow, and L- box tests have been recorded according to the limitation of EFNARC [23] as shown in Figure 2. The average 28-day compressive strengths of SCC and LWSCC based on cubes (150 x 150 x 150) mm and splitting tensile strength of (20 mm diameter, 200 mm height) of cylinder and flexural strength for (100 x 100 x 500) mm prism and density for all mixes are listed in Table 3. The average density of partial replacement of aggregate mix (for all types of fibers) was around 1930 kg/m³ while it was around 1630 kg/m³ for full aggregate replacement mix.
These values agrees with the definition of ACI Committee 213 [24]. All experimental work has been done at Civil Engineering Structural Lab at Al-Qadissyah University.

![Geometry and reinforcement of the beam](image)

Figure 1 Geometry and reinforcement of the beam

| Properties       | Steel fiber | Polypropylene fibers |
|------------------|-------------|----------------------|
| Diameter         | 0.2-.25 mm  | 0.032 mm             |
| Length           | 12-14 mm    | 12 mm                |
| Tensile strength | 2850 MPa    | 600-700 MPa          |

Table 1 The properties of steel and polypropylene fibers

| Mix name | LECA kg | Cement kg/m³ | Sand kg/m³ | Gravel kg/m³ | SF% | POLY S% |
|----------|---------|---------------|------------|--------------|-----|---------|
| S00-F0   | 0       | 468           | 754        | 858          | 0   | 0       |
| S50-F0   | 100     | 468           | 754        | 429          | 0   | 0       |
| S100-F0  | 200     | 468           | 754        | 0            | 0   | 0       |
| S50-F1   | 100     | 468           | 754        | 429          | 1   | 0       |
| S100-F1  | 200     | 468           | 754        | 0            | 1   | 0       |
| S50-F2   | 100     | 468           | 754        | 429          | 0.75| 0.25    |
| S100-F2  | 200     | 468           | 754        | 0            | 0.75| 0.25    |

Table 2 Mix proportions
3. Experimental Tests
All specimens have been tested using a four-point load configuration. Testing has been conducted using hydraulic jack as shown in Figure 3 with 1,000 kN capacity using a constant rate of loading 5 kN/min. An electronic dial gauge has been attached to the mid-span bottom face to record the central deflection. The instrumentations have been connected to automatic data acquisition devices to record the test deflection results. Cracks have been recorded during the loading stages based on visual inspection. Beams have been considered to be failed when excessive deflection is recorded, or the load had dropped significantly.
4. Results and Discussions

The control beam (S00-F0) has been manufactured with normal SCC without adding any type of fibers. The load-vertical displacement relationship is shown in figure 4.1. The first crack has been observed at a load level of 39 kN with 1.36 mm corresponding central deflection. The cracks continued to propagate and spread within the flexural region until the failure. However, the first shear crack appeared at 136 kN load level. The ultimate load for this specimen has been 262 kN with 16.36 mm corresponding central deflection. The load-vertical displacement relation for S0-F0 is shown in Figure 4.

4.1. Effect of using Light-Weight Concrete

Two percentages of aggregate replacement by LECA have been employed (50% and 100%). For a beam that contains 50% LECA (S50-F0), the first crack has been observed at a load level of 32 kN with 1.17 mm corresponding central deflection while the shear crack appeared at a load level of 135 kN with central deflection of 5.94 mm. The ultimate load for this specimen has been 212 kN, while the central deflection at this load level has been 12.5 mm. For a beam with full replacement (S100-F0), the first crack appears at 13 kN with 0.81 mm central deflection. However, the shear crack has been observed at load 123 kN with a corresponding central deflection of 5.7 mm. Moreover, the ultimate capacity for this specimen has been 197 KN with an 11.55 mm corresponding mid-span deflection. The effect of employing LECA in SSC beams is shown in Figure 5. From this figure and Table 4, there is a reduction
in ultimate load by (19%) and (24.8%) for S50-F0 and S100-F0 beams, respectively. It can also be noticed that the S50-F0 has the same initial stiffness compared to the control beam while there has been a slight difference in the initial stiffness for S100-F0. However, in the post-cracking region, a reduction in stiffness of the beam with 50% LECA replacement can be seen.

![Image](image_url)

Figure 5 Effect of LECA replacement in SSC beam

4.2. Effect of Using Steel Fiber
The effect of adding steel fiber on the performance of the LWSCC reinforced beam has been studied. The percentage of steel fiber that has been used with both 50% and 100% LECA replacement has been 1% as a volumetric ratio. For the S50-F1 beam which represents the SCC beam with partial aggregate replacement and 1% steel fiber, the ultimate load has been 236 kN which is higher than the ultimate load for S50-F0 (without steel fiber) by 11.32%. The deflection that corresponding to the ultimate load level has been 15.2 mm. The first crack for S50-F1 appeared at a load level of 38 kN with a deflection of 1.03 mm. However, the first shear crack appeared at a load level of 105 kN with a corresponding deflection of 4.123 mm. The ultimate load level for the beam that full replacement of coarse aggregate and 1% steel fiber (S100-F1) has been 220 kN with represents a 10.45% increase in the load level compared to S100-F0 (without steel fiber). The deflection corresponding to the ultimate load level has been 15.3 mm. The first crack appeared at a load of 27 kN with 1.15 mm mid-span deflection. Moreover, the shear crack has been noticed at a load level of 117 kN with 4.96 mm corresponding mid-span deflection. Figure 6 shows the load- vertical displacement relation and effect of using steel fiber with LWSCC. It can be noticed that the use of steel fiber enhances the beam stiffness, post-cracking behavior, and load-carrying capacity. It can be seen that steel fibers delayed the cracks formation and flexural strength due to the high tensile properties of steel fibers.

![Image](image_url)

Figure 6 Load-Vertical Displacement Relation and Effect of Using Steel Fiber with LWSCC
4.3. Effect of Using Poly-Propylene fibers

The effect of hybrid fibers on the behavior of the LWSCC beam has been studied. The hybrid fibers in this study consist of 0.75% steel fibers and 0.25% polypropylene fibers. Both beams with 50% and 100% LECA replacement and hybrid fibers have been studied. The S50-F2 beam (50% replacement and hybrid fibers) reached an ultimate load level of 225 kN with 14.5 mm corresponding central deflection. The first crack appeared at load level 38 kN with 1.4 mm central deflection. The shear crack has been recorded at a load level of 106 kN accompanied 4.1 mm central deflection. The S100-F2 beam (100% replacement and hybrid fibers) showed an increase in the ultimate load (5.58%) compared to S100-F0. The ultimate load has been 208 kN with 12.22 mm corresponding central deflection. The first crack appeared at a load level of 21 kN with a central deflection of 0.98 mm. However, the shear crack has been recorded at a load level of 86 kN with 3.9 mm central deflection. Figure 7 shows the load-vertical displacement relationship and effect of using hybrid (polypropylene and steel) fiber with LWSCC. All results in terms of cracking and ultimate load and their corresponding deflection are listed in Table 4.
Table 4 Test results

| Sample name | Cracking load (kN) | Displacement at cracking load (mm) | Ultimate load (kN) | Displacement at ultimate load (mm) |
|-------------|--------------------|-----------------------------------|--------------------|-----------------------------------|
| S00-F0      | 39                 | 1.36                              | 262                | 16.36                             |
| S50-F0      | 32                 | 1.17                              | 212                | 12.5                              |
| S100-F0     | 13                 | 0.81                              | 197                | 11.55                             |
| S50-F1      | 38                 | 1.03                              | 236                | 15.2                              |
| S100-F1     | 27                 | 1.15                              | 220                | 15.9                              |
| S50-F2      | 38                 | 1.4                               | 225                | 14.5                              |
| S100-F2     | 21                 | 0.98                              | 208                | 12.22                             |

5. Conclusions

This study investigated experimentally the performance of light-weight self-compacted concrete (LWSCC) with and without different types of fibers. Seven beams have been cast and tested and the results have been compared in terms of crack patterns, ultimate load, and deflection. The main findings and conclusions of this study have been:

1- Adding Light Expanded Clay Aggregate (LECA) can be considered a good way to produce light-weight concrete, where the density of mixed concrete decreased by about 14.9% for partially aggregate replacement (S50-F0) and 29% for full aggregate replacement (S100-F0).

2- The average dry density of 50% coarse aggregate (partial) replacement was 1930 kg/m³ and 1630 kg/m³ for 100% coarse aggregate (full) replacement. With these values, the produced concrete can be classified as a light-weight concrete in accordance with ACI committee 213R-03 definition.

3- The result showed an improvement in the compressive, tensile, and flexural strength when using a 1% volumetric percentage of steel fiber due to high tensile of steel fiber and there has been a little effect on the compressive strength when used hybrid fiber (steel and polypropylene).

4- Hybrid fiber improved the splitting tensile strength by about 50.5% for (S50-F2) and 60.7% for (S100-F2) and the flexural strength improved by about (33.3%) for (S50-F2) and (53.8%) for (S100-F2).

5- The steel fiber and hybrid fiber improved the structural behavior of the beams for both (50,100) % LECA replacement, the formation of the crack has been delayed and decreased, and the ultimate load has been improved with more ductile behavior and good stiffness.
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