VOL. 13, NO. 24, DECEMBER 2018 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

STRUCTURAL BEHAVIOR OF SUSTAINABLE HOLLOW CORE SLABS REINFORCED WITH HYBRID FIBERS

Zainab M. Hussein[1], Wasan Ismail Khalil[2] and Hisham Khalid Ahmed[2]
[1]College of Engineering, Al Mustansiriyah University, Baghdad, Iraq
[2]Building and Construction Engineering Department, University of Technology, Baghdad, Iraq
E-Mail: zainabali@uomustansiriyah.edu.iq

ABSTRACT

Concrete Hollow Core Slabs (HCS) is one type of roofing that are widely used in all the world in residential and industrial buildings due to, the reduction of self-weight, and the economic and thermal insulation of these building units. The recycling of waste from construction and demolition of old buildings minimizes the environmental problems and encourages sustainability. The aim of this study is to produce sustainable HCS specimens reinforced with mono or hybrid (triple) fibers of different types and dimensions and studying their structural behavior. Fibers used include, hooked end steel fiber with aspect ratio of 60 (type S_1), micro-steel fiber with aspect ratio of 65 (type S), and polypropylene fiber (PP) with aspect ratio of 667. Five hollow core slabs (HCS) were casted including, three HCS specimens containing crushed clay brick as coarse Lightweight Aggregate (LWA), the first one is plain HCS specimen (without fibers), the second is HCS with mono fiber (macro-steel fiber type S_1 with volume fraction of 0.75%), and the third is HCS specimens reinforced with triple hybrid fiber (0.25% steel fiber type S_1+ 0.25% polypropylene fiber + 0.25% steel fiber type S), two HCS specimens with artificial LWA, one is plain HCS specimen (without fibers) and the other is one HCS specimens reinforced with triple hybrid fiber (0.25% steel fiber type S_1+ 0.25% polypropylene fiber + 0.25% steel fiber type S) were prepared. Load-deflection relationship, first crack and ultimate loads, and ductility ratio of HCS specimens were studied. Hollow core slab specimens reinforced with fibers show considerable improvement in ductility ratio in ductility ratio relative to plain specimens. The percentages of increase in ductility ratio of HCS specimen containing crushed clay brick LWA reinforced with mono steel fiber and specimen reinforced with triple hybrid fiber are 297.4% and 351.3% respectively, while for HCS specimen with artificial LWA reinforced with triple hybrid fiber is 386.5% relative to the corresponding reference HCS specimen. Generally, the experimental results indicate that HCS specimens containing produced LWA have better properties than specimens containing crushed clay brick LWA. Generally, the results indicate that sustainable HCS reinforced with fibers can be used as roofing system in buildings.

Keywords: sustainable concrete, hollow core slab, hybrid fiber, crushed brick, artificial LWA.

INTRODUCTION

Hollow Core Slabs (HCS) have recently used as the main floor systems for different structures such as buildings, hotels, trade buildings, residential house, cultural facilities and high rise buildings. In addition to their structural advantage and the ability to cover large spans, hollow core slabs have many other advantages such as, the relative low weight, ease in construction, high thermal and acoustical properties, rise fire resistance, and comparatively fast construction rate [1].

Generally, alternative materials such as construction and demolition waste as well as other industries by-products are increasingly being tested and used as environmental sustainable natural aggregates substitutes in concrete [2].Construction industry is producing large quantities of crushed brick waste and construction demolition waste [3]. The natural lightweight aggregate large consumption leads to production and use of artificial LWA, also the use of waste material as LWA is the main aim of many researchers. Artificial LWA can be produced from a wide variety of raw material and production procedures [4].The existence of Iraqi clay deposit with various types and characteristics leads to the idea of production artificial LWA in the laboratory. The use of crushed clay brick from construction and demolition waste and artificial LWA causes reduction in environmental pollution and developed the structural application of sustainable Lightweight Aggregate Concrete (LWAC) in Iraq. The use of sustainable LWAC in production of HCS building units contributes to the reduction of construction cost, maintaining natural lightweight aggregates, reducing environmental pollution and increasing thermal insulation in buildings. Lightweight aggregate concrete demonstrate brittle behavior. The inclusion of fibers improves concrete properties. Fibers bridge the cracks and prevent them from growing, so it increases toughness of the matrix [5]. The most commonly used of the various types of fiber is steel fiber which is used for structural and non-structural applications. It is essential to have a large number of short discrete fibers to bridge or delay the propagation of micro-cracks in composite under load, and it is necessary to use long discrete fibers to bridge macro-cracks at high load. The volume of fraction of short and long fibers should be specific with care [6].

There are some researches investigate the use of crushed clay brick or artificial aggregate as coarse aggregate in hollow concrete blocks [7, 8]. There is no detailed study available to produce hollow core slabs containing either crushed clay brick from construction and demolition waste or artificial LWA produced from local material as lightweight aggregate and reinforced with mono or hybrid fibers.

Researches significant

- Producing high performance sustainable hollow core concrete slab units containing recycled crushed clay brick or artificial aggregate as coarse LWA and studying there structural behavior.
- Studying the influence of inclusion mono and hybrid fibers on the properties of the produced high performance LWC hollow core slab units.

EXPERIMENTAL PROGRAM

Materials and concrete mixes

In previous research [9] two sustainable high performance lightweight aggregate concrete (HPLWAC) mixes were prepared. These mixes were used to produce the hollow core slabs in this investigation. The following materials were used in these mixes:

- Ordinary Portland cement Type I from Bazian Company in Iraq. The test results indicate that the adopted cement conforms to the Iraqi Specification No. 5/1984.

- Normal weight natural sand with maximum size of 4.75 mm and its gradation lies in zone 2. The results indicate that the grading of the fine aggregate, physical properties and sulfate content are within the requirements of the Iraqi Specifications No. 45/1984.

- Two types of sustainable LWA were used including, crushed clay brick and artificial LWA:

a) The recycled crushed clay brick was used as a sustainable lightweight aggregate with maximum aggregate size of 12.5 mm. The grading of coarse crushed clay brick aggregate which conforms ASTM C330-03[10] specification is shown in Table-1.Thephysical and chemical properties of the crushed clay brick aggregate were determined. Table-2 lists these properties and their corresponding adequate Specifications.

Table-1. Grading of coarse crushed brick LWA.

Sieve size (mm)	**Cumulative passing** (%)	**Cumulative passing according to ASTM C 330** (%)
12.5	100	100
9.5	85	80-100
4.75	15	5- 40
2.36	0	0- 20
1.18	0	0-10

Table-2. Properties of coarse crushed brick LWA*.

Properties	Specifications	Test results
Specific gravity	ASTM C127-01	1.89
Absorption (%)	ASTM C127-01	19.1
Dry loose unit weight, kg/m^3	ASTM C330	636**
Dry rodded unit weight, kg/m^3	ASTM 29/C29M/97	729
Aggregate crushing value, (%)	BS 812-part 110-1990	65.6
Sulfate content (as SO_3), (%)	BS 3797-part 2-1981	0.89***

Physical analysis was conducted by National Center for Construction Laboratories and Researches (NCCLR)
* * Within the limit of ASTM C330 ≤ 880 kg/m³
*** Within the limit of BS 3797 part 2 ≤1.0%

b) An artificial lightweight aggregate was produced from bentonite clay and sodium silicate liquid waste from glass plant through this study, as referred by previous research [11]. Many trials were carried out to select the proper amount of sodium silicate that produces a paste of adequate plasticity. Sodium silicate liquid waste with 50% mixing ratio by weight (clay: sodium silicate, 1:1) was selected. The clayey paste was rounded by handed to form balls, then they were left to dry at laboratory temperature for 24 hours to avoid the formation of shrinkage cracks. The clayey balls were then dried in an oven for 24 hours at 100 °C to ensure complete drying, and then they were burned at different high temperatures. It was found that burning these balls at temperature between 750 - 800 °C for two hours produces lightweight aggregate with properties conform to ASTM C 330 Specifications [10]. Finally the furnace was opened and the specimens were left inside the furnace until they were cooled to laboratory temperature. The clayey balls were crushed manually to smaller size by means of a hammer, and then screened on standard sieve series in order to prepare lightweight aggregate with grading which conforms to ASTM C 330 Specifications [10]. Table-3 shows the properties of the produced lightweight aggregate.

- Deformed welded wire fabric mesh steel bars of nominal diameter of 5 mm were placed in tension face of the slab. The average ultimate strength of the wire fabric mesh is 690 MPa.

- Two types of concrete admixtures were used:

a) High Range Water Reducing Admixture (HRWRA) based on modified polycarboxylic ether (Sika-Viscocrete-5930) was used. It is a third generation superplasticizer meets the requirements of ASTM C494M/04 types F.

b) Silica fume used in this investigation is produced by Sika Company. The results show that the silica fume used conforms to the chemical and physical requirements ofASTM C1240.

Table-3. Properties of the produced LWA*.

Properties	Specification	Test results
Specific gravity	**ASTM C127**	**1.53**
Absorption, %	ASTM C127	12.9
Dry loose unit weight, kg/m^3	ASTM 29/C29M	538.22**
Dry rodded unit weight, kg/m^3	ASTM 29/C29M	543.21
Aggregate crushing value, %	BS 812-part 110-1990	51.6
Sulfate content (as SO_3), %	BS 3797-part 2-1981	0.97***

* Physical analysis was conducted by National Center for Construction Laboratories and Researches (NCCLR).
** Within the limit of ASTM C330 ≤ 880 kg/m³.
*** Within the limit of BS 3797 part 2 ≤ 1.0%.

- Three types of fiber were used:

a) Macro-hooked steel fibers type S_1 with 30 mm length and 0.5 mm diameter (aspect ratio l/d = 60). The ultimate tensile strength and density for individual fibers are 1180 MPa and7800 kg/m^3 respectively.

b) Straight steel fibers type S with 13 mm length and 0.2 mm diameter (aspect ratio l/d = 60), the ultimate tensile strength for individual fibers is 1180 MPa and the density is 7800 kg/m^3.

c) Micro polypropylene fiber (PP) with 12mm length, 18 micron diameter (aspect ratio l/d= 677) and minimum tensile strength of 350 MPa.

Concrete mixes

Concrete mixes were designed in accordance with ACI committee 211-2[12] to have a compressive strength of 20 MPa at 28 day. The mix proportion used is 1:1.18:0.73 (Cement: Sand: LWA) by weight with cement content of 550 kg/m^3, w/c ratio of 0.44. Several trail mixes were carried out to select the proper dosages of HRWRA and silica fume to prepare high performance LWAC. The selected mix (Reference mix) contains HRWRA of 2.5 liter/100 kg and 3 liter/100 kg of cement, 10% silica fume as a replacement by weight of cement with w/c ratio of 0.26 and 0.25 for crushed brick LWA and artificial LWA respectively. Two reference mixes (without fiber) were used to prepare two HCS specimens. The first mix (MBR) contains crushed clay brick as coarse LWA; while the second reference mix (MAR) contains artificial LWA. Two concrete mixes containing crushed clay brick as coarse LWA were reinforced with mono, and hybrid triple fiber, while one concrete mix containing artificial LWA were reinforced with triple fiber were used to prepare three HCS specimens.

Table-4 demonstrates the details of HCS specimens prepared and studied in this investigation.

Table-4. Details of lightweight aggregate concrete mixes.

Hollow core slab symbol	**Fiber volume fraction (%)**		
	S_1	**S**	**PP**
MBR	0	0	0
MBS_1	0.75	0	0
MBH_3	0.25	0.25	0.25
MAR	0	0	0
MAH_3	0.25	0.25	0.25

Preparation, casting and testing of specimens

This study includes the production and testing of five hollow core slab specimens with the dimensions of 800×400×100 mm. These slabs were reinforced with steel welded wires fabric mesh placed in tension face of the slab. Hollow core slabs were designed according to ACI 318. The mold and the dimensions of the hollow core slab are shown in Figures 1and 2 respectively.

Figure-1. The mold and reinforcement of hollow core slab.

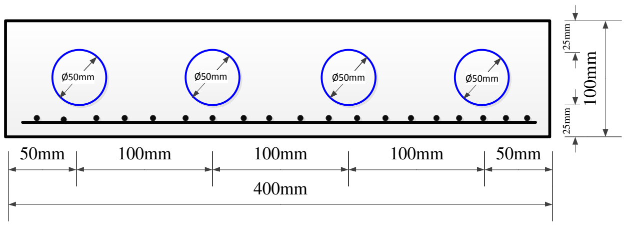

Figure-2. Dimensions of concrete hollow core slab concrete.

A universal hydraulic machine with 300 ton capacity was used for testing the hollow core slab specimens. All hollow core slabs were removed from the curing water tank at the age of 28 day. Before testing, the hollow core slabs were cleaned and painted white to allow easy detection of crack propagation. The hollow core slab was placed on its supports in the machine with a clear span of 600 mm. Loading was applied through two steel rods welded with plates to avoid stress concentration on the slab, as shown in Figure-3. All hollow core slabs were tested under two points loading. The dial gage of 0.01 mm sensitivity mounted on a steel frame was placed in the middle of the clear span of the hollow core slab to record the deflection. The magnitude of the load at every single step of loading was chosen according to the expected strength of the slab. At each load value, the deflection dial gage reading was recorded and a search was made for the appearance of the cracks by using a magnifying glass. The positions and extents of the first and the other consequent cracks were marked on the surface of the slab and the magnitude of the applied load at which these cracks occurred was written. The slab was considered to reach failure when it showed a drop in loading with increasing deformation. The failure load was thus recorded.

Figure-3. Test set-up for hollow core slab specimen.

RESULTS AND DISCUSSIONS

Five HCS with different concrete mixes (MBR, MBS_1, MBH_3, MAR and MAH_3) were casted in this investigation as shown in Figure-4.

Figure-4. Cross section of hollow core slab concrete.

Load - deflection relationship

The load - deflection curves of the HPLWAC hollow core slabs are presented in Figures5 and 6. It is clear from these curves that HPLWAC hollow core slabs reinforced with fibers generally exhibit three stages in load- deflection relationship. The first stage is the elastic or un-cracked stage at which the deflection increases almost linearly with load, the matrix and the fiber reinforcement in this portion act as a continuum. Further increases in the load above the point of deviation from linearity, causes the first crack to occur and beyond the first crack load, there is a high increase in deflection. The second stage is a quasi - elastic stage, it is associated with cracking of matrix and the stress in the matrix is progressively transferred to the fibers. The third stage is the plastic stage which represents the failure of all specimens corresponding to the failure of tensile face of the hollow core slab. The load - deflection relationship for plain HPLWAC hollow core slabs and slabs reinforced with mono steel fiber and triple hybrid fiber containing crushed clay brick LWA is shown in Figure-5. This figure indicates that the load-deflection curve for the plain HCS (specimen MBR) was initiated in a linear form with constant slope at the stage of elastic behavior then there is as slight change in the slop after the appearance of first crack. The load-deflection relationship for HPLWAC hollow core slab with crushed clay brick aggregate reinforced with type S_1 mono steel fiber (MBS_1) is greatly enhanced compared with plain hollow core slab. It can be seen that the linear un-cracked portion is followed by increasing load with the increase in deflection until the specimen collapsed. Hollow core slab specimen reinforced with triple hybrid fiber (MBH_3) exhibited improved load-deflection curve relative to mono fiber reinforced HCS specimen. This is due to the combined effect of lengths and synergetic action of varying fiber dimensions used in this specimen.

Figure-6 shows the load-deflection curve of plain HPLWA hollow artificial aggregates and slab reinforced with triple hybrid fiber (MAH_3). Hollow core slab specimen with triple hybrid fiber (MAH_3) shows improved load-deflection curve compared with plain specimen. This is due to the effect of different fibers in bridging the micro-cracks.

VOL. 13, NO. 24, DECEMBER 2018 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

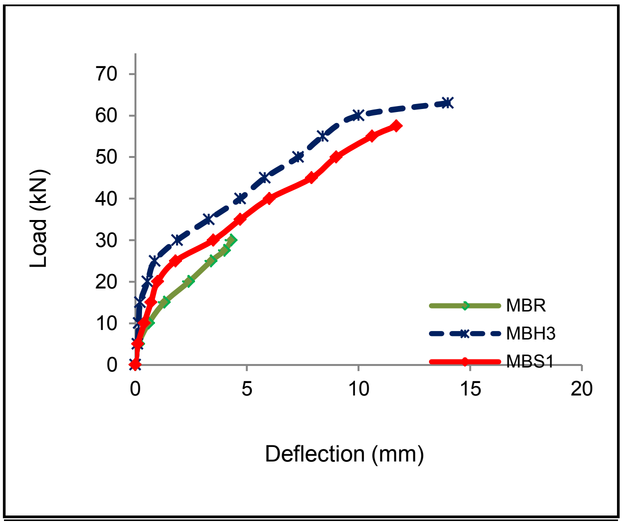

Figure-5. Load –deflection curves for different fibrous HCS specimens containing crushed clay brick LWA

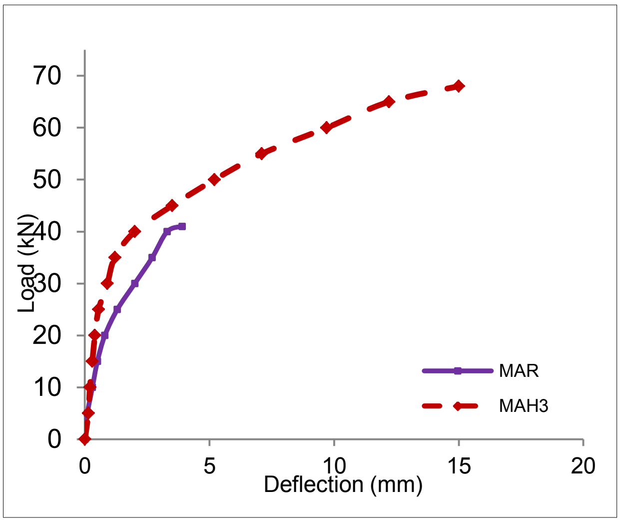

Figure-6. Load-deflection curves for different HCS specimens containing artificial LWA

The comparison between the load-deflection curve of hollow core slab specimens containing crushed clay brick lightweight coarse aggregate and artificial lightweight coarse aggregate are demonstrated in Figure-7. It can be seen that the load-deflection relationship of HCS specimens containing artificial lightweight aggregate is improved relative to specimens containing crushed clay brick LWA. This may be due to higher strength of HPLWAC containing artificial lightweight aggregate prepared in this investigation.

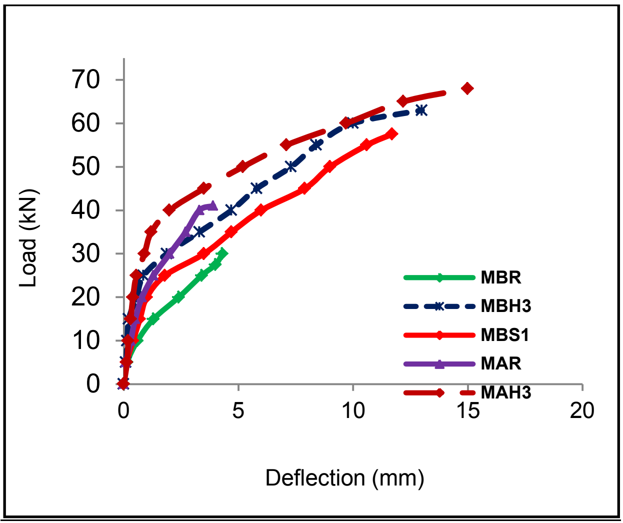

Figure-7. Load- deflection curves for All HSC specimens.

First crack and ultimate loads

The flexural test results of the hollow core slab specimens are shown in Table-5. It can be seen that the values of first crack load for the specimen with crushed clay brick LWA and reinforced with fibers increase compared with reference slab specimen (MBR). The percentage increase for specimen reinforced with mono steel fiber type S_1 (MBS_1) and specimen with triple hybrid fiber (MBH_3) are 17.9% and 23.6% respectively relative to the reference HCS (MBR). The results also show that the first crack of HCS with artificial LWA and reinforced with triple hybrid fiber (MAH_3) increases by about 17.7% relative to the reference HCS with artificial LWA (MAR).

The values of the ultimate load for HCS specimens are also shown in Table-5. Generally it can be seen that the values of ultimate load for all fiber reinforced specimens (MBS_1 and MBH_3) significantly increase over the corresponding reference specimen (without fiber). It is clear that, the percentage of increase in ultimate load for specimen with crushed clay brick LWA reinforced with mono steel fiber and specimen reinforced with triple hybrid fiber are 79.3% and 98% respectively compared with the reference specimen. The percentage increase in ultimate load of specimen with artificial LWA reinforced with triple hybrid fiber is about 83.8% compared with reference specimen (MAR). The improvement in the values of first crack and ultimate loads for HCS reinforced with fibers is attributed to the ability of fiber to arrest cracks.

Ductility ratio

Ductility ratio represents the deflection at ultimate load to the deflection at first crack load. It can be observed from Table-5 that the ductility ratio of hollow core slab specimens reinforced with fibers is greatly enhanced relative to the reference HCS specimen. The percentages of increase in ductility ratio for HCS with crushed clay brick aggregate reinforced with mono steel fiber (MBS_1) and specimen reinforced with triple hybrid fiber (MBH_3)are 297.4% and 351.3% respectively relative

VOL. 13, NO. 24, DECEMBER 2018 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

to the reference hollow core slab specimen (MBR). The percentage increase of hollow core slab specimen containing artificial lightweight aggregate and reinforced with triple hybrid fiber (MAH_3) is 386.5% relative to the reference hollow core slab specimen (MAR). This is due to the fact that the inclusion of fiber in concrete improves its ductility.

Table-5. Flexural test results of HPLWAC hollow core slabs at 28 days age.

HCS symbol	**First cracking load, Pcr** (kN)	**Deflection at first crack load**Δ_{cr} (mm)	**Ultimate load, Pu (kN)**	**Deflection at ultimate Load,** $\Delta_\circ$ (mm)	**Ductility ratio***(Ψ)
MBR	14	1.1	30	4.3	3.90
MBS_1	16.5	0.75	53.5	11.7	15.50
MBH_3	17.3	0.71	59.5	12.5	17.60
MAR	16.5	0.96	37	3.2	3.33
MAH_3	18.6	0.76	68	12.3	16.2

*Ductility Ratio (**Ψ**) = $\frac{\Delta_\circ}{\Delta_{cr}}$ where Δ_{cr} and $\Delta_\circ$ are the mid-span deflections at first crack load and ultimate load respectively

Cracking pattern and failure mode

Typical cracking patterns for the hollow core slab specimens are shown in Figures 8 and 9. The first crack was initiated at the extreme fiber of the tension face at the constant moment zone for all HCS specimens, as loading increased, more cracks appeared and first crack became wider due to the yielding of reinforcement. No crushing of the concrete was observed on the compression face on all hollow core slabs and no visible debonding occurred at the tension face of slabs. All the HCSs were intact and showed very little signs of damage. Also it was observed that the use of mono steel fiber or hybrid triple fibers has no significant effect on cracking pattern and mode of failure of the specimens. The inclusion of triple hybrid fiber reinforcement in HCS specimen containing artificial LWA (MAH_3) ingresses the number of cracks and reduces the width of these cracks at failure compared with the reference HCS specimen (MAR), as shown in Figure-9.

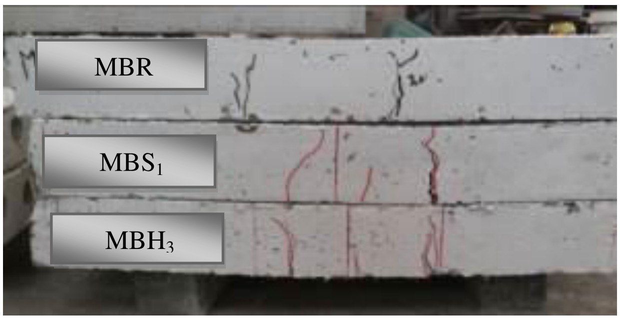

Figure-8. Effect of fibers on crack pattern of HCS specimens containing crushed clay brick.

Figure-9. Effect of fibers on crack pattern of HCS specimens containing artificial LWA.

CONCLUSIONS

a) Hollow core slab containing crushed brick LWA or artificial LWA specimens reinforced with mono or triple hybrid fiber exhibited a considerable improvement in load - deflection curve relative to plain HCS specimens.

b) The ductility ratio of HCS specimens reinforced with fibers is greatly enhanced relative to reference HCS specimens (without fiber).The percentages of increase in ductility ratio of HCS containing crushed clay brick LWA reinforced with mono steel fiber specimen and reinforced with triple hybrid fiber are 297.4% and 351.3% respectively, while for HCS specimens reinforced with artificial LWA reinforced with triple hybrid fiber is 386.5% relative to the corresponding reference HCS specimens.

REFERENCES

[1] Monisha K., SrinivasanG. 2017. Experimental Behavior of Prestress Hollow Core Slab, RC Hollow Core Slab and Normal RC Solid Slab. International Research Journal of Engineering and Technology. 04(04).

[2] Cachim P. B. 2009. Mechanical Properties of Brick Aggregate Concrete. Construction and Building Materials. 23(3): 1292-1297.

[3] Afify M. R. and Soliman N. M. 2014. Improvement Properties of Recycle Concrete using Clay Brick as a Coarse Aggregate. International Journal of Current Engineering and Technology. 4(1): 119-127.

[4] Chi J.M., Huang R., Yang C.C. and Chang J.J. 2003. Effect of Aggregate Properties on the Strength and Stiffness of Lightweight Concrete. Cement and Concrete Composites. 25(2): 197-205.

[5] Victor C. L. 2002.Large Volume, High-Performance Applications of Fibers in Civil Engineering. Journal of Applied Polymer Science. 83(3): 660-668.

[6] Mehta P.K. and Monteiro P.J.M. 2006. Concrete; Microstructure, Properties, and Materials. Third Edition, New York: McGraw-Hill.

[7] Aliabdo A., Abd-Elmoaty A. and Hassan H. 2014. Utilization of Crushed Clay Brick in Concrete Industry. Alexandria Engineering Journal, Available at, ww.elsevier.com/locate/aej, www.scincedirct.com

[8] Poon C. and Chan D. 2006. Paving Blocks Made with Recycled Concrete Aggregate and Crushed Clay Brick. Construction and Building Materials. Vol.20.

[9] Khalil W. I., Ahmed H. K. and Hussein Z. M. 2017. Properties of Sustainable High Performance Lightweight Aggregate Concrete with Fibers. Diyala Journal of Engineering Science. 10(3).

[10] ASTM C330-03. 2003. Standard Specification for Lightweight Aggregates for Structural Concrete. Annual Book of ASTM Standards, Vol.04-02, Concrete and Aggregates, United States.

[11] Khalil W. I., Ahmed H. K. and Hussein Z. M. 2015. Properties of Artificial and Sustainable Lightweight Aggregate. 17th International Conference on Building Science and Engineering, Berlin, Germany, Sep, 14-15, Part IV, 19(9).

[12] ACI Committee 211. 2004. Standard Practice for Selecting Proportion for Structural Lightweight Concrete. ACI Manual of Concrete Practice, Part 1, pp. 211-218.