

## Energy Absorption Capacity Of Layered Lightweight Reinforced Concrete Beams With Openings In Web

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Received 17 January 2019; Accepted 09 March 2019

### Abstract

This research presents the flexural behavior on reinforced concrete beam with transverse web opening constructed from layered concrete. The layered concrete combining normal concrete and lightweight aggregate concrete (LWC) are depended in present study. In the experimental program, 13 models of normal and layered reinforced concrete beams are tested under the effect of four-point loads. All beams had the same overall geometrical dimensions and main longitudinal top and bottom with internal diagonal reinforcement provided around the openings. One of the beam specimen is tested as control beam and the other specimens are divided into three groups [G1, G2, and G3] to study the effects of the following variables: effect of presence of web openings, layered system, lightweight aggregate (partially volumetric replacement of normal aggregate by thermestone) on the ultimate load, cracking load, cracking pattern and energy absorption capacity. The existing of an opening in beam specimens reduced the flexural capacity of beams with a percentage depending on the size of opening and opening number. The test data obtained from the adopted layered technique of (NEW) and (LWC) have shown that for beams constructed from two layered concrete (LWC with thermestone in the web and bottom flange of I-beam section) ultimate load is decreased about (9.3%-48.8%). It has also, the beams constructed from three-layered of concrete (LWC with thermestone in the web of I-beam section), their ultimate load is decreased about (25.6%-58.1%). On the other hand, magnitude increased of energy absorption capacity are achieved by the decreased opening size, introducing the full size opening of dimension (100×1000) mm reduces the energy absorption capacity of the RC I-section beams at least 80% compared to solid beam while the beam with opening size (100×100) mm decrease up to 16%. In the case of the layered concrete beams specimen, the real influence of lightweight concrete (LWC) type in the layered reinforced concrete is observed significantly after increasing the length of opening more than 100 mm.

*Keywords:* Layered Concrete; Lightweight Aggregate Concrete; Openings; Thermestone Aggregate; Energy Absorption Capacity.

### 1. Introduction

In civil engineering construction, the objective of using or selecting any material is to make full utilization of its properties in order to get the best performance for the formed structure. The features of a material are based on factors such as availability, workability, structural strength, durability, and cost. As it is difficult to find a material, which possesses all these properties to the required level, the engineer's problem consists of an optimization involving different materials and methods of construction.

Hybrid layered systems of various strength materials can be used in civil engineering construction. The hybrid concrete structure under flexural as consists of two layers; for an example the compressive layer, which is made of a

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 <http://dx.doi.org/10.28991/cej-2019-03091279>

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high compressive material, and the tension layer, which is made of lightweight material to get the best performance of this structure with lower cost and weight.

The term "Lightweight concrete" is generally used for concrete of density lesser than 2200 kg/m<sup>3</sup>. The utilization of lightweight concrete is ruled primarily by economic considerations [1]. LWC is not just one item, it is a spectrum of different concrete with a variety of characteristics and it fills in a number of needs. It is produced by including large quantities of air in the aggregate or in a matrix or between the aggregate particles [3]. There are several types of lightweight concrete such as no-fines concrete, aerated concrete, and lightweight aggregate concrete [1].

Beam openings may be of several shapes, sizes and are generally located close to the supports where shear is dominant. Practically, it is quite often employed to provide convenient passage of environmental services such as a network of pipes and ducts which reduce the story heights of buildings and weight of construction as it progresses the demand on the supporting frame both under gravity loading and seismic excitation which results in an economical design [9].

In reinforced concrete beams the structural engineer is often challenged with the problem of providing convenient passage. Due to abrupt changes in sectional configuration, the corners of the opening would be subjected to stress concentration and it is possible to induce transverse cracks in the beam. Also, it can reduce the stiffness, which leads to deformations and excessive deflections under service load and considerable distribution of forces and internal moments in a continuous beam. So, the effect of openings on the ultimate strength and behavior of reinforced concrete beams must be regarded and the design of these beams needs special consideration. However, current codes of practice for design of reinforced concrete structures do not provide provisions for the design of R.C beams with openings [8].

Oukaili and Shammari, (2013) carried out an experimental test on T-reinforced concrete beams with a circular opening. Seven beams with simply supported and having multiple web circular openings were tested using concentrated static load at mid-span. The test variables were number of circular openings web (4 or 6) and the technique which was used to strengthen the member at openings (utilize internal deformed steel bars as in the case of the openings are planned before casting the beams) or using carbon fiber reinforced polymer (CFRP) fabric as in the case of the openings will be created in the present beams). The obtained laboratory results indicated that the strengthening of beams at openings may compensate the decrease of the beam capacity due to the existence of the openings under static loading [14].

Zaki et al., (2017) tried to trace the effect of introduced opening (unsymmetrical) in the reinforced concrete beam. Eleven reinforced concrete beams (150×300×1500 mm) were tested under to two-point load with different opening size. Test results showed that the ultimate load reduced about 70% by opening (120×360mm) as compared to the control beam (without opening) [13].

The effect of small circular opening on the shear and flexural and ultimate strength of beams were investigated. The main factors of the test are the diameter changes and the opening position. In this study, five beams were casted and tested using C20 concrete and Fy415 steel. The first beam was solid and was used as control for comparison with other beams with an opening. The second beam opened at distance of L/8 by 110mm (0.55D), third beam opened at distance of L/8 by 90mm (0.45D). Beam number four and beam number five had openings at distance L/4 as mentioned above. The tested beams were loaded with two concentrated and symmetrical load as simple beam. They conclude that the reduction of ultimate strength increased and cracking patterned as well as the beam failure mode when the opening diameter increased. To increase the ultimate shear strength of the beam, they recommended the use of diagonal reinforcement and stirrups in top and bottom chords of opening. They also concluded that the most critical opening position to achieve the ultimate strength in beams is near the support and that the best opening place in these beams is mid span (flexure zone) [18].

The experimental and finite element (FE) method is used to investigate the shear behavior of the reinforced concrete beams with openings. The main variables were the shear span-to-depth ratios ( $a_v/d$ ), the size of openings, and the opening location. Based on the shear span-to-depth ratio the beams were divided into three series. Test data showed that the openings in a high shear area (the line connecting the load and support points) led to the early collapse of the beams [17].

On the other hand, the authors define in this paper the energy absorption capacity is the area under the structural loading-displacement curve. There are few research works on the energy absorption capacity of reinforced concrete beam with openings. The energy absorption capacity of the beam with circular openings significantly more than energy absorption capacity of the beam with square openings. Also, failure of beam due to Vierendeel truss action reduce the ductility and energy absorption capacity [16].

So, the main aims of this study was evaluated experimentally the energy absorption capacity and the behavior of layered reinforced concrete I-section beams with openings.

## 2. Experimental Program

### 2.1. Material

General description of the material in this study is listed below:

#### 2.1.1. Cement

Ordinary Portland cement (type I) is used throughout in this study. It satisfies to the Iraqi specification No.5 [10].

#### 2.1.2. Fine Aggregate

Natural sand From Qara salm area in Iraq is used as fine aggregate in this work. The maximum size of the fine aggregate has 4.75 mm with rounded-shape particles. The sieve analysis of fine aggregate indicates that the fine aggregate grading is submitted the requirements of Iraqi Specification No. 45 [11].

#### 2.1.3. Coarse Aggregate

Crushed gravel from laylan /Iraq is utilized in this work as coarse aggregate passing sieve No.12.5.The specific gravity of aggregate used is 2.6 with grading satisfying the requirements of Iraqi Specification No. 45 [11]

#### 2.1.4. Steel Bars

Two sizes of deformed steel bars of nominal diameter (12 mm and 8mm) are utilized as main reinforcing bars. While the 6 mm diameter deformed steel bars are utilized as stirrups. The result of testing this bar meet the A615 [7] requirements for Grade 60.

#### 2.1.5. Thermostone

One kind of blocks, produced from cellular concrete (also known as autoclaved aerated concrete), is known as thermostone. These blocks are increasingly used as an alternative to bricks in multi-story buildings in order to reduce the total load of the building as well as to ensure thermal comfort inside it. In this study looking for the effect of using recycled lightweight aggregate from lightweight concrete blocks (gathered from the waste products of construction or thermostone factories) as a coarse aggregate. The recycled aggregate is obtained by crushing lightweight concrete waste, brought from thermostone factory in Kirkuk city, into a similar grading to that of the natural aggregate 12.5mm, and is used in the saturated surface dry condition. This is then used to replace the coarse aggregate only with 50% ratio. The replacement is volumetric for lightness weight of thermostone aggregate, Table 1 and Table 2 show grading and physical properties of thermostone respectively.

**Table 1. Grading of thermostone aggregate**

Sieve size (mm)	Cumulative passing %	Limit of ASTM C330-99 [19]
12.5	99	90-100
9.5	77	40-80
4.75	5.4	0-20

**Table 2. Properties of thermostone aggregate**

Properties	Specification	Test Results	Limits of specification
Specific gravity	ASTM C127 [20]	1.01	-
Absorption %	ASTM C127 [20]	43.5	-
Dry loose unit weight kg/m <sup>3</sup>	ASTM C29/C29M [21]	355	-
Sulfate content (as SO <sub>3</sub> ) %	Iraqi specification [11]	0.3	1(max. value)

### 2.2. Mix Proportion

After casting two trail mixes, as shown in the Table 3. , and making necessary alterations. The concrete mix that is obtained following the ACI Committee-211 [15] (specifications of concrete mix design) achieved comparatively a good degree of workability, minimum density and an acceptable level of strength (30MPa) which is targeted. It is utilized for casting large-scale reinforced concrete beams, and standard cylinders. Further for investigation of the effect on the behavior of lightweight aggregate concrete.

Table 3. Trail mix

Trail Mix	Cement Content (kg/m <sup>3</sup> )	Coarse Aggregate (kg/m <sup>3</sup> )	Fine Aggregate (kg/m <sup>3</sup> )	w/c	Density (kg/m <sup>3</sup> )	Compressive strength at 28 Day (MPa)
1	400	1200	600	0.4	2413	24
2*	460	920	782	0.38	2370	33

\*concrete mix which were used in this study.

## 2.3. Mechanical Property of Normal and Lightweight Concrete

### 2.3.1. Concrete Compressive Strength ( $f_c'$ )

The compression test is carried out according to ASTM C39 [4] on cylinders of 150X300 mm .Results of the tests for all concrete mix in this study at 28 days are higher than (17) MPa. This is the minimum required strength recommended by ACI Committee-213 [2] for structural LWC, as shown in Table 4. Summarizes the compressive strength for the normal concrete and lightweight concrete mix are given.

### 2.3.2. Splitting Tensile Strength ( $f_{ct}$ )

The indirect tensile strength (The splitting tensile strength) is performed according to ASTM Standard C496[5]. Cylinders of 150×300 mm were loaded continuously up to failure .As shown in the Table 4, the reduction in the tensile strength of concrete is about 33% as compared to the normal concrete when the aggregate is replaced by 50% thermestone aggregate. This reduction in the tensile strength could be attributed to the effect of the cellular structure of lightweight aggregate (thermostone) that enhanced the initiation and growth of microcracks in concrete under tensile loading.

Table 4. Properties of hardened concrete

Type of concrete	Curing period	Density kg/m <sup>3</sup>	$f_c'$ (MPa)	$f_{ct}$ (MPa)	$f_r$ (MPa)
NWC	7 days	2373	33	4.3	5.84
	28 days	-	34.14	4.41	7.68
LWC	7 days	2082	15.29	2.53	4.44
	28days	-	23.68	2.95	5

### 2.3.3. Modulus of Rupture ( $f_r$ )

Using the flexural strength testing machine of 150 kN capacity, prismatic specimens of 100×100×500 mm are tested under two-point loading for modulus of rupture according to ASTM C78 [6].The reduction in the modulus of rupture of concrete is about 22% as compared to the normal concrete when the aggregate is replaced by 50% thermestone aggregate. As shown in the Table 4.

### 2.3.4. Unit Weight

As it is shown in Table 4, the unit weight for concrete mixes produced from 50% thermestone aggregate at 7 days met the requirement of ACI Committee-213[2] for structural LWC. The reason behind that is due to the porous structure of this type of aggregate compared to the natural aggregates due to the unit weight of the lightweight concrete blocks (thermostone) is about 600 – 800 kg/m<sup>3</sup>.

## 2.4. Details of Specimens

For investigate the flexural behavior, (13) reinforced concrete I-shaped cross-section beams are exposed to four point load after curing for 28 days. Designation of test specimens divided into three groups according to the type of concrete and opening in the web. Their details are listed in Table 5. One of these beams is a control beam without openings. The square and rectangular opening are created by inserting a box fabricated from styrobore. The distance between the support and the center of opening is (250, 350, 400, 750) mm respectively, for two square, rectangular, square, full-size openings. The main steel reinforcement consists of two Ø12 mm, the compression reinforcement consists of two Ø8mm. Stirrups consist of Ø6 mm at 100 mm center to center. This reinforcement is utilized for the reference beam, for beams with strengthened openings with pre-fabricated internal steel bars consisting of Ø6 mm as diagonal bars around the openings for each side. A schematic diagram of the test beam specimens showing the dimensions and details of the reinforcement is depicted in Figures 1 to 6.

Table 5. Details of specimens

Sample	Description		
BN	B:beam	N:normal concrete	
G1			
BN1	B:beam	N:normal concrete	1:rectangulare open
BN2	B:beam	N:normal concrete	2: square open
BN3	B: beam	N: normal concrete	3: two square open
BN4	B:beam	N:normal concrete	4:full size open
G2			
BT1-1	B:beam	T: LWC* (50% normal aggregate. +50% thermostone aggregate)	1:1 <sup>st</sup> group(two layer)
BT1-2	B:beam	T: LWC (50% normal aggregate. +50% thermostone aggregate)	1:1 <sup>st</sup> group(two layer)
BT1-3	B:beam	T: LWC (50% normal aggregate. +50% thermostone aggregate)	1:1 <sup>st</sup> group(two layer)
BT1-4	B:beam	T: LWC (50% normal aggregate. +50% thermostone aggregate)	1:1 <sup>st</sup> group(two layer)
G3			
BT2-1	B:beam	T: LWC (50% normal aggregate. +50% thermostone aggregate)	2:2 <sup>nd</sup> group(three layer)
BT2-2	B:beam	T: LWC (50% normal aggregate. +50% thermostone aggregate )	2:2 <sup>nd</sup> group(three layer)
BT2-3	B:beam	T: LWC (50% normal aggregate. +50% thermostone aggregate )	2:2 <sup>nd</sup> group(three layer)
BT2-4	B:beam	T: LWC (50% normal aggregate. +50% thermostone aggregate )	2:2 <sup>nd</sup> group(three layer)

LWC\*: lightweight concrete

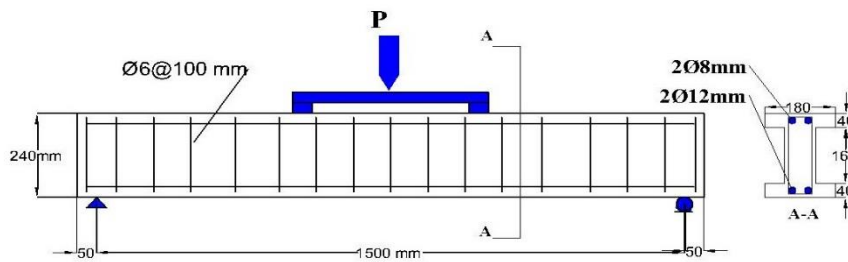


Figure 1. Detail of reinforced concrete beam (reference)

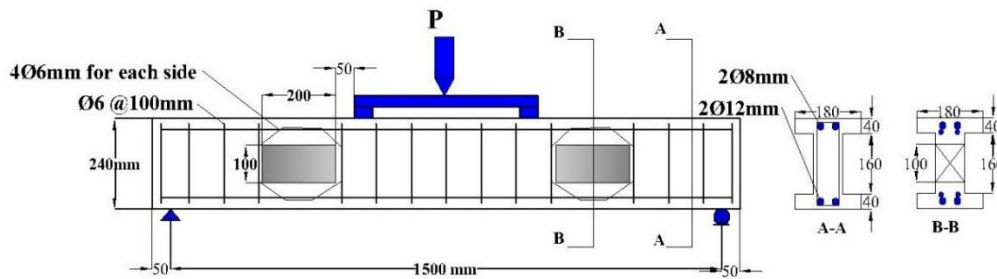


Figure 2. Detail of reinforced concrete beam with rectangular opening

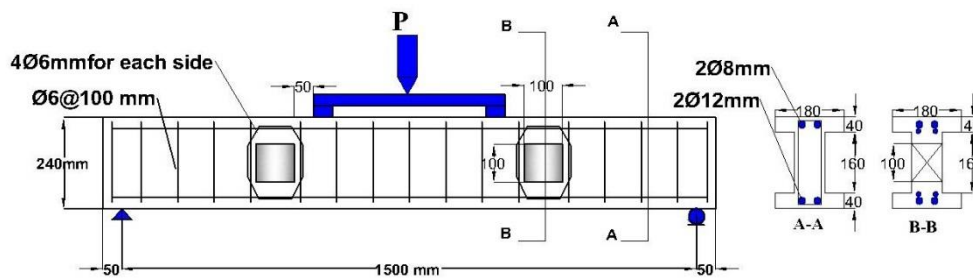


Figure 3. Detail of reinforced concrete beam with square opening

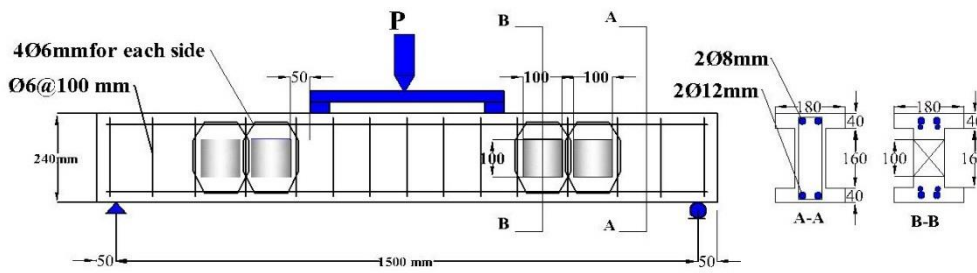


Figure 4. Detail of reinforced concrete beam with two square opening

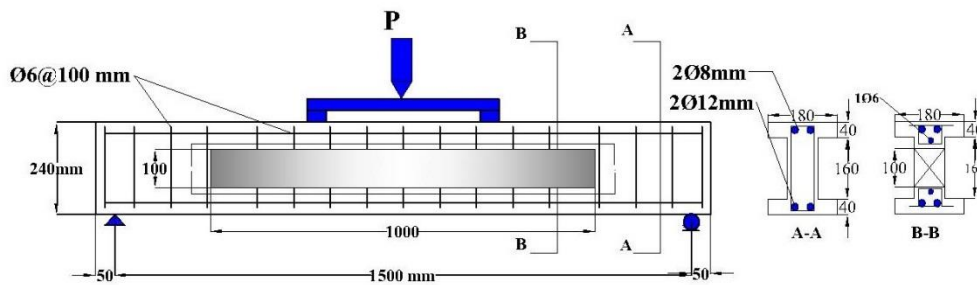


Figure 5. Detail of reinforced concrete beam with full-size opening

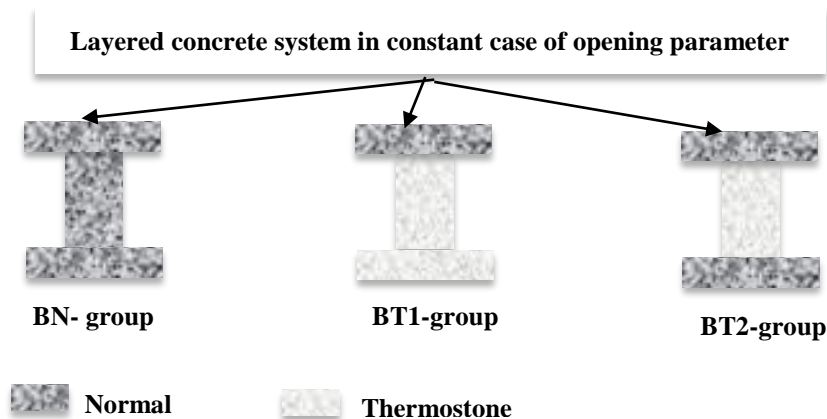


Figure 6. Layered reinforced concrete group to be studied

### 3. Results and Discussion

#### 3.1. Ultimate Load and Cracks Pattern ( $P_u$ )

The ultimate loads are presented in Table 6 and Figures 7 to 11 each one represents the modes of failure and cracks pattern. The solid reference beam (BN) failed in flexure mode. The failure is due to yielding of the tensile reinforcement at ultimate load. This type of failure mode is typical for under-reinforced beams, as illustrated in Figure 7. The ultimate load was 95 kN corresponding mid-span deflection of 12.7 mm.

Generally, all beams with openings exhibited diagonal cracks originating at the opening corners nearest to the support and load points because of stress concentration. Based on the beams result, an increasing of opening diameter leads to increasing of cracks around the opening at all load stages whereas the type and pattern of cracking in these beams are different. In beam (BN2) the direction of shear cracks that is passed through the center of the opening and rapidly grows through the top and bottom section of the beam. With increasing the width of these cracks, the beam under the load of 92.8 kN is subjected to shear failure. According to Mansur & Tan [12], this kind of failure is known as beam failure type. The mode of failure for both shapes of the square opening is illustrated in Figure 9. For the beam (BN1), first shear crack induced under 33.15 kN, the direction of these preliminary cracks, which has an angle of approximately 45 degrees relative to the horizontal direction, passed through the centre of the opening, but with an increase of load, its direction changes nearly in the horizontal direction. As the amount of the load increased, additional cracks on top and bottom of

opening will form. These cracks join the horizontal cracks and when the total amount of applied load reaches 81.8 kN the beam suddenly failed in frame type mode while the opening position on the other side remained undisturbed, as shown in the Figure 8. For beam (BN3) (two square opening of dimension 100×100 mm) that shown in Figure 10, the first crack is initiated at the opening corner nearest to the support. As the load increased, circumferential cracks are observed at the top and bottom chord of the opening, the beam failed by shear action at a load of (70.7) kN. The major cracks are located at the line joining the points of the opening corners and the nearest the support toward the point of load application. Similarly, minor cracks are observed at the four corners of the two square opening. However, the crack condition is not as severe as the other opening. The mode of failure, as indicated by Figure 10 was a typical shear failure.

The crack pattern for the beam (BN4) with opening length 1000mm was shown in Figure 11. The first crack at the mid-span of the beam is initiated at 11.05 kN. Then, the crack at the shear zone is initiated at the opening corner nearest to the support at a load level of 33.15 kN. As the load increased, additional new cracks are observed at the top and bottom chord of opening and the beam failed by a shear action at 61.9 kN. In addition, the major crack is located at the line joining the points of the opening corners and the point of load application. The mode of failure, as indicated by the Figure 11 is a shear failure.

The type of concrete has significant effect on the crack pattern around the opening and also on the value of ultimate strength. This is illustrated in group [G2] and [G3]. The ultimate load recorded for specimens (BT1-1, BT1-2, BT1-3, BT1-4, BT2-1, BT2-2, BT2-3 and BT2-4) was (66.3, 86.2, 66.3, 48.6, 61.9, 70.7, 61.9, and 39.8) kN respectively. In comparison to similar beam made out of normal concrete, it fails under low loads and shows larger cracks.

**Table 6. Experimental result of beams**

Beam	Open dimension ( $l_o \times d_o$ )***	load (kN)		Deflection (mm)		Capacity decreasing (%)	E.A.C**** kN.mm	Mode of failure
		P <sub>cr</sub>	P <sub>u</sub>	$\Delta_{cr}$	$\Delta_u$			
BN*		33.15	95	2	12.7	-	816.77	flexure
G1								
BN1	100×200	33.15	81.8	2.31	11.4	13.9	636.73	shear
BN2	100×100	33.15	92.8	1.7	11.5	2.3	681.43	shear
BN3	D**(100×100)	33.15	70.7	2.9	8.1	25.6	567.92	shear
BN4	100×1000	11.05	61.9	1.26	4.62	34.8	127.76	shear
G2								
BT1-1	100×200	22.1	66.3	2.2	8.53	30.2	397.36	shear
BT1-2	100×100	33.15	86.2	1.58	10.55	9.3	673.93	shear
BT1-3	D(100×100)	22.1	66.3	1.44	8.85	30.2	477.01	shear
BT1-4	100×1000	11.05	48.6	1.23	4.42	48.8	103.56	shear
G3								
BT2-1	200×100	22.1	61.9	1.47	8	34.8	329.48	shear
BT2-2	100×100	22.1	70.7	1.62	6.14	25.6	275.86	shear
BT2-3	D(100×100)	22.1	61.9	1.47	6.9	34.8	267.81	shear
BT2-4	100×1000	11.05	39.8	0.94	4.05	58.1	88.30	shear

B\*=reference beam specimen; D\*\*= double square opening; E.A.C\*\*\*\*:= energy absorption capacity (kN.mm)  
( $l_o \times d_o$ )\*\*\*= (width of opening × height of opening).

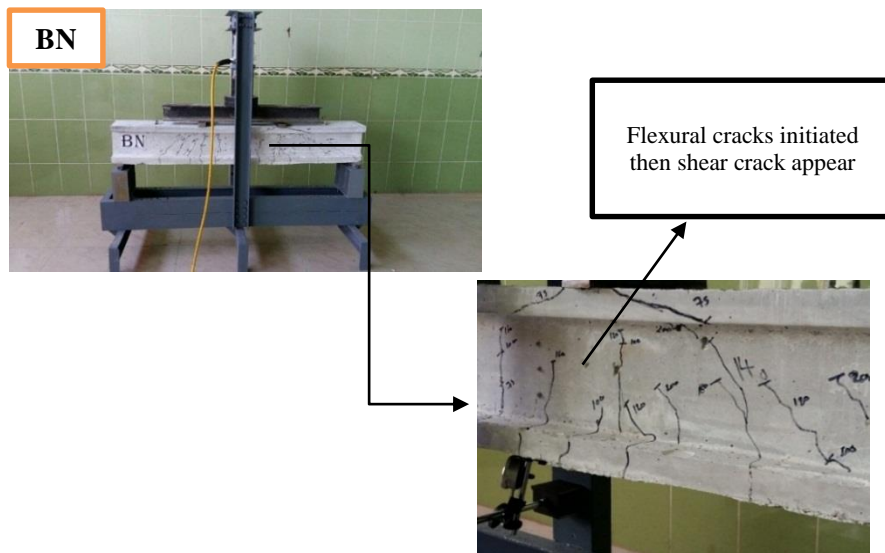


Figure 7. Crack pattern for specimen BN (reference)

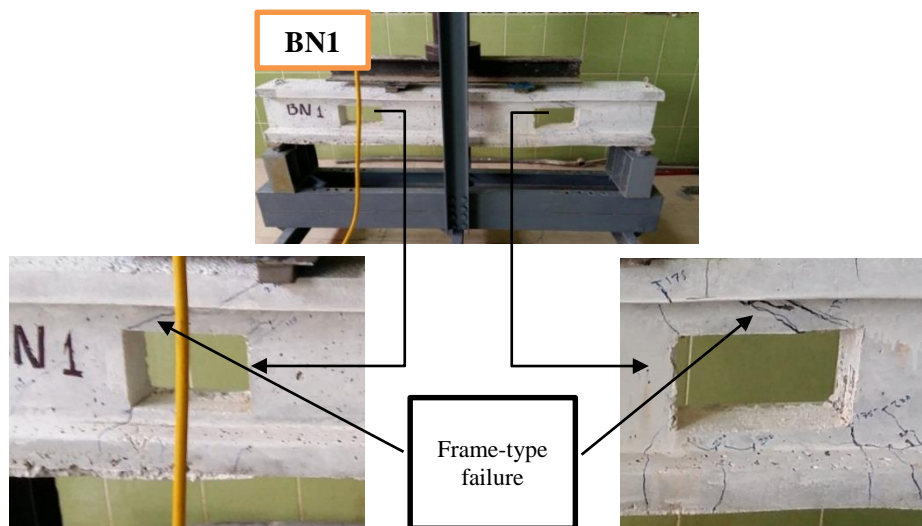


Figure 8. Crack pattern for specimen BN1 (rectangular opening)

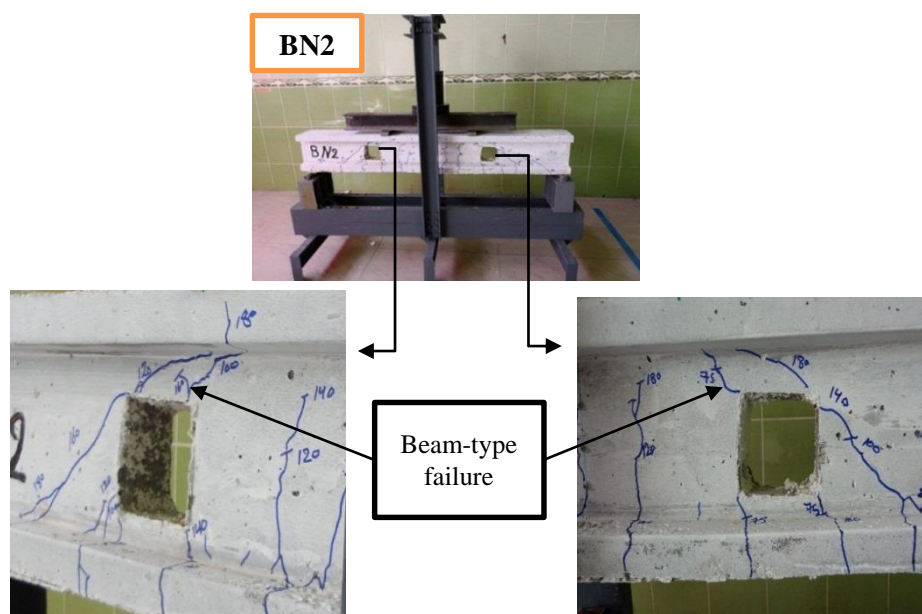


Figure 9. Crack pattern for specimen BN2 (square opening)



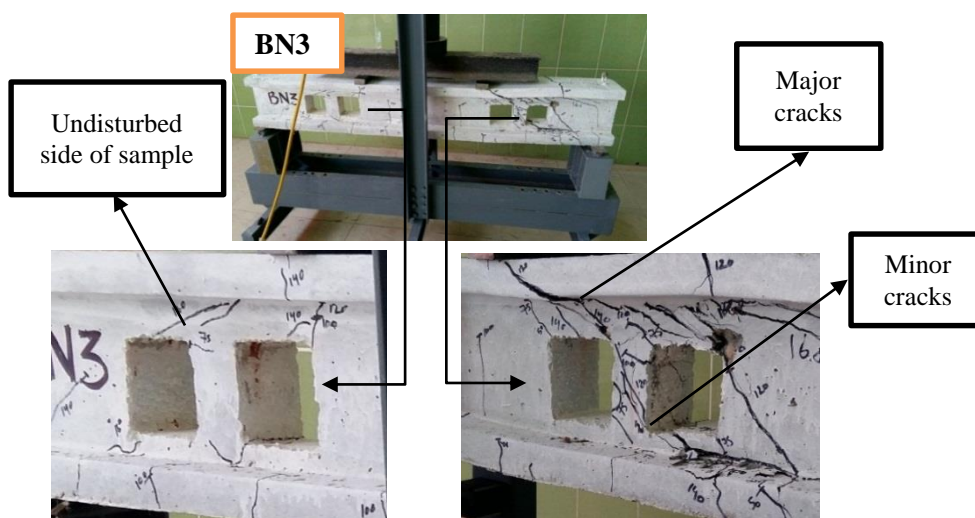


Figure 10. Crack pattern for specimen BN3 (two square opening)

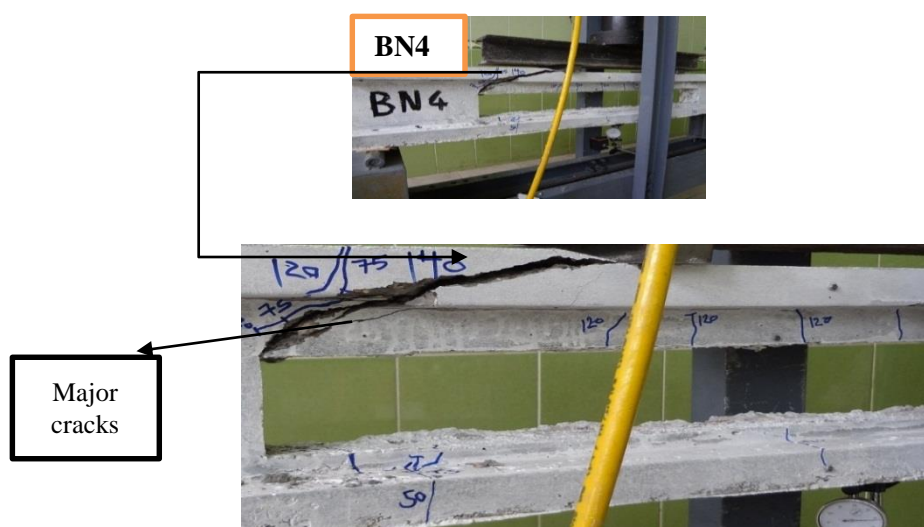


Figure 11. Crack pattern for specimen BN4 (full-size opening)

### 3.2. Energy Absorption Capacity

It is the capacity of a material, section, structural element or structural system to tolerate large inelastic deformations prior to total collapse. Without such a property, structural members would a diminished ability to resist loads beyond their maximum strength. The area under the load-deflection curve is considered in this study.as shown in the Table 6. As Compared to the control beam, the energy absorption capacity of the normal concrete beam with opening length (1000mm) decrease up to 84% while the beam with opening size (100×200) and (100×100) respectively, decrease up to 22% and 16%. So, magnitude increased of energy absorption capacity was achieved by the decreased opening size, as shown in the Figures 12 and 13.

In case of the two layered concrete beams, the real influence of lightweight concrete (LWC) type in the layered reinforced concrete is observed significantly after increasing the length of opening more than 100mm, for instance : the energy absorption capacity of the beam specimen which constructed from LWC thermestone BT1-2 is 10% less than the beam specimen BN2. With increased the opening dimension in the beam specimen BT1-1, the energy absorption capacity decreased up to 45% in compare with BN1.

In addition, the energy absorption capacity of the beam BT1-1 is greater than that of the beam BT2-1 in the rate of 6%, similarly between the beams BT1-2and BT2-2.These results indicate that the experimental results of increasing layered number for layered concrete beam exhibited a negative performance on the energy absorption capacity, as shown in the Figures 14 and 15.

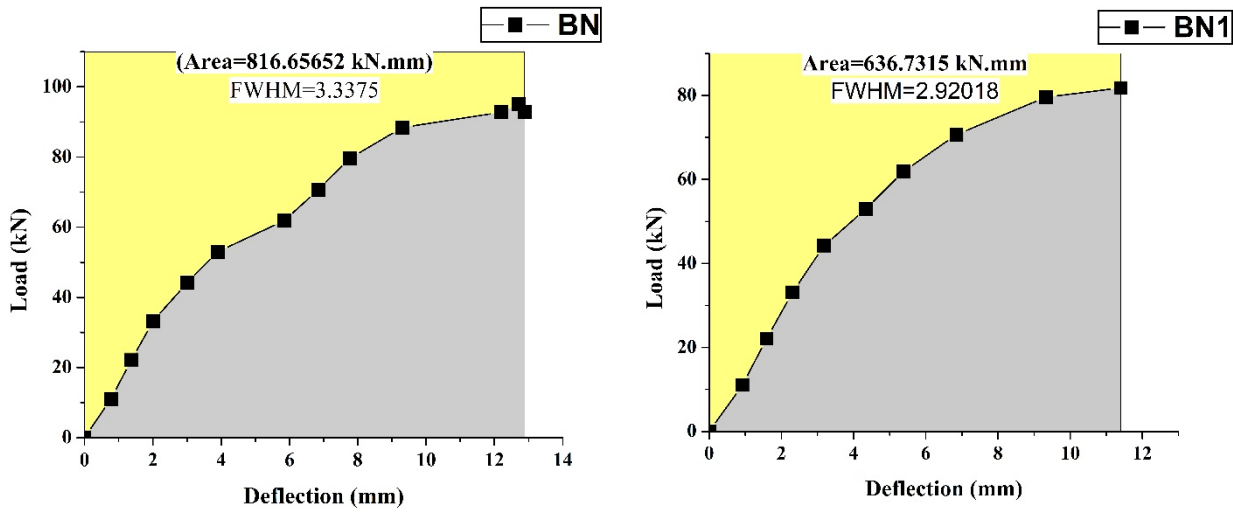


Figure 12. Energy absorption capacity for reinforced normal concrete beams (reference and rectangular openings)

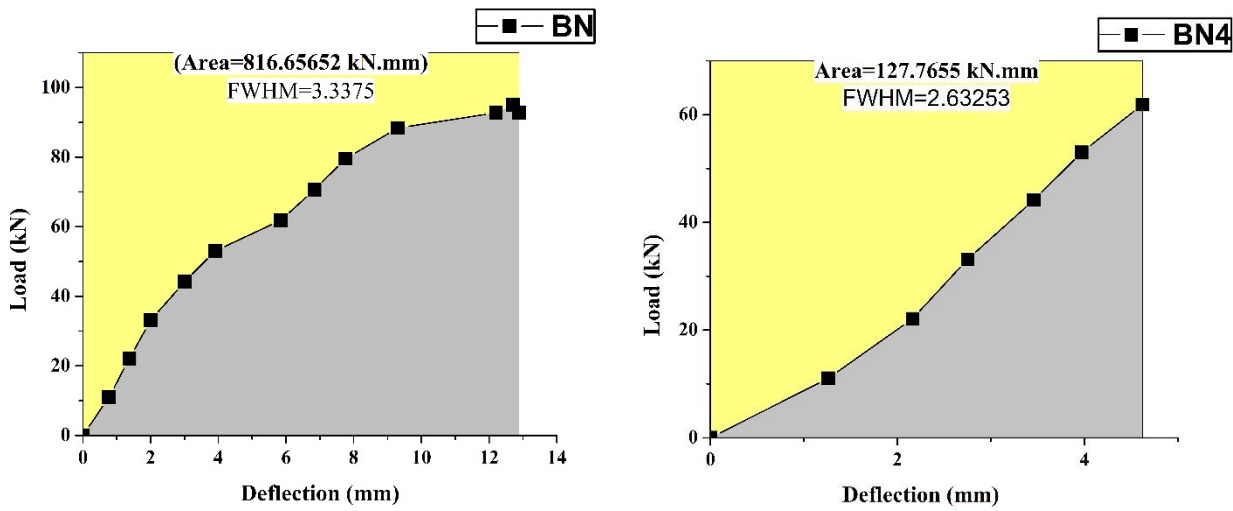


Figure 13. Energy absorption capacity for reinforced normal concrete beams (reference and full-size openings)

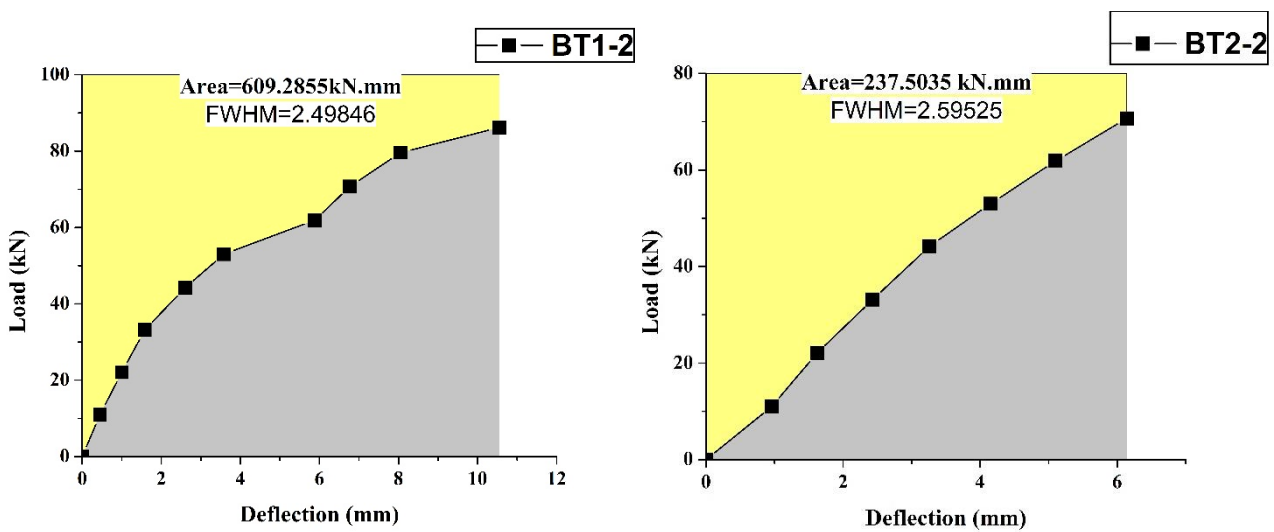


Figure 14. Energy absorption capacity for reinforced layered concrete beams with square openings

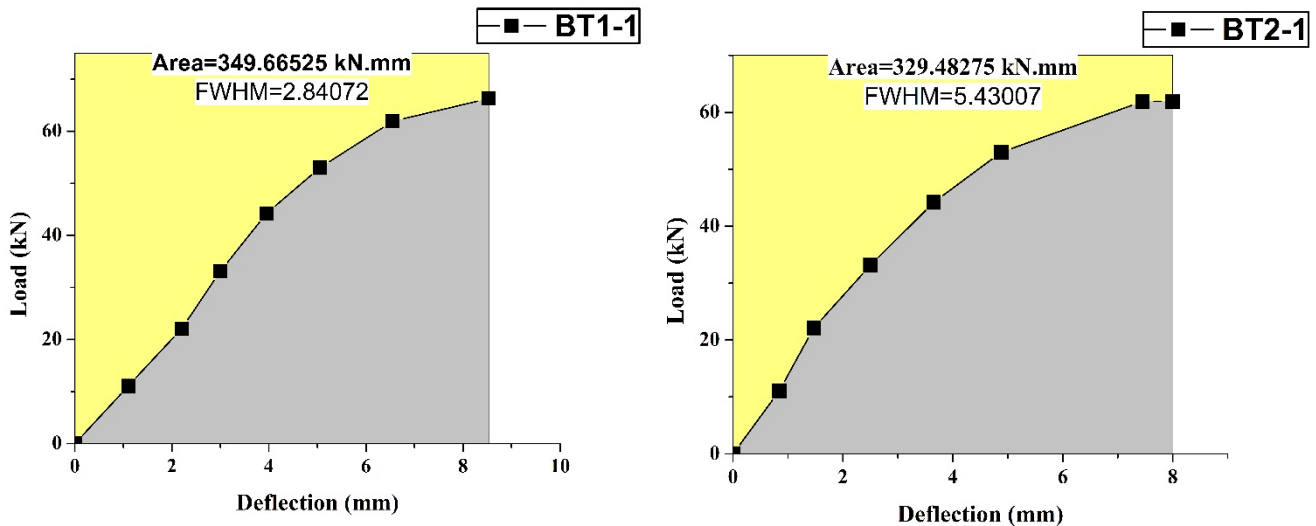


Figure 15. Energy absorption capacity for reinforced layered concrete beams with rectangular openings

#### 4. Conclusions

- It is possible to produce lightweight concrete by using locally available materials, thermestone, as coarse lightweight aggregate.
- The test results show there is a trivial difference between beams with opening and control beam till opening size of 100mm in (length).
- By making a square opening in the beam (100×100) mm, the cracks appeared around the opening most of them started from two opening corners to the edge of the beam and the beam failure occurred in the opening region. So we can say that failure occurred in the beam (BN2) is beam type failure and this gives us an indication that beam with existed small opening gives us an alarm before failure.
- In normal reinforced concrete beam with small opening at shear zone, the maximum reduction in ultimate load was about (2.3%).
- In normal reinforced concrete beam with large opening (length of opening more than 100mm) at shear zone, excessive shear cracks were found around the openings. The failure mode was in shear. Providing large opening in reinforced concrete beam decreased the ultimate load about (34%).
- The experimental test results obtained from the adopted layered technique of (NEW) and (LWC) have shown that for beams constructed from two layered concrete (LWC with thermestone in the web and bottom flange of I-section beam), the ultimate load was decreased about (9.3%-48.8%).
- The beams made from three layered of concrete (LWC with thermestone in the web of I-beam section), their ultimate load is decreased about (25.6%-58.1%).
- The two layered concrete show that good performance more than the three layered.
- Introducing the full size opening of dimension (100×1000) mm reduces the energy absorption capacity of the RC I-section beams at least 80% compared to solid beam.
- In the three layered concrete beams specimen, the load-displacement curve shifts to the left and becomes stiffer, which reduces the energy absorption capacity of concrete beam.

#### 5. Acknowledgement

The author acknowledge Tikrit University and Kirkuk University for their help to done this research works.

#### 6. Conflicts of Interest

The authors declare no conflict of interest.

#### 7. References

- [1] Abtan, Yaarub G. and Hind T. Jaber” Behavior Of Hybrid Reinforced Concrete Beams Combining Reactive Powder Concrete And Varying Types Of Lightweight Concrete.” Journal of Engineering and Sustainable Development 20, no. 2 (2016): 204–223.

- [2] ACI Committee, American Concrete Institute, and International Organization for Standardization. "Guide for structural lightweight aggregate concrete (ACI 213-03)." American Concrete Institute Committee: Farmington Hills, MI, USA.
- [3] Al-Jumaily, Ibrahim A., Abdulkader I. Al-Hadithi, and Noor S. Al-Samarai "Mechanical Properties of Carbon Fiber Lightweight Aggregate Concrete Containing Acrylic Polymer." Anbar Journal for engineering sciences 6, no.3 (2013): 358.
- [4] ASTM C39/C39M-18, "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens." ASTM International, West Conshohocken, PA, 2018. doi: 10.1520/C0039\_C0039M-18.
- [5] ASTM C496-09, "Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens." ASTM International, West Conshohocken, PA, 2009. doi:10.1201/9781420091175-c28.
- [6] ASTM C78/C78M-18, "Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)." ASTM International, West Conshohocken, PA, (2018). doi: 10.1520/C0078\_C0078M-18.
- [7] ASTM A615 / A615M-16, "Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement." ASTM International, West Conshohocken, PA. (2016), doi: 10.1520/a0615\_a0615m-16.
- [8] Eldemerdash Waleed E., Mohamed E. ElZoughiby, Ahmed A. Ghaleb, and Salah E. ElMetwally "Design of Reinforced Concrete Beams with Openings." Arabian Journal for Science and Engineering 41, no.2 (2016): 401-424.
- [9] Hafiz, Rezwana Binte, Shaibal Ahmed, Saikat Barua, and Sharmin Reza Chowdhury. "Effects of Opening on the Behavior of Reinforced Concrete Beam." IOSR Journal of Mechanical and Civil Engineering 11, no. 2 (2014): 52–61. doi:10.9790/1684-11275261.
- [10] Specification, Iraqi No. 5 "Portland Cement", Baghdad (1984).
- [11] Specification, Iraqi No. 45 " Natural Sources for Gravel that is Used in Concrete and Construction", Baghdad (1984).
- [12] Mansur, M. A., and K. H. Tan "Concrete Beams with Openings: Analysis and Design." Choice Reviews Online 36, no. 11 (July 1, 1999): 36–6307–36–6307. doi:10.5860/choice.36-6307.
- [13] Zaki, Michael M., Mostafa A. Osman, Ata E. Shoeib, and Megdy M. Genidi "The effect of created opening under working load on behavior of R.C beams." Proceedings of the ninth international conference on NANO-technology in construction (NTC 2017).
- [14] Oukaili, Nazar K. and Abeer H. Shammari "Response of reinforced Concrete Beams with Multiple Web Openings to Static Load." Proceedings of the fourth Asia-pacific conference on FRP in structures (APFIS 2013).
- [15] ACI Committee, American Concrete Institute, and International Organization for Standardization. "Standard practice for selecting proportions for normal, heavyweight and mass concrete (ACI 211-91)." American Concrete Institute, Farmington Hills, Michigan, USA.
- [16] Aykac, Bengi, Ilker Kalkan, Sabahattin Aykac, and Yusuf Emre Egriboz. "Flexural Behavior of RC Beams with Regular Square or Circular Web Openings." Engineering Structures 56 (November 2013): 2165–2174. doi:10.1016/j.engstruct.2013.08.043.
- [17] Osman, Bashir H., Erjun Wu, Bohai Ji, and Suhaib S. Abdulhameed. "Shear Behavior of Reinforced Concrete (RC) Beams with Circular Web Openings Without Additional Shear Reinforcement." KSCE Journal of Civil Engineering 21, no. 1 (April 25, 2016): 296–306. doi:10.1007/s12205-016-0387-7.
- [18] Saksena, Nilesh H., and P. Patel. "Experimental study of reinforced concrete beam with web openings." International Journal of Advanced Engineering Research and Studies-India 2, no. 3 (2013): 66-68.
- [19] ASTM C330, "Standard Specification for Lightweight Aggregates for Structural Concrete." ASTM International, West Conshohocken, PA. (1999).
- [20] ASTM C128 "Standard Test Method for Relative Density (Specific Gravity) and Absorption of Fine Aggregate". ASTM International, West Conshohocken, PA. (2015).
- [21] ASTM C29/C29M "Standard Test Method for Bulk Density (Unit Weight) and Voids in Aggregate." ASTM International, West Conshohocken, PA. (2009).