Diyala Journal of Engineering Sciences

Journal homepage: https://djes.info/index.php/djes

ISSN: 1999-8716 (Print); 2616-6909 (Online)

The Effect of Steel Fiber Content on the Behavior of Reinforced Concrete Bubbled Slab: Experimental Investigation

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ARTICLE INFO

Article history:
Received May 29, 2022
Accepted July 16, 2022

Keywords:
One way slab
Bubble slab
Steel fiber

ABSTRACT

Utilizing Bubbles in the slab is a revolutionary way to get rid of the concrete in the middle of a traditional slab; since this concrete serves no structural purpose and adds a lot of dead weight to the structure, using a bubble in the slab will weaken the slab and reduce its efficiency by (10%), this research presents an experimental study of steel fiber effects on bubble slabs and checks if steel fiber covers the messing efficiency and the effect on the type of failure. The program for the experiment is to test five slabs with (1760 mm × 420 mm × 125 mm) dimensions, divided into one solid slab without bubbles and steel fiber, one bubble slab without fiber, and three bubble slabs with three different fiber percentages, the experimental results shows that the three steel fiber bubble slabs (0.5%S.F.B.S, 1%S.F.B.S, 1.5%S.F.B.S) show an increase in yield load and ultimate load by (16%,20%,26.3%) for yield load and (14.5%,20.26%,25.2%) for the ultimate load respectively compared with the solid slab (S.S), and increases yield load and ultimate load by (31.8%,36.36%,40.9%) for yield load and (26.8%,33.2%, 39.8%) for ultimate load compared with bubble slab (B.S), for first crack load in solid slab (S.S) and bubble slab (B.S) first crack appeared at (13kN, 11kN) and for steel fiber bubble slabs (0.5%S.F.B.S, 1%S.F.B.S, 1.5%S.F.B.S) first crack appeared at (18 kN, 22 kN, 24 kN) respectively and change of type of failure from brittle sudden shear failure for the bubble slabs to ductile flexural failure.

1. Introduction

The slab is the most important part of a building's structure and consumes the most concrete; the structure's deadweight is increased when large amounts of concrete are used. Due to their substantial dead weight and increasing inertia forces, heavy structures are less resistant to seismic shocks than light ones. Finish material costs rise when support beams are added at a floor-to-floor height [1,2]. The "Bubble-Deck System," developed in the nineties by (Jorgen Breuing), was designed to eliminate the slab's weight. This technology creates air holes using spherical balls made of recycled industrial plastic to provide strength by an arching movement while also using recycled industrial plastic. With the same thickness, these bubbles may reduce deadweight by 35% while increasing capacity by almost 100%. The building's long-term reaction costs when the dead load is reduced, whereas the slab's deflection rises when the dead load is offset [3, 4]. [5] studied the shear span to effective depth ratio (a/d) used three different ratios (2, 3.5, 5); the results recorded that the balls' presence made slabs fail abruptly due to shear mode regardless of the a/d ratio [6]. The effect of construction type on bubbling one-way slabs' strength and behavior was tested experimentally for (simple and filigree bubbled slabs). Compared to a solid

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DOI: 10.24237/djes.2022.15309

slab, the results showed a 10% to 12% increase in deflection at yield load (Δy) and a drop of 13% to 40% in the crack load, respectively [7]. studied the effect of differences in compressive strength on bubble slabs (30 and 60 MPa), and results showed the ultimate load increased by (17.6-58.5 %) when using (60 MPa) concrete compared with (30 MPa) concrete specimens. Specimens with concrete of (30 MPa).[8] studied the flexural capacities and flexibility of two-way hollow slabs with spherical voids known as the Bubble-Deck slab system. The ratio of bubble diameter to slab thickness affects Bubble Deck slab behavior. When the bubble diameter to slab thickness ratio is reduced by 10%, the ultimate capacities are reduced by 10%. (0.80).[9] studied the effects of two types of steel fiber-reinforced C50 manufactured using traditional and C60 vibratory mixing methods, concrete sample test compression, flexural, splitting tensile, and bending. The results show improvements in mechanical properties of steel fiber-reinforced concrete when compared to the traditional mixing method to vibratory mixing methods.[10] studied the effect of fiber dosage on concrete, the results show an increase in fiber dosage improves the energy absorption capacity and enhances the robustness of concrete.

2. Experimental program

2.1. *Materials*

- Cement

Ordinary Portland cement (type I) produced by the Tasluja factory in (Iraq) was utilized for this project. The chemical composition and physical properties match the (Iraqi Portland Cement Standard Specification)[11].

- Fine Aggregate

The fine aggregate utilized in this project was acquired from natural sand from the Al-Sidor area. It has a modulus of fineness of 2.38. Conformity of the grading and physical qualities of fine aggregate to the limitations of the (Iraqi Specification (I.Q.S. No.45, 1984) [12].

- Coarse Aggregate

In this investigation, coarse aggregates are composed of natural gravel with a maximum particle size of (12.5mm). The area of Al-Sidor supplied the natural gravel. The gravel was washed and then dried in the air. The aggregates' physical qualities and grading met the requirements of (Iraqi standard No. 45, 1984) [12].

- Steel Fiber

This study used hook ends steel fiber with a length (35cm), diameter (0.55mm) and aspect ratio (65), tensile strength equal to (1000MPa), and density (7.85 g/cm3) to improve concrete properties[13-16].

- Superplasticizer

A superplasticizer enhances the workability of concrete without creating segregation, hence making it simpler to handle. "Sika Viscocrete 5930" is the brand name for the material used in this investigation.

- Plastic Ball

The recycled plastic material was used to create plastic balls with a diameter of (85 mm) and (20 g) in weight, creating gaps inside the slabs in this investigation. Employing plastic material is to preserve energy since reprocessing recycled resources into new material requires far less energy than processing virgin materials. Additionally, recycling reduces global warming and air pollution by lowering the quantity of industrial labor required to manufacture a new product. Before, during, and after pouring, the ball must be sufficiently rigid to withstand the imposed weight securely.

- Steel Reinforcement

Deformed steel bars are employed as steel reinforcement at the top and bottom of all slabs. The primary reinforcement measures (10mm) and the secondary reinforcement measure (4 mm). Table (1) lists the mechanical parameters of the tested steel bar.

Table 1: Mechanical properties of steel reinforcement

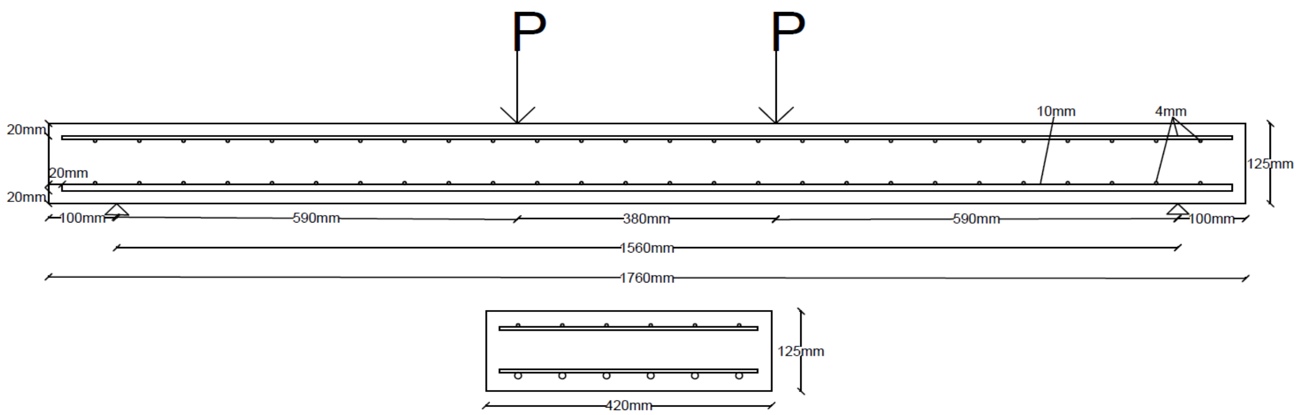
Nominal diameter (mm)	Actual diameter (mm)	Surface texture	Yield stress (MPa)	Ultimate stress (MPa)
4	4.3	deformed	583.30	666.23
10	10.4	deformed	550.83	642.71

2.2. Specimens description

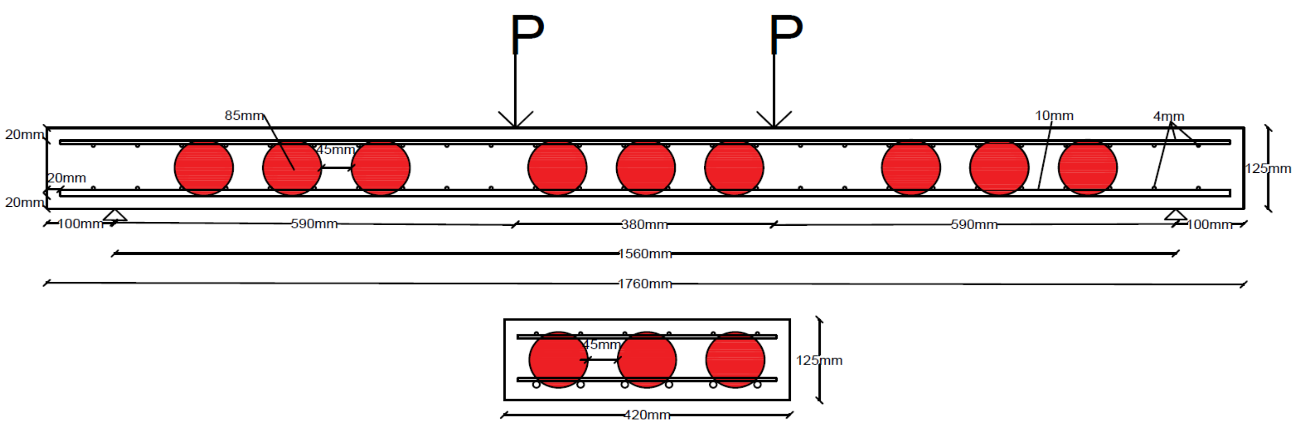
This study contains five slab specimens, the slab designed according to (ACI 318-19: Building Code) [17]. A solid slab, bubble slab, and three steel fiber bubble slabs. The tested parameters include the presence of plactic ball and steel fiber with deffrent percentage. Table (2) and Figure (1) explain the description and details of the tested slabs, all dimensions in (mm).

Table 2: Description and symbols of specimens

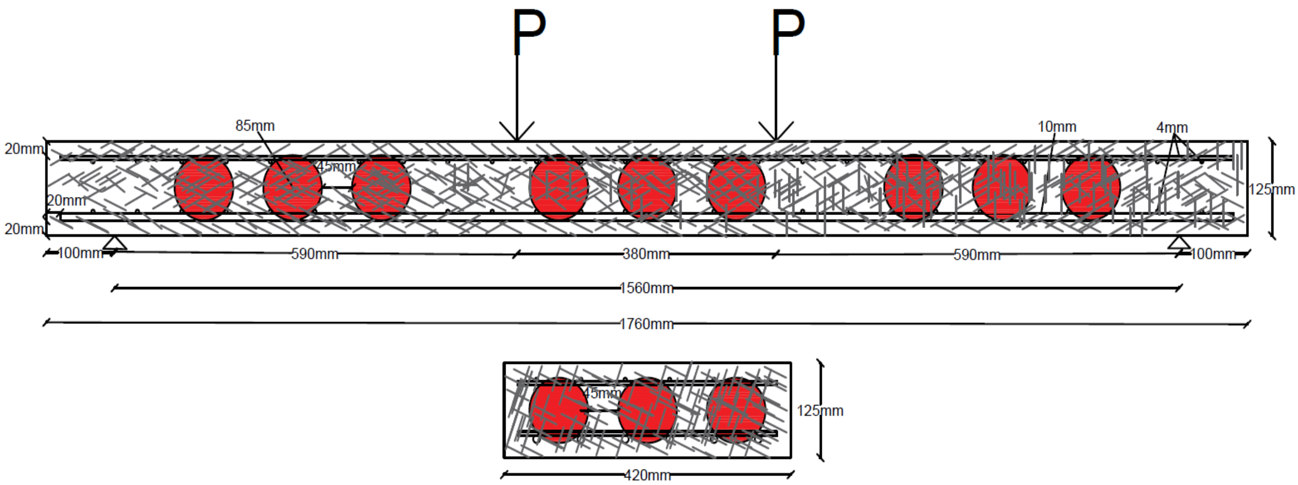
Slab samples	Description of Specimens	Ball Diameter (mm)	Spacing Between Balls (mm)	Fiber Percentage
S.S	Solid slab	--------	--------	--------
B.S	Bubble slab	85	45	--------
S.F.B.S		85	45	0.5%
S.F.B.S	Steel fiber bubble slab	85	45	1%
S.F.B.S		85	45	1.5%



(a) Solid Slab



(b) Bubbled Slab



(c) Steel Fiber Bubbled Slab

Figure 1. Details of slabs reinforcement

2.3. Concrete mix

The concrete mix proportions are shown in Table (3). The concrete properties are shown in table (4) for compressive strength, and tensile three cylinders were used for each test, and three prisms were used for the flexure test; all tests at the age of 28 days and according to (ASTM Designation (C39/C39M-15a, 2015)[18].

Table 3: Concrete mix proportions per cubic meter

Type of concrete	Cement content (kg/m^3)	Fine Aggregate (kg/m^3)	Coarse Aggregate (kg/m^3)	Fiber (kg/m^3)	Superplasticizer From cement weight	Water (kg/m^3)
N.C	450	850	900	----	0.040%	225
0.5% S.F.C	450	850	900	39.25	0.045%	225
1.0% S.F.C	450	850	900	78.5	0.050%	225
1.5% S.F.C	450	850	900	117.75	0.055%	225

Table 4: Concrete properties result

Specimen Symbols	F'c Mpa 28 days	Fr Mpa 28 days	Ft Mpa 28 days
N.C	35.4	3.93	3.02
0.5% S.F.C	38.3	5.4	3.47
1.0% S.F.C	40.1	7.25	4.25
1.5% S.F.C	42.2	9.05	4.75

2.4. Test specimen

All slabs were tested at the age of 28 days. They were cleaned and painted white so that expanding cracks could be noticed. The slabs were simply supported across a clear span of 1,560 mm and subjected to two concentrated loads; the load was applied, and the readings were obtained at each (10kN). The applied load, deflection, crack width, and steel and concrete stresses were measured manually and recorded at each phase. After failure, the load indication was decreased, or recording was halted, and the deflection increased fast without a proportional increase in the applied load.

3. Results and discussion

3.1. Ultimate load capacity

The result of the five tested slabs is shown in table (5). The results show a reduction in the yield load and ultimate loads of bubbled slabs (B.S) compared with solid slabs (S.S) by (12% and 9.7%), respectively. The cause of this reduction is attributed to the plastic balls placed in the core of the bubbled slabs sections. And The tested slabs of three steel fiber bubble slabs (0.5%S.F.B.S, 1%S.F.B.S, 1.5%S.F.B.S).

Show an increase in steel fiber percentage increase in yield load and ultimate load by (16%,20%,24%) for yield load and (14.5%,20.26%,26.3%) for the ultimate load, respectively, compared with the solid slab (S.S.). And increases yield load and ultimate load by (31.8%,36.36%,40.9%) for yield load, and (26.8%,33.2%, 39.8%) compared with bubble slab (B.S).

Table 5: Tested slab result

Slab symbol	Yield load P_y (kN)	Yield deflection Δ_y (mm)	Ultimate load P_u (kN)	Ultimate Deflection Δ_u (mm)	Ductility ratio Δ_u/Δ_y
S.S	75	12.8	84.4	32.5	2.38
B.S	66	12	76.2	23.4	1.95
0.5%S.F.B.S	87	14.3	96.63	35.8	2.5
1.0% S.F.B.S	94	15	101.5	39.33	2.62
1.5% S.F.B.S	98	16	106.6	42.5	2.71

3.2. Load–Deflection relationships

The deflection result shows a reduction of Yield deflection (Δ_y) and ultimate deflections (Δ_u) by (6.2% and 23.3%) respectively, comparing bubble slab (B.S.) with sold slab (S.S.). and an increase in yield deflection (Δ_y) and ultimate deflections (Δu) of steel fiber bubbled slabs (0.5%S.F.B.S , 1%S.F.B.S ,1.5%S.F.B.S) by (11.7% ,17.2% ,28.1) respectively for yield deflection and (10.5%, 21.4%, 37.3%) for ultimate load compared to solid slab (S.S). And increase yield deflection (Δ_y) and ultimate deflections (Δ_u) by 17.4%, 28.8%, 46%) for yield deflection respectively and (53% ,68%,90.2%) respectively for ultimate deflection compared with bubble slab (B.S) as shown in Figure (2). This increase is attributed to the presence of steel fiber in the bubble slab, which gives concrete ductility characteristics.

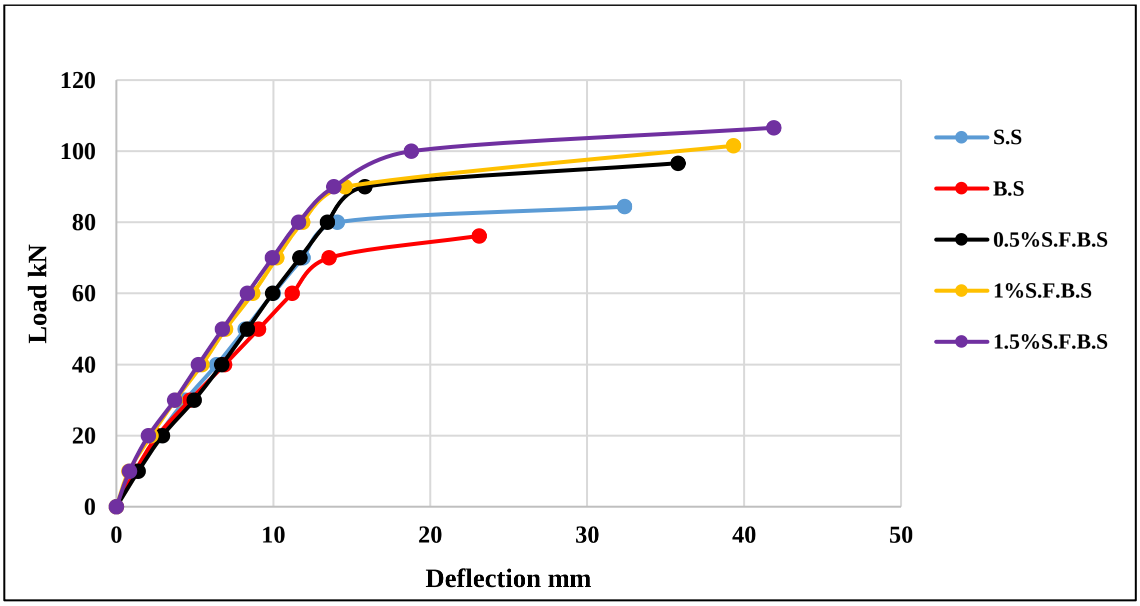


Figure 2. Load-deflection curves in slabs

3.3. Concrete surface strain

The concrete surface strain was determined by two strain gages set in the center of the top surface of the slabs. Due to the plastic balls that lower the volume of concrete in the compression zone of bubbled slab specimens, Figure (3) shows that the concrete surface strain is greater for bubbled slab specimens than for solid slab specimens at all stages of loading. And for steel fiber bubble slabs, the findings indicate an increase in compressive strain in ultimate load compared to solid (S.S) and bubble slab (B.S), although this increase in strain value begins to diminish as the steel fiber increases.

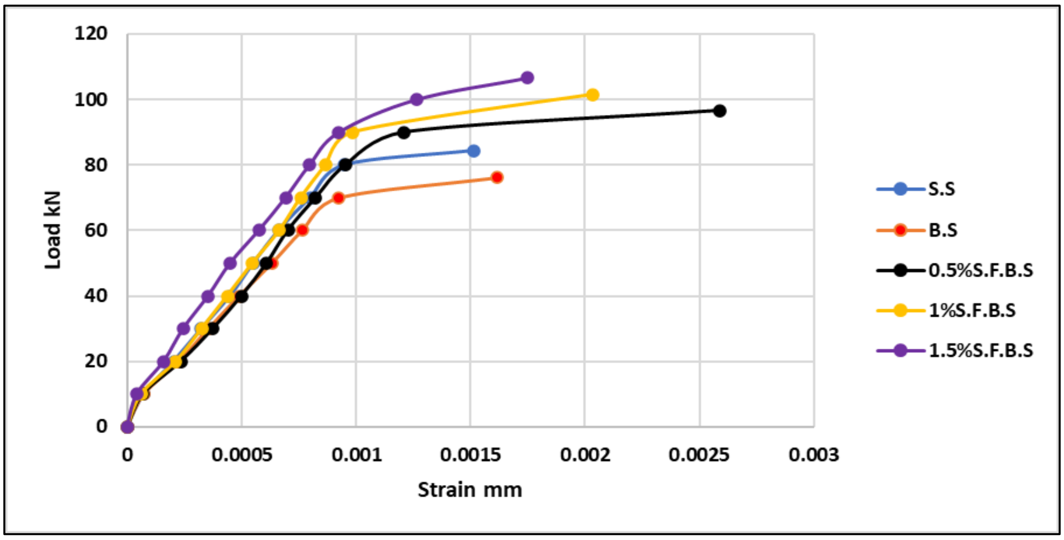


Figure 3. Load- concrete Strain Curve for Slabs Specimen

3.4. Steel reinforcement strain

Two electrical resistance strains placed in the center of two intermediate longitudinal reinforcing bars were used to measure reinforcement stresses. Figure 4 shows that reaching crack load, the strain in steel reinforcing bars in all specimens of slabs is small. After then, dramatic strain reading changes were reported. The result indicates a reduction in strain value when comparing a bubble slab to a solid slab by (7.6%); however, steel fiber bubble slabs (0.5%S.F.B.S, 1%S.F.B.S,1.5%S.F.B.S) indicate an increase in strain value when compared to a solid by (3.4%, 19%,27.76%) and by (11.8%,28.8%,38.2%) compared bubble slab.

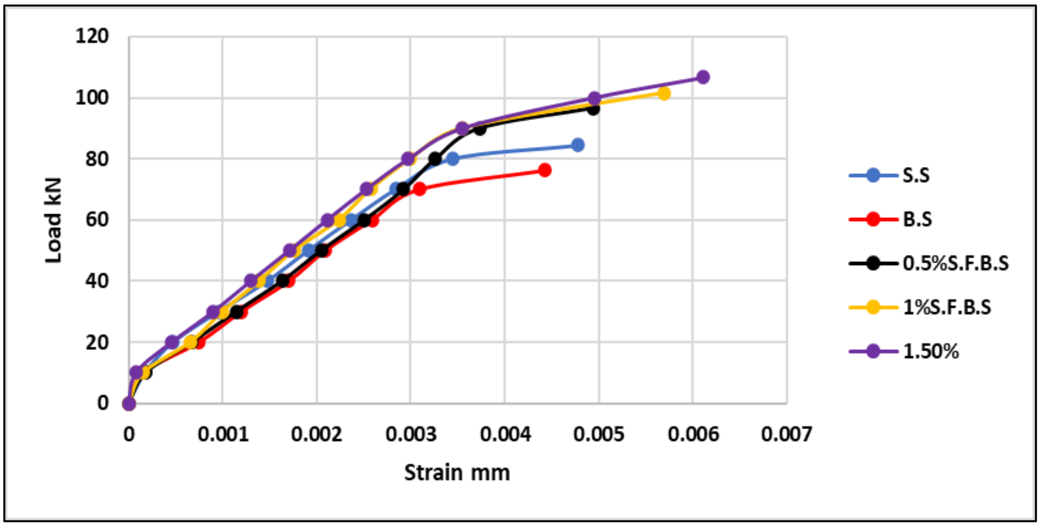
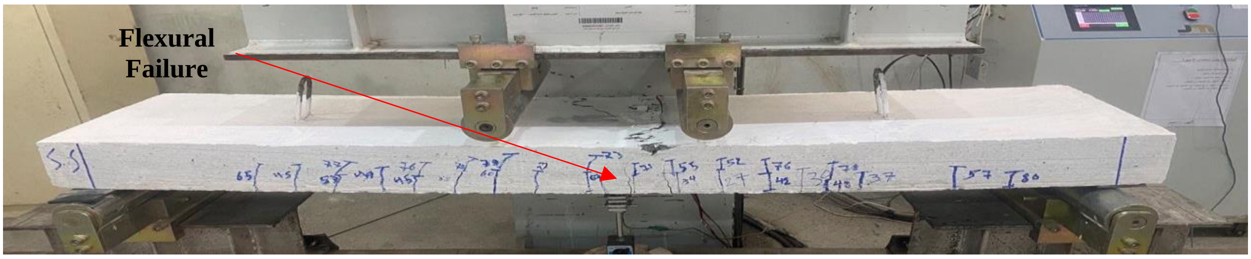


Figure 4. Load-steel strain curve for slabs specimens

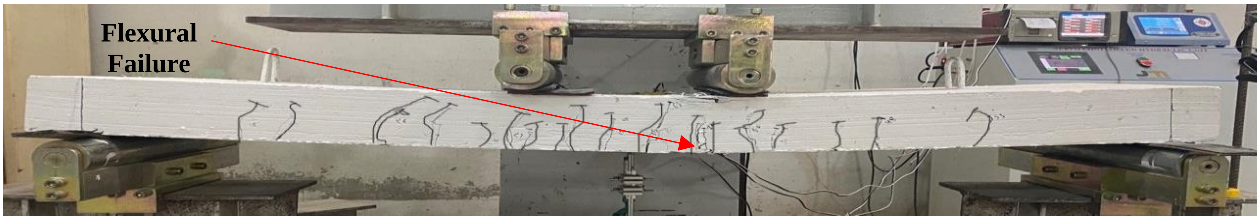
2.5. Crack pattern and failure

All slab failure modes and fracture dispersion are shown in Figure 5. Initial cracking was seen in the stress zone of the slab around the slab's center for all tested slabs. The first flexural fracture is started at (13kN) in the solid slab and (11kN) in the bubble slab. As loading rises, the concrete's tensile stress exceeds the modulus of rupture, and cracking begins at the zone of highest tensile stress. And for steel fiber bubble slabs (0.5% S.F.B.S,1% S.F.B.S,1.5% S.F.B.S) higher crack load owing to the presence of steel fiber which strengthens the stress zone that the bubble has already degraded; the results were (18 kN, 22 kN, 24 kN) accordingly. The bubble slab collapsed with brittle shear failure due to a plastic bubble in the tension zone that lowered the shear strength. The shear strength of a slab with bubbles. The shear strength is equal (0.6) to that of a solid concrete slab of the same thickness[19].



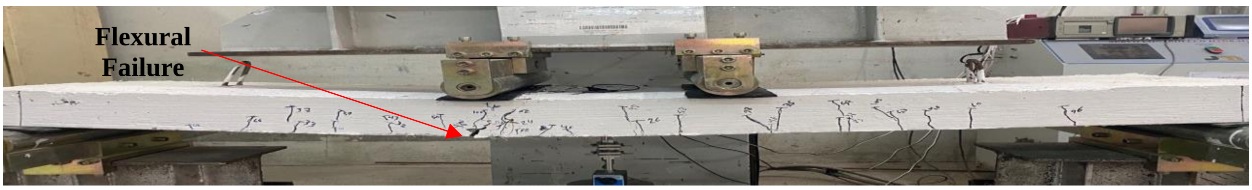
(a) Solid slab[2]

(b) Bubble slab



(c) Bubbled slab (0.5%S.F.B.S)

(d) Bubbled slab (1%S.F.B.S)



(e) Bubbled slab (1.5%S.F.B.S)

Figure 5. Crack pattern and mode of failure for all slabs

3. Conclusion

1. Decrease in the ultimate strength of bubbled slabs compared with the solid slab by 10%.
2. Using steel fiber in bubble bubbled slabs improves the load-bearing capacity to be overhead of solid and bubble slabs the ultimate load increased with increasing steel fiber percentages (0.5% ,1%, 1.5%) compared to solid slab and bubble slab by (14.5%,20.26%,26.3%) compared to sloid slab and (26.8% ,33.2%,39.8%) compared to bubble slab.
3. An increase in ultimate deflection (Δ_u) for all steel fiber bubbled slabs is more than that in the solid and bubble slabs for all percentages (0.5% ,1%, 1.5%) by (10.5%, 21.4%, 37.3%) compared to solid slab and by (34.5% ,40.5%,44%) compared tobubble slab.
4. The presence of a plastic bubble in the slab will weaken the tension zone.
5. The presence of steel fiber switches the failure mode from shear to flexural failure in bubble slab.
6. For strain in steel reinforcing bar for all percentages (0.5% ,1%, 1.5%) bubble slabs indicate an increase in strain value when compared to a solid by (3.4%, 19%,27.76%) and by (11.8% ,28.8%, 38.2%) compared bubble slab.
7. Recycled plastic balls replaced concrete in the core of the slab to reduce the amount of cement. So, no cement would be made, and CO2 emissions worldwide would decrease. So, this technology is good for the environment and will last.
8. Reducing the amount of materials used expedites the building process. Additionally, it decreases dead weight, which provides a smaller building foundation; the reduction was (9.5%).

4. Acknowledgments

This study was supported by the Civil Engineering Department at the University of Diyala, which is gratefully appreciated.

References

[1] C. J. Midkiff, "Plastic voided slab systems: applications and design," 2013.

[2] T. S. Al-Gasham, A. N. Hilo, and M. A. Alawsi, "Structural behavior of reinforced concrete one-way slabs voided by polystyrene balls," *Case Studies in Construction Materials*, vol. 11, p. e00292, 2019.

[3] T. Lai, "Structural behavior of BubbleDeck® slabs and their application to lightweight bridge decks," Massachusetts Institute of Technology, 2010.

[4] T. S. S. Al-Gasham, "Structural performance of reinforced concrete bubble slabs after exposing to fire flame," *Journal of Engineering and Sustainable Development*, vol. 19, no. 4, pp. 1-14, 2015.

[5] H. A. Jabir, J. M. Mhalhal, and T. S. Al-Gasham, "Conventional and bubbled slab strips under limited repeated loads: A comparative experimental study," *Case Studies in Construction Materials*, vol. 14, p. e00501, 2021.

[6] A. M. Ibrahim, M. A. Ismael, and H. A. A. Hussein, "Effect of construction type on structural behaviour of RC bubbled one-way slab," *Diyala Journal of Engineering Sciences*, vol. 12, no. 1, pp. 73-79, 2019.

[7] N. K. Oukaili and L. F. Husain, "Punching shear in reinforced concrete bubbled slabs: experimental investigation," *Smart monitoring, assessment and rehabilitation of civil structures, Zurich, Switzerland*, 2017.

[8] A. M. Ibrahim, N. K. A. Oukaili, and W. D. Salman, "Flexural behavior and sustainable analysis of polymer bubbuled reinforced concrete slabs," in *Fourth Asia Pacific Conference on FRP in Structures (APFIS 2013)*, 2013, pp. 11-13.

[9] Y. Zheng, X. Wu, G. He, Q. Shang, J. Xu, and Y. Sun, "Mechanical properties of steel fiber-reinforced concrete by vibratory mixing technology," *Advances in Civil Engineering*, vol. 2018, 2018.

[10] S. Grzesiak, M. Pahn, M. Schultz-Cornelius, S. Harenberg, and C. Hahn, "Influence of Fiber Addition on the Properties of High-Performance Concrete," *Materials*, vol. 14, no. 13, p. 3736, 2021.

[11] I. S. No, "Portland Cement, the Iraqi Central Organization for Standardization and Quality Control," ed: Baghdad-Iraq, 1984.

[12] I. specification No, "45 (IQ. S 45)―Aggregate from Natural Sources for Concrete and Construction,‖ Central Organization for Standardization and Quality Control," ed: Bagdad, 1984.

[13] F. Koksal, A. Ilki, and M. Tasdemir, "Optimum mix design of steel-fibre-reinforced concrete plates," *Arabian Journal for Science and Engineering,* vol. 38, no. 11, pp. 2971-2983, 2013.

[14] A. Basheerudeen and S. Anandan, "Simplified mix design procedures for steel fibre reinforced self compacting concrete," *Engineering Journal*, vol. 19, no. 1, pp. 21-36, 2015.

[15] Y. Jia, R. Zhao, P. Liao, F. Li, Y. Yuan, and S. Zhou, "Experimental study on mix proportion of fiber reinforced cementitious composites," in *AIP Conference Proceedings*, 2017, vol. 1890, no. 1: AIP Publishing LLC, p. 020002.

[16] G. Campione, "Performance of steel fibrous reinforced concrete corbels subjected to vertical and horizontal loads," *Journal of structural engineering*, vol. 135, no. 5, pp. 519-529, 2009.

[17] A. Committee, "ACI 318-19: Building Code Requirements for Structural Concrete and Commentary," *American Concrete Institute: Farmington Hills, MI, USA,* 2019.

[18] A. Standard, "C39/C39M-15a, 2015," *Standard test method for compressive strength of cylindrical concrete specimens*, 2015.

[19] BubbleDeck. "Shear capacity." bubbledeck.com/implementation, 2020.