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Research Article

Effect of Implementing LECA in LWC Waffle Slabs

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ABSTRACT

A two-way waffle slab system might consist of slabs with a flat flange plate or deck and two orthogonally spaced parallel beams. The key objective of using two-way ribbed (waffle) slabs is to decrease the quantity of concrete and reinforcement and, therefore, the structure's weight. This study investigates the behaviour of two-way waffle slabs that contain lightweight expanded clay aggregate (LECA) to produce LWC. Results stated that (LECA) could produce structurally lightweight concrete by completely replacing coarse aggregates. It would maintain the same compressive strength as NWC with a 26.2 % lower concrete dry density.

Keywords: replacing, behaviour, orthogonally, density

1. INTRODUCTION

Lightweight Expanded Clay Aggregate (LECA) has currently drawn much attention as a suitable replacement for traditional aggregates in concrete. Some unique properties of LECA are lower density, improved thermal insulation, and workability, which make it desirable for many applications in construction [1]. It is manufactured by the high-temperature expansion of clay and results in a lightweight aggregate with a porous structure while retaining excellent mechanical properties [2]. The specific gravity of LECA is generally between 0.8 and 1.2 g/cm³, much lower than that of conventional aggregates, which require greater structural loads [3].

Experimental investigation into reinforced concrete waffle slabs with a square rib layout and a 1540 mm side dimension stated that for slabs with consistent rib reinforcement, the ultimate load-carrying capacity increased linearly with the number of ribs [4]. Rib dimensions must be increased with increasing floor area or the waffle slab's live load capacity [5].

An experimental and numerical approach was carried out to investigate a waffle slab flexural strengthen full-scale slab (12.90 ×11.14 m) with a rib dimension of (250×120 mm) and 75 mm topping thickness. A linear load deflection curve with limited cracks was recorded [6]. An opening adjacent to the applied load highly deteriorates the slab's punching capacity, which is more effective than increasing the size or number of openings [7].

Approximately a 48% increase in energy absorption, a 26% increase in the ductility index, and a 106% increase in crack width for the ferrocement slabs compared to those without LECA [8]. As the percentage of LECA increased, the slabs exhibited more significant deflection. The ultimate slab deflection was 37.2% higher than NWC and combined significant deterioration in failure load by 35.1% [9].

2. EXPERIMENTAL PROGRAM

This study involves six specimens; the overall dimensions were (1050 ×1050 mm) and precise topping thickness (50 mm), while the joist dimension was (100 × 50 mm). Steel reinforcement was arranged orthotopically, consisting of mesh at the top (ϕ6 mm @ 75 mm c/c), and the bottom of the joists contained (1 ϕ8 mm) as shown in fig. (1).

The slabs were classified into three NWC and three LWC slabs, which are identical geometry slabs. For LWC, a control slab without an opening (LU) and a square central opening (LRC) made using LECA as coarse aggregate.

At the same time, the slab (LRCNB) had a basalt bar in a near-surface mounted strengthening technique NSM around the central opening, as demonstrated in Fig. (1). NWC slabs (U, RC and RCNB) had the same geometry and properties as LWC slabs, respectively. All slabs were subjected to a uniform distributed load under simply supported conditions from the four edges. Table (1) illustrates the slabs geometry.

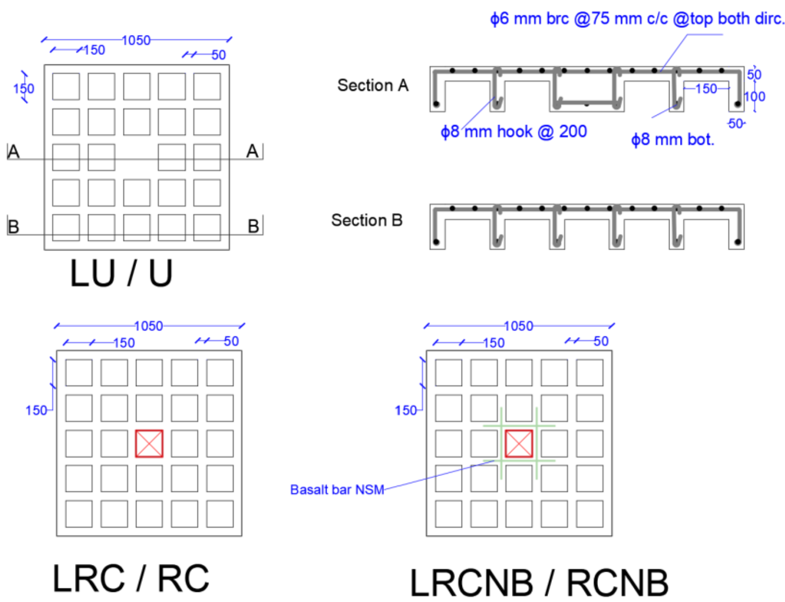

Fig.1 Slabs geometry

To investigate lightweight concrete, a complete gravel replacement by the semi-rounded / crushed structural type LECA Fig. (2), with a size (4-10) mm. Table 2 shows the tested properties. According to ASTM C330/C330M – 23 [10], dry sieving results are listed in Fig. (3).

Table 1. Specimens details

Specimens	**Opening size (mm)**	**Concrete Type**	**Opening position**	**Strengthening**
LU	----	LWC	----	----
LRC	150 x 150	LWC	At Centre	----
LRCNB	150 x 150	LWC	At Centre	B-NSM
U	----	NWC	----	----
RC	150 x 150	NWC	At Centre	----
RCNB	150 x 150	NWC	At Centre	B-NSM

Figure (2) LECA Particles

Table (2) LECA Properties

Type of test	The results
24 h water absorption: %	9
Crushing Strength (MPa)	5
Specific gravity	1.08
Loose bulk density (kg/m3)	667

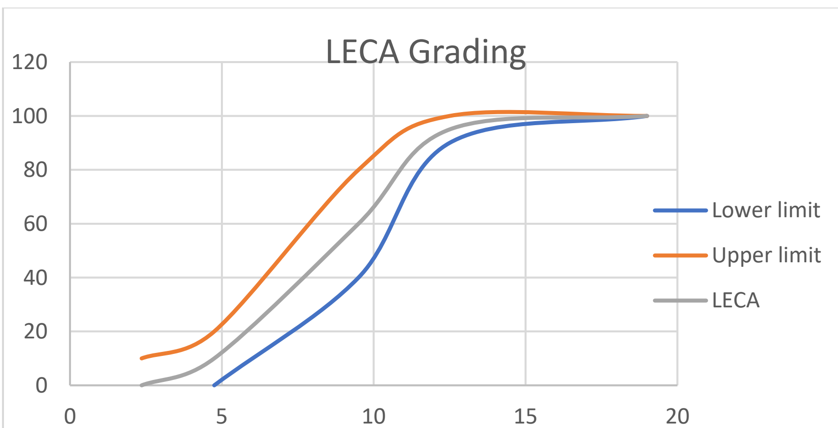

Fig. (3) LECA Grading

An 8 mm deformed basalt fibre-reinforced polymer bar was used in the near-surface mounted (NSM) technique. It had the following properties tested according to ASTM A615/A615M-20 [11], as shown in Table (3). Steel rebar yielding and tensile strengths are shown in Table (4).

Table (3) Basalt bar properties

bar size	Tensile Strength	Elongation (%)	Tensile modulus of elasticity
8 mm	835 MPa	1.5 %	55.7 GPa

Table 4. Steel reinforcement properties

Bar diameter	Fy (Mpa)	Fu (Mpa)
6	350	470
8	430	546

Several trial concrete mixes were cast to determine a concrete mix that meets the requirements of this research. The mixing ratios were selected using normal-weight concrete (NWC) and lightweight concrete (LWC), The workability was checked as the control test for the fresh concrete properties. If the mix passed the test, six cubes of dimensions 150×150×150 mm were cast to be tested after 28 days.

The process included mixing several patches with different ingredient content. The final mixing ratios that satisfied the same strength of Normal NC and lightweight concrete LWC by fully replacing gravel by LECA were as mentioned in Table (5).

Table (5) Concrete mix component in one cubic meter

Component	NC (per 1m^3)	LWC (per 1m^3)	Unit
Cement	400	475	kg
Water to cement ratio	45	22	%
Sand	700	675	kg
Gravel	1100	------	kg
LECA	-----	500	kg
Admixture	3.5	4	litre
compressive strength	35.2	34.4	MPa
Modulus of elasticity	27805.5	19299.3	MPa
Density	2320	1712	kg\m3

3. RESULTS AND DISCUSSION

Table (6) illustrates the experimental results of the tested specimens. The observed cracking load, maximum loading capacity, failure mode, and maximum deflection were listed. Generally, flexural failure with rib cracking was the dominant behaviour for all slabs.

Table 6. Experimental results

specimens	**Cracking load Pcr (kN)**	**Failure load Pu (kN)**	**Decreasing in loading capacity %**	**Crack width at 0.65 Pu (mm)**	**Max crack width (mm)**	**Max deflection (mm)**	**failure mode**
LU	50	310	0.23	0.38	4.03	10.51	flexural failure with ribs cracking
LRC	32	208	0.21	0.3	2.7	8.52	
LRCNB	32	282	0.087	0.27	2.5	12.22	
U	85	405	-----	0.38	6.5	20.24	
RC	60	263	-----	0.32	4.5	13.45	
RCNB	60	309	-----	0.27	5.1	14.12	

Cracks pattern

The two-way waffle slabs' cracking performance followed the general deformation structural effect and could be divided into three main stages. At the start of applied loading (concentrated and uniformly distributed), elastic deformation dominates the slabs until the first crack appears on the middle zone ribs close to the solid portion.

In the elastoplastic stage, the cracks start to spread to cover most of the ribs and keep widening until a plastic stage combines fast-spreading and wider cracks than previous stages.

Although crack patterns were almost similar between the two types of concrete, the cracks appeared earlier and wider than NC slabs due to weaker coarse aggregate and lower modulus of elasticity, as shown in Fig. (4).

Cracks width

The crack width performance seems highly influenced by slab geometry, mainly when central solid portions are eliminated by opening. Fig. 5 illustrates the curves of maximum crack width against load for all slabs, demonstrating the progression of cracks from their initial appearance to failure. The control slab U exhibited a higher envelope, and the NSM technique highly improved cracking propagation.

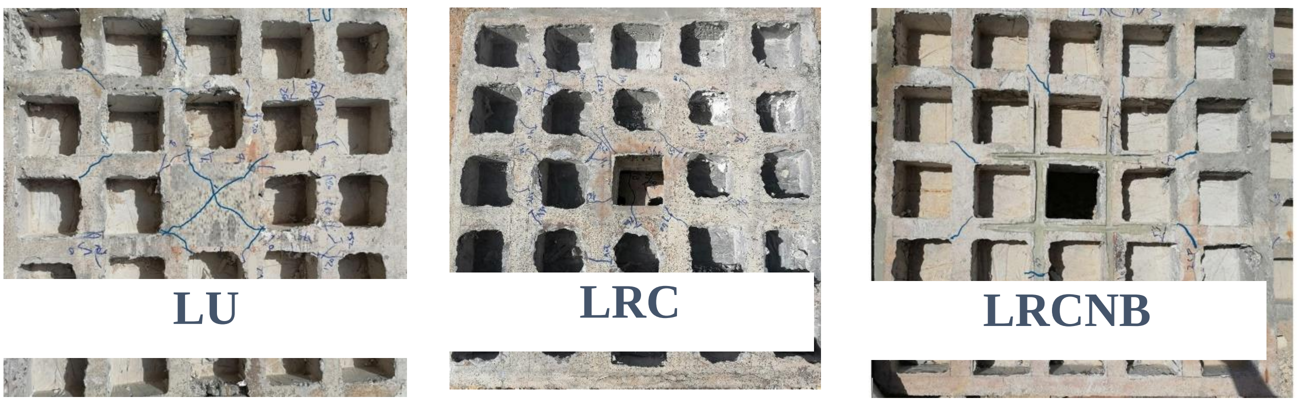

Fig. 4 Cracked slabs

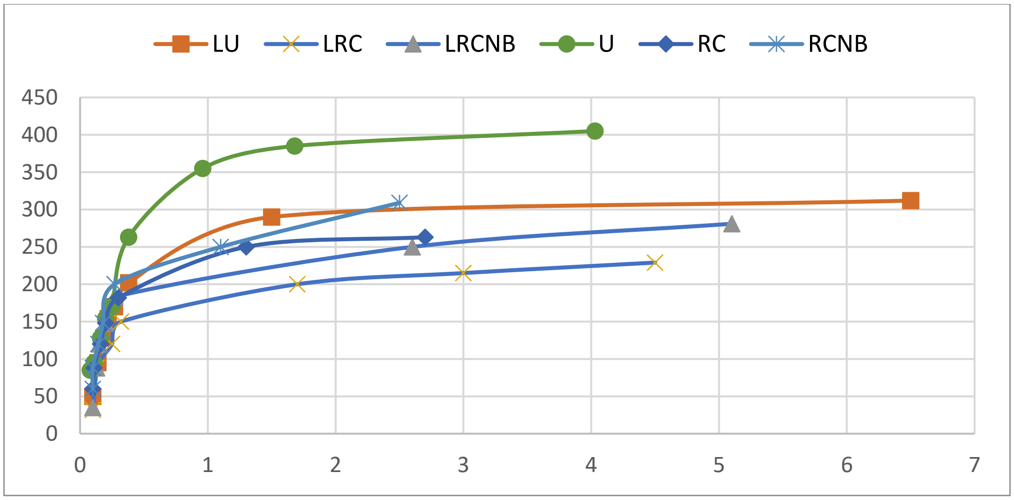

Fig. 5 max cracks width

Using LECA to produce LWC instead of gravel resulted in the deterioration of cracking loads of the slabs (LU, LRC and LRCNB) by (41.17, 46.67 and 41.67%) compared with NC waffle slabs (U, RC AND RCNB) respectively.

Load deflection behavior

The load-deflection curves in Fig. (6) exhibited an initial elastic behaviour, after which the first cracking appearance influenced the three-phased curves. Once the steel reinforcement reached yielding stress, the plastic phase, the final phase in slabs, became dominant, leading to a rapid increase in displacement data records with an insignificant load rise.

Lightweight concrete has lower structural characteristics than NC concrete due to strength, stiffness, and density differences between coarse aggregate types (gravel and LECA). The percentage difference in ultimate load and deflection between solid slabs was higher than that of opening ones, and the ratio decreased further using the NSM technique in both types of concrete.

The slabs (U, RC, and RCNB) resulted in higher load (23 %, 20.91 %, and 8.74%) and increased maximum deflection (48.07 %, 36.35 %, and 13.46 %) than the LWC waffle slabs (LU, LRC, and LRCNB), respectively, as shown in Figure (6).

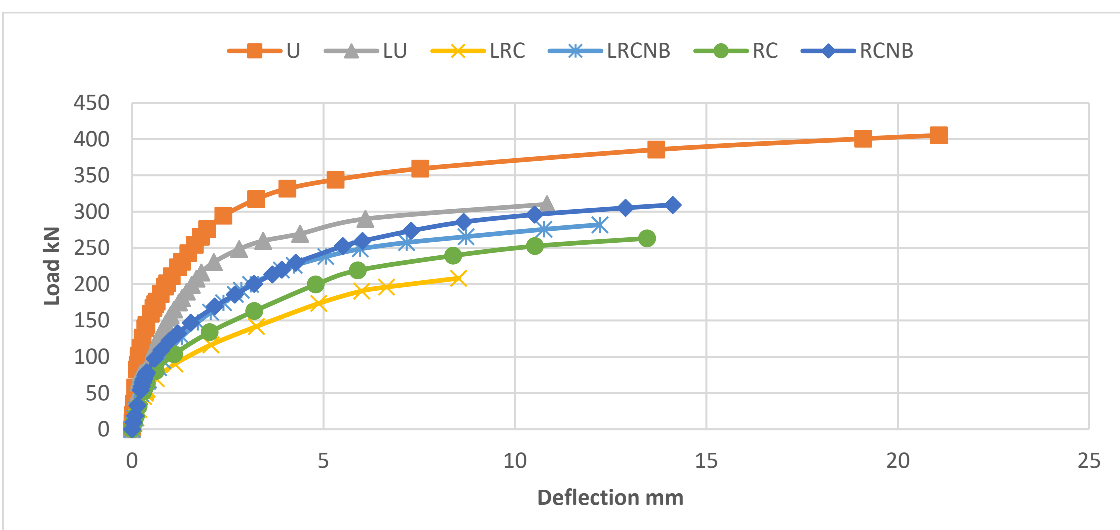

Fig. 6 Load-deflection curves

Waffle slab stiffness

The stiffness of the waffle slabs was recorded at the service load level (0.65 Pu)[12]. From the values listed in Fig.7, The solid waffle stiffness reveals a unique stiffens (162.2 kN/mm). At the same time, the opening slabs decreased by (43~70 %). With better behaviour under NSM strengthening.

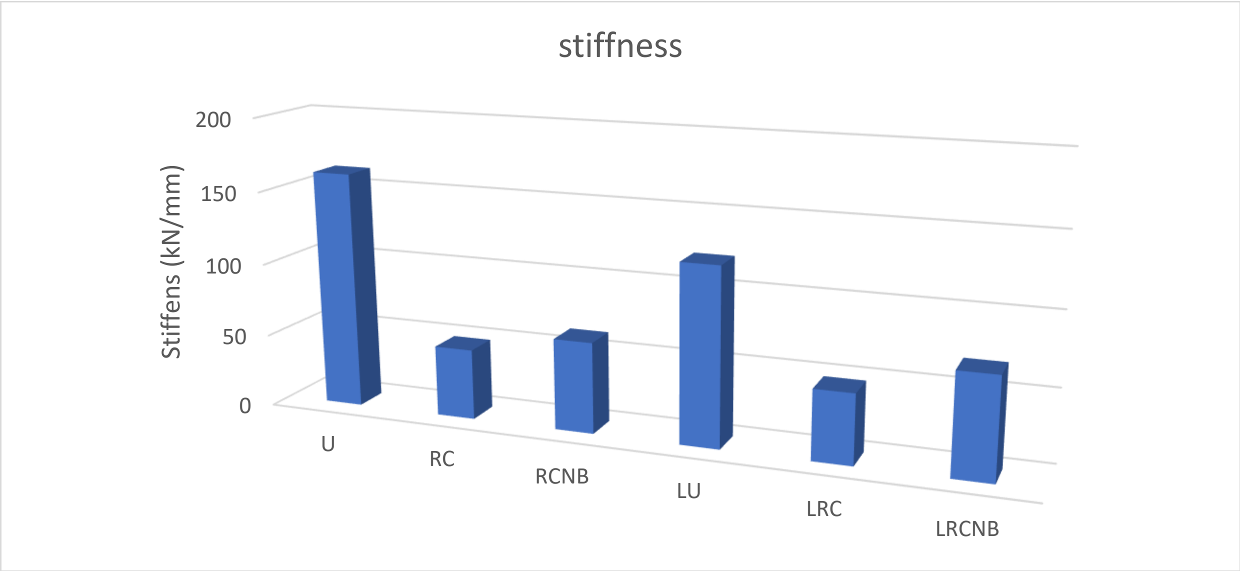

Fig. 7 Stiffness of waffle slabs

Ductility ratio

The ductility ratio was calculated from the division of max deflection over deflection at the service load level, as shown in Fig. 8. Solid slab had the highest ductility value. NSM technique reveals a significant improvement in waffle slab stiffness.

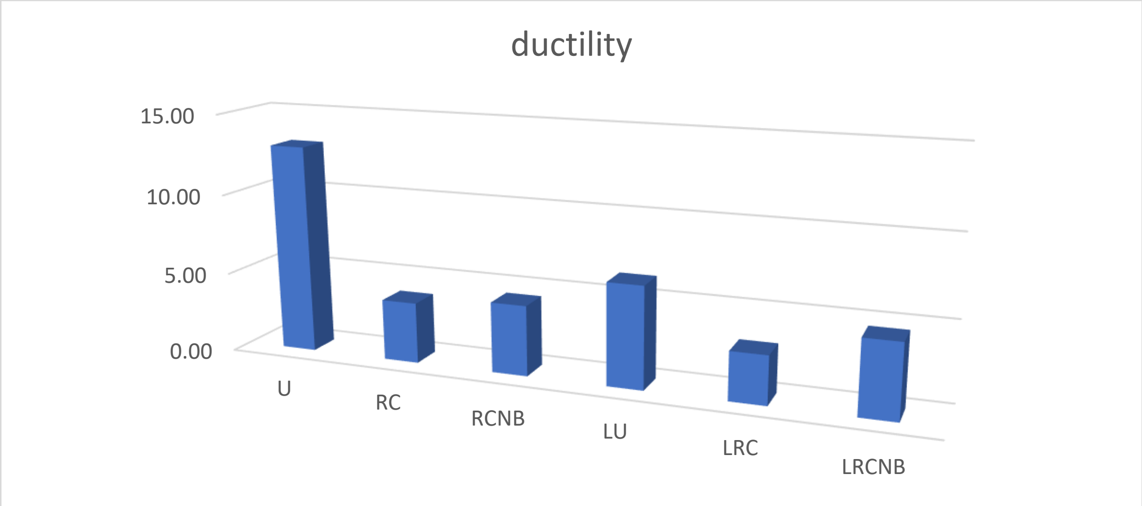

Fig. 8 Ductilty ratio

Toughness results

Solid Slabs shows a spectacular result in stiffness, while cutting opening in slab led to a deterioration in waffle slab energy absorption by 63.4 %. The slabs (U, RC, and RCNB) resulted in higher Toughness (62 %, 53 %, and 21%) than the LWC waffle slabs (LU, LRC, and LRCNB), respectivelyas shown in Fig.9.

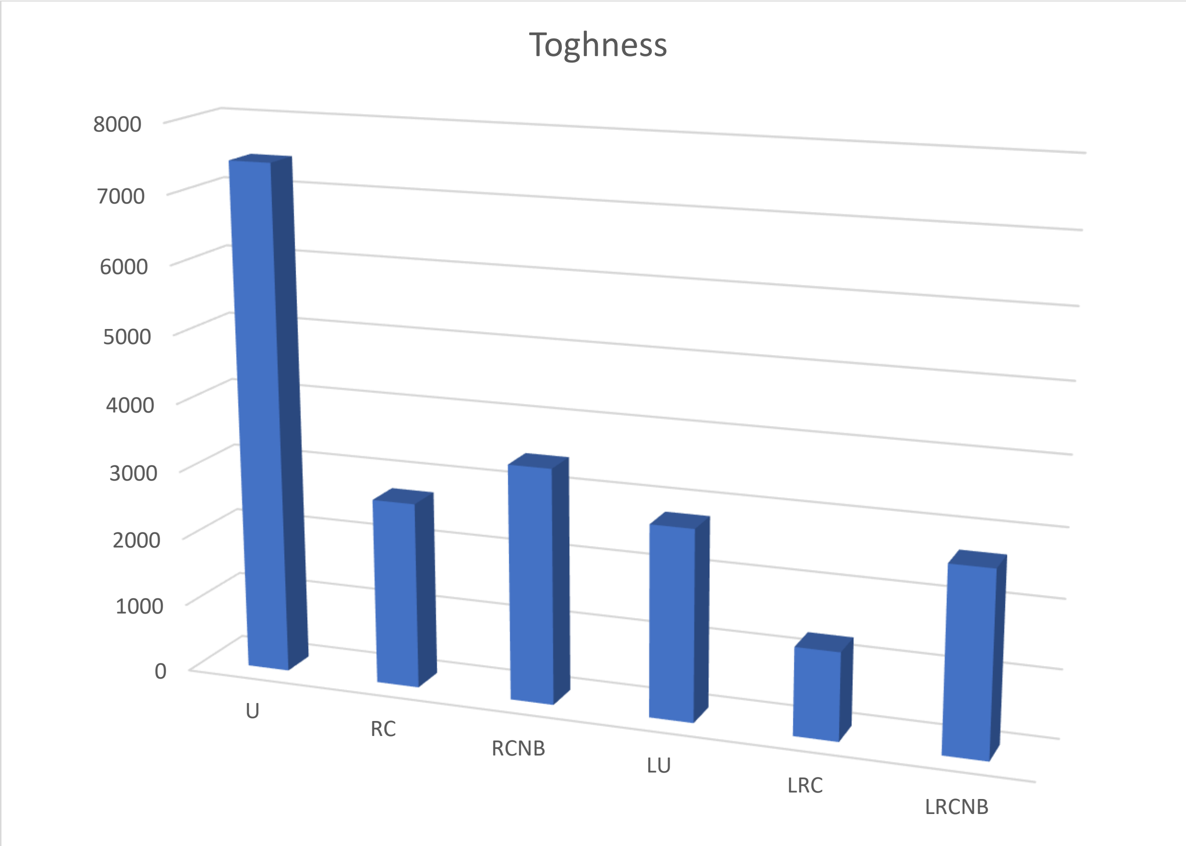

Fig. 9 Toughness of waffle slabs

4. CONCLUSIONS

1. Light expanded clay aggregate (LECA) could produce structural lightweight concrete by completely replacing coarse aggregates. It would maintain the same compressive strength as NWC with a 26.2 % lower concrete dry density.
2. A significant deterioration in the waffle slab's structural capacity resulted from the opening. The central opening eliminates most of the solid middle part in the maximum moment zone, considerably altering loading capacity and ability to absorb energy by slabs.
3. Regarding LWC, the opening impact recorded a lower effect on the waffle slab than NWC. Load capacity and maximum deflection were dropped by (26.6 % and 18.93%) for slab LRC when compared to LU, respectively.
4. Using NSM with basalt rebar was highly effective on the ultimate load capacity and deflection of LWC slab LRCNB, which recorded (35.58 % and 43.4 %) higher than LRC slab, respectively.
5. Lightweight concrete has lower structural characteristics than NC concrete due to strength, stiffness, and density differences between coarse aggregate types (gravel and LECA). The slabs (U, RC, and RCNB) resulted in higher load (23 %, 20.91 %, and 8.74%) and increased maximum deflection (48.07 %, 36.35 %, and 13.46 %) than the LWC waffle slabs (LU, LRC, and LRCNB), respectively.

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