Flexural performance of reinforced concrete beams containing treated attapulgite as lightweight aggregate

Z A Mirza, N N Khalid
Mustansiryah University, Civil Engineering Department, Baghdad, Iraq.

* Corresponding author: nnkhalid12@gmail.com

Abstract. The amount of the dead load caused by the weight of the structural concrete elements can be reduced when using lightweight aggregate in addition to saving in construction cost. Flexural behavior tests were conducted on five simply supported singly rectangular reinforced concrete (RC) beams of lightweight coarse aggregate concrete subjected to four points bending test up to failure. Lightweight coarse aggregate was produced from natural material locally available (Attapulgite) by burning it at 1100°C for 30 minutes and treating it with sodium hypochlorite of 6% concentration for 24 hour. The effect of silica fume replacement ratios (10 and 20%) by weight of cement and steel fiber content (0.5 and 1%) of volume fraction were investigated. The Attapulgite concrete mechanical properties were determined, as well as the flexural performance for the tested beams is evaluated in terms of cracking and ultimate load capacity, load-deflection relationships, failure mode and crack pattern. The test results show that treating the Attapulgite with sodium hypochlorite enhances the compressive strength of the concrete by about 18%. Adding silica fume and steel fiber contribute to enhance the mechanical properties of Attapulgite lightweight concrete. Significant warning of failure was observed for all beams, and 80% of the total load capacity was achieved after the cracking load. The beam of 1% steel fiber fraction had the largest experimental ultimate load capacity in this study. All tested beams exhibited a typical tension failure.

1. Introduction
The dead load resulted from self-weight is one of disadvantages of conventional concrete. The density of the normal weight concrete varies from 2200 kg/m³ to 2600 kg/m³. This heavy weight can make it somewhat an expensive building material. The structural lightweight concrete can be used in different types of construction. Lighter concrete and stronger enough for using with steel reinforcement, will result in getting more economical concrete than the conventional concrete. Therefore, concrete that merges lightness and strength will own an undoubted frugal advantage [1]. Lightweight concrete has many advantages, including reducing the self-weight of dead load results in the production of smaller supporting members such as girder, beams, deck, and piers. The type of coarse aggregate is a significant factor affecting the lightweight concrete (LWC) strength [2]. Attapulgite clay is mineral clay (crystalloid hydrous Magnesium–Aluminum silicate mineral), also known as Palygorskite [3, 4]. Attapulgite is a natural resource to make a lightweight aggregate locally in Iraq. AL Aridhee [5] observed that lightweight aggregates of 808 kg/m³ bulk density, and 1.45 of specific gravity can be obtained through burring Attapulgite clay at 1100°C for 30 minute. It was observed that the compressive strength of Attapulgite lightweight aggregate concrete (ALWAC) was 27.7 MPa at age 28 day with dry density of 1824 kg/m³ and there was a significant enhancement in the mechanical properties of LWAC due to use the Attapulgite as coarse aggregate as compared with porcelainite aggregate concrete in another study. Several studies have been done to determine the factors affecting the mechanical properties of LWC.
Duzgun et al. [6] obtained that adding steel fibers leads to increase the compressive strength, flexural strength and unit weight of concrete; also, deformation capability and modulus of elasticity decrease as the steel fiber ratio and pumice aggregate ratio increase instead of natural aggregate by volume in the mixture. Mortazavi and Majlessi [7] have reported that silica fume decreases the density and increases the compressive strength of LWAC, and 8-12% was the optimum percent of silica fume.

There are many factors can enhance the flexural performance of lightweight RC beams. Altun and Aktas [8] found that adding of steel fiber increases the ductility and toughness of LWA concrete. The ductility and bearing strength of RC beams were increased in the presence of steel fiber, which reduces the formation and development of cracks, especially in the tension zone. AL Nasser et al. [9] investigated experimentally the flexural performance of under RC beams made with scoria, which is natural lightweight aggregates (LWA), with two values of compressive strength of concrete, 25 and 45 MPa and corresponding air dry density of 1854 and 1961 kg/m$^3$ respectively. It was found that, the crack pattern was typical of flexural beam and identical to the one informed for normal weight concrete beam, the average ultimate load capacity and the average moment capacity of beams increased due to increase the compressive strength. In this experimental study, the main objective is to produce a lightweight coarse aggregate from Attapulgite (natural local material), after treating it with sodium hypochlorite of 6% concentration for 24 hour, and to investigate the flexural behavior of reinforced treated ALWAC beams. Factors that considered in the parametric study including the volume fraction of steel fiber and the content of silica fume. The flexural performance is evaluated in terms of ultimate load capacity, load-deflection relationships, failure mode and crack pattern.

2. Experimental program

2.1. Manufacture of treated lightweight Attapulgite

The produce the lightweight coarse aggregate, Attapulgite was used as a raw material, clay hunks were crushed to obtain the required size about 9.5mm as a maximum size aggregate. According to the recommended specifications of the method used by Al-Aridhee [8], Attapulgite was burned in a kiln at a temperature of 1100ºC for 30 minutes to crystallize it and to increase the bonding between its particles by removing the absorbed water. The physical and chemical properties of Attapulgite are listed in Table 1, which conforming to ASTM C330/C330M-17a, ACI 213R-14 [10, 11]. Attapulgite was treated in a sodium hypochlorite of 6% concentration for 24 hour in order to enhance its mechanical properties, and then it was washed by water and dried at a temperature of 110 ºC for an hour.

| Table 1. Physical and chemical properties of Attapulgite |
|-----------------|------------------|
| Property               | Test results |
| Dry loose bulk density (kg/m$^3$) | 787.35 |
| Specific gravity       | 0.9 |
| Absorption (%)         | 15.64 |
| Sulfate content (SO$_3$) (%) | 0.037 |

2.2. Materials and mix proportions

The materials used in the concrete mixture were, Ordinary Portland cement with a specific surface area of 317m$^2$/kg and compressive strength at 7 days of 29.8, fine aggregate of a natural sand of 4.75 mm and 2.82 as a maximum size and fineness modulus, respectively, and the Attapulgite was used as the lightweight coarse aggregate. The water/cement ratio (w/c) of 0.29 was adopted. Silica fume and high rang water reducer admixture (HRWRA) of Glenium51 were used to enhance the strength and workability of LWAC mixture. Hooked-end steel fiber of 55 as an aspect ratio was adopted in investigation the influence of steel fiber on the mechanical properties, as well as the flexural performance of RC beams. Steel fiber properties are given in Table 2. Table 3 summarizes the mix proportions of the mixtures.
Table 2. Steel fiber properties.

| Shape          | Length (mm) | Diameter (mm) | Tensile strength (MPa) | Aspect ratio |
|---------------|-------------|---------------|------------------------|-------------|
| Hooked-end    | 30          | 0.55          | ≥ 1000                 | 55          |

Table 3. Mix proportions

| Cement (kg/m³) | Sand (kg/m³) | Attapulgite (kg/m³) | Water (kg/m³) | HRWRA (L/m³) | Mix type | Silica fume SF (%) | Steel fiber, V_f (%) |
|----------------|--------------|---------------------|---------------|--------------|----------|---------------------|----------------------|
| 570            | 525          | 390                 | 167           | 6            | M0       | 0                   | 0                    |
|                |              |                     |               |              | MS,10    | 10                  | 0                    |
|                |              |                     |               |              | MS,20    | 20                  | 0                    |
|                |              |                     |               |              | MV,0.5   | 0                   | 0.5                  |
|                |              |                     |               |              | MV,1     | 0                   | 1                    |

[Note] HRWRA= high rang water reducer admixture, V_f = volume fraction, M0= reference mixture, MS= silica fume mixture, MV=steel fiber mixture.

2.3. Test setup for ALWAC beams
The experimental program consists of five reinforced ALWAC beams. The beams had rectangular section of cross section dimensions 120 mm x 200 mm wide and overall depth. The beam length is 1200 mm with clear span 1100 mm. The longitudinal reinforcement consists of deformed bars of 12 mm grade 400. The yield strength of the reinforcing steel is 476 MPa. Shear stirrups (90° hook) with nominal diameter of 6 mm steel bar, and yield strength of 612 MPa, placed at 60 mm center to center spacing over all the length of the cage. To support the stirrups, two smooth steel bars of 4 mm diameter were used at the compression zone. The details and test setup of reinforced ALWAC beams are shown in figure 1.

The beams were divided into two sets according to the various parameters.
Set #1, two beams with silica fume (SF) of 10% and 20% content denoted by B2 and B3 in addition to the reference beam, B1 without SF.
Set #2, two beams with steel fibers of 0.5% and 1.0% volume fraction denoted by B4 and B5 in addition to B1.

The mechanical properties of the concrete mixture were determined using cylinder specimens of 100x200 mm, prisms of 100x100x500 mm and cylinders of 150x300 mm. The casting of the beams and specimens included placing the steel cages in oiled wooden molds, pouring the concrete mixture into the molds in three layers and finally, the beams were compacted using electrical vibrator. After 24 hours of casting, the beams were merged into curing tanks for 28 days.

The specimens were tested to determine the mechanical properties of the ALWAC according to ASTM standard test methods. The theoretical values of the mechanical properties of M0 and MS mixture were calculated according to ACI 318 code [12]; while for MV mixtures were calculated based on Gao et al. [13] model. The modulus of elasticity was determined based on Lee et al. [14] model in addition to Gao et al. [13]. The procedure of calculating the mechanical properties of the steel fiber mixtures is given by the following equations:
Figure 1. Details of reinforced ALWAC beams.

Gao et al. [13] model

\[ f_{st} = 0.94f_t (1-V_f) +3.02V_f l_f/d_f \]  
\[ f_{st} = 0.92f_t (1-V_f) +4.19V_f l_f/d_f \]  
\[ E_c = E_m (1+0.173V_f l_f/d_f) \]  

Lee et al. [14] model

\[ E_c = (-367V_f (l_f/d_f) +5520) f_c^{0.41} \]  

Where: \( f_{st} \) is the splitting tensile strength of fibrous concrete, while \( f_t \) for non-fibrous ones,  
\( V_f \) is the steel fiber volume fraction,  
\( l_f/d_f \) is the steel fiber aspect ratio,  
\( f_{sf} \) and \( f_r \) are the flexural strength of fibrous and non-fibrous concrete, respectively,  
\( E_c \) is the modulus of elasticity of steel fiber reinforced concrete and \( E_m \) is the modulus of elasticity of concrete.

All beams were tested using hydraulic universal testing machine (MFL) of 3000 kN capacity. Four points bending flexural test was applied to the beams. The cracking load value was recorded at the appearance of the first crack. The load was applied until the failure of the beams, and the ultimate load of each beam was taken. The deflections at mid span of each tested ALWAC beam was measured using ELE dial gauge of 0.01mm accuracy.

3. Experimental results and discussion

3.1. Mechanical properties of treated ALWAC

Table 4 lists the experimental results for mechanical properties of treated ALWAC. The compressive strength of the reference mixture (M0) was 38.5 MPa at age of 28 days. There is an increase in \( f'c \) by 9.61% for specimen of 10% silica fume, and 15.06% for 20% silica fume content as compared to the reference mix (M0). The results indicate that there is a significant effect for replacing silica fume with cement, especially at 20%, on the compressive strength of LWAC, figure 2. It can be attributed to the increase in coherence between the ingredients of cement paste, as well as the bond between it and the aggregate particles. The particles of silica fume surround each cement grain and filling the voids in the matrix with strong hydration products [15]. The rates of increasing in compressive strength due to adding
steel fiber were determined as 2.6% and 6.75% for steel fiber content of 0.5% and 1%, respectively, figure 3. Adding of steel fiber led to form a cohesive structure, thus increasing the ability of the resulting concrete to resist the applied loads. The density increased slightly, but it remained within the required limits of ACI 318-19 [12] code for lightweight concrete in spite of the heavy weight of steel fiber, which indicates the possibility of producing lightweight concrete using steel fiber. The compressive strength of treated ALWAC is more affected and improved by the addition of silica fume than steel fiber.

**Table 4. Mechanical properties of treated ALWAC**

| Mix Type | Density (kg/m³) | Compressive strength f_c (MPa) | Experimental splitting strength f_s (MPa) | Experimental flexural strength f_r (MPa) | Experimental modulus of elasticity Ec (MPa) |
|----------|-----------------|-------------------------------|----------------------------------------|----------------------------------------|------------------------------------------|
| M0       | 1910            | 38.5                          | 3.54                                   | 3.82                                   | 22908.2                                  |
| MS,10    | 1825            | 42.2                          | 4.23                                   | 4.05                                   | 28605.3                                  |
| MS,20    | 1860            | 44.3                          | 4.37                                   | 3.84                                   | 24927.4                                  |
| MV,0.5   | 1940            | 39.5                          | 5.98                                   | 4.50                                   | 25170.5                                  |
| MV,1     | 1967            | 41.10                         | 6.45                                   | 5.17                                   | 26881.4                                  |

![Figure 2. Silica fume vs. compressive strength](image2.png)

![Figure 3. Steel fiber vs. compressive strength](image3.png)

The increase in the splitting strength was determined as 19.5% and 23.45% for silica fume content of 10% and 20%, respectively, figure 4. Significant increases were obtained in the splitting strength by 68.93% and 82.20% as increasing the steel fiber V_f of 0.5% and 1%, respectively, with maximum value of 6.45 MPa for splitting tensile strength, figure 5. Concrete containing steel fiber transfers the tensile stresses to the fiber that resists these stresses, hence adding steel fiber to the mixture results in an enhancement in the splitting strength of LWAC, and changes its characteristic from brittle to ductile material. Replacing 10% of cement weight by silica fume increases the flexural strength of ALWAC as a result of enhancement of the interfacial area by improving the bond between the aggregate and adhesives materials in the concrete mixture. While 20% replacement led to decrease the flexural strength, figure 6 which indicates that the ratio of 20% increased the concrete brittleness. The increases in f_r(exp.) were 17.8% and 35.34% for 0.5% and 1% V_f, respectively, figure 7. Addition of steel fibers greatly contributed to prevent separating of prism to two halves after failure. Due to its filler mechanism, using silica fume with the concrete mixture enhanced the modulus of elasticity of LWAC by 24.87% at 10% of silica fume. While replacement ratio of 20% of silica fume increased the modulus of elasticity just by 8.81% as compared to M0, figure 8. The experimental values of modulus of elasticity of the fibrous mixtures increased by 9.87% and 17.34% for 0.5% and 1% V_f, respectively, figure 9. The experimental values of the mechanical properties were higher than the theoretical values. The ACI code
provisions gave more precautions. The materials strength, which composing the concrete mixture, have a significant effect on the mechanical properties of concrete, especially the coarse aggregate. Treating coarse aggregate (Attapulgite) by sodium hypochlorite solution of 6% concentration greatly contributed to enhance the coarse aggregate strength and thus improving its mechanical properties.

3.2 Flexural behavior of reinforced treated ALWAC beams

3.2.1. Cracking and ultimate load
Cracking and ultimate loads are given in Table 5. First cracking occurred in B1, B2 and B3 in the flexural zone at about 14.3%, 18.9% and 18.7% of the ultimate load, respectively. Due to the strong cohesion of silica fume concrete, first cracking load increased significantly from 17.5 kN to 25 kN as a result of adding 10% silica fume, it remains constant when the percentage of silica fume is doubled in B3. It was
obtained that; silica fume enhanced the ultimate load by 9.39% as a maximum percent of increasing in B3.

### Table 5. Cracking and ultimate load of tested beams

| Beam no. | Silica fume (%) | Steel fiber (%) | Cracking load (kN) | Ultimate load (kN) |
|----------|-----------------|-----------------|--------------------|--------------------|
|          |                 |                 | Experimental result | ACI 318 | ACI 544 | Kim et al. |
| B1       | 0               | 0               | 17.5               | 122.5              | 85.92  | -         | -         |
| B2       | 10              | 0               | 25                 | 132.5              | 86.62  | -         | -         |
| B3       | 20              | 0               | 25                 | 134               | 86.97  | -         | -         |
| B4       | 0               | 0.5             | 23.5               | 137.5              | 86.12  | 88.49     | 88.66     |
| B5       | 0               | 1               | 27.5               | 152.5              | 86.43  | 91.21     | 91.93     |

[Note] B= beam.

The steel fiber prevents the cracks from propagation, the first benefit of using steel fiber was to delay the appearance of first crack in the ALWAC beams as seen from test results, especially for B5. First cracking occurred in B5 and B6 in the flexural zone at about 17.1% and 18.03% of ultimate load, respectively. 1% of steel fiber was the optimum ratio for enhancement the cracking and ultimate load of the beam, which achieved the highest value of ultimate load by 152.5 kN in this study. A comparison between the experimental ultimate flexural load \( P_{u\text{ (exp.)}} \) and the theoretical ultimate flexural load \( P_{u\text{ (theo.)}} \) was made according to ACI simplified method by using equations 5 and 6 for all beams, ACI 544 [16] and Kim et al. model [17] for steel fiber beams (B5 and B6). The ACI simplified method equations are given as:

\[
M_n = A_s f_y \left[ d - \left( \frac{a}{2} \right) \right] \quad (5)
\]

\[
M_n = P_u \frac{l_n}{6} \quad (6)
\]

Where \( M_n \) is the nominal moment capacity, \( A_s \) is the area of steel reinforcement, \( f_y \) is the yield strength of steel bar, \( d \) is the effective depth of the beam, \( a \) is the depth of the concrete rectangular block, \( P_u \) is the ultimate load and \( l_n \) is the clear span length of beam. The ACI 544 [16] model considers the height of the area over which the tensile stresses are distributed is \( h-e \) as shown in figure 10. While Kim et al. [17] model considers the height of the area over which the tensile stresses are distributed is \( h-c \) as shown in figure 11, the procedure of calculating the failure ultimate load of the fibrous beams is given by the following empirical formulas:

ACI 544 [16]

\[
M_n = A_s f_y \left[ d - \left( \frac{a}{2} \right) \right] + \sigma_b \left[ (h/2) + (e/2) - (a/2) \right] \quad (7)
\]

\[
\sigma_b = 0.00772 \left( \frac{l_f}{d_f} \right) V_f F_{be} \quad (8)
\]

Where \( \sigma_b \) is the tensile stress in fibrous concrete, \( h \) is the overall height of beam, \( e \) is the distance from the extreme compression fiber to the top of tensile stress block of steel fiber concrete, and \( F_{be} \) is the fiber bond efficiency which equal to 1 through 1.2 according to the geometry characteristic of fiber.

Kim et al. [17] model

\[
M_n = A_s f_y \left[ d - \left( \frac{a}{2} \right) \right] + f_{u\text{ (fib)} \ (h+c-a)/2} \quad (9)
\]

\[
f_{u\text{ (fib)}} = 15V_f f_{spfc} \quad (10)
\]

\[
f_{spfc} = \left[ f_{ucf} \left( 20\sqrt{F} \right) \right] + 0.7 + 1.0\sqrt{F} \quad (11)
\]
Where, $c$ is the neutral axis depth, $f_{tu}$ is the residual tensile stress, $f_{spfc}$ is the splitting cylinder strength of fibrous concrete, $f_{cuf}$ is the cube strength or 1.2 cylinder strength of fibrous concrete, $F$ is the fiber factor and $b_{f}$ is the bond factor: 0.5 for round; 0.75 for crimped; and 1.0 for indented fiber. Figures 12 (a and b) show the percent of increasing in experimental ultimate load compared to the theoretical value, which indicate a significant increment in flexural load capacity in ALWAC beams. The ACI-318 building code equations were found to be extremely conservative in obtaining the ultimate load for non-fibrous ALWAC beams.
Figure 12. Increasing percentage of experimental ultimate load compared to the theoretical value for
a) the non-fibrous beams
b) the fibrous beams

3.2.2. Load- mid span deflection
The results are discussed based on a comparison of all beams with B1 in the sets according to the parameters of this study. Figure 13 shows that the behavior of B1, B2 and B3 in pre-cracking stage is linear as increasing of loading up to first cracking. After first cracking load, the slope of the load-mid span deflection curves begins to deviate. B3 exhibits significant stiffness reduction after first cracking. However, it has the highest ultimate deflection in this set. In general, the results indicate that, silica fume has slightly influence on the load-mid span deflection behavior of ALWAC beams. Adding of steel fiber increases the stiffness of ALWAC beams and reduces the deflection at all stages of loading, figure 14. The steel fiber enhanced significantly the splitting tensile strength and modulus of elasticity for MV,0.5 and MV,1.0, respectively. The fact that the ability of tension zone to keep its contribution to the stiffness of beam even near conditions of failure implies that debonding of steel fibers does not take place until after the ultimate load is reached [18]. Therefore, adding of steel fiber improved the capacity of residual load after failure. It is also found that the flexural strength of RC beams is enhanced in the presence of the steel fiber more than increasing the compressive strength by adding the steel fiber, which is verified previously by Abbass et al [19].

3.2.3. Failure mode and crack patterns
The failure occurs when the deflection increases with the decrease in load, in addition to the yielding of reinforcement and/or concrete crushing. Figure 15 shows the failure modes and crack patterns for all lightweight RC beams. All beams showed a typical flexural failure with forming cracks in the tensile zone. For B2 and B3, the yielding of steel was followed by crushing of concrete cover in the compression zone. Silica fume makes the ingredients of concrete cohesive and transfers stress between aggregate and matrix [20]. However, the crushing zone of concrete cover of B3 (SF=20%) was larger than B2 (SF=10%), taking into account that the brittleness of concrete was increased as the silica fume content increased. B4 and B5 exhibited development in the characteristics of plastic deformation before the ultimate applied load was reached. Thus, the steel fiber concrete beams were more ductile than the reference beam (B1) without fiber. The steel fiber efficiency in resisting the external load is evident right up to failure. Crushing of concrete cover took place after yielding of steel reinforcement. It was noticed that B2 had less extent of the flexural cracks when compared to B1 and B3. Therefore, silica fume content of 10% minimizes the penetration of the cracks towered the compression zone. The cracks became straighter as the silica fume content increased; adding 20% of silica fume achieves better distribution of the flexural cracks in the beam. Steel fiber enhanced the crack control mechanism of the ALWAC beams. Thus the formation of the flexural cracks was small for B4 (Vf=0.5%) compared to B1 (Vf=0%). The number and extent of flexural cracks increased slightly with the increase of steel fiber content from 0.5 to 1%. Therefore, the effect of steel fiber in increasing the ultimate load capacity prevents the cracks developing and increases the post-cracking stiffness.
Figure 13. Influence of silica fume on the load-mid span deflection curve

Figure 14. Influence of steel fiber on the load-mid span deflection curve

Figure 15. Failure mode and crack patterns of tested beams

4. Conclusion
The following conclusions of the experimental results can be drawn:

- Lightweight coarse aggregate can be produced from natural material, Attapulgite, has a dry loose bulk density of 787.35 kg/m³. Treating the Attapulgite aggregate with sodium hypochlorite of 6% concentration increases the compressive strength of ALWAC by 18% to be 38.5 MPa. The unit weight is 1910 kg/m³.
- The experimental load carrying capacity of the ALWA reinforced concrete beams is greater than the predicted theoretical load which can be attributed to the good strength of the producing aggregate (Attapulgite) since the mechanical properties of concrete, thus the structural behavior of beam, are greatly depends on the strength of LWA.
- Using Attapulgite as coarse aggregate reduces the propagation of cracks and improves the fracture energy, the cracking load to the ultimate load was found to be less than 20% for all beams.
- Content of silica fume and volume fraction of steel fiber contributed to increase significantly the cracking load as well as the ultimate load of beams. The optimum ratio was 20% for silica fume and 1% for steel fiber. Silica fume showed insignificant effect in terms of load-deflection.
behavior in lightweight beams. Steel fiber beams exhibited a reduction in the deflection values from earlier stage of loading until failure.

- The mode of failure of the tested beams was flexural. Vertical cracks created at the beams midst and increased in number, as well as depth until reaching failure. Smoother cracks can be satisfactorily as the silica fume percent increased. Steel fiber prevented the extension of cracks in beams.

5. References

[1] Shetty M S 2000 Concrete Technology Theory and Practice New Delhi S Chand & Company LTD.

[2] Newman J and Choo B S 2003 Advanced Concrete Technology. Great Britain Elsevier Ltd.

[3] Tichapondwa S M and Biljon J B V 2019 Adsorption of Cr (VI) Pollutants in Water Using Natural and Modified Attapulgite Clay Chemical Engineering Transactions, vol.74 pp.355-360.

[4] Frieh K J, Abbas W A and Malik S H 2014 Investigate about the Iraqi Attapulgite Clay as a Mineral Admixture for Concrete Engineering &Technology Journal vol.32 no.10 pp.2364-2375.

[5] Al- Aridhee M J H 2014 Some Properties of Lightweight Concrete Containing Attapulgite M.Sc. Thesis University of Technology College of Engineering Department of Building and Construction Engineering 106 p.

[6] Duzgun O A, Gul R S and Aydin A C 2005 Effect of Steel Fibers on the Mechanical Properties of Natural Lightweight Aggregate Concrete Materials Letters vol.59 pp.3357–3363.

[7] Mortazavi M and Majlessi M 2013 Evaluation of Silica Fume Effect on Compressive Strength of Structural Lightweight Concrete Containing LECA as Lightweight Aggregate Advanced Materials Research vol.626 pp.344-349.

[8] Altun F and Aktas B 2013 Investigation of Reinforced Concrete Beams Behavior of Steel Fiber Added Lightweight Concrete Construction and Building Materials vol.38 pp.575–581.

[9] AL Nasser S, Shannag M J and Abdelhamid C 2014 Structural Behavior of Reinforced Concrete Beams made with Natural Lightweight Aggregates Proceedings of the Second International Conference on Advances In Civil, Structural and Environmental Engineering pp.176-179.

[10] ASTM C330/C330M 2017a Standard Specification for Lightweight Aggregates for Structural Concrete United States American Society for Testing and Materials.

[11] ACI Committee 213 2014 Guide for Structural Lightweight-Aggregate Concrete (ACI 213R-14) American Concrete Institute Farmington Hills.

[12] ACI Committee 318 2019 Building Code Requirements for Structural Concrete (ACI 318-19) American Concrete Institute Farmington Hills.

[13] Gao J, Sun W and Morino K 1997 Mechanical Properties of Steel Fiber-reinforced High-strength, Lightweight Concrete Cement and Concrete Composites vol.19 pp.307-313.

[14] Lee S-C, Oh J-H and Cho J-Y 2015 Compressive Behavior of Fiber-Reinforced Concrete with End-Hooked Steel Fibers materials pp.1442-1458.

[15] Chandra S and Berntsson L 2002 Lightweight Aggregate Concrete, Science Technology, and Applications New York Noyes Publications.

[16] ACI Committee 544 1988 (Reapproved 1999) Design considerations for steel fiber reinforced concrete (ACI committee 544.4R) American Concrete Institute Farmington Hills.

[17] Kim W, Kim J and Kwak Y-K 2016 Evaluation of flexural strength prediction of reinforced concrete beams with steel fibers Journal of Structural Integrity and Maintenance vol.1 no.4 pp.156–166.

[18] Swamy R N, AL-Taan S and Ali S A R 1979 Steel Fibers for Controlling Cracking and Deflection Concrete International pp.41-49.

[19] Abbass A, Abid S, Arna'ot F, Al-America and R, Özakçaa M 2020 Flexural response of hollow high strength concrete beams considering different size reductions Structures 23, 69-86.
[20] Alengaram U J, Mahmud H and Jumaat M Z 2010 Development of Lightweight Concrete Using Industrial Waste Material, Palm Kernel Shell as Lightweight Aggregate and its Properties 2nd International Conference on Chemical Biological and Environmental Engineering pp. 277-281.