IRAQI JOURNAL OF CIVIL ENGINEERING (2020) 014–002

IRAQI Academic Scientific Journals

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Journal homepage: https://www.iasj.net/iasj?func=issues&jId=141&uiLanguage=en

Flexural Strength and Behavior of Reinforced Izocrete Light Weight Beams

Aso A. Faqe Rahim[a] and Muhamad R. Abdulqadir[b]

[a] Assistant Lecture, Department of Water Resources Engineering, University of Sulaimani, College of Engineering, Sulaimani.46001, Iraq.

[b] Professor, Department of Civil Engineering. University of Sulaimani, College of Engineering, Sulaimani. 46001, Iraq.

ARTICLE INFO

Article history:
Received 28 / 08 / 2020….
Received in revised form 10 /10/ 2020.
Accepted 16 /10 / 2020.

Keywords:
Beam in Flexure
Beam Failure Load
Izocrete, EPS beads
Mechanical Properties of Concrete

ABSTRACT

This study describes the results of tests carried out in order to investigate the structural behavior of reinforced concrete beams containing Expanded Polystyrene (EPS) stabilized Polystyrene beads. Three concrete mixtures were used with densities 350kg/m3, 500 kg/m3 and 600 kg/m3. A total of 12 beams, with control specimens were tested after 28 days of curing immersion in water. Four types of steel reinforcement were utilized: Two ratios of tensile steel reinforcement without compression steel and the same two ratios of tensile reinforcement with compression steel and stirrups. The beams were tested under 4- points loading up to failure. The main variables considered in this study were: different types of Izocrete densities and types of reinforcement steel bars. The results indicated that the amount of polystyrene beads significantly affects the strength of the concrete produced. In general, it can be observed that the compression, tensile and flexure strengths decreased as the EPS beads contents increased, and the moment capacity of the beams reduced with the increase of the beads ratio.The load deflection behavior of the Izocrete beams were similar to other lightweight concrete beams .The failure in most of the beams was initiated at the compression region undergoing large deformation due to the high compressibility of the material.

1. Introduction

As building construction increases demand increases for construction materials, and need for alternative sustainable environmentally friendly materials to be developed. One of the best environmental alternates is the recycling and reuse of waste materials in construction industry. Expanded Polystyrene (EPS) is one of such waste materials.[1]

The Expanded Polystyrene is a chemically stable, low density foam which can be used in concrete. The polystyrene beads are smooth, round in shape, and can be used in mortar or concrete to form lightweight concrete with different densities [2]. EPS beads cannot absorb water, they are used as partial replacement of sand or gravel in concrete.

In general merits of light weight concrete include better heat preservation and sound insulation, flexibility in design, reduction in dead load consequently cost savings. Applications of polystyrene concrete in building include partition walls, facade panels, and flooring systems [3]. It has good energy absorbing characteristics; hence it is also used as protecting material against impact in structures. [3].

Researches regarding mechanical properties of light weight concrete incorporating EPS are many and most of them have used EPS beads as a replacement for aggregates.

Park and Chisholm [4] have carried out investigation on polystyrene aggregate concrete and have used several mixes using cement, sand and fly ash and polystyrene to replace course gravel. Volume ratios from 850-1000(loose packed l/m3) were used, the density ranged from 550 to 1050 kg/m3. The compressive strength was in the range of 0.7 to 6.7 MPa. They have concluded that PES concrete can be used for non-structural applications because of its low weight and low thermal conductivity.

Kuhail and Shihada [5] studied properties of light weight concrete using 36 different mix proportions, the volume of the polystyrene beads varied from 0.3 to 0.7 m/m, the concrete compressive strength varied from 3 to 22 MPa depending on the ratio of the beads and water cement ratios. They found that compressive strength was meaningfully influenced by the mix ratios and curing period. Also, the compressive strength, tensile strength and flexure of concrete mix reduced when the EPS beads were increased.

Kan A. and R. Demirboga [6] studied the effect of cement: EPS beads

* *Corresponding author.* Tel.: 09647701571864
E-mail address aso.faqi@univsul.edu.iq

ratio on the density and compressive strength of LWC. Mix ratios of cement: EPS beads of 1:0 ,1:4, 1:2, 3:4, and 1:1 by volume were used with constant EPS content. Results showed that with EPS decrease, both density and compressive strength increased. Density ranged from 464 to 1940 kg/m3 and compressive strength from 0.11 to 38.5 MPa respectively.

Jain T. and Tiwari A. [7] have mixed EPS beads with cement, fly ash, and sand to develop light weight blocks and bricks. The experimental works investigated mechanical properties of lightweight bricks and compared its properties with conventional bricks. It was found that bricks with EPS possess good thermal insulation properties, and their stiffness and compressive strength are similar to medium clay bricks.

Miled K. et al. [8] investigated effect of size of EPS beads on behavior of lightweight expanded polystyrene concrete. (EPS) volume fraction from 10% to 50% was investigated. The results indicated that the EPS concrete compressive strength increases when EPS beads size decreases for the same mix density, and that in low porosity concrete this size effect is very pronounced and becomes negligible as the EPS percentage increases.

Pecce M. et al. [9] investigated the bond properties between concrete and steel bars for EPS concrete demonstrated a good performance of the bond behavior of concrete with EPS, although the failure is more brittle, and they have suggested that the correlations between compressive, tensile and bond strength have to be reviewed with respect to those used for normal concrete.

Testing of reinforced concrete beams containing ESP to study their structural strength and behavior are few and uses EPS as aggregate replacement or added to the normal mixes.

Herki B. and Khatib J. [10] tested 24 beams of 700x150x100 mm under four points loading with different steel ratio using waste ESP aggregate and 10% clay and 10% cement, the ratio of the EPS varied from 10 to 100% as replacement of the natural aggregate. The EPS were crushed then mixed with clay and cement, dried then crushed again and used. The weight of the concrete varied from 1000 to 2000kg/m3 and the compressive strength of the concrete varied from 4.56 to 16.66 MPa. It was found that the structural behavior of the stabilized polystyrene aggregate beams is comparable to other types of light weight aggregate concrete.

Based on the review of literature, concrete incorporating Expanded Polystyrene (EPS) has been mainly used in the construction of non-structural elements for buildings. Light weight concrete beams with different materials with densities more than 1000kg/m3 have been studied with respect to their structural strength and behavior [11], however, studies on the structural use of this material where the density is much lower is not available, therefore its structural use is ignored. The current study reveals the findings of an experimental study into the structural behavior of reinforced Izocrete beams, which is cast without aggregate and it can be considered as a type of LWC.

2- Research Significance

This research was carried out to investigate the strength and structural behavior of concrete beams made from cement and Expanded Polystyrene Beads (EPB) as replacement of both coarse & fine aggregate with densities of 350, 500 and 600 kg/m3. The novelty of this research is using EPS concrete (Izocrete) as structural member which has not been investigated. Because of its light weight this type of reinforced Izocrete beam can be used as a pre-cast lintel over opening during construction of masonry wall instead of using normal concrete or steel beam sections.

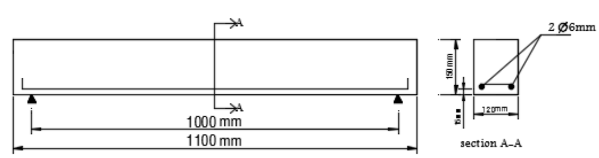
3.0 Experimental Program

3.1. Testing Program

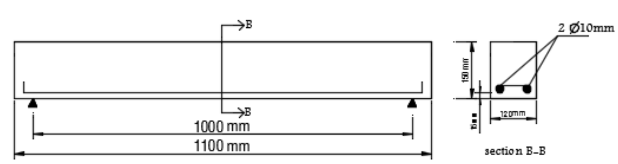
The experimental program consisted of testing twelve reinforced beam made with Izocrete of size 120x150x 1100 mm. The details of tested beams are shown in Table1 and Fig 1. Along with the beams, compression strength, split tensile strength, modulus of rupture tests were carried out on cubes, cylinders and prisms. The beams are designated by two numbers, the first no denotes the type of density and the second no denotes the types of reinforcement.

Table 1-Details of the tested beams

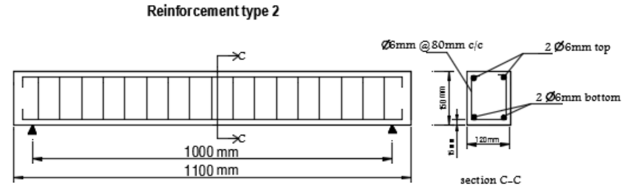
Beam Designation	Beam Size(B*D) mm	Izocrete Density Kg/m³	Rein. Type	Tension Rein. (No. & Size)	Top Rein. (No. & Size)	Stirrup (Size & Spacing)
B11	120*150	350	1	2 ø 6	0	Nil
B12	120*150	350	2	2 ø 10	0	Nil
B13	120*150	350	3	2 ø 6	2 ø 6	ø6mm@60mmc/c
B14	120*150	350	4	2 ø 10	2 ø 6	ø6mm@60mmc/c
B21	120*150	500	1	2 ø 6	0	Nil
B22	120*150	500	2	2 ø 10	0	Nil
B23	120*150	500	3	2 ø 6	2 ø 6	ø6mm@60mmc/c
B24	120*150	500	4	2 ø 10	2 ø 6	ø6mm@60mmc/c
B31	120*150	600	1	2 ø 6	0	Nil
B32	120*150	600	2	2 ø 10	0	Nil
B33	120*150	600	3	2 ø 6	2 ø 6	ø6mm@60mmc/c
B34	120*150	600	4	2 ø 10	2 ø 6	ø6mm@60mmc/c



Reinforcement type 1



Reinforcement type 2



Reinforcement type 3

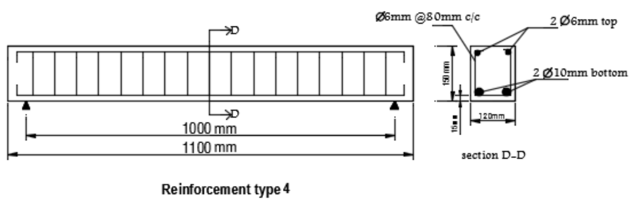


Fig. 1 Reinforcement details and dimensions of tested the beams.

3.2. Material

The Izocrete used in this study was obtained from a local plant manufacturing this type of concrete. Ordinary Portland cement (type 1) was used throughout this study. Spherical EPS beads of size 3-6 mm with density of 29 kg/m3 were used as shown in Fig.2. Two steel bar diameters were used for the beams, 6 mm and 10 mm diameter bars. Properties of the steel bars are given in Table 2. The manufacturer produces three Izocrete densities which are used here (350, 500, and 600 kg/m3). Izocrete mixture volume and percentage values are given in Table 3.

Table 2- Properties of steel reinforcement

Diameter (mm)	Yield stress (MPa)	Tensile strength (MPa)	Max. Elongation (%)
6	511	564	8
10	512	621	23

Table 3- Details of Izocrete mixtures

Types	Mix density(kg/m^3)	EPS (beads) Lit	Cement kg/ m^3	Water kg/ m^3
Izocrete 1	350	500	290	140
Izocrete 2	500	875	320	155
Izocrete 3	600	1000	375	180

3.3. Test specimens and testing procedure

The flexure tests were conducted on four types of reinforced Izocrete beams for three different Izocrete density mixes. The beams dimensions were 120x150x1100 mm and their reinforcements details are shown in Fig.1. Castings were made in plywood molds. The reinforcing cages were prepared and set inside the molds. Mixing of the beads and the cement slurry was carried out at the factory using their special mixers which insured the production of a high consistency homogeneous mix with no beads floating at top, hence it required very little hand compaction using a steel rod.

The beams were tested under four-points loading with ends simply supported as shown in Figs 3 & Fig. 4. Two 20x50 mm thick steel plates were placed below the load points to avoid local bearing failure and stress concentration under loading points. Vertical deflection measurement was taken using a (0.001) mm dial gage placed at the mid length of the beam. During loading stages crack initiation was also observed and recorded. In order to visualize the crack pattern and sequence of its appearance, a digital camera was also used to record the test measurements. Compressive strength of the Izocrete was measured using three 100x200mm cylinders and three 100x100x100mm cubes. Also, the split tensile strength was measured using 3 cylinders of 100x200mm. Three specimens of size 500x100x100 mm were used for measuring the modulus of rupture of the Izocrete. All tests were performed according to standard specification for normal concrete [12].

Fig. 2 EPS beads

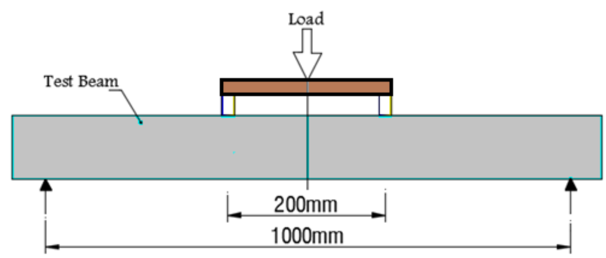


Fig. 3 Details of loading set-up for the Izocrete beam specimens.

Fig. 4 Testing of Izocrete Beams.

4. RESULTS & DISCUSSIONS

4.1. Izocrete Strength Properties

The cube and cylinder compressive strength, flexural strength and the indirect tensile strength values of the Izocrete with different densities are given in Table 4 and the relationship for the cylinder compressive strength vs. Izocrete densities is shown in Fig. 5. The results as expected indicate that inclusion of higher amount EPS beads (lower concrete densities) produced a decreasing in the compression, indirect tensile, and flexural strengths of concrete, however within the range of concrete densities tested the rate of strength decrease in compression at higher densities (less EPS beads) is less.

The ratio of the cube compressive strength to cylinder compressive strength ranges from 1.1 to 1.3 which is close to that of normal weight concrete. The ratios of the indirect tensile strength to cylinder compressive strengths for the mixes range from 0.15 to 0.20. and the ratio of the modulus of rupture to cylinder compressive strength ranges from 0.26 to 0.67. These ratios are high compared to that of normal weight concrete.

Table 4- Strength properties of Izocerte.

Type of Mix	Weight Kg/m^3	Cube compressive strength: f_{cu} (MPa)	Cylinder compressive strength: f_c' (MPa)	Indirect tensile strength: f_t (MPa)	Flexural strength f_r (MPa)
Iz. 1	350	0.95	0.86	0.185	0.49
Iz. 2	500	3.4	2.62	0.396	0.69
Iz. 3	600	3.5	2.67	0.455	1.21

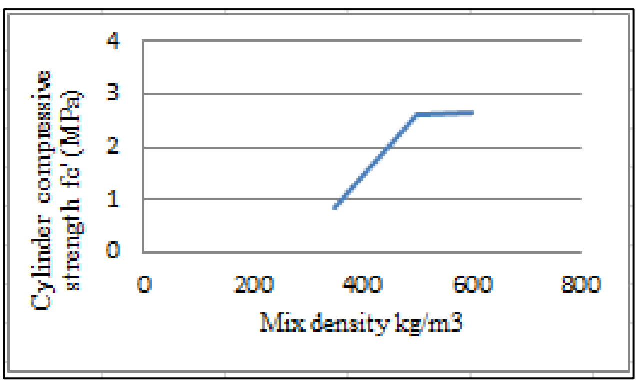


Fig. 5 Relationship between compressive strength, and mix density.

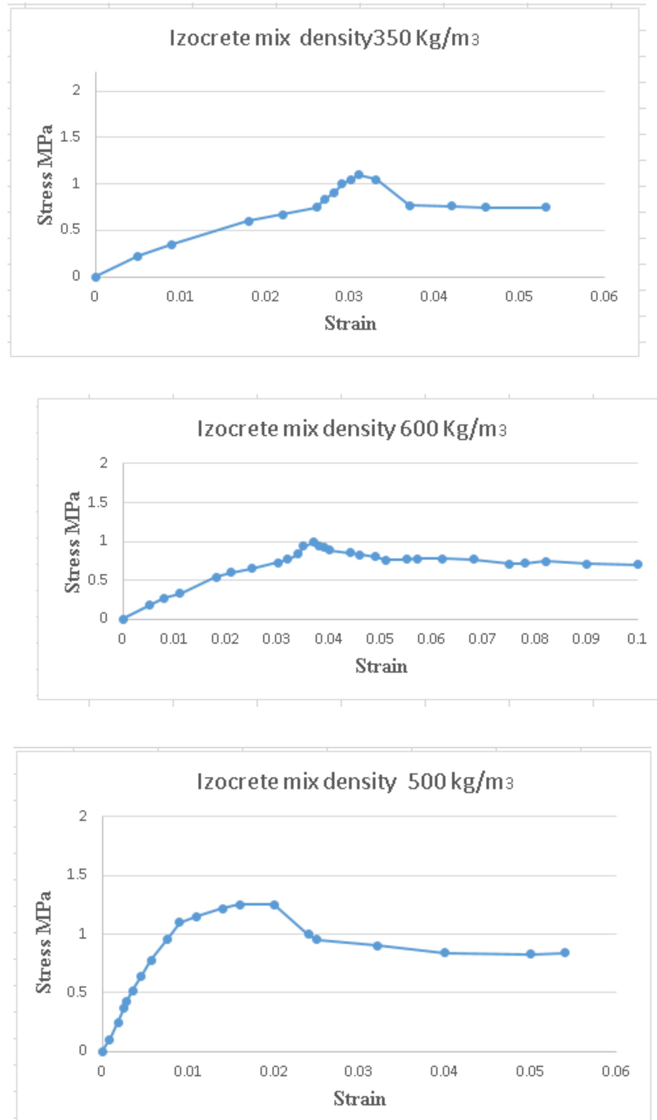


Fig. 6 Stress - Strain relationships for the different Izocrete mix densities under compression

4.2. Load - deformation relationship of the Izocrete mixes under compression

The deformation of the Izocrete under compression loading was measured for the concrete cube samples up-to failure. The tests results are shown Figs 6. The mixes with the three different densities showed different load deformation relationships, however a pattern of a linear relationship followed by a nonlinear part extending up to the ultimate load then descending down slowly was observed in all cases. There was a large deformation under compression due to the high compressibility of the beads under continued loading without sudden brittle failure as in normal weight concrete under compressive loading. Thus the EPS beads gave the Izocrete a ductile behavior. Finally, the cubes failed by crushing with very large deformation in the pattern as seen in Figs 7. This behavior was clearly observed also in the beams tested especially those without the top bar reinforcements. This type of failure controlled the failure of most of the beams.

Cube 100x100mm(mix 350 kg/m^3)

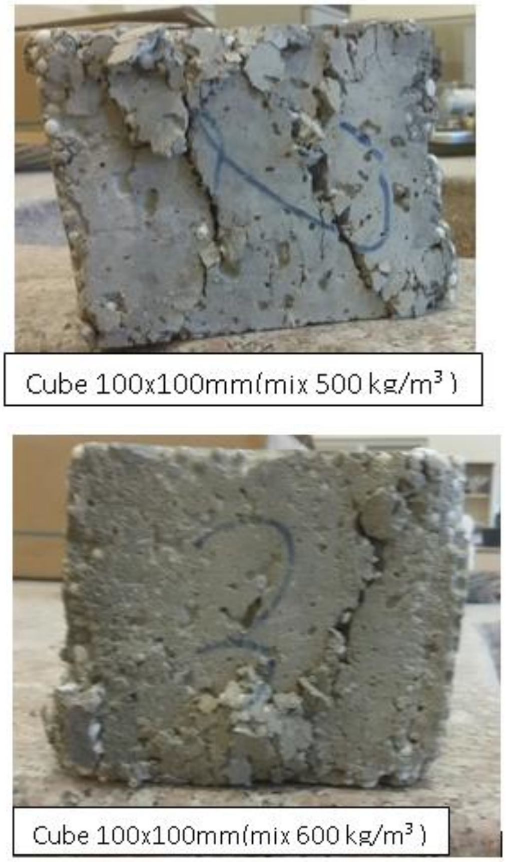


Fig. 7 Mode failure for three different mixes density.

4.3. Cracking and failure loads

Table 5 and Figs.8 and 9 show the load at first crack and at failure for the beams with different mix densities for different types of reinforcement.

Results show that as the density of the Izocrete decreased (more EPS beads), the value of the first crack load and failure load decreased. However, for the same type of mix (density), the presence of reinforcement increased both the first crack and failure loads capacity and they are increased with the increasing of reinforcement ratio and increased also with the presence top reinforcement and shear links. The decrease in first crack load and failure load was consistent with the decreasing of compressive strength and tensile strength of the Izocrete property control tests.

Comparison of the beams test results with or without shear stirrups for the same Izocrete mix density shows that the beams with shear reinforcement possess higher failure load. The stirrups are used when top steel is added; hence the increase in cracking and failure loads is from the combined effect mostly due to the top reinforcement which increases the top compression block capacity of the beams. The stirrups have the role of changing the failure mode in some of the beams from shear failure to bending failure as will be discussed next.

Fig. 10 shows the percentage ratio of cracking load to failure load. The (Pcr/Pfail %.) ranges from [90 to 97], [80 to 93], [75 to.92] for the three 350,500, and 600 kg/m3 mixes respectively. The ratios indicate that for low density mixes the ratios are higher. The ratios for the beams with top reinforcement are much lower because the top bars have increased the failure load significantly increasing the differences between the two loads.

Table 5- First crack and failure loads for the different types of beams

Beam Designation	Density Kg/m³	Tension Rein. /Top Rein.	Cracking Load kN	Failure Load kN
B11	350	2ø6 / 0	1.5	2.3
B12	350	2ø10 / 0	2.2	2.6
B13	350	2ø6 / 2ø6	4.5	7.4
B14	350	2ø10 / 2ø6	5.5	9
B21	500	2ø6 / 0	5	6.5
B22	500	2ø10 / 0	5.3	7
B23	500	2ø6 / 2ø6	11.5	16.5
B24	500	2ø10 / 2ø6	19.5	22
B31	600	2ø6 / 0	6.5	7.5
B32	600	2ø10 / 0	7.5	9
B33	600	2ø6 / 2ø6	13.4	19
B34	600	2ø10 / 2ø6	22	27.4

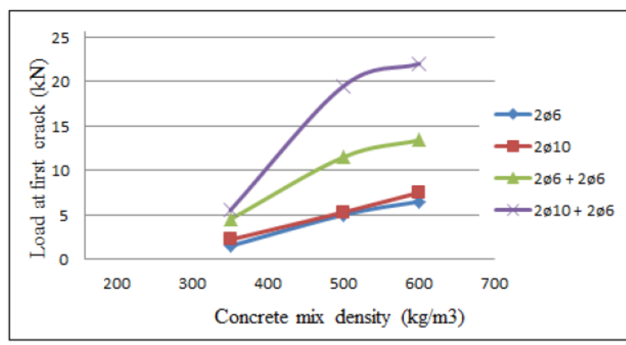


Fig. 8 Load at first crack for beams with different densities and reinforcements

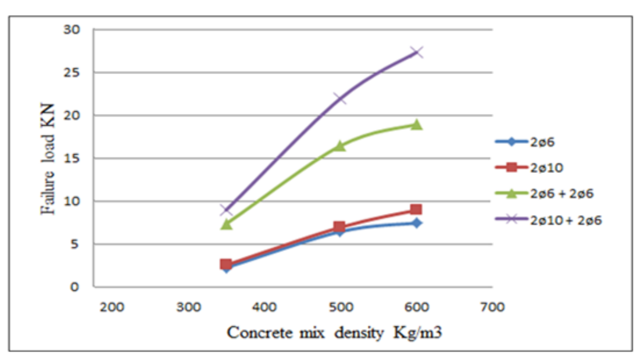


Fig.9 Failure load for beams with different densities and reinforcements

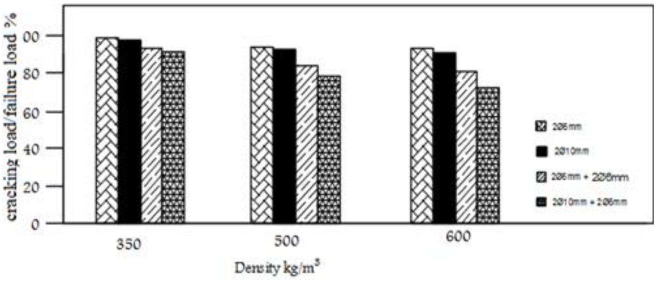
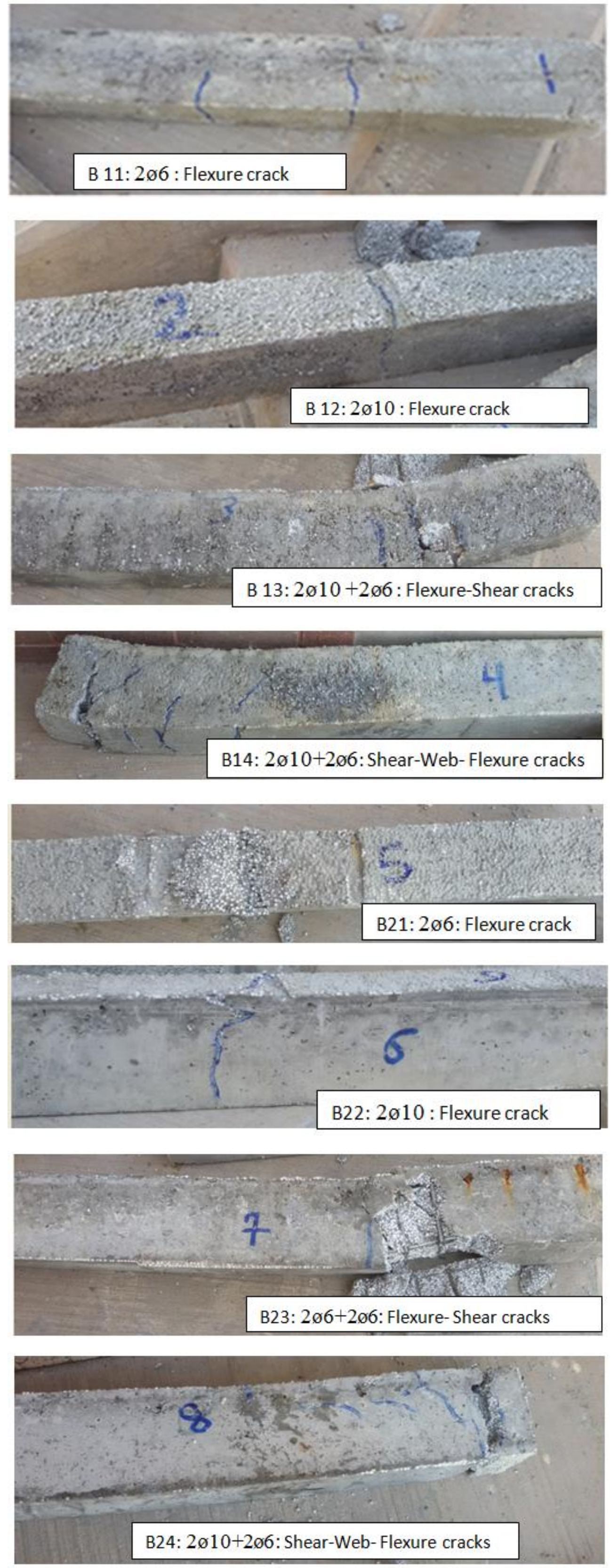


Fig.10 Percentage of first crack load to failure load of the beams.



In all the different mixes, the ratio of first crack load to the failure load is higher for the beams with low steel reinforcement (90-97%). This indicates that for lower steel reinforcement, the first crack appears close to the failure load. This test result is consistent with the results of other research findings [13] who have found in light weight concrete beams, different ratios of reinforcement produce different effect on the initiation of the first crack in relation to its failure load.

4.4. Modes of Failure

The initial cracks of all the beams were flexural cracks at or near the middle of the beams in the constant moment region as shown in Figs.11. Some cracks appeared also in the shear span. Some of the beams showed different modes of failure. In beams B14 (350 kg/m3 with compression steel) the cracks were very close to the support in the shear span and after initiating vertically it became slightly inclined similar to shear crack. However, it did not show brittle and sudden failure because of the presence of stirrups, but the final failure was the opening and enlargement of the crack. In beam B23 (500 kg/m3 with compression steel) the concrete cover below the two tension bars delaminated close to failure load and resulted in final failure. In beams (B33 and B24) both with compression bars the failure seems to have initiated from loss of end anchorage of the bottom bars resulting failure at the ends.

In the beams without top bars, the failure was initiated by the compression failure at the compression zone at the upper face of the beam. No compression failure similar to typical normal concrete failure was observed. However, the compression zone experienced large compressive strain and deformation similar to the cubes and cylinder tests under compression. The beams except those experienced end failures underwent large deflection under reduced load below the ultimate demonstrating some ductility before final failure. Even those beams with the failure at the end experienced some ductility. In general, Izocrete beams with EPS beads at the early stages of loading and during initial cracking demonstrate comparable behavior to that of lightweight concrete beams, for example with oil palm shell [14,15 and 16]. Nevertheless, at failure stage the beams showed increased ductility while they undergo compression deformation at top fibers, and yet no steel yielding has been observed. The beams moment capacity is increased as the steel ratio increased but the steel ratio is not a controlling factor, it is the Izocrete compressive strength, and it decreases as the bead's content ratio increased.

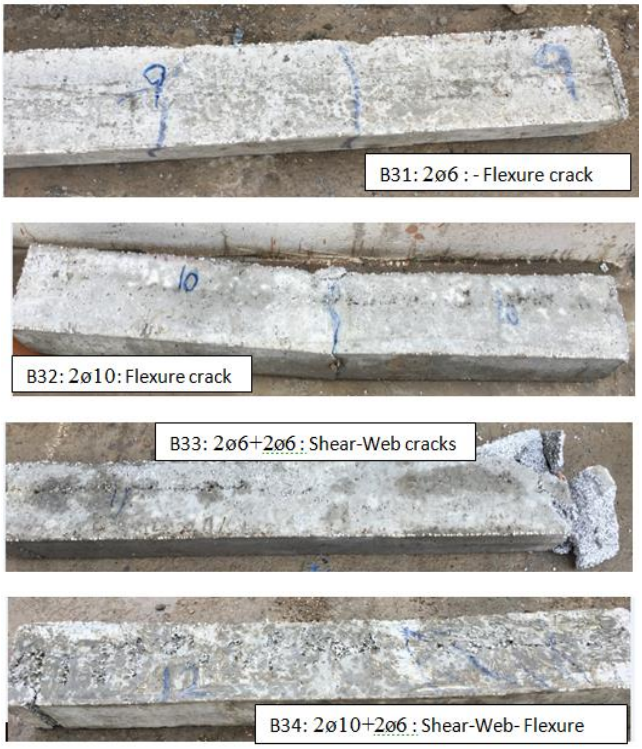


Fig.11 Mode Failure of the izocrete beams

4.5. Effect of EPS bead content

The load-deflection curves for beams with densities of 350kg/m3, 500 kg/m3, 600kg /m3 for the two different amount of reinforcements 2 No 6 and 2 No 10 bars without compression bars, 6 beams are shown in Figs.12. For beams, the load has a tendency to rise sharply and linearly till the appearance of the first crack with a small increase in deflection. The first cracks were primarily affected by the Izocretes flexural strength, which in turn depends on the bond strength between the beads and cement.

The slope of the curves decreased after the first crack which varied depending on the

amount of EPS beads content and the amount of reinforcement. The relationship approximately continued linear until maximum load. Beyond the point where the Izocrete was compressed extensively at the compression zone showing high deformation due to high degree of compressibility of the beads, the beams showed large increase in deflection with small increase in load. Based on the results it could be suggested that the incorporation of EPS influence the load deflection behavior. In general, as the volume percentage of EPS beads in the mix increased, the deflection likewise increased, which was consistent for all the beams for all four types of reinforcements. Increased deflection gave an indication of enhanced ductility. The increase of EPS reduces the failure loads. This can be because EPS beads in the concrete mix resulted in a large decrease in the concrete toughness [13]. The load at failure is lesser for beams having low density which contain higher EPS beads. For the same loading level, the deflection is more for instance, the deflection of the 350 kg/m3 mix is more than that of other mixes (500 & 600) kg/m3 for both percentage of reinforcements.

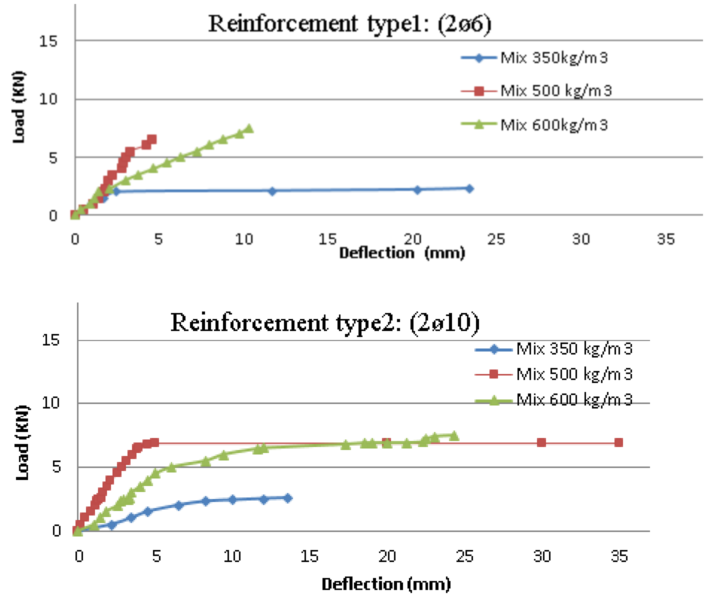
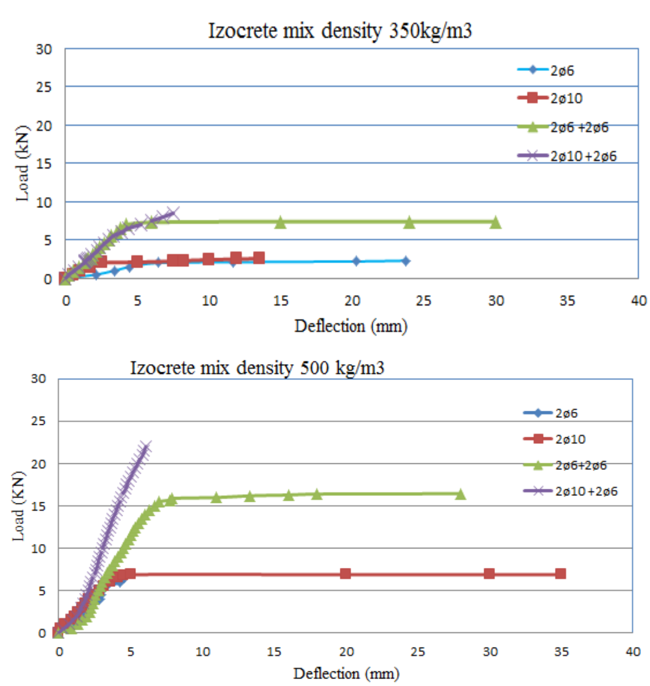


Fig. 12 Load-deflection curves for beams with two different amounts of reinforcement.

4.6. Effect of reinforcement ratio and Top bars

The load-deflection curves for beams with different reinforcement types 1 to 4 are shown in Figs. 13. It can be observed that the beams with 2ø6 tension steel without shear stirrups have more deflection at smaller loads as compared to beams with 2ø10 tension steel without shear stirrups



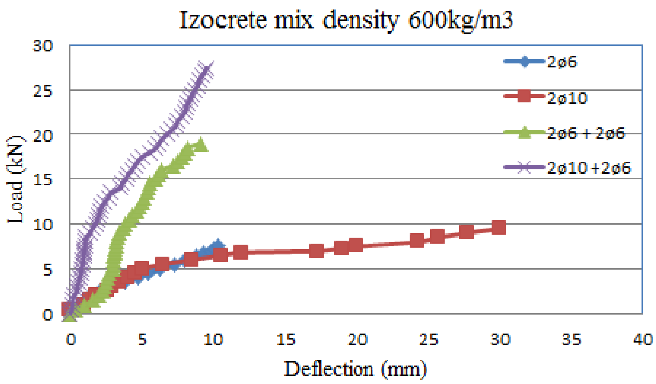


Fig. 13 Load-deflection curves for beams with different reinforcements for the three mixes.

In all the beams it is observed that as the reinforcement ratio is increased (from 2/6mm to 2/10mm) the slope of the load / deflection (stiffness) after cracking and the failure load of the beams are increased. The same observation is true for the beams with top bars and shear stirrups. The top bars compensate for the reduced compressive strength of the Izocrete and increases the compressive force at top hence increasing the moment capacity of the beam as shown from the table of loads. The stirrups have two roles they confine the concrete from expanding due to high compressibility of the beads, hence increasing the carrying capacity of the Izocrete in compression as well as their role in carrying the shear load on the beam. Both the longitudinal bars and the stirrups combined increase the carrying capacity of the beams as clearly can be seen from the load deflection curves and the load values from the table. These results are consistent with the research findings on light weight concrete [13] that investigated the flexural behavior of beams with different amount of steel reinforcement. It has been indicated that the deflection of LWC beams with less reinforcement under smaller load is more than the deflection of LWC beams with more rreinforcement.

5. CONCLUSIONS

As a result of the experimental tests carried out in this investigation the following conclusions are made:

1.Increase in EPS beads content in the Izocrete mixes reduced the density and strength of the concrete. Decreasing the density from (600to 350kg/m3) reduced the compressive strength, and the tensile strength, from (3.5 to 0.95 MPa.), and from (0.455 to 0.185 MPa.) respectively.

2. As the amount of EPS beads increased the deflection of the reinforced Izocrete beams increased, which were consistent for the four reinforcement types, the increased deflection indicated increased ductility of the beams.

3.Increasing the amount of EPS beads (mix density form 600-350kg/m3) reduced the flexure strength of the beams from 7kN to 2.3kN (67%)

4.Increasing reinforcement ratio increase cracking, failure loads, and stiffness of the Izocrete beams.

5.Providing top reinforcement increases flexure strength of reinforced Izocrete beams and it increases as the volume percentage of EPS decrease.

6.The results suggest that EPS concrete can be used for non-structural applications as a light weight concrete, and when reinforced with steel bars as secondary structural members such as lintels over openings with small span load

Acknowledgements

Thanks, and appreciation are presented to the Izocrete company and the staff of Concrete aboratory-College of Engineering- University of Sulaimani and Concrete laboratory-Tishk International University- for their help and support to finalize the experimental works.

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