Effect of Steel Fiber on Ultrasonic Pulse Velocity and Mechanical Properties of Self-Compact Light Weight Concrete

Ahmed S D AL-Ridha¹, Ali Kadhim Ibrahim², Hayder Mohammed AL-Taweel³ and Layth Sahib Dheyab⁴

¹Assistant Professor (PhD), Civil Engineering Department, College of Engineering, Mustansiriyah University.
²Lecturer (PhD), Civil Engineering Department, College of Engineering, Mustansiriyah University.
³Assistant Lecturer (MSc), Highway and Transportation Department, College of Engineering, Mustansiriyah University.
⁴Consultant Engineer, Baghdad, (Iraq)
¹dr.ahmed.al_ridha@uomustansiriyah.edu.iq, ²ali_kadhim@uomustansiriyah.edu.iq, ³hayder.moh.al_taweel@uomustansiriyah.edu.iq

Abstract. In this research, an attempt has been made to study the velocity of ultra-sonic pulse Velocity (UPV) transmitted through self-compacting lightweight concrete (SCLC) with and without steel fiber (SF) for different specimen lengths (i.e. 100 mm cubes and 200 mm cylinders). Two volume fractions of SF "0.4%" and "0.8%"(as an indication to steel fiber content (SFC) were also studied to explore their contributor role. It was found that, for the (100 mm) cubic specimens and the (200 mm) cylindrical specimens, the UPV increment with increasing SFC, but the percentage of increase is higher in cylinders than in cubes. It was also found that, for the same SF volume fraction, the UPV in the SCLC, increases with the decreasing of specimen length, from (200 mm) cylinders to (100 mm) cubes. The percentage of this increase decreases with the increment of SFC. The influence of SF on three mechanical properties of the SCLC (namely: the compressive strength, the splitting tensile strength, and the bulk density) was also studied. It was found that the three mentioned properties are enhanced with the increment of SFC, but this increase is moderately in compressive strength, extremely in tensile strength, and slightly in bulk density.

Keywords: Self-compact lightweight concrete, Ultrasonic Pulse Velocity, Steel fiber, Mechanical properties.

1. Introduction:
Self-compacting concrete (SCC) is a flowable concrete and accomplish sufficient compaction without using external vibration. Furthermore, it has good resistance to bleeding and segregation due to its consistency characteristics [1]. To overwhelmed tendency of SCC to crack small quantities of SF can be utilized. Using fibers lead to restrain the formation of cracks and regress their growth and propagation [2].

Fiber reinforced concrete becomes a substantial option when safety or durability respects are design criteria. They enhance the execution (i.e. strength and toughness) and effectiveness of bridging
cracks of brittle cement-based materials, conveying stress across a crack, and restraining the crack development [3]. Several works have been accomplished to improve the SCC by adding SF to it [4-6]. The non-destructive UPV technique has been extensively utilized for examining the mechanical properties and safety of concrete structures [7-13]. Researchers have studied the validity of applying UPV to estimate the quality of concrete for many years. It has evidenced to be of real importance as a beneficial achievement for evaluating the mechanical properties of concrete in structures and its quality. The utmost likable side of this technique is that the concrete remains undamaged while being tested, besides the promptness and easiness in using it, in addition to the accessibility of the test results on the site and the low cost of equipment that utilized for this purpose [14-18]. Pulse velocity is influenced by many variables such as w/c ratio [19, 20], mix proportions, moisture content, type of aggregate, the age of concrete, etc [21].

2. Experimental Work:

2.1 Materials

2.1.1 Cement

In this research local ordinary Portland cement from "Tasluja" factory was utilized in this work.

2.1.2 Normal Fine Aggregate

The fine aggregate utilized in this work was brought from "Al-Ukhaidhir" region with a Specific gravity of (2.6). The chemical and physical tests made for this aggregate were performed by The National Center for Research and Construction Laboratories. The test outcomes revealed that this aggregate was conformable to the Iraqi standard No. 45/1984 [22].

2.1.3 Lightweight Aggregate

Natural occurred locally Lightweight aggregates of Porcelinite stone brought from Trefawi region (Rutba) in Al-anbar governorate was utilized as coarse aggregate in this work. It was imparted and tested with the assistance of the State Company of Geological Survey and Mining. At first the Porcelinite lumps are manually crushed into smaller size using a hammer to simplify the intromission it through the opening of the Jaw crushing machine, which was setup to provide aggregate with maximum size around 10 mm. The Porcelinite aggregate was conformed to the requirements of the ASTM C330-87[23].

2.1.4 Admixtures (Superplasticizer)

A suitable superplasticizer called “Sika Visco Cete-PC 20” was utilized with a quantity of 3.5 L/100 kg of cement, this dose had been fixed according to trail mixes. The properties of the superplasticizer utilized are demonstrated in Table 1.

| No | Property          | The description                          |
|----|-------------------|------------------------------------------|
| 1  | Commercial name   | SikaViscoCete-PC 20                      |
| 2  | Chemical Base     | Modified polycaboxylates based polymer   |
| 3  | Color             | Light brown                              |
| 4  | Form              | Liquid                                   |
| 5  | PH                | 3 - 7                                    |
| 6  | Chlorides         | Free from chlorides                      |

*Supplied by the industrialist.
2.1.5 Steel Fiber

Commercially known "Dramix-Type ZC" hooked end SF with (50mm) long and of (0.5mm) diameter (i.e. their aspect ratio: l/d =100) were utilized in this research. The properties of SF are given in Table (2).

| Commercial term | Configuration | Property                        | Specifications |
|-----------------|---------------|---------------------------------|----------------|
| Dramix ZC 50/0.5| Hooked ends   | Ultimate strength               | 1130 MPa       |
|                 |               | Elastic Modulus                 | 200x10^3 MPa   |
|                 |               | Density                         | 7860 kg/m^3    |
|                 |               | Strain at proportion limit      | 5650 x10^-6    |
|                 |               | Poisson’s ratio                 | 0.28           |
|                 |               | Aspect ratio (L_f / D_f)        | 100            |
|                 |               | Average length                  | 50 mm          |
|                 |               | Nominal diameter                | 0.5 mm         |

*Supplied by the industrialist

2.1.6 Limestone Powder

This material is a filler known as “Al-Ghubra”. It is a white lime stone grinding material and frequently used in the many construction aspects.

2.2 Concrete Mix

In this work, three mixes were produced with: 0.0%, 0.4%, and 0.8% volume fraction of SF respectively. The following mixing proportions (by weight) were utilized for non-fibrous concrete: [1:0.05:1.95:0.95] for cement, limestone powder, sand and Porcelinite coarse aggregate respectively. The ratio of w/c utilized was (0.44) and the superplasticizer was 3.5% of cement weight. These mixing proportions have tended to follow the British practice which has largely trended to use a large amount of sand with (10 mm) maximum size to ensure better spread of SF in the mix [24].

Fiber reinforced concrete was achieved using up to (0.8%) SF to the fresh plain concrete and remixed the mix. The two significant features that affected the quality of fibrous concrete are the workability and the uniform distribution of the SF.

2.3 Mixing Procedure

The procedure of mixing has a substantial influence for attaining SCLC. The following mixing procedure was done:

1. In the beginning, the filler, the fine, and the Porcelinite coarse aggregate were poured in the pan and mixed for three minutes, then the cement was added, and they are all mixed until a uniform combination is achieved.
2. Since; w/c = 0.44, then, the total quantity of water: w = 0.44c. In order to have an efficient mixing process, this total quantity was divided into four parts: w_1 = 0.2c, w_2 = 0.08c, w_3 = 0.12c, w_4 = 0.04c.
3. The quantity (w_1) was first poured on the mix in the pan and all constituents were remixed for a few minutes.
4. The quantity (w_2) was supplemented to the quantity of the super plasticizer and they both were added to the mix and remixed again, then left for about five minutes.
5. Next, the quantity (w_3) was added and remixed until acquired homogeneous fresh concrete.
6. At last, the remaining quantity \( w_4 \) was added and the whole components were remixed to be prepared for the casting.

7. For the mixes comprises SF, to evade agglomeration and ensure good distribution of SF, the SF was regularly added to the mixture using hand sprinkling. Then remixed till achieved uniform distribution of the fiber.

### 2.4 Casting and Curing

After mixing, the fresh concrete was emptied in the moulds as presented in Figure 1 and vibrated by hammering at base and sides of the samples till complete casting. Then the samples were wrapped with a nylon sheet to preclude water evaporation. After one day, the samples were taken out from the moulds and cured in a water bath. To preserve the bath temperature constant at around 25º to 30º, two heaters (which were taken from ornamental fish ponds and modified for our work) were used, a water pump was also utilized to distribute the heat over the entire bath water. After about one month the control specimens were stripped out from the water bath and tested.

![Figure 1. Details of Forms](image)

### 2.5 Testing of Fresh Concrete

#### 2.5.1 Slump Flow Test and T-50 Test

The slump flow test is most commonly utilized in SCLC to measure the horizontal free flow of this type of concrete. It provides some indication of segregation resistance. Moreover, T-50 test is a measure of the viscosity and flow speed of SCLC [25]. This test was originally utilized to estimate the viscosity of underwater concrete and assess highly flowable concretes [26]. Table 3 demonstrated the outcomes of slump flow tests. The \( D \) value illustrate the flow diameter, whereas the \( T_{50} \) value illustrates the required time to reach the concrete a 50 cm diameter), (see Figure 2). This table (3) also showed agreeable outcomes with criteria for SCLC [27] and illustrates that the flowability was reduced when adding SF to the concrete.
2.6 Testing of Hardened Concrete

2.6.1 Ultrasonic Pulse Velocity Test

The measurement of UPV comprises transfer a wave pulse into concrete and evaluating the time for the pulse to transmit inside it. In order to ensure effective transfer of the wave between concrete and transducer, a thin grease layer is applied to the surface of the transducer. The UPV test was accomplished according to ASTM C597–02 [28], using L = 100mm (cube), and L = 200mm (cylinder). (See Figure. 3).

The pulse velocity is calculated by the expression:

\[ v = \frac{L}{t} \times 1000 \text{.................} \] [1]

Where:

- \( v \) = pulse velocity, (m/s).
- \( L \) = distance between the center of transducers faces, (mm).
- \( t \) = trans. time traveled, (μs).

| \( V_f \) % | T50 (Sec.) | D (mm) | Acceptance criteria for SCLC |
|-------------|------------|--------|-------------------------------|
| 0.0         | 6          | 630    | T50= 25, T50= 3               |
| 0.4         | 7          | 620    | Slump flow via Abrams cone    |
| 0.8         | 9          | 610    | Max. (mm), Min. (mm)          |

**Figure 2.** Slump flow test.

Table 3. Slump Flow Test and Acceptance criteria for SCLC

| Vf % | T50 (Sec.) | D (mm) | Acceptance criteria for SCLC |
|------|------------|--------|-------------------------------|
| 0.0  | 6          | 630    | T50= 25, T50= 3               |
| 0.4  | 7          | 620    | Slump flow via Abrams cone    |
| 0.8  | 9          | 610    | Max. (mm), Min. (mm)          |

**Typical range of values**

- Slump flow via Abrams cone
- T50cm slump flow

\[ v = \frac{L}{t} \times 1000 \]
2.6.2 Compressive Strength test
This test was executed according to (BS 1881: part 116:1989) [29]. The test was accomplished on 100 mm cubic specimens utilizing (2000 KN) capacity electrical testing machine. The test was performed for samples at ages of about 28 days for non-fibrous concrete, and about 34 days for fibrous concrete. (Figure 4a).

2.6.3 Splitting Tensile Strength test
This test was accomplished according to ASTM C496-86 [30] on (100×200) mm cylindrical concrete samples. The test was achieved utilizing the same machine used for the compressive strength test. (Figure 4b).

2.6.4 Unit weight (bulk density)
The unit weights of SCLC (with three SFC) were measured utilizing the formula below:

\[
\text{Density} = \frac{W_A}{(W_A - W_W) / \gamma_w} \quad [2]
\]

Where: \( W_A = \text{weight in air} \), \( W_W = \text{weight in water} \), \( \gamma_w = \text{mass density of water} \)
3. Results and Discussion:

3.1 Effect of SF on UPV of SCLC for different specimen lengths

Table 4 and Figure 5 show that the UPV is increased with increment the SFC. This behavior may be interpreted through the fact that the UPV is faster in minerals than in nonmetallic materials and it is axiomatically that as the fiber content increase the specimen environment approaches metallic materials, therefore the UPV increases. It is also obvious from the table and figure (mentioned above) that the percentage of increase of UPV is higher in cylindrical specimens than in cubic ones. The reason behind this result may be attributed to:

1. In (100mm) cubic specimens, because of the smallness in distance between sender and receiver of the ultrasonic testing device, the probable number of internal voids and cracks (in concrete) that are crossing ultrasonic wave path is small, so that their effect on the UPV is limited. Furthermore, because of the small distance between sender and receiver, the number of SF crossing the ultrasonic wave path is small, therefore their effect on (UPV) will be limited.

2. In (200mm) cylindrical specimens, the distance between sender and receiver of the ultrasonic testing device is larger, so the probable number of voids, cracks, and SF crossing the ultrasonic wave path is larger, therefore their effect on the UPV is obvious.

Table 4. Effect of SF on UPV SCLC for different specimen lengths

| Length of specimen (mm) | Mix No. | Vf % | Ultrasonic Pulse Velocity UPV (m/s) | Percentage of increase |
|-------------------------|---------|------|-----------------------------------|-----------------------|
| 100 cube                | Mix1    | 0.0  | 3587.53                           | "         |
|                         | Mix2    | 0.4  | 3620.20                           | 0.91      |
|                         | Mix3    | 0.8  | 3660.76                           | 2.04      |
| 200 cylinder            | Mix1    | 0.0  | 3052.83                           | "         |
|                         | Mix2    | 0.4  | 3127.44                           | 2.44      |
|                         | Mix3    | 0.8  | 3231.02                           | 5.84      |

Figure 5. Effect of SF on UPV of SCLC Concrete for different specimen lengths
3.2 Effect of specimen Length on UPV of SCLC for different SFC

Table 5 and Figure 6 shows the outcomes of the UPV in (100mm) concrete cubes and (200mm) concrete cylinders for the same content of SF. The results indicated that the UPV is higher in cube than in cylinder for the same SFC. The results also revealed that the percentage of increment in the UPV between cube and cylinder decreases with increasing SFC.

| Mix No. | Vf (%) | Length of specimen (mm) | Ultrasonic Pulse Velocity UPV (m/s) | Percentage of increase |
|---------|--------|-------------------------|------------------------------------|-----------------------|
| Mix1    | 0.0    | 100 cube                | 3541.11                            | 17.51                 |
| Mix1    | 0.0    | 200 cylinder            | 3052.83                            | -----                 |
| Mix2    | 0.4    | 100 cube                | 3577.82                            | 15.76                 |
| Mix2    | 0.4    | 200 cylinder            | 3139.72                            | -----                 |
| Mix3    | 0.8    | 100 cube                | 3660.76                            | 13.30                 |
| Mix3    | 0.8    | 200 cylinder            | 3231.02                            | -----                 |

This behavior in non-fibrous concrete might be due to the probable number of voids and cracks (crossing the ultrasonic wave path) which is greater in (200mm) cylinders than in (100mm) cubes.

In fibrous concrete the reason behind this behavior may be attributed that the SF create an environment approaching to the metallic one and hence reduce the bad effect of voids and cracks in the concrete which leads to reduce the difference in UPV between cubes and cylinders.

Figure 6. Effect of sample Length on UPV of SCLC for different SFC
3.3 Effect of SF on Compressive Strength of SCLC

Figure 7 and table 6 show the influence content of SF on the compressive strength of SCLC. The outcomes illustrate that the compressive strength of SCLC moderately enhanced with increment the SFC.

### Table 6. Influence of SF volume fraction (Vf) % on compressive strength of SCLC

| Mix No. | Volume fraction of steel fiber Vf % | Compression strength $f_{cu}$ (MPa) | Percentage of increase |
|---------|------------------------------------|--------------------------------------|------------------------|
| Mix 1   | 0.0                                | 19.00                                | ---------              |
| Mix 2   | 0.4                                | 20.65                                | 8.68                  |
| Mix 3   | 0.8                                | 22.17                                | 16.67                 |

![Figure 7. Influence of increasing SF volume fraction (Vf) % on compressive strength of SCLC](chart)

3.4 Effect of SF on Splitting Tensile Strength of SCLC

Figure 8 and table 7 display the outcomes for the influence of SF on splitting tensile strength of SCLC. These results reveal that the splitting tensile strength of SCLC extremely enhanced with increasing the content of SF.

### Table 7. Influence of increasing SF volume fraction (Vf) % on splitting tensile strength of SCLC

| Mix No. | Volume fraction of SF Vf % | Splitting tensile strength $f_{t}$ (MPa) | Percentage of increase |
|---------|----------------------------|------------------------------------------|------------------------|
| Mix 1   | 0.0                        | 1.99                                     | ---------              |
| Mix 2   | 0.4                        | 2.46                                     | 23.61                 |
| Mix 3   | 0.8                        | 3.42                                     | 72.00                 |
Figure 8. Influence of increasing SF volume fraction ($V_f$) % on splitting tensile strength of SCLC

3.5 Effect of SF on the bulk density of SCLC

Figure 9 and Table 8 displays the bulk density results of the SCLC. These results revealed that the bulk density increases slightly with the increment of volume fraction of SF.

Table 8. Influence of increasing SF volume fraction ($V_f$) % on bulk density of SCLC

| Mix No. | Volume fraction of SF $V_f$ % | Bulk Density Kg/m$^3$ | Percentage of increase |
|---------|-------------------------------|-----------------------|------------------------|
| Mix 1   | 0.0                           | 2023                  | ------                 |
| Mix 2   | 0.4                           | 2065                  | 1.31                   |
| Mix 3   | 0.8                           | 2086                  | 2.03                   |

Figure 9. Influence of increasing SF volume fraction ($V_f$) % on bulk density of SCLC
4. Conclusions:

1- The UPV in the SCLC increases with increment the SFC, and the percentage of this increases is greater in cylinders than in cubes.
2- For the same SFC, UPV in the SCLC increases with the decreasing of specimen length, from (200mm) cylinders to (100mm) cubes. The percentage of this increase was reduced with the increment of SFC.
3- The compressive strength of SCLC moderately enhanced with the increment of SFC.
4- Splitting tensile strength of SCLC extremely improved with increment of SFC.
5- The bulk density of SCLC was slightly increased with increasing SFC.

References:

[1] Okamura H., and Ouchi M., 2003 “Self-Compacting Concrete”, Journal of Advanced Concrete Technology, 1(1), pp. (5-15).
[2] Abbas AL-Ameeri 2013 "The Effect of Steel Fiber on Some Mechanical Properties of Self Compacting Concrete" American Journal of Civil Engineering; 1(3), pp.102-110.
[3] Grunewald S., and Walraven J.C., 2009 “Transporting fibers as reinforcement in self-compacting concrete”, HERON, 54 (2/3), pp. 101-126.
[4] AL-Ridha A. S. D 2014 “The Influence of Size of Lightweight Aggregate on The Mechanical Properties of Self-Compacting Concrete with and Without Steel Fiber” International Journal of Structural & Civil Engineering Research, 3 (1).
[5] Ismael M. A, 2015 " Flexural Behavior of Steel Fiber-Self Compact Concrete Slabs" Second Engineering Scientific Conference College of Engineering –University of Diyala 16-17 December. pp. 83-99.
[6] AL-Ridha A. S. D" Effect of Fibrous Concrete Layers on Behavior of Self-Compacting Concrete Slabs under Uniform Load" International Journal of Engineering Sciences & Research Technology, 3(5): May 2014.
[7] R.S. Ravindrarajah, 1997 Strength evaluation of high-strength concrete by ultrasonic pulse velocity method, NDT E Int. 30 (4), pp. 262.
[8] A. Galan Estimate of concrete strength by ultrasonic pulse velocity and damping constant, ACI J. 64 (10), 1967, pp. 678–684.
[9] R. Sols-Carcabó, E. Moreno, 2008 Evaluation of concrete made with crushed limestone aggregate based on ultrasonic pulse velocity, Construct. Build. Mater. 22 (6), pp. 1225–1231.
[10] ACI 228.2R-98, Nondestructive test methods of evaluation of concrete in structures, ACI Committee 228.
[11] M. Sansalone, W.B. Streett, Impact-echo Nondestructive Evaluation of Concrete and Masonry, Bullbrier Press, Ithaca, NY, 1997.
[12] W.F. Price, J.P. Haynes, 1996 In situ strength testing of high strength concrete, Mag. Concr. Res. 48 (176), pp. 189–197.
[13] S. Nazarian, M. Baker, K. Crain, 1997Assessing quality of concrete with wave propagation techniques, ACI Mater. J. 94-M35, pp. 296–305.
[14] Z. Grdic, 2011 GT. Curcic, N. Ristic, I. Despotovic, Concrete consistency and compressive strength dependency on the quantity of cement paste among the aggregate grains, Revista Romana de Materiale, 41(2), pp. 91.
[15] D. Bojovic, D. Jevtic, M. Knezevic, Application of neural networks indetermination of compressive strength of concrete, Romanian journal of materials, 42(1), pp.16.
[16] F. Khademi, M. Akbari, SM. Jamal, 2015 Measuring Compressive Strength of Puzzolan concrete by Ultrasoi Pluse Velocity Method, i-Manager's journal of civil Engineering, 5(3), pp. 23.
[17] M. Shariati, 2011 NH. Ramli-Sulong, MM. KH, P. Shafigh, H. Sinaei, Assessing the strength of reinforced concrete structures through the Ultrasoi Pluse Velocity Schmidt rebound Hammer tests, scientific research and essays, 6(1), pp. 213.
[18] G. Trtnik, F. Kavčič, G. Türk, 2009 "Prediction of concrete strength using Ultrasound Pulse velocity and artificial neural networks", Ultrasonics, 49(1), pp. 53.

[19] Bogas, J. A, Gomes. M. G, Gomes. A 2013 "Compressive strength evaluation of structural lightweight concrete by non-destructive ultrasonic pulse velocity method" Ultrasonics 53, pp. 962–972.

[20] Khademi, F, Akbari. M, Jamal. S. M 2016 "Prediction of concrete compressive strength using ultrasonic pulse velocity test and artificial neural network modeling" Romanian Journal of Materials, 46 (3), pp. 343 – 350.

[21] Lin, Y., Kuo, S-F, Hsiao C., Lai, C-P 2015 “Investigation of Pulse Velocity- Strength Relationship of hardened Concrete” ACI Materials Journal, 104 (4), July.-Aug. 2007 , pp. 344- 350. Cited by Al-Nu’man. B. S, Aziz. B. R, Abdulla. S. A, Khaleel. S. E. "Compressive Strength Formula for Concrete using Ultrasonic Pulse Velocity" International Journal of Engineering Trends and Technology (IJETT) 26 (1).

[22] Iraqi Specifications (45) "aggregate of the natural sources used in concrete construction" Central Organization for standardization and quality control, Baghdad, 1980.

[23] ASTM C 330-87, 1989 "Standard Specification for Lightweight Aggregate for Structural Concrete”, Annual Book of ASTM Standards, 04(2), pp.190-192.

[24] Hannant, D. J., “Fiber Cement and Fiber Concrete”, John, Wiley and Sons, Ltol. N. Y. 1978, pp. 219.

[25] EFNARC, (2002), "Specification and Guidelines for Self-CompactingConcrete", pp.32, www.efranice.org . Cited by Dr. Zena K. Abbas Al-Anbori. Effect of External Sulfate Attack on Self Compacted Concrete. Eng.&Tecg.jornal, 31 (6), 2013.

[26] Al-Jabri L A " The Influences of Mineral Admixtures and Steel Fibers on the Fresh and Hardened Properties of SCC. M. Sc. Thesis, University of Al-Mustansiriyah University, Baghdad, 2005.

[27] JSCE, “Recommendation for Self-Compacted Concrete”, Tokyo-Japan Society of Civil Engineers, Concrete Engineering Series 31, 1999. Cited by reference [26].

[28] ASTM C597-02, 2002 “Standard Test Method for Pulse Velocity through Concrete”, Annual Book of ASTM Standards, American Society for Testing and Materials, 04(2).

[29] BS 1881, Part 116, 1989 "Method for Determination of Compressive Strength of Concrete Cubes", British Standards Institution, pp.3.

[30] ASTM C 496-86, 1989 "Standard Test Method for Splitting Tensile of Cylindrical Concrete Specimens", Annual Book of ASTM Standards, 04(2), pp.259-262.

Acknowledgments:
Authors wishing to acknowledge Al-Mustansiriyah University (www.uomustansiriyah.edu.iq) Baghdad – Iraq for its support in the present work.