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Behavior of Strengthened Semi-Lightweight Reinforced Concrete Beams

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الملخص
تبحث هذه الدراسة تجريبياً تأثير استخدام الألواح الفولاذية في تقوية الكمرات الخرسانية شبه الخفيفة الوزن لمقاومة قوى القص. تم استخدام سبعة كمرات بأبعاد 1800x200x100ملم، تم تقوية أربعة منها باستخدام ألواح الصلب. تم تحضير ثلاثة عشر خليطاً تجريبياً لإنتاج خرسانة شبه خفيفة الوزن عن طريق استبدال الركام الناعم والخشن بالستايروفوم من حيث الحجم. تمت إضافة الملدنات الفائقة والسيليكا فيوم والرماد المتطاير لتعزيز قوة وأداء الخرسانة. تم تحقيق خرسانة شبه خفيفة الوزن ذات قوة ضغط تبلغ 22.26 ميجا باسكال وكثافة 1.89 كيلونيوتن/م3 من خلال استبدال 40% من الركام بالستايروفوم من حيث الحجم. تم صب سبعة كمرات شبه خفيفة الوزن واختبارها من حيث قوة الضغط، الانحراف، نمط الفشل، فعالية العزم، نمط التشقق، ومقارنة مقاومتها لقوى القص مع وبدون تقوية. تشير نتائج البحث إلى أن معامل مرونة الخرسانة (S-lwc) في نتائج الاختبار كان أقل بنسبة 50% من القيم النظرية لـ (N-wc). تقوية العتبات الخرسانية المسلحة شبه خفيفة الوزن بألواح فولاذية مقاس 50 عرض و 160 ارتفاع و 3 سماكة بالملم، إما عن طريق اللصق بمادة الإيبوكسي وحدها أو عن طريق لصق الإيبوكسي مع المسامير والبراغي في منطقة القص، يزيد من قدرة القص وقوة الانحناء بنسبة 28% إلى 37%. بالإضافة إلى ذلك، فإن استخدام ألواح فولاذية على شكل حرف U بمقاس 50 عرض و180 ارتفاع و3 سماكة بالملم، إما عن طريق اللصق بالإيبوكسي وحده أو عن طريق اللصق بالإيبوكسي مع المسامير والبراغي في منطقة القص، يزيد من قدرة القص وقوة الانحناء بنسبة 37% إلى 40%.

الكلمات الرئيسية: الخرسانة شبه خفيفة الوزن ؛ التقوية ؛ ألواح الصلب ؛ الستايروفوم ؛ مقاومة القص ؛ منحنى الإجهاد والإنفعال؛ الهبوط .

Abstract. This study investigates experimentally the effect of using steel plates to strengthening semi-lightweight concrete beams against shear forces. Seven beams, measuring 100x200x1800 mm, were utilized, with four of them strengthening using steel plates. Thirteen experimental mixtures were prepared to produce semi-lightweight concrete by substituting fine and coarse aggregate with Styrofoam by volume. Super plasticizers, silica fumes, and fly ash were added to enhance concrete strength and the concrete's performance. Semi-lightweight concrete with a compressive strength of 22.26 MPa and density of 18.9 kN/m^3 was achieved by replacing 40% of the aggregate with Styrofoam by volume. Seven semi-lightweight beams were cast and tested for compressive strength, deflection, failure pattern, moment effectiveness, crack pattern, and comparison of resistance to shear forces with and without strengthening. The research findings indicate that the modulus of elasticity of concrete (S-lwc) in the test results was 50% lower than the theoretical values of (N-wc). Strengthening semi-lightweight reinforced concrete beams with steel plates size 50 Width, 160 Height, and 3 Thickness in mm, either by gluing with epoxy alone or by gluing with epoxy combined with nails and screws in the shear zone, increases shear capacity and flexural strength by 28% to 37%. Additionally, using U-shaped steel plates of the size 50 Width, 180 Height, and 3 Thickness in mm, either by gluing with epoxy alone or by gluing with epoxy combined with nails and screws in the shear zone, increases shear capacity and flexural strength by 37% to 40%.

Keywords: Semi-Lightweight concrete; Strengthening; steel plate; Styrofoam; Shear strength; stress-strain curve; Modulus of Elasticity; Deflection.

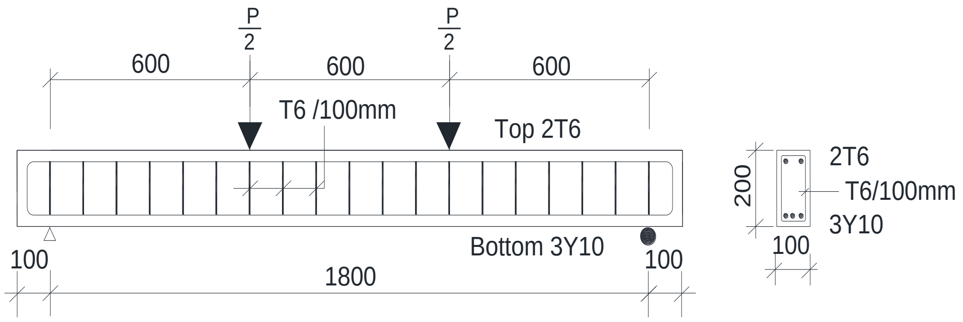
1. Introduction

Lightweight concrete (LWC) is of paramount importance to the construction industry due to its cost-effectiveness and significant advantages. The primary benefit of lightweight concrete is the reduction of the structure's dead weight, foundation loads, cross-sectional areas of all structural elements, and consequently, the overall cost of the structure. Additionally, the reduced mass decreases the lateral load on the structure during earthquakes, simplifying and reducing the lateral load-bearing system. The lighter weight of LWC also decreases the hydrostatic pressure on the formwork accordingly. This secondary characteristic would also impact the labor costs of the structure.Styrofoam, a locally available material, has recently found application in the concrete industry as a means to reduce weight. The objective is to create semi-lightweight concrete by substituting Styrofoam for traditional fine and coarse-sized aggregates. Furthermore, a study was conducted to analyze the performance of semi-lightweight beams, some of which were reinforced with steel plates, under various loads through laboratory experiments. structural lightweight concrete typically exhibits a dry density ranging from 11.20 kN/m³ to 19.20 kN/m³. This density makes it approximately 23–80% lighter in weight compared to normal weight concrete, provided that it achieves a cylinder compressive strength greater than 17 MPa after 28 days [1]. Satish Chandra and Leif Berntsson (2002), compared lightweight concrete to normal weight concrete, finding that lightweight concrete typically saves 20%-40% more than normal concrete. Resulting in potential savings in reinforcement, transportation of precast elements, reduced formwork for in-site construction, and smaller foundation sizes, as mentioned in the guide to the use of lightweight aggregate concrete in bridge construction. Other benefits include reduced inertial seismic load and the ability to manufacture large and long precast elements without compromising insulation due to the porosity in the aggregate [2]. Four types of concrete were analyzed based on their production method, including Normal Weight Concrete (NW), Lightweight Aggregates (LA), Lightweight Aggregate Foamed Concrete (LF), and Foamed Concrete (FC). Concrete samples were tested using a 1000 MTS hydraulic machine after being cast in steel molds and undergoing vibration. Results showed that the compressive strength at 28 days was 36.5, 39.6, 38.3, and 34.0 MPa, respectively. However, the fresh density was 23.50, 18.6, 15, 15.5 kN/m3, respectively [3]. Dinakar (2013), Used the same mixture proportions by volume for water/binder ratios varying from 0.3 to 0.5 in LWC and CC mixtures and compared the mechanical properties. Use of the natural coarse aggregate and Lytic coarse aggregates were the only differences in the mixtures. As a result, they observed 7- 9% variation of the ratio of splitting tensile/ compressive strength in both LWC and CC specimens that was beyond the range given in European code of practice, CEB-FIP [4]. Lim C., Ozbakkaloglu T. (2014), In both normal weight concrete (NWC) and lightweight concrete (LWC), the stress-strain curve during uniaxial compression follows a typical pattern. It starts with linear and elastic behavior, followed by nonlinear behavior as micro-cracks develop. The maximum stress is reached when significant crack networks form. After the peak load, stress decreases while strain continues to increase. Strain at rupture is approximately 3% for NWC and 4% for LWC. The descending part of the curve, known as the post-peak response, shows strain softening due to micro-crack coalescence. Strain at collapse is around 5% for both NWC and LWC. Determining this segment of the curve requires specialized testing equipment [5]. Nguyen et al. (2014), conducted a study to investigate the impact of mixture parameters and volume fraction on the thermal and mechanical properties of lightweight concrete (LWC). Through testing seven types of fine and coarse lightweight aggregates from three different environments in twelve mixtures, they observed a linear decrease in the modulus of elasticity and compressive strength with decreasing LWC density. Specifically, replacing normal-weight fine aggregate with lightweight fine aggregate at a rate of 100 kg/m³ led to a reduction in compressive strength and modulus of elasticity by 2.3-3.8 MPa and 1.7-2.6 GPa, respectively [6]. Huang and Chen (2011), compared the shear behavior of full-size reinforced lightweight concrete (LWAC) beams to normal weight concrete (NWC) beams. They found that while LWAC beams exhibited similar shear failure modes to NWC beams, they showed smoother failure paths, indicating a more brittle failure mode. The study also revealed that the ACI equation tended to be conservative in predicting shear strength for both LWAC and NWC beams with certain shear-span-to-depth ratios [7]. The effectiveness of reinforcing concrete beams using bonded steel plates and epoxy resin was investigated[8],[9]. Key parameters included shear-span-to-depth ratios and adhesive thicknesses. Results indicated different failure modes and load-carrying capacities influenced by width-to-thickness ratios (b/t) and shear-span-to-depth ratios (a/d). Strengthened beams showed increased maximum loads and stiffening effects compared to the control beam, demonstrating the complex relationship between parameters and beam performance. Neelamegam et al. (1998) tested reinforced concrete (RC) beams strengthened with bonded steel plates. Results showed increased first crack, service, and ultimate loads, along with reduced deflections. Lower width-to-thickness ratios in the steel plates led to higher load enhancements [10]. The study suggests that shear-span does not significantly affect plate-end shear resistance, but un-plated length determines shear crack location.

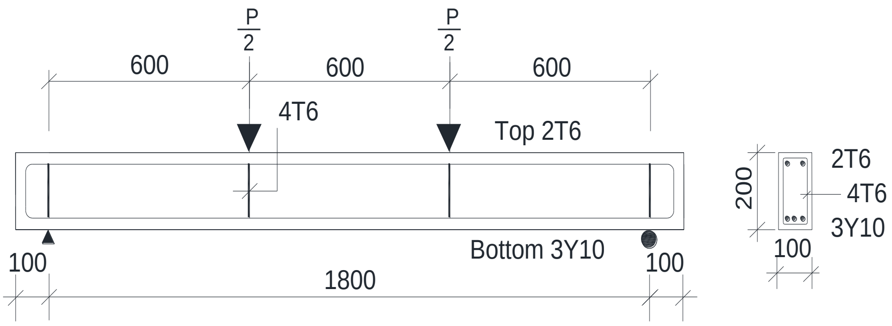
2. Experimental Work And Procedures

2.1. Description of Test Specimens

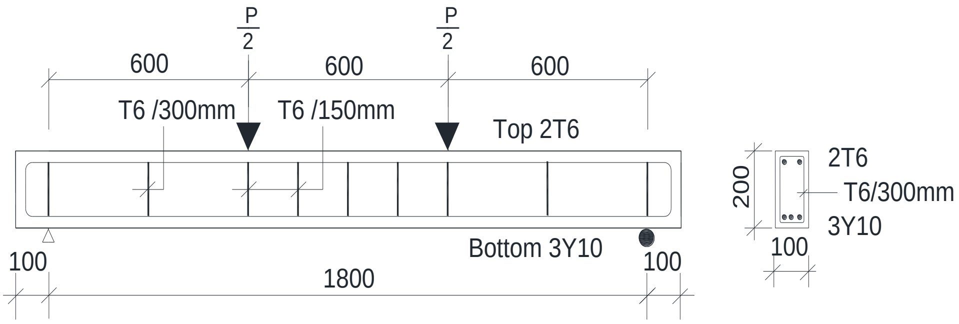
The experimental work in this research was carried out at the Laboratory, Faculty of Engineering at Al-Azhar University. Al the tested beams have the same dimension of 100 mm width, 200 mm depth, an effective span 1800 mm with overall length of 2000 mm, as shown in **figure 1.** The longitudinal bottom reinforcement in each beam is (3Y10) while the tap reinforcement is 2T6. The stirrups details are shown in table (1). Average compression strength of 22 MPa and density of 18.9 kN/m3 were achieved. Three beams B1, B2 and B3 were tested as control beams and the other four Beams were grouped into two main groups.The first groups consisted of two beams, B4 and B5. Each beam strengthened in the shear zone with steel plates. The steel plates had thickness 3 mm, a width of 50 mm, a height of 160 mm, and the distance between the center lines of plates was 150 mm. in the shear zone. B4 was strengthened by gluing the steel plates with epoxy only on both sides of the beam. B5 was strengthened by gluing the steel plates with epoxy and nails and screws to increase the tightens of the steel plate on both sides of the beam. The second group consisted of two beams, B6 and B7. B6 was strengthened by gluing the steel plate only. B7 was strengthened by gluing the steel plate and nails and screws to increase the tightens of the steel plate. The steel plate was attached from the bottom and both sides by a U-shape with a thickness 3 mm, a width of 50 mm, and a height of 180 mm. the distance between the center line of plates 150 mm in the shear span. All specimens' details are shown in **fig 1.** and **table1.**



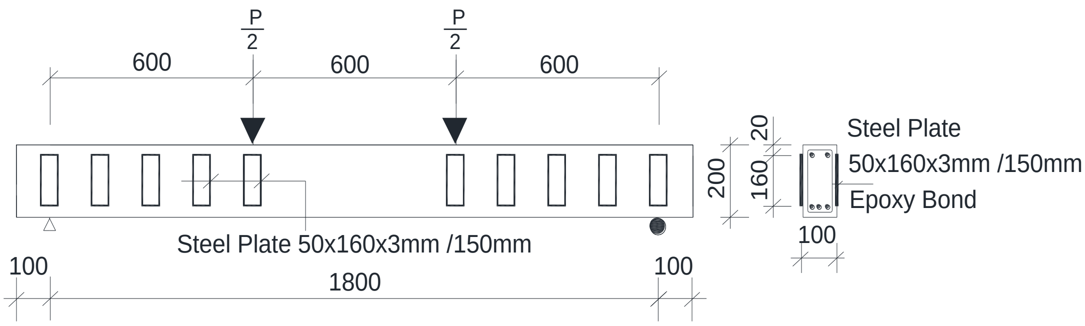
Beam 1



Beam 2



Beam 3



Beam 4

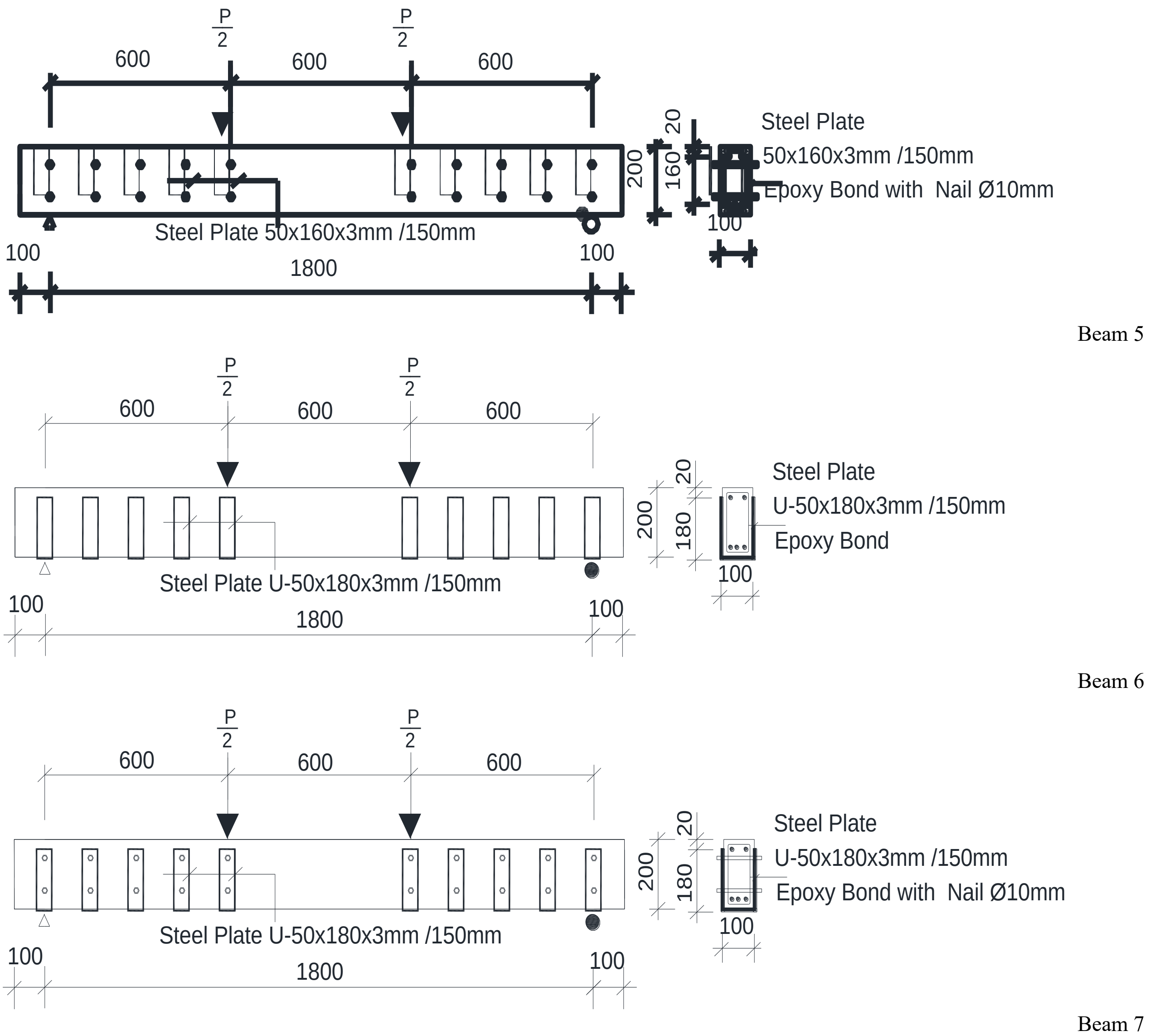


Fig. (1): Specimens Details for All Beams.

Table (1): Specimens Reinforcement Details.

NO.	Dimension mm	Bottom steel	Top steel	Vertical stirrups	F_{cu} MPa
B1	100x200x2000	3Y10	2T6	T6 every 100 mm	22.26
B2				No stirrups	22.11
B3				T6 every150 mm in the middle span T6 every 300 mm at shear zone	22.19
B4					22.35
B5					22.17
B6					22.18
B7					22.9

2.2. Production of semi-lightweight concrete(S-LWC)

In this study, commercially available materials and conventional production techniques are ado pled. Semi- lightweight concrete has been produced using a wide range of quality materials based on the results of trial mixes.Primary conclusions for the selection of materials and mix proportions to produce a semi– lightweight concrete with the desired workability, strength, and density in this study are based on the following tests of designing concrete mixes, as reported in previous works:

- 16 mm maximum size crushed coarse aggregate having grading within limits ASTM is recommended.
- Coarse natural sand having fineness modulus more than 2.70 is recommended to produce semi- lightweight concrete.
- Mixes having course to fine aggregate ratio equal to 2.00 produced semi- lightweight concrete (S-LWC).
- Trial mixes must be made on selected materials (cement, additives) to ensure that they are compatible in combination for use in producing (S-LWC).

2.2.1. Materials

2.2.1.1 Cement

One type of cement was used for all the trail mixes, ordinary Portland cement (CEM I 52.5N) from Sina Company. The dosages of cement in trail mixes were 350, 400, 450, and 500 kg/m3 content.

Fig. (2): Type of cement

2.2.1.2. Styrofoam

In this study, Styrofoam in the form of small pellets with a size ranging between 3.5 mm was vitalized. The Styrofoam was replaced by volume of weight of course and fine aggregate in range 20, 30, and 40 percent.

Fig. (3): Styrofoam.

2.2.1.3. Admixtures

Three types of admixtures were used in this research, fly ash, sika fume, and super plasticizer from Sika Company.

Fig. (4): sika Fly-Ash. **Fig. (5):** silica fume. **Fig. (6):** Sikament-163M.

2.2.1.4. Sikadure-330

The steel plates were affixed to both sides of the beams. Using sikadure-330 epoxy glue from Sika Company.Sikadure-330 is two components, the steel plates were affixed to the sides of the specimens (beams) using Sikadur-330 epoxy glue from Sika Company. Sikadur-330 is a two-component, thixotropic epoxy-based impregnating resin and adhesive. This adhesive is specifically designed for bonding various materials, including steel, concrete, and other substrates, providing high-strength and durable adhesion suitable for structural applications like strengthening concrete beams.

Fig. (7): Epoxy sika-dure-(330).

2.2.1.5. Reinforcement steel

The longitudinal bottom reinforcement in each specimen was prepared using high-grade steel bars with a diameter of 10 mm, as well as smooth steel bars with a diameter of 6 mm was using for top reinforcement and stirrups.

The mechanical properties of the steel bars and steel plates were determined through tension tests conducted on specimens randomly selected for each bar diameter and steel plates, as shown in **table (2)** and **table (3).**

Table (2): Properties of reinforcement steel bars.

Diameter in mm	6	10
Average cross-sectional area in mm^2	28.26	78.5
Yield strength in (MPa)	220	550
Ultimate strength in (MPa)	425	700

Table (3): Properties of strengthening steel plates.

Width (mm)	50

Thickness (mm)	3
Yield strength in (MPa)	320
Ultimate strength in (MPa)	420

2.2.1.6. Trail mixes:

Trail mixes consisted of thirteen experimental mixtures of semi- lightweight concrete. These mixtures were developed. By adjusting mixing ratios until suitable consistency and strength was achieved.

Table (4): Shows the contents of the mixtures and materials used in concrete mixtures.

Concrete Mix	Cement Content Kg/m^3	Cement Kg/60kg	Coarse Aggregate Kg/60kg	Fine aggregate Kg/60kg	Styrofoam %	Water Cement Ratio %	Sika ment 163m kg/60kg	Sika fum kg/60kg	Fly ash kg/60kg	Density kN/m^3	Strength MPa 28 days
Nwc 1	350	8.5	32	16	__	0.4	0.128	__	__	2.63	40.6
Nwc 2	400	9.72	31.2	15.6	__	0.4	0.145	__	__	2.46	46.2
Nwc 3	450	11	28.8	14.4	__	0.4	0.165	__	__	2.58	49.7
Nwc 4	500	12.15	29.8	14.9	__	0.4	0.185	__	__	2.67	43.1
S-Lwc 5	450	11	22	11.5	20	0.4	0.165	__	__	2.2	25.1
S-Lwc6	450	11	20.2	10.1	30	0.4	0.165	__	__	2.06	23.52
S-Lwc 7	450	11	17.5	8.65	40	0.4	0.165	__	__	1.89	9.3
S-Lwc8	500	10.95	15.30	7.65	40	0.3	0.185	__	__	1.95	14
S-Lwc9	500	11.55	18	9	40	0.3	0.185	0.6	__	2.08	19.6

S-Lwc10	500	9.10	18	9	40	0.3	0.185	—	3.05	2.01	20
S-Lwc 11	450	11	18.4	9.2	40	0.3	0.165	—	—	1.87	11.1
S-Lwc 12	450	8.2	18.4	9.2	40	0.3	0.165	—	2.75	1.97	20.4
S-Lwc13	450	10.40	18.4	9.2	40	0.3	0.165	0.55	—	1.89	22.26

2.2.1.7. Casting, Compaction, and Curing

The test specimens consisted of concrete samples cast in molds (cube, cylinders) and shapes (beams width 100× height 200×clear span1800 mm), using mix number (s-lwc13) as shown in **table (4),** see **figure (8).**

Following mixing, the freshly prepared concrete was compaction using vibrating table. After that, the molds and forms were removed from the vibrating table and covered with wet burlap 24 hours. After that, were carefully extracted from the molds and forms, labeled for identification, and transferred to a curing room.

Fig. (8): Casting and compaction cube, cylinder and beams.

Fig. (9): Curing of cubes, cylinders and beams

2.2.1.8. Beams Preparation And Testing Procedure

The test specimens, consisting of beams and their corresponding control cubes, were cured for 28 days before testing. After curing, they were air-dried and prepared for testing with consistent markings for effective span, support points, load points, strain gauge positions, and points for deflection measurements (LVDT). Support points were marked symmetrically around the center of each beam, providing an effective span of 1800 mm. Load points were designated at two positions, dividing the span into three equal parts of 600 mm each. Strain gauges were installed to measure flexural strain in the compression zone and in tension rang or cement, fixed 60 mm from the top surface of the beams at the midpoint. Beams were transported to the testing apparatus using a four-point loading system. A calibrated hydraulic jack applied load to the beams, with a load distributing beam ensuring even load distribution. Before testing, beams were coated with white plaster for crack determination. LVDT were positioned directly under the loads and at the mid-span point to measure deflection. Load was applied gradually, with LVDT readings recorded after each increment until the desired load was reached visual. Cracking load, crack patterns, failure load, and failure type were recorded during testing.

Fig. (10): General arrangement of testing setup for beams.

3. Results And Discussion

3.1. Mixing results

The study examined how mix ingredients influence the production of semi-lightweight concrete (S-LWC) using commercially available materials and conventional methods. In this research program, all the control specimens to study the properties of semi-lightweight concrete and the beams to investigate the behavior of strengthening semi-lightweight concrete beams in shear were made with the same concrete mix proportion. This concrete mix was made from:

- Ordinary Portland cement (CEM I 52.5N) with a quantity of 450 kg/m³ was used.
- Crushed dolomite with a maximum size coarse aggregate not exceeding 10 mm.
- Natural silica sand with fineness modulus not less than 2.70.
- Coarse to fine aggregate ratio was 2:1.
- Water-cement ratio was 0.30.
- Styrofoam with small pelts a size in ring 3.5 mm, replaced by volume of weight of course and fine aggregate mix in range 40%.
- Silica fume and super plasticizer were added to the mix, the dosage was 1% by weight of the cement.

3.2. Properties of Semi Lightweight Concrete:

Table (5) displays the mechanical property findings for semi-lightweight concrete in comparison to normal-weight concrete, including compressive strength, tensile strength, density, and modulus of elasticity.

Table (5): Mechanical Properties Comparison Between Semi-Lightweight Concrete and Normal-Weight Concrete.

Mix	Styrofoam ratio %	Compressive strength MPa	Splitting tensile strength MPa	Density kN/m³	Modulus of Elasticity GPa
N-wc3	0	49.7	2.91	25.8	26.44
S-lwc5	20	25.1	-	22	-

S-lwc6	30	23.52	-	20.6	-
S-lwc13	40	22.26	2.9	18.9	13.28

3.3. Shear Behavior and effect of Styrofoam.

The effect of presence of Styrofoam on shear strength of semi-lightweight concrete beams with and without strengthening are presented in **table (6).**

Table (6): Experimental shear strength.

No.	b mm	t mm	d mm	F_{cu} MPa	Vertical Stirrups	2P kN	q_u MPa	$\frac{qun}{*\,qu}$
B1	100	200	180	22.26	T6 every 100 mm	48	1.34	1.55
B2	100	200	180	22.11	No stirrups	31	0.86	1
B3	100	200	180	22.19	T6 every150 mm in the middle span T6 every 300 mm at shear zone	36	1	1.163
B4	100	200	180	22.35		40	1.1	1.28
B5	100	200	180	22.17		42.4	1.18	1.37
B6	100	200	180	22.18		43.4	1.205	1.40
B7	100	200	180	22.9		42.3	1.175	1.37

*q_u = shear strength of B2 (without stirrups). q_{un} =shear strength of all Beam with stirrups and strengthened beams. $q_u=\frac{p}{b\times d}$.

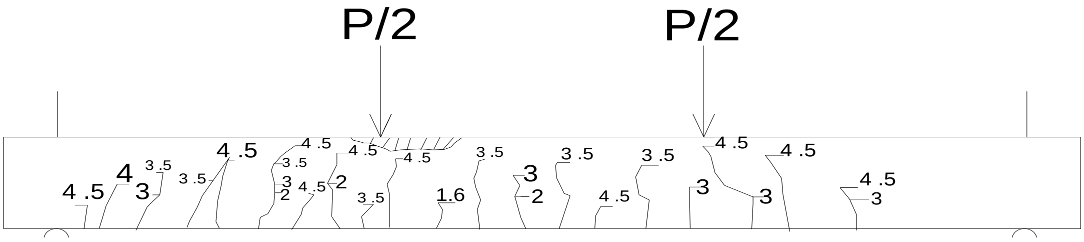
Table (6) includes test date for reinforced semi-lightweight concrete beams with and without strengthening. Test results show that:

- Shear strength of beam (B2) without stirrups decrease than shear strength predicted by Egyptian code.
- The equation $q_{cu}=0.225\sqrt{\frac{fcu}{\gamma c}}$ MPa, can be used to predict the shear strength of semi-lightweight concrete beams without stirrups.
- Beams with stirrups T6 every 100 mm and T6 every 300 mm at shear zone. showed an increase in the shear strength of the beam without stirrups by 55% and 16.3%, respectively.
- Beam strengthening by plate 50×160×3 mm at both sides of beam were glued with Epoxy glue only (B4) increased the shear capacity by 28 percent compared to B2 and increased 11.7 percent compared to B3.
- Shear capacity increased for (B5) by 37 percent and 20.7 percent compared to B2 and B3 respectively.
- Shear capacity increased for (B6) by 40% and 23.7% compared to B2 and B3 respectively.
- There was no significant effect shown for use nails screws to increase the lightness of the steel plates on shear capacity.

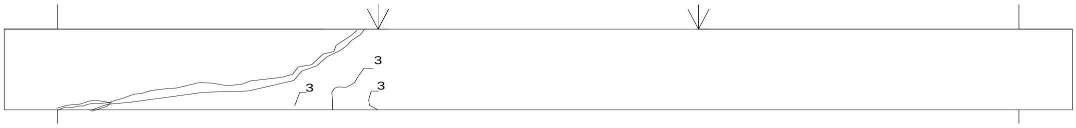
3.4. Crack pattern and failure mode

According to the observations of the cracking progress with loading of specimens, the following results were concluded in accordance to crack patterns and failure modes of the beams, as shown in **fig. (11):**

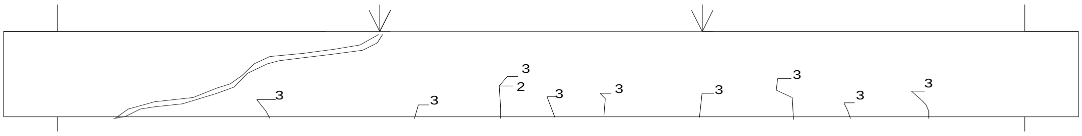
- For beam B1, typical flexural cracks occurred at the bottom in mid span and progressed with increasing the load to spread toward the supports with increasing incitation due to the combination with shearing force as well as increase in the initial crack width and failed due to compression failure.
- Beams B2 and B3 filled due to diagonal tension crack only.
- For beam (B4), cracks at the beginning of test started at the mid span as ordinary flexural cracks however, the failure mode was peeling of the plate continuing with a diagonal tension crack, as shown in **Fig (11).**
- Beams B5, B6, and B7 with little number of cracks due to strengthened of beams and failed in compression failure.



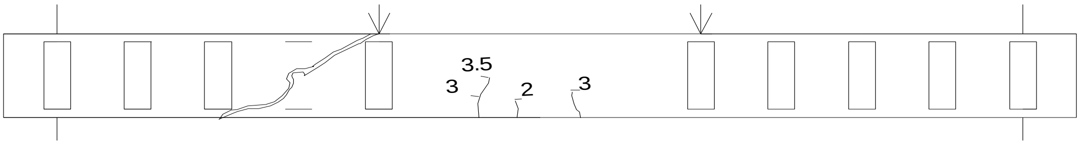
Crack Pattern for beam (B1)



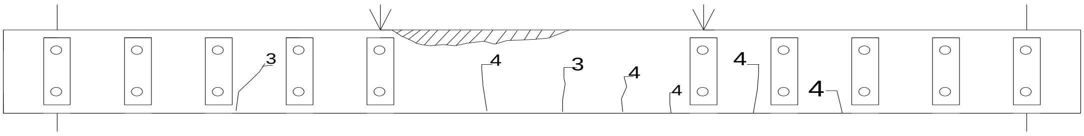
Crack Pattern for beam (B2)



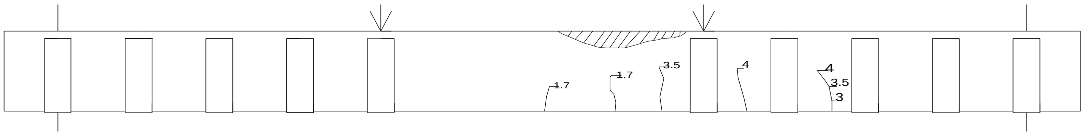
Crack Pattern for beam (B3)



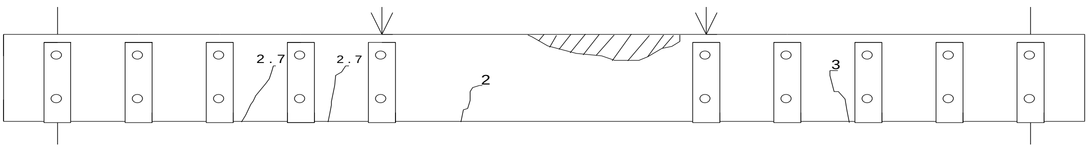
Crack Pattern for beam (B4)



Crack Pattern for beam (B5)



Crack Pattern for beam (B6)



Crack Pattern for beam (B7)

Fig. (11): crack pattern for all tested beams.

B1

B2

B3

B4

B5

B6

B7

Fig. (12): Types of failure for all tested beams.

3.5. Flexural behavior

The effect of presence of Styrofoam flexural strength of beams with different shear reinforcement and with and without strengthening of beams by different steel plates fixed by epoxy glue only or epoxy glue and trail and screws were studied. **Table (7)** showing the percentage of failure moment of each beam with respect to the ultimate moment of the control specimens (B1).

Table (7): Ratios of failure moment for different not strengthening and strengthening specimens to moment of control beam.

No.	b mm	t mm	D mm	F_{cu} MPa	Vertical Stirrups	2P kN	M_u kN.m	$\frac{Mun}{* Mu}$	$\frac{Mun}{** Mu}$
B1	100	200	180	22.26	T6 every 100 mm	48	14.4	1	1.55
B2	100	200	180	22.11	No stirrups	31	9.3	0.65	1
B3	100	200	180	22.19	T6 every150 mm in the middle span T6 every 300	36	10.8	0.75	1.16
B4	100	200	180	22.35		40	12	0.83	1.29
B5	100	200	180	22.17		42.4	12.72	0.88	1.37

B6	100	200	180	22.18	mm at shear zone	43.4	13.02	0.94	1.40
B7	100	200	180	22.9		42.3	12.69	0.88	1.37

- Neglected o.w. of beams, Mun = moment strength of (B1↔B7),*Mu = moment strength of (B1), **Mu = moment strength of (B2), Mu = 0.60×$\frac{P}{2}$ kN.m.

Test results show that:

- The beam without stirrups (B2) reduce the flexural capacity about 35% than control beam (B1).
- Beam (B3) with stirrups T6 every 300 mm at shear zone reduce the flexural capacity about 25% than control beam (B1), with increasing 10% than beam (B2) due to stirrups T6 every 300 mm.
- All methods of strengthening showed significant regain of flexural capacity in range 0.83 to 0.94%.

3.6. Load- deflection behavior:

All load- deflection curve show approximately for all beams smooth linear up to cracking level and then parabolic up to failure. The load- deflection responses of each of the seven semi- lightweight concrete beams with and without strengthening and having with and without nails and screws are shown in **figs. (13-19).** In general, the following could be seen from these figures:

- The beam without web reinforcement (B2) or lower web reinforcement (B3) without strengthening exhibited a catastrophic shear failure. Lower load capacity, and the post- peak portion of the load- deflection curve is vanished.
- All strengthening beams showed a higher stiffness than beams without web reinforcement, **Fig. (15),** and higher failure loads. Strengthening beams showed less deflection at the same load level, Fig (18).
- **Fig. (16)** shows the load- deflection curve of beam (B4) strengthening by steel plate 160×50×3 mm. every 150 mm at shear span, gluing with epoxy only, and beam (B6) strengthened by U-shape steel plate 180×50×3 mm. gluing with epoxy only every 150 mm at shear span. This figure shows no significant change in the load- deflection curve, but (B6) was higher failure load.
- **Fig. (17)** shows the load deflection curve of beam (B5) strengthened by steel plate 160×50×3 mm. gluing with epoxy and nails and screws and (B7) strengthened by U- shape steel plate 180×50×3 mm. gluing with epoxy and nails and screws. This Figure showed beam (B7) less deflection at the same load level and the same failure load.
- All beams strengthened by steel plate gluing with epoxy only showed higher deflection than control beam (B1).
- All beams strengthened by steel plate gluing with epoxy and nails and screws showed lower deflection than control beam (B1) at the same load level.

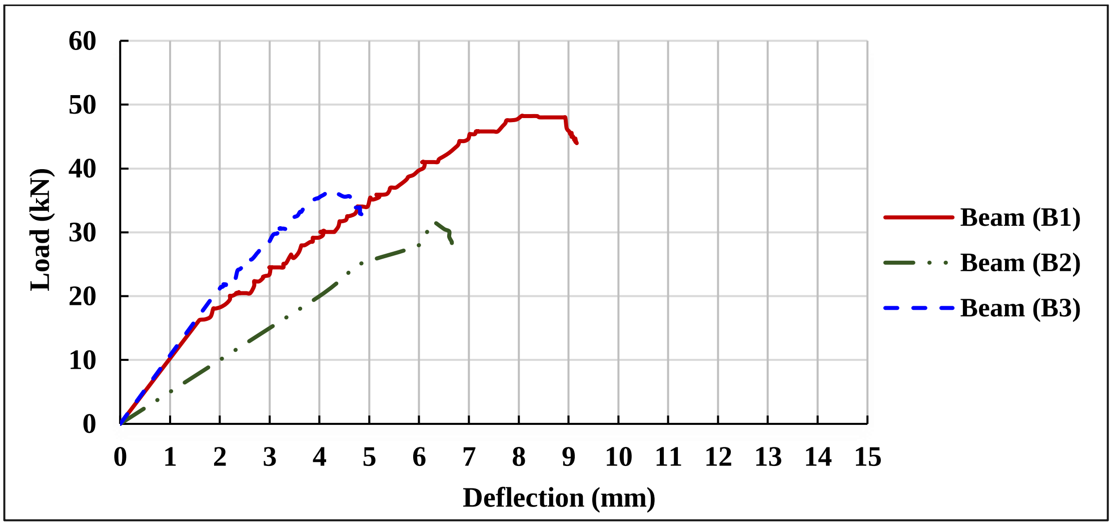


Fig. (13): Load Deflection Curve at the middle Span for Beams (B1, B2, B3).

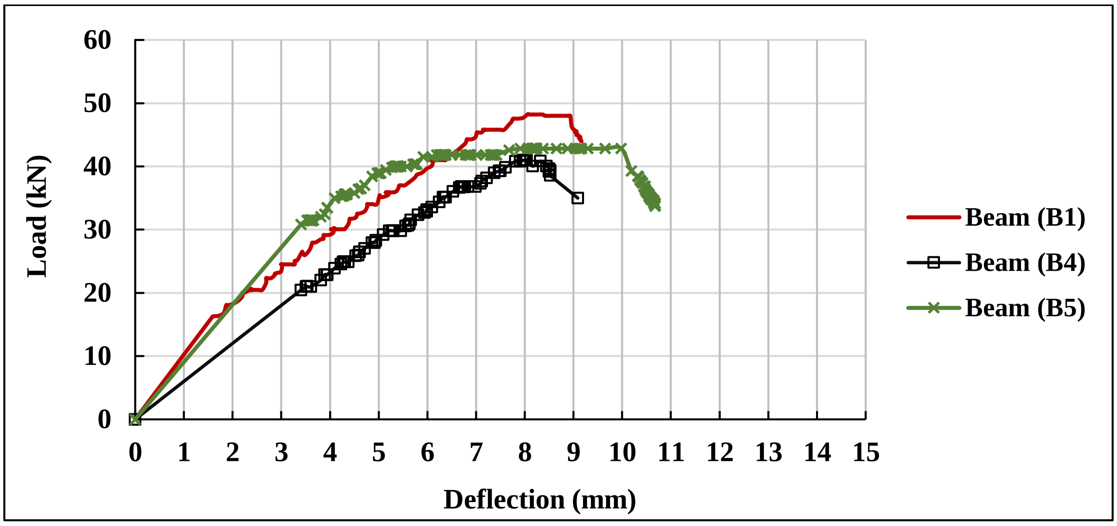


Fig. (14): Load Deflection Curve at the middle Span for Beams (B1, B4, B5).

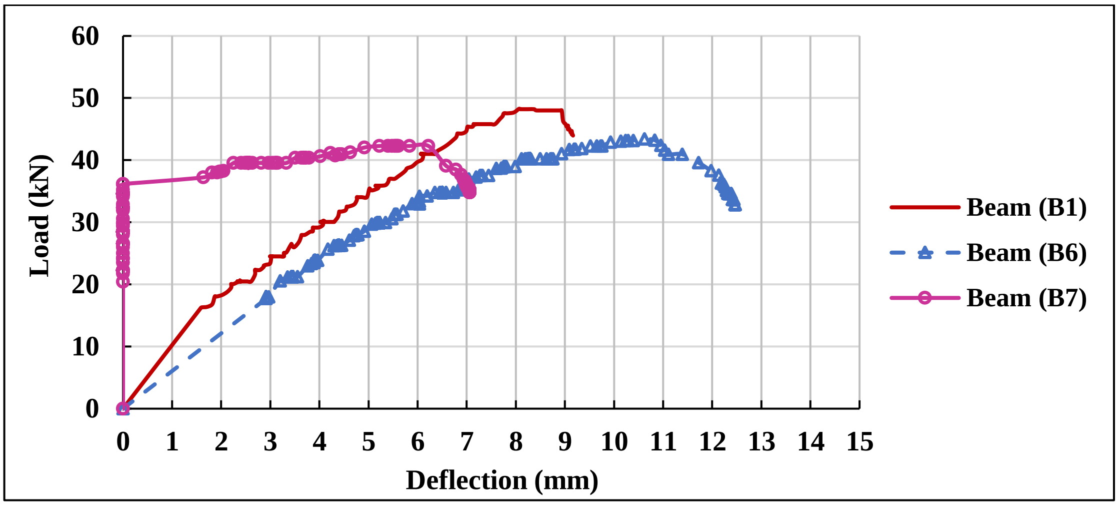


Fig. (15): Load Deflection Curve at the middle Span for Beams (B1, B6, B7).

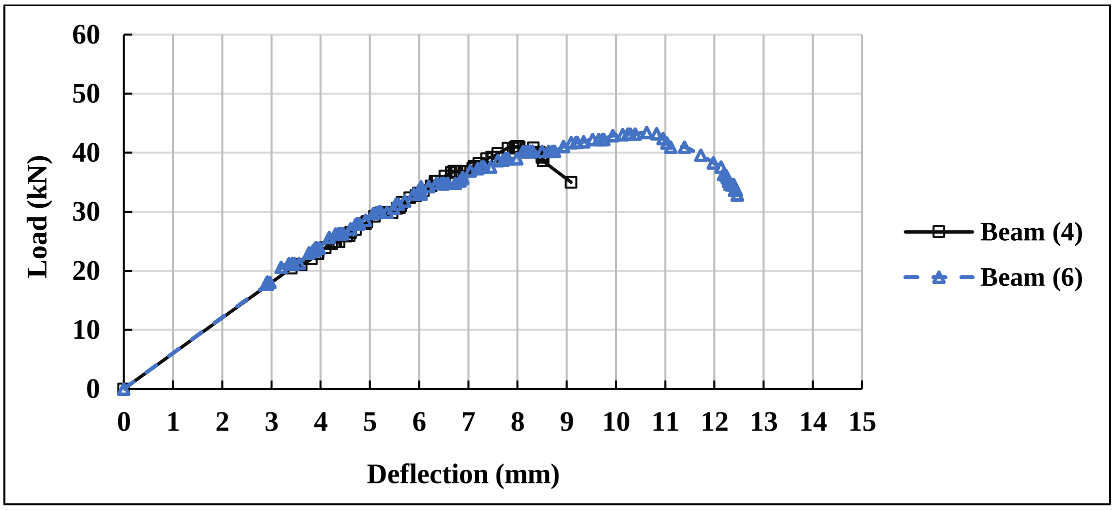


Fig. (16): Load Deflection Curve at the middle Span for Beams (B4, B6).

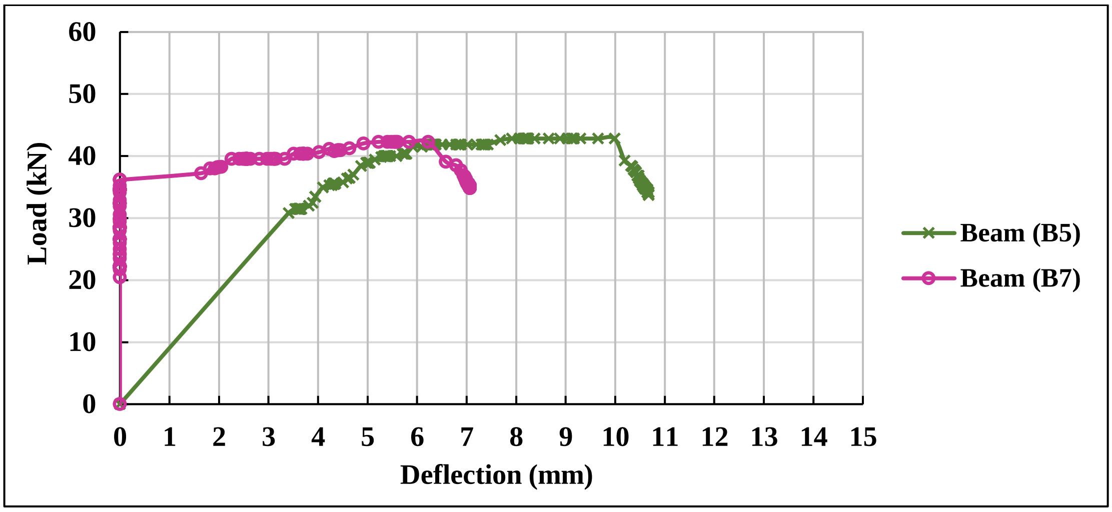


Fig. (17): Load Deflection Curve at the middle Span for Beams (B5, B7).

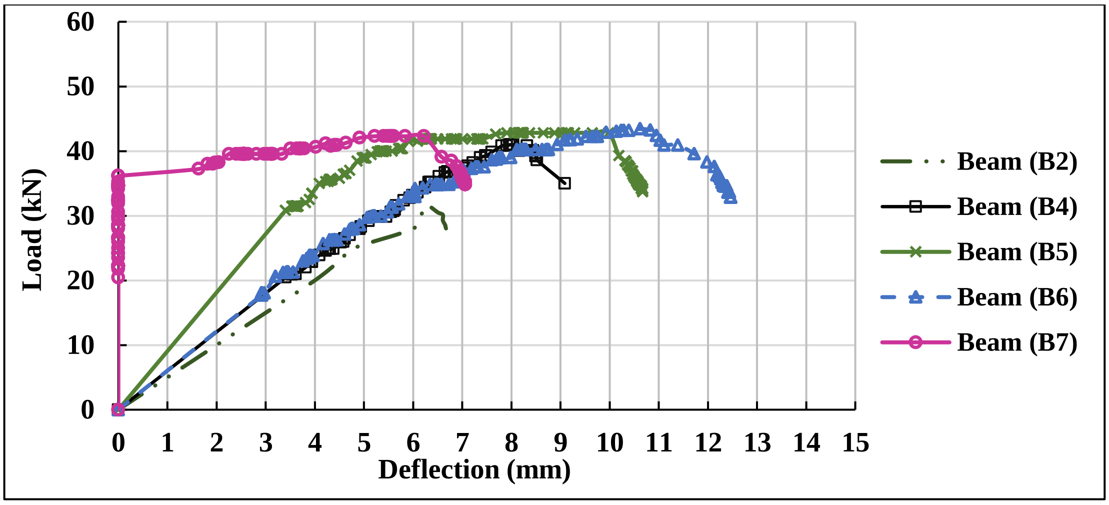


Fig. (18): Load Deflection Curve at the middle Span for Beams (B2, B4, B5, B6, B7).

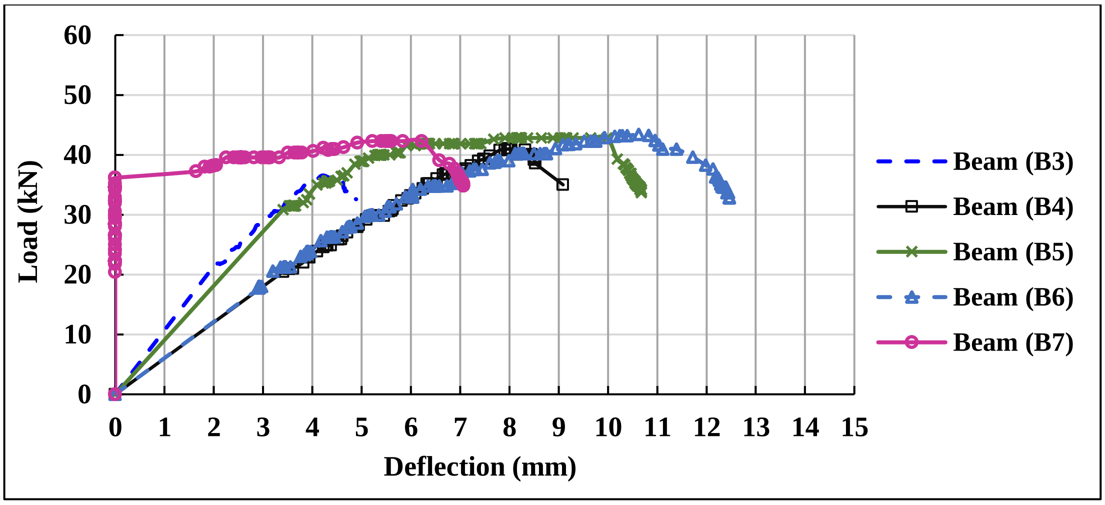


Fig. (19): Load Deflection Curve at the middle Span for Beams (B3, B4, B5, B6, B7).

3.7. Flexural Toughness and Toughness index

This section deals with discussion of Toughness computed using the load-mid span deflection behavior of 100×200×1800 mm semi-lightweight concrete beams with and without strengthened at shear span. Toughness is defined as the area under the load- mid span curve of beams up to specific point. In the present study, this point is defined as deflection at maximum load. toughness index is defined as the ratio of each beam, toughness of semi- lightweight concrete with and without strengthened to the control beams. Based on the test results from table (8) and figures of load-deflection curve and observation made during testing, the following observation can be had regarding the flexural Toughness of semi- lightweight concrete beams with and without strengthened:

- The Toughness and toughness index (T1) of semi lightweight concrete beam without web reinforcement and without strengthened (B2) is smaller than other beams. Also, the beam (B3). For beams without web reinforcement (B2), and with web reinforcement T6 every 300 mm, the toughness is measured as area under load-deflection curve up to failure load.
- Semi-lightweight concrete beam with strengthened by gluing the U-shape steel plates (B6) showed higher flexural toughness and toughness index than beam with strengthened by gluing the steel plate 150×160×3 mm on both sides of the beam at shear zone.
- Semi-lightweight concrete bean (B5) with strengthened by gluing the steel plate 150×160×3 mm with Epoxy and nails and screws at both sides has Toughness and Toughness index higher than for beam (B4) with strengthened by gluing the steel plate 150×160×3 mm with Epoxy only.
- The was no significant increase in Toughness and Toughness index shown between (B6) and (B5).
- All beams strengthened showed significant regain of Toughness and Toughness index but indifferent ratio.
- Beam (B1) with web reinforcement, pre-designed to resist the shear stress by web reinforcement showed higher flexural capacity, shear resistance, and Toughness.

Table (8) Flexural Toughness and Toughness index for tested beams.

Beam	Toughness	Toughness index (T1)	Toughness index (T2)	Toughness index (T3)
B1	228	1	2.53	2.81
B2	90	0.40	1	1.11
B3	81	0.36	0.9	1
B4	177	0.78	1.97	2.2
B5	249	1.09	2.77	3.07
B6	258	1.13	2.87	3.19
B7	204	0.90	2.27	2.52

B1 = control beam1., B2 = control beam 2. And B3 = control beam 3.

Toughness index (T1) = $\frac{\text{Toughness (B1)}}{\text{Toughness of (B1}\leftrightarrow\text{B7)}}$, Toughness index (T2) = $\frac{\text{Toughness B2}}{\text{Toughness of strengthened beam}}$

and Toughness index (T3) = $\frac{\text{Toughness B3}}{\text{Toughness of strengthened beam}}$.

4. Conclusion

An extensive experimental work on semi-lightweight concrete (strength bigger than 20 MPa and density lower than 20 kN/m3), using commercially available materials, conventional production Techniques, and using Styrofoam in the formal small pellets with a size ranging between 3.5 mm has been cored out in this research. The results of study allow to draw the following conclusions:

4.1. Production of semi-lightweight concrete

Based on the test results of production of semi-lightweight concrete with density lower than 20 kN/m3 and strength bigger than 20 MPa. The followings are concluded by trail mixes must be made on selected materials to ensure that they are compatible in combination for use in producing semi-lightweight concrete:

- 16 mm maximum size crushed dolomite coarse aggregate.
- Coarse natural sand.
- Ordinary Portland cement type (CEM I 52.5N) from sina company.

- The optimum cement content of semi-lightweight concrete mixes containing admixtures was 450 kg/m3 concrete.
- A chemical admixture such as a super plasticizer, sikament-163M and sika fume has shown to be effective in producing semi-lightweight concrete.
- Mixes having coarse to fine aggregate ratio equal to 2.0.
- Water-cement ratio equal 0.30.
- The addition of Styrofoam into semi-lightweight concrete in range 40 % weight of coarse and fine aggregate with ratio 2:1 by volume decreases the cube compressive strength of semi-lightweight concrete in the range 54 %, in this research.
- Modulus of elasticity of semi-lightweight concrete was 50 % lower than of normal-weight concrete.

4.2. Behavior of beams

The contribution of steel plates to the enhancement of the flexural and shear strength, the flexural rigidly and ductility of semi-lightweight concrete beams was investigated, Trying various methods fixation of the steel plates to the beams. Based on the test results, the following conclusions can be drawn:

- Strengthening semi-lightweight reinforced concrete beams using steel plates 50×160×3 mm by gluing with Epoxy only or with gluing by Epoxy and nails and screws in shear zone increases the shear capacity and flexural strength from 28 % to 37 %.
- Strengthening semi-lightweight reinforced concrete beams using U-shape steel plates 50×180×3 mm by gluing with Epoxy with and without fixation by bolts increases the load caring capacity and shear strength from 37 to 40%.

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