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Flexural Behavior of Reinforced Concrete One-Way Slabs with Different Ratios of Lightweight Coarse Aggregate

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ABSTRACT

The aim of the present research includes an experimental investigation of flexural behavior of lightweight reinforced concrete one-way slabs with different ratios of course aggregate. Nine lightweight reinforced concrete one- way slabs incorporated by two types of lightweight course aggregate were tested in these investigation. Also the mechanical properties and workability test for concrete used in the study. There was chosen eight concrete mixes were casted by replacing the normal coarse aggregate by lightweight course aggregate; claystone (bonza) and thermostone. Different percentage of aggregate replaced were done (25, 50, 75 and 100) %, in addition to the reference mix of (0%) replacement ratio was casted. For each concrete mix: Three cylinders for compressive strength and density of saturated and dry surface concrete tests, three cylinders for splitting tensile strength test and three prisms for modulus of rupture test were prepared. Also for each mix was casted, prepare a one slab specimen for bending moment test for all mixes contain a light coarse aggregate and reference mix. The main results of mechanical properties are ((38.44-12.38), (3.969-2.172) and (10.467-3.194)) MPa, for compressive, splitting and flexural strength respectively with differences of (67.79, 45.12 and 69.48) % respectively compared with the reference mix. Also the flexural capacities of the lightweight concrete slabs that contained a different ratios of light coarse aggregate (0.028 and 0.026) MPa were recorded with (22.5 and 28.62) % compared with reference sample of 0.035 MPa.

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تصرف الانثناء للبلاطات الخرسانية المسلحة أحادية الاتجاه مع نسب مختلفة من الركام الخشن الخفيف الوزن

الخلاصة

البحث يهدف الى دراسة تصرف الانثناء للبلاطات الخرسانية الخفيفة المسلحة احادية الاتجاه وباستخدام خرسانة الركام الخشن الخفيف الوزن بنوعيها. واستخدم تسع عينة من الخرسانة المسلحة العادية والخرسانة المسلحة خفيفة الوزن لبلاطات احادية الاتجاه وبأدراج نوعين من الركام الخشن الخفيف في الفحوصات، اذ تمت دراسة قابلية التشغيل والخواص الميكانيكية لهذه الخرسانة، حيث تم عمل عدة خلطات تجريبية للحصول على أفضل خلطة ومن ثم عمل 8 خلطات خرسانية عن طريق استبدال الركام الخشن الاعتيادي بركام خشن خفيف من الصخور الطينية (بونزا) والثرمستون وبنسب حجمية مختلفة (25، 50، 75، 100) % بالإضافة الى الخلطة المرجعية التي لاتحتوي على ركام خشن خفيف الوزن. لكل خلطة خرسانية تم صب 3 اسطوانات لفحص مقاومة الانضغاط والكثافة في حالة النموذج مشبع جاف السطح، صب 3 أسطوانات لحساب مقاومة شد الانشطار و3 مواشير لحساب معاير الكسر، لكل خلطة من خلطات خرسانة ركام الخشن الخفيف والخلطة المرجعية تم صب بلاطة واحدة لفحصها فحص انثناء. النتائج الرئيسية للخصائص الميكانيكية هي ((38.44 - 12.38)، (3.969 - 2.172) و (10.467 - 3.194)) MPa، لمقاومة الانضغاط، مقاومة الشد الانشطاري ومعاير الكسر على التوالي مع وجود اختلافات (67.79، 45.12 و 69.48) ٪ مقارنة مع الخلطة المرجعية. كما تم ايجاد مقاومة الانثناء للبلاطات الخرسانية خفيفة الوزن التي احتوت على نسب مختلفة من الركام الخشن الخفيف (0.028 و 0.026) MPa بنسبة (22.5 و 28.62)٪ مقارنة مع العينة المرجعية (0.035) MPa.

1. INTRODUCTION

The lightweight concrete is of great importance to civil engineering. It is used in structural elements such as walls, slabs, and beams. It is also used in the production of lightweight blocks, which are used as thermal insulation compared with the typical building blocks. The lightness of the concrete reduces the loads because of its good

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insulation and low weight besides, it reduces the energy consumption of cooling and heating as well as the lightness of the weight leads to the reduction of the size of the structural elements and this reduces the cost required for the installations. The slabs are regarded to be one of the structural element using lightweight concrete slabs, which used and contributed significantly to reduce the whole weight of the structure.

The main disadvantages of traditional concrete (2200 to 2500 kg / m^3) as a construction material compared with wood and iron, is relatively heavy. The weight of the building parts compared to the loads is high in all cases. Therefore, light concrete should be preferable because it weighs less than 2000 kg / m^3. Moreover, it is possible to manufacture structural concrete weighing 1400 to 1900 kg/m^3 with a slight increasing in costs. As well as, the production of semi-structural concrete for internal blocks weighing 900 kg / m^3 and used efficiently as internal walls. Light concrete is generally less than 2,000 kg / m^3. The purpose of their use is to reduce the self-weight and thus reduces the cost of foundations and for thermal insulation purposes [1].

2. MATERIALS

2.1. Cement

The local Iraqi cement was used (Mass), which is an Ordinary Portland Cement, the results to examine matching Iraqi Specification Standard (IQS No.5 / 1984) [2].

2.2. Fine Aggregate

The sand used in the concrete mix is river sand, and its source is from al-Dibs area in Kirkuk governorate. After the analysis of it, it was found to be in accordance with (IQS No. 45/1984. 34) [3].

2.3. Coarse Aggregate

Normal Coarse Aggregate

The crushed gravel was used in the area of Lailan district in Kirkuk governorate and the gravel was used for a maximum nominal size of (12.5 mm).

Claystone Coarse Aggregate

The lightweight coarse aggregate used in this research is the claystone, locally called "Bonza". It is a lightweight coarse aggregate that is available in the light building blocks production plant in Erbil governorate. It is used as a fine crust after crushing it when producing structural blocks that are used as breakers in buildings. In this study, it was used as coarse aggregate without crushing with a maximum nominal size of (12.5 mm). Different volume replacement of (0, 25, 50, 75, 100%) of the coarse aggregate volume in the concrete mix were used, the volumetric was chosed because of lightweight and to maintain the size of the natural mix. Fig. 1, recombined according to the grading requirements for lightweight aggregates for structural concrete at (ASTM C330–99,2005) [4].

Fig. 1. Claystone lightweight coarse aggregate.

Thermostone Aggregate

Thermostone blocks are lightweight building blocks consisting of aerated concrete. This concrete is produced by inserting a certain air or gas into the cement bond, forming a ventilated concrete from cement bond, water, aluminum powder added 0.2% of cement weight, in addition to the fine sand siliceous and is not used in normal coarse aggregate. Mixing the previous components form bubbles of hydrogen within the cement block resulting from the reaction of aluminum powder and hydroxide calcium found in the cement element, these bubbles cause the expansion of the mixture before the drought and thus form the cellular structure and there is no risk of fire due to the presence of hydrogen because it is implemented based on the cells replaced by air completely [5].

In this study, the light-smoothed thromostones of the building waste were used in the building of housing in the city of Kirkuk after being manually cut by the hand hammer without the presence of a crusher in the laboratory. It was broken down in to multiple cracking stages as shown in Fig. 2, after which it was screened to obtain the required gradient.

Fig. 2. Stages of breaking thermostone blocks.

This aggregate is used with a maximum nominal size of 12.5 mm and different replacement ratios (0, 25, 50, 75 and 100%) of the normal coarse aggregate volume and the replacement is volume due to its light weight. This aggregate is immersed in water for a day before use, so that it is saturated to dry the surface so as not to absorb the mixing water and thus reduce the resistance of light concrete. The water absorption of this type of aggregates is high, and to gradation the light coarse aggregate as conform to (ASTM C330-99,2005) [4].

Mix Water

The drinking water was used in the preparation of mixtures. The same water was used in the treatment of the samples, the pH test was conducted, and it was found to be (7.4).

Steel Reinforcement

Reinforcing concrete slabs were used in reinforced steel bars with a diameter of 8 mm. The tensile strength test was performed and the rate of three models was obtained. These results were in accordance with (ASTM A615) [6].

3. RESULTS AND DISCUSSION

3.1. Compressive Strength

The compressive strength test was performed according to (ASTM C39-86) [7] Fig. 3. The test was conducted on cylinder using an electrical testing machine with a capacity of 3000 kN at loading rate of 0.4kN per second. The average of compressive strength of the three cylinders was adopted for each test; the tests were conducted at ages of (28) days. Table 1 shows a decrease in compressive strength, with an increase in the ratio of light coarse aggregates (claystone coarse aggregate Bonza light, light crushed thermostone aggregate) compared to the reference ratio. This decrease occurs due to the presence of many gaps in light coarse aggregates. It is impossible to prefer a reduction in compressive strength in return for a lower weight of concrete. However, the reduction should be as low as possible to obtain compressive strength within the standard range. Also obtain lightweight concrete, thus reducing the original self-weight, which is the main objective of the present research.

It is also noted in Fig. 8 that the amount of the decrease is significantly increased at replacement rates (75, 100)% of the normal coarse aggregate size of either the claystone or thermostone aggregate, this may be the result of the lack of normal coarse aggregate at a high rate, so that they bear the bulk of the load on the model and thus increase the compression strength as occurred at other replacement ratios (25, 50)%.

Fig. 3. Compressive strength test.

3.2. Splitting Tensile Strength

The splitting tensile strength test was performed according to (ASTM C496-96,2004) [8]. (150×300) mm cylindrical concrete specimens which were used in Fig. 4, the specimens were tested at age of 28 days by using an electrical testing machine with capacity of 3000 kN. The test splitting tensile strength is done in an easy way, so the compressive strength is exerted along the concrete cylinder, this load causes tensile stress to have the load level. Relatively high compressive stresses near to the load and the failure occurs tensile tension instead of compression because the areas of application of the load in a state of compression there is a resistance to compression is much higher than tensile. As shown in Table 2 and Fig. 9, the reduction of indirect tensile strength with the increase in the ratio of light coarse aggregates is due to the lightweight of coarse aggregates and the result of gaps or many pores inside it led to a reduction in the specific weight.

Fig. 4. Splitting tensile strength test.

3.3. Modulus of Rupture Test

Flexural strength of concrete was measured in (100×100×500 mm) prism specimens in conformity with (ASTM C78-02,2004) [9]. The prisms were subjected to one-point loading Fig. 5, the loading rate was 1 MPa/min. The specimens were tested at age of 28 days and the average of three specimens in each mix was taken. As shown in Table 3 and Fig. 10 decreased flexural resistance with increased ratio lightweight coarse aggregate, this decrease is small compared to the lower compressive strength and fracture resistance of the concrete. This decrease is due to the lightweight of the coarse aggregate due to the presence of internal pores of aggregate.

Fig. 5. Flexural strength of prism.

3.4. Density Test

The density of the concrete was measured by dividing the weight of the model in case (S.S.D) to the size of the model after the water treated for 28 days. The test was done by cylindrical concrete models with dimensions of

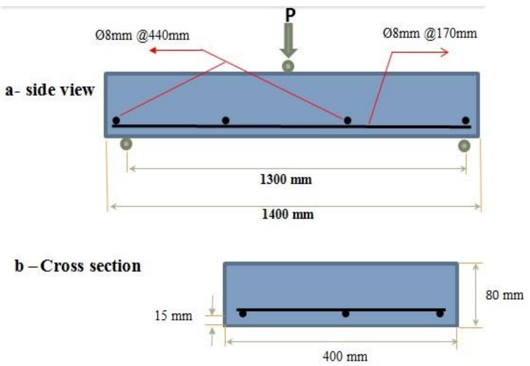
150×300 mm and three cylinders for each mix. Table 4 and Fig. 11, the density drop of all concrete mixtures, except the reference mix, is shown to be low with the increase of the light coarse aggregates. This is due to the presence of many gaps or pores in light coarse aggregates, the decrease was noted, and the reason is that the coarse aggregates constitute the largest proportion of the percentage of the materials forming the concrete. The effect of the materials on the concrete is large and the weight is low.

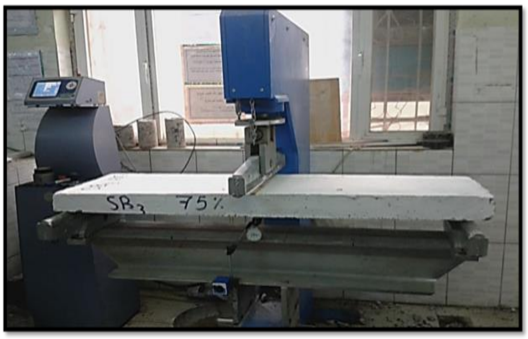
3.5. Flexural Strength Test of Reinforced Concrete Panels

The study was conducted on (9) reinforced concrete slabs with dimensions of (1400×400×80) mm. The treatment was 28 days, with the same reinforcing for all slabs. All slabs were designed to flexural failure, Based on the curve (load - deflection) curve at the mid- span. The present study includes the effect of the use of light coarse aggregate and internal voids on the behavior of the slab as follows:

3.6. Ultimate Loading

This point topic includes the determine the effect of replacing the normal coarse aggregates with a light coarse aggregate on the maximum loading capacity up to the failure for the slab samples. The effect of increasing the ratio of light coarse aggregates to the maximum load tolerated by the slabs, Fig. 6 shows flexural testing setup of reinforced concrete slab, Table 5 and Figs. 12-17 show the results obtained from the flexural test. The load was also found at the first crack through the monitoring, and

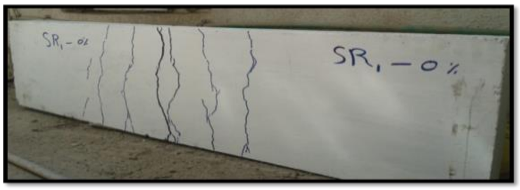




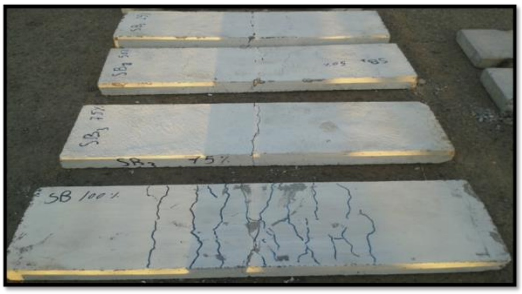
(c) Flexural testing of one-way slab

Fig. 6. Flexural testing setup of reinforced concrete slab (a, b, c).

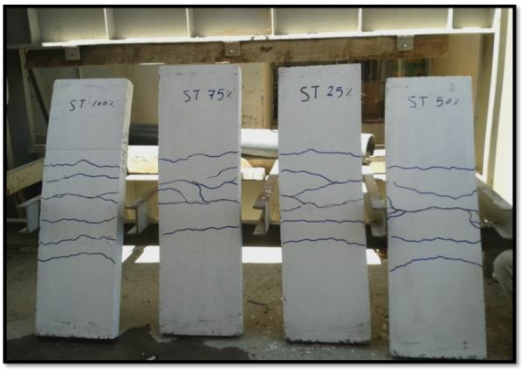
then is recorded a load at the first crack. Based on the results of the tests shown in Table 5 and Figs. 12-17 the reduction of the maximum load as well as the decrease in the load at the first crack, this is due to the increase in the percentage of light coarse aggregates which has a specific weight less than the specific weight of normal coarse aggregates due to the many gaps or pores in the light coarse aggregates, which is a weak point in the coarse aggregate but it reduces the density of concrete to keep the flexure capacity with in the field of concrete construction and this is important. When comparing (the difference in compressive strength between mixtures including reference) and (difference in maximum load and bending resistance between slabs of the same mix), the lower maximum load and bending resistance for all slabs compared to the maximum load and bending resistance of the reference slab is low.



(a) Reference slab.



(b) Patterns failure in slabs container the light coarse bonza aggregate.



(c) Failure crack patterns in slabs containe a thermstone lightweight.

Fig. 7. Patterns failure in slabs container a lightweight coarse aggregate.

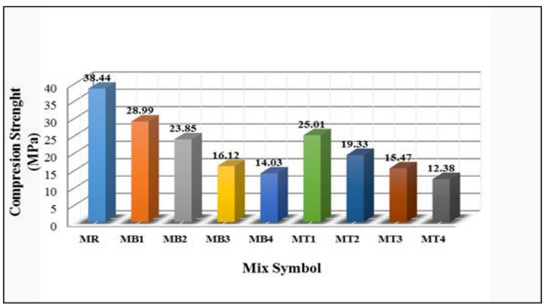


Fig. 8. Compressive strength test results for all concrete mixtures.

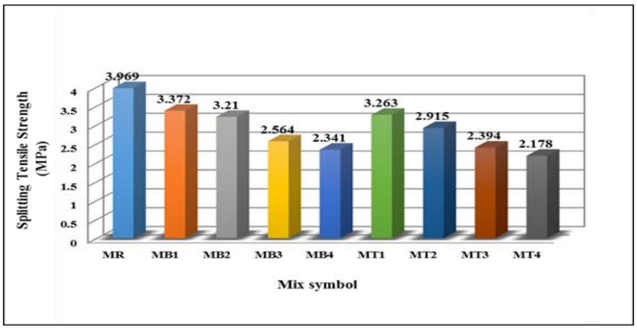


Fig. 9. Results of splitting tensile strength test for all concrete mixtures.

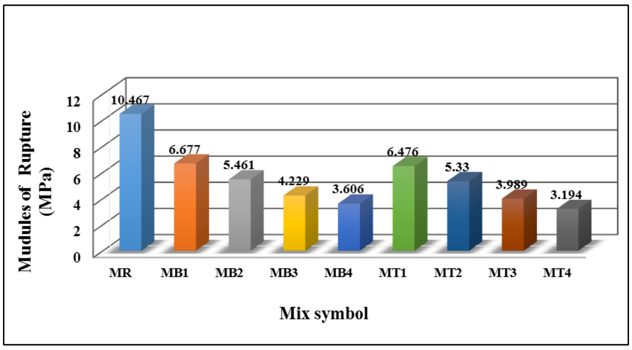


Fig. 10. Results of modulus of rupture test for all concrete mixtures.

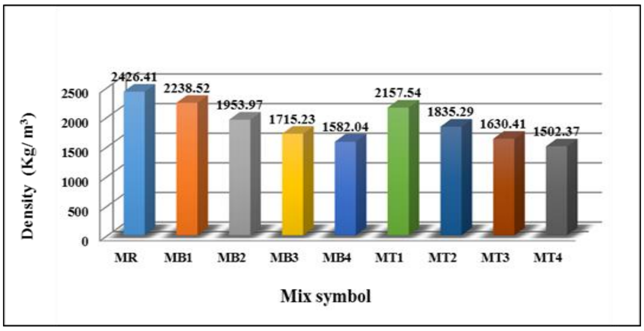


Fig. 11. Results of density test for all concrete mixtures.

3.7. Ductility

The ductility index is defined as the ratio between the deflection at the maximum load and the deflection at the bearing of the reinforcing steel [10], which can be found in the (load-deflection) curve of the slab when the curve moves from the elasticity stage to the plasticity phase as shown. Table 6 and Fig. 18 show the values of the ductility found from the slabs for each replacement ratio using the equation below:

$$\mu\Delta = \Delta u / \Delta y \quad (1)$$

μΔ: ductility index.
Δu: maximum deflection at failure.
Δy: deflection at the yielding point.

The results show that ductility for the slabs containing the bonza aggregate is greater than the ductility for the slabs that contain the thermostone aggregate at the same replacement ratio. This indicates that the resistance of the bonza aggregate samples for deflection is greater than the resistance of thermostone aggregate samples. This is the result of the higher specific weight for bonza aggregate. It is worth noting that ductility is needed when it is perferable to provide more safety for construction when a failure occurs.

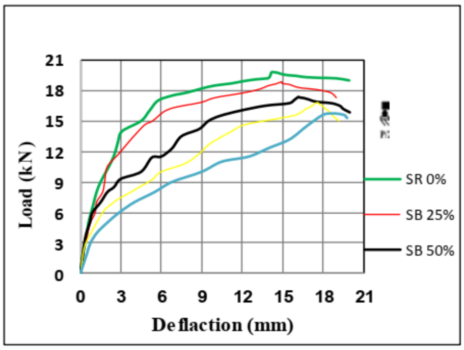


Fig. 12. Load - deflection relationship of lightweight aggregate slab with claystone coarse aggregate.

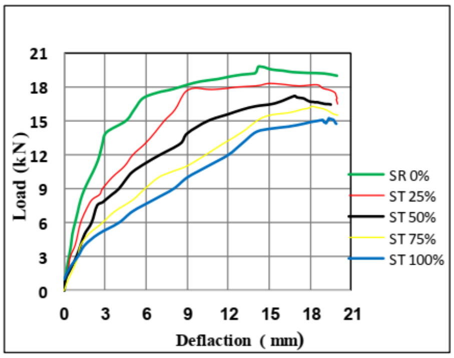


Fig. 13. Load - deflection relationship of lightweight aggregate slab with thermostone coarse aggregate.

3.8. Stiffness

The Stiffness of the reinforced concrete slabs was calculated based on the maximum load of the slabs by taking 45% of the maximum load and casting it on the (load - Deflection) curve and extracting the value of the deflection corresponding to this load. By dividing the calculated load on the resulting deflection found stiffness of the concrete slabs [11] the results of stiffness values for concrete slabs can be illustrated by Table 7 and Fig. 19, which represent the effect of light coarse aggregates on the stiffness.

The results in Table 7 and Fig. 19 indicate that the concrete slabs containing volume ratio lightweight coarse aggregate (Bonza and Thermostone) have less stiffness than the reference slab (SR), the value of the stiffness is reduced by increasing the content of the light coarse aggregate in the mixtures. This is done in order to increase in the content of air gaps and pores, these reduces the stiffness of the slabs for the load. The results indicate that the value of Stiffness has decreased in all slabs; the lower Stiffness of the slabs when compared to the reference slab.

3.9. Mode of Failuer

The failure of the reinforced concrete slabs is concerned with flexion (failure of tensile at the bottom of the slab due to flexing) and is obtained as a result of bending the reinforcing steel with cracks under the slab. In general, all slabs in the current study indicate that in the early stages of loading the initial cracks begin to grow at the bottom of the slab. Over time, the loading of cracks begins to spread and become wider. Fig. 7 shows the patterns of failure and cracks in the slabs where the form of failure of one slab was taken for each replacement ratio, most of the slabs were caused by a failure in the form of one main line with minor cracks near the main crack below the slab where these lines are located on the ends of the middle third of the slab and most cracks are in the middle third and this is the result of the loading point located in the middle of the slab, where the bending moment is as far as possible and the shear stress is zero. Cracks have penetrated the light coarse aggregate due to the presence of many internal pores that are weakened by the bearing of light coarse aggregates.

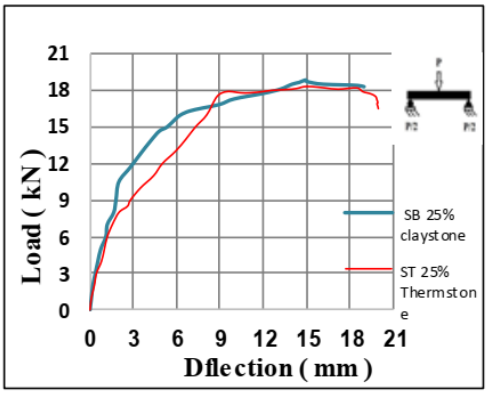


Fig. 14. Load - deflection relationship of reinforced concrete slabs (SB1 and ST1).

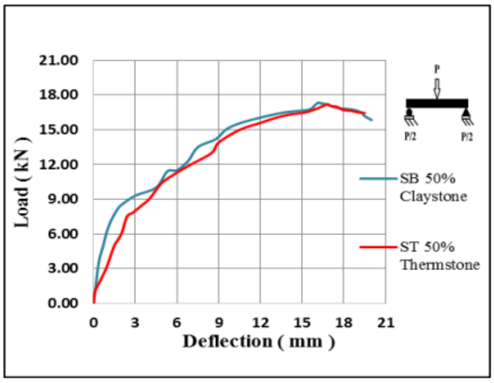


Fig. 15. Load - deflection relationship of reinforced concrete slabs (SB2 and ST2).

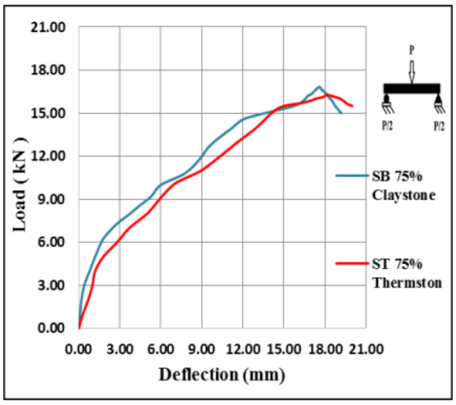


Fig. 16. Load - deflection relationship of reinforced concrete slabs (SB3 and ST3).

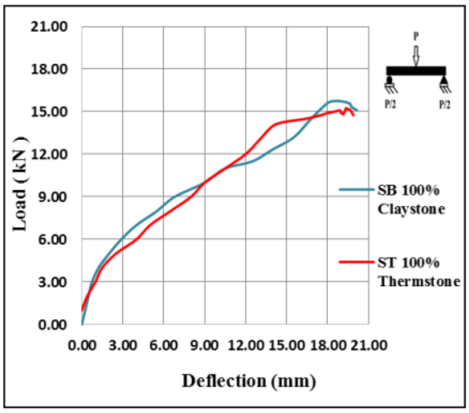


Fig. 17. Load - deflection relationship of reinforced concrete slabs (SB4 and ST4).

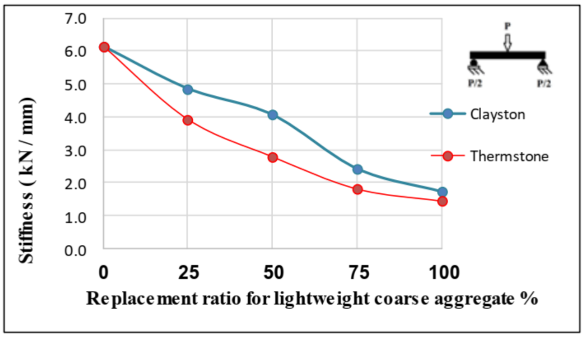


Fig. 18. The effect of lightweight coarse aggregates on the ductility index.

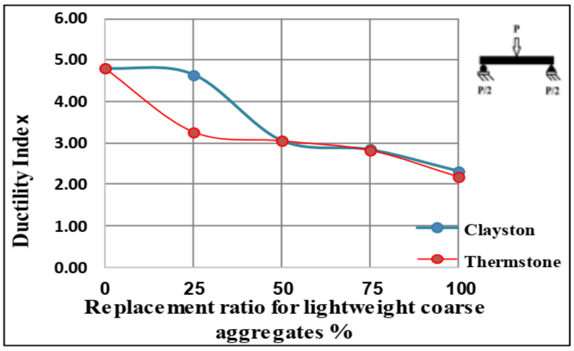


Fig. 19. The effect of light weight coarse aggregates on the stiffness.

4. CONCLUSIONS BASED ON EXPREIMENTAL WORK

Through the laboratory tests carried out in this study and based on the results obtained, the following conclusions can be reached:

1- A Lower compressive strength of concrete by increasing the content of lightweight coarse aggregates. It is found that the compressive strength of the concrete containing the thromestone aggregate at replacement rates (25,50,75 and100)% is less than the compressive strength of the bonza coarse aggregate at the same replacement rates because of the larger specific weight of the bonza aggregate. The reduction in compressive strength is significant at replacement rates (75, 100) % compared to replacement rates (25, 50%), which can have the normal coarse aggregate higher.

Table 1
Results compression strength test for all concrete mixtures.

Mix symbol	Normal weight Coarse agg.%	Thermostone Coarse Agg. %	Claystone Coarse Agg.%	Comp. strength at 28 Day (MPa)	Decreasing %
MR	100	0	0	38.44	-
MB1	75	0	25	28.99	24.58
MB2	50	0	50	23.85	37.95
MB3	25	0	75	16.12	58.06
MB4	0	0	100	14.03	63.5
MT1	75	25	0	25.01	34.93
MT2	50	50	0	19.33	49.71
MT3	25	75	0	15.47	59.75
MT4	0	100	0	12.38	67.79

MR : Mix reference, MB: Mix content bonze aggregate, MT: Mix content Thermostone aggregate

Table 2
Results of splitting tensile strength test for all concrete mixtures.

Mix symbol	Normal weight Coarse agg.%	Thermostone Coarse Agg. %	Claystone Coarse Agg. %	Splitting Tensile Strength at 28Day (MPa)	Decreasing %
MR	100	0	0	3.969	-
MB1	75	0	25	3.372	15.04
MB2	50	0	50	3.210	19.12
MB3	25	0	75	2.564	35.39
MB4	0	0	100	2.341	41.01
MT1	75	25	0	3.263	17.78
MT2	50	50	0	2.915	26.55
MT3	25	75	0	2.394	39.68
MT4	0	100	0	2.178	45.12

Table 3
Results of modulus of rupture test for all concrete mixtures.

Mix symbol	Normal weight Coarse agg. %	Thermostone Coarse Agg. %	Claystone Coarse Agg. %	Modulus of Rupture at 28 Day (MPa)	Decreasing %
MR	100	0	0	10.467	-
MB1	75	0	25	6.677	36.2
MB2	50	0	50	5.461	47.82
MB3	25	0	75	4.229	59.59
MB4	0	0	100	3.606	65.54
MT1	75	25	0	6.476	.38.13
MT2	50	50	0	5.330	49.07
MT3	25	75	0	3.989	61.88
MT4	0	100	0	3.194	69.48

Table 4
Results of density test for all concrete mixtures.

Mix symbol	Normal weight Coarse agg. %	Thermostone Coarse Agg. %	Claystone Coarse Agg. %	Density at 28 Day (kg/m³)	Decreasing %
MR	100	0	0	2426.41	-
MB1	75	0	25	2238.52	7.74
MB2	50	0	50	1953.97	19.47
MB3	25	0	75	1715.23	29.3
MB4	0	0	100	1582.04	34.79
MT1	75	25	0	2157.54	11.08
MT2	50	50	0	1835.29	24.36
MT3	25	75	0	1630.41	32.8
MT4	0	100	0	1502.37	38.08

Table 5
The results of the ultimate load.

Slab No.	Thermostone Coarse Agg. %	Claystone Coarse Agg. %	Load at First Crack (kN)	Failure Load(P_u) (kN)	Decreasing of Failure Load %	(δ_u) (mm)
SR	0	0	13.6	19.825	-	14.23
SB1	0	25	12.5	18.92	4.89	14.92
SB2	0	50	11.3	17.367	11.23	16.2
SB3	0	75	10.1	16.82	18.47	17.56
SB4	0	100	9.5	15.72	22.5	18.73
ST1	25	0	11.5	18.306	2.17	15.4
ST2	50	0	10.8	17.21	6.7	16.82
ST3	75	0	9.5	16.3	20.42	18.3
ST4	100	0	8.9	15.09	28.62	19.35

SR : Slab reference, SB: Slab content bonze aggregate, ST: Slab content Thermostone aggregate

Table 6
Ductility index for reinforced concrete slabs.

Slab No.	Normal weight Coarse Agg. %	Therm. Coarse Agg. %	Claystone Coarse Agg. %	(δ_u) (mm)	(δ_y) (mm)	Ductility index ($\mu_{\Delta=\delta_u/\delta_y}$)
SR	100	0	0	14.23	2.97	4.81
SB_1	75	0	25	14.92	3.2	4.66
SB_2	50	0	50	16.2	5.29	3.06
SB_3	25	0	75	17.52	6.18	2.84
SB_4	0	0	100	18.37	7.9	2.32
ST_1	75	25	0	15.4	4.71	3.26
ST_2	50	50	0	16.82	5.51	3.05
ST_3	25	75	0	18.12	6.41	2.82
ST_4	0	100	0	19.35	8.85	2.18

Table 7
The results of stiffness values for concrete slabs.

Slab No.	Normal weight Coarse Agg. %	Therm. Coarse Agg. %	Claystone Coarse Agg. %	45%(P_u) (kN)	Deflection @45%(P_u)(mm)	Stiffness (kN/mm) $st_{=P_u/\delta}$
SR	100	0	0	8.92	1.45	6.15
SB_1	75	0	25	8.51	1.75	4.86
SB_2	50	0	50	7.81	1.92	4.06
SB_3	25	0	75	7.57	3.12	2.42
SB_4	0	0	100	7.07	4.1	1.72
ST_1	75	25	0	8.23	2.1	3.92
ST_2	50	50	0	7.74	2.78	2.78
ST_3	25	75	0	7.33	4.05	1.8
ST_4	0	100	0	6.86	4.8	1.43

2- The decreasing in splitting tensile strength with the increasing of light coarse aggregates is not particularly significant at the replacement rates of (25 and 50) % unlike ratios (75 and 100) %. This is due to a large percentage of the normal coarse aggregates.
3- Examination modulus of rupture of the concrete containing the bonza aggregates is higher than the modulus of rupture of the concrete containing the thermistone aggregate, this is the result of the higher specific weight of the bonza aggregates than the specific weight of the thermistone aggregate. Certainly, the higher the specific weight of rough aggregates, the greater the ability for the loads and thus increase the ability of concrete means increase the resistance of the concrete to the flexure.
4- Through the results of the test, note that the density of the concrete in the mixtures (MB1, MB2, MB3, MB4) higher than the density of concrete in mixtures (MT1, MT2, MT3, MT4), the reason was that the mixtures contains bonze light coarse aggregate which has a higher weight than the specific weight of the thromestone light coarse aggregate found in other mixtures except for the reference mixture.
5- The ultimate load and the load at the first crack for the slabs decreases with the increase of light coarse aggregates. The increase of the deflection is also observed by increasing the ratio of light coarse

aggregates compared to the deflection of the reference slab.

6- Low ductility index for the slabs by increasing the light coarse aggregates, ductility is the slabs that contain the bonza aggregates which is greater than the ductility for the slabs containing the thermistone aggregate and the same percentage of replacement.

7- The value of the stiffness is reduced by increasing the content of the light coarse aggregate in the mixtures. This is caused by the increase in the content of air gaps and pores, this reduces the stiffness of the slabs for the load. The results indicate that the value of stiffness has decreased in all slabs; the lower stiffness of the slabs when compared to the reference slab was as a result of the lower initial load with the increase in the deflection.

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