



Flexural Behavior of Normal and Lightweight Concrete Composite Beams

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Abstract

This paper presents an experimental study of the behavior of Normal Concrete Beams (NCB) and composite beams with lightweight foamed concrete (CB), reinforced with steel bar measuring 2 ϕ 8 mm in the compressive section and 2 D 16 mm in the tensile section, shear steel bar ϕ 8 mm. The sample consisted of two normal concrete beams (NCB) and two composite beams with lightweight foamed concrete (CB). The main variables in this study are the type of concrete, the type of steel bar and the flexural behavior. The beam samples were tested by two-point loading, failure mode and crack width were observed. The results showed that the flexural process of normal concrete blocks (NCB) and composite beams with lightweight foamed concrete (CB) was almost the same. There is no slip failure at the combined interface, the flexural capacity of the composite beam with lightweight foamed concrete can be calculated based on the statics analysis and plane-section assumptions. To calculate the ultimate capacity of a composite beam with lightweight foamed concrete is to convert a section consisting of more than one fc' to an equivalent section consisting of one fc'. Furthermore, it is validated by calculating the theoretical moment capacity and comparing the theoretical moment capacity of the experimental results. The results of the flexural test, composite beam with lightweight foamed concrete (CB) showed ductile deflection behavior, diagonal crack patterns, and low flexural capacity of the beam (NCB).

Keywords: Flexural Capacity; Normal Concrete; Foam Concrete; Composite Beam.

1. Introduction

The purpose of using composite beams with lightweight foamed concrete is to reduce the total weight of the structure by using materials with low mass. And because natural normal-weight aggregate sources are already depleted and more crushed stone is being used at increasing rates [1]. On beams, the stress on the external fibres are higher, so it should be used a stronger material. In the internal fibres the stress is lower so it could be used a less resistant material. There are a number of studies which analyse separately the behaviour of both materials. However the references about the combine use is quite reduced [2]. Foam concrete is a lightweight material consisting of Portland cement paste or cement filler matrix (mortar) with a homogeneous void or pore structure created by introducing air in the form of small bubbles, At higher foam volume, results in wide distribution of void sizes and lower strength [3].

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Foamed concrete is a revolutionary and an adaptable construction material, which consists of cement and fine aggregate mixed with air bubbles to a minimum of 20%. Slender sections can be designed by the use of these foamed concrete beams, which are light in weight as well as with densities less than 1800 kg/m^3 [4]. Foamed concrete is defined as a light cellular concrete which can be classified as a lightweight concrete (density of $400\text{--}1850 \text{ kg/m}^3$) with random air-voids created from the mixture of foam agents in mortar [5]. Foamed concrete is a lightweight porous material made from cement, sand and entrained with air bubbles. Different from normal concrete, foamed concrete possesses many advantageous properties owing to the introduction of air bubbles, therefore, can be widely used in the area of building construction and other civil engineering application [6]. Foam concrete is a type lightweight concrete which can be produced with different quality [7].

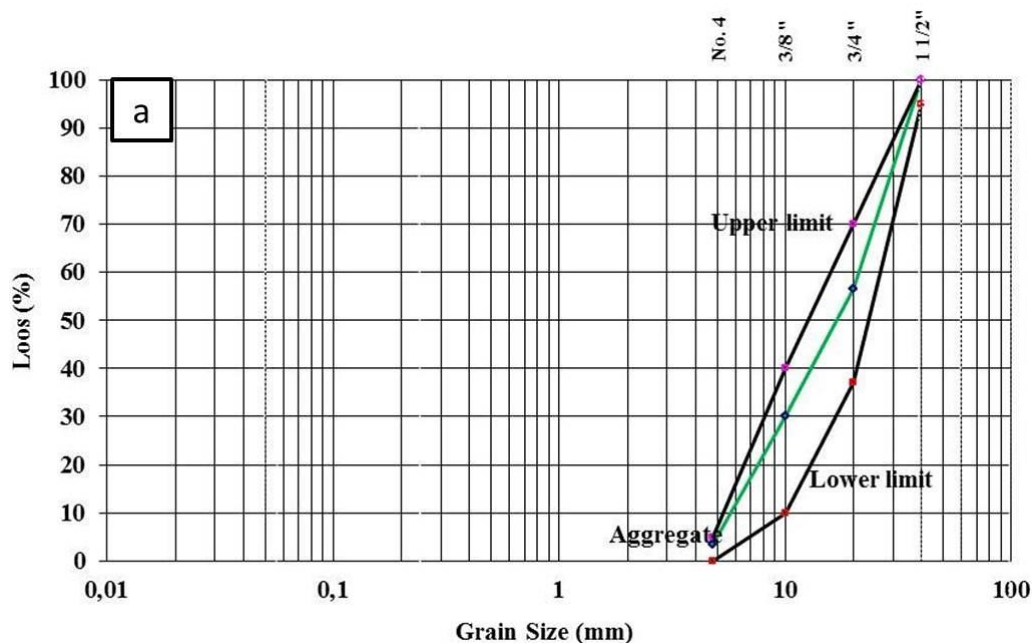
Suhad and Ghalib (2018) investigated, a total of four reinforced concrete beams were cast, consisting of two beams of lightweight foamed concrete and two beams of normal weight concrete with a length of 1500 mm, width of 200 mm, height of 250 mm. For lightweight foamed concrete beams, the target density is 1800 kg/m^3 . By comparing lightweight foamed concrete reinforced with GFRP bars to normal concrete beams it was found that the increase in the load capacity for lightweight foamed concrete is 3.6% of the load capacity for normal concrete beams. By comparing lightweight foamed concrete beams reinforced with GFRP bars, it was found that the increase in the load capacity for beam reinforced with GFRP is 11.54% of the load capacity for beams reinforced with steel bars [8]. Lee et al. (2017) investigated seven beams of lightly foamed mortar and three beams of normal weight concrete as control samples, the experimental results of the flexural behavior of beams and reinforced concrete slabs made of lightweight foamed mortar with a density ranging from $1700\text{--}1800 \text{ kg/m}^3$, show that light foamed mortar beams can withstand ultimate loads about 8 to 34% lower than normal weight reinforced concrete with the same reinforcing configuration [9].

This study is about the flexural behavior of lightweight foamed concrete (CB) at both ends which are given normal weight concrete anchors and normal reinforced concrete (NCB) using 2 ϕ 8 mm steel bar in the compressed cross-section and in the tensile section 2 D 16 mm and shear steel bar ϕ 8 mm. consists of two composite beams of lightweight foamed concrete (CB) and two beams of normal weight concrete (NCB) as control, beam dimensions 1600 mm (length), 200 mm (height), 150 mm (width) with the same reinforcing configurasi.

2. Materials and Methods

2.1. Aggregate Gradation

Gradation is in the form of distribution of aggregate grains in percentage units, the coarse aggregate the material passing through 20 mm size sieve, and the sand passing through 4.75 mm sieve. The requirements of SNI 03-1968-1990 (Indonesian Standard of Test Method for Sieve Analysis of Fine and Coarse Aggregate) [10]. Selecting the wrong gradation might lead to an insufficient or excessive depth of the coarse aggregate exposure and their ravelling [11]. Figure 1 show the gradation of coarse and fine aggregates made according to standard specifications in Indonesia.



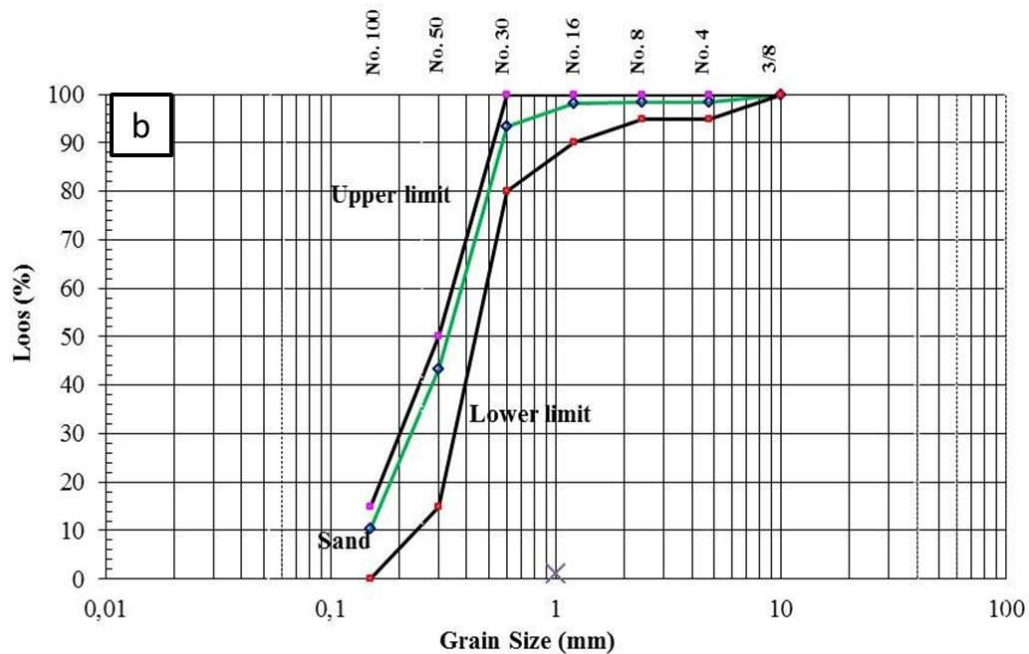


Figure 1. Gradations (a) Gradation of coarse aggregate, (b) Gradation of fine aggregate

2.2. Material and Mix Proportion

Four beams of reinforced concrete, consisting of two normal weight concrete beams and two composite beams of lightweight foamed concrete. For lightweight foamed concrete beams, the target density is $\leq 1400 \text{ kg/m}^3$. Materials for making lightweight foamed concrete consist of Ordinary Portland Cement Type 1 (OPC), sand, water, foam agent, sikament LN as hardener. Pre-formed foam is produced by diluting the foaming agent liquid with water into a container then stirring with a propeller for 6-10 minutes, 1:40 ratio by volume. Foamed concrete is a porous material formed by mixing cement and water into cement slurry and mixing with a certain proportion of foaming agent [12]. Stability is the key of the successful application of concrete, and stability refers to the ability of concrete mixture to maintain homo- geneous distribution of all constituent materials [13]. Table 1 shows the mix proportion of lightweight foamed concrete. Table 2 shows the mix proportion of normal concrete.

Table 1. Mix proportion of lightweight foamed concrete

Cement (kg/m^3)	Sand (kg/m^3)	Water (lt/m^3)	Foam agent (ml)	Sikament LN (ml)
518,01	1162,02	290,51	600	1162,02

Table 2. Mix proportion of normal concrete

Cement (kg/m^3)	Sand (kg/m^3)	Water (lt/m^3)	Split (kg/m^3)	w/c
353,63	595,79	176,81	1247,60	0,5

2.3. Foam Agent

The texapon N70 foam agent is a clear gel solution material with general characteristics made from sodium laureth sulfate, cells or bubbles ranging from 0.1 to 1 mm apart. Foam concrete is a lightweight material consisting of Portland cement paste or cement filler matrix (mortar) with a homogeneous void or pore structure created by introducing air in the form of small bubbles. At higher foam volume, results in wide distribution of void sizes and lower strength [14]. Figure 2 shows the foam used in this study.



Figure 2. (a) Foam agent, (b) Foam, and (c) Foam concrete slurry

2.4. Mechanical Properties of Concrete

The compressive strength of normal concrete plans is 20 MPa and foam concrete is 5 MPa. The mechanical behavior of lightweight foamed concrete is markedly affected by microstructural properties, related to the distribution of air bubbles and development of hydration products [15]. Tested after 28 day of curing and the result were calculated from the mean of specimens [16]. Even though lightweight concrete is not generally used as a major component of structures, there are minimum requirements regarding its mechanical proper- ties, when it is to be used as a part of structures, with compressive strength being an important property regulating concrete quality [17]. Cylindrical tests were carried out to see the mechanical properties of concrete. The average compressive strength and the average split tensile strength of cylinders is shown in Table 3 the mechanical properties of normal concrete and foam concrete used. On the results of the compressive strength, the ratio of lightweight concrete to normal concrete is 1:3.58, unit weight of foamed concrete is lighter with a ratio of 1: 1.66 the ratio of tensile strength of foamed concrete to normal concrete is 1: 40. Actual mechanical properties of the reinforcing steel allow evaluating the expected variability of reinforced concrete (RC) performance, and thus reduce the uncertainty in the seismic response assessment of structural systems [18]. Table 3 shows the mechanical properties of concrete. Table 4 shows the mechanical properties of tensile steel. Figure 3 shows the concrete compressive strength test, concrete split tensile test and steel tensile test.

Table 3. Mechanical properties of normal concrete and foam concrete

No.	Sampel	Load	Compressive strenght (f'_c)	Specific gravity (gs)	Split strenght (f_{ct})
1	Normal concrete	159,99 kN	20,37 MPa	2,28 kg/m ³	2,07 MPa
2	Foam concrete	44,79 kN	5,70 MPa	1,37 kg/m ³	0,52 MPa

Tabel 4. Mechanical properties reinforcing steel

No.	Sampel	f_y	$f_{s \max}$
1	ϕ 8	377,87 MPa	429,96 MPa
2	D 16	388,33 MPa	448,40 MPa

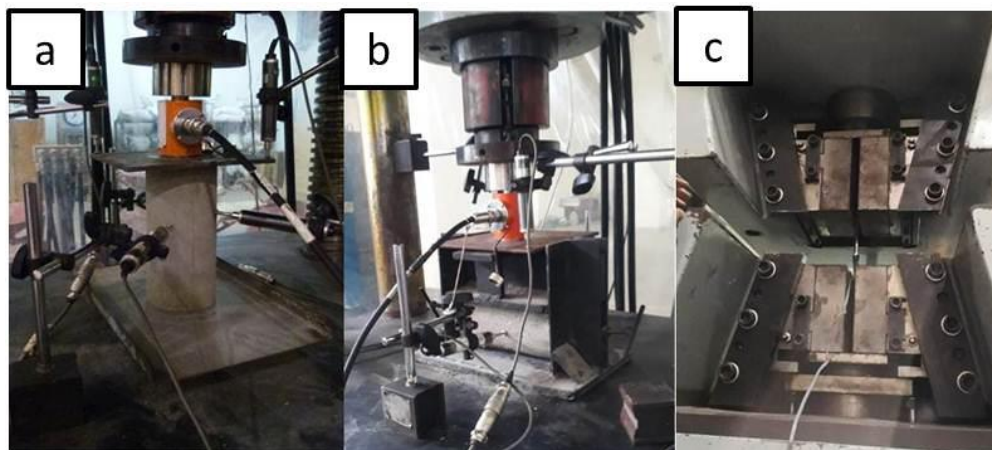


Figure 3. Testing (a) Compressive strength, (b) Tensile strength, (c) Tensile strength of steel bar

2.5. Specimens of Normal Beams and Foamed Concrete Composite Beams

Four reinforced concrete beams, consisting of two normal weight concrete beams and two foamed concrete composite beams with dimensions, length 1600 mm, height 200 mm, width 150 mm are shown in Figure 4, the first variation (NCB) of normal concrete beam. Figure 5 shows the second variation (CB) foamed concrete composite beam, 100 mm high and 1200 mm long, Both ends using normal weight concrete as anchors. The test beam is cast using fresh concrete with a compressive strength of 20 MPa normal concrete and 5 MPa of foamed concrete. The specimens were tested after curing for 28 days. Both of Type NCB and CB are reinforced with same steel bars.

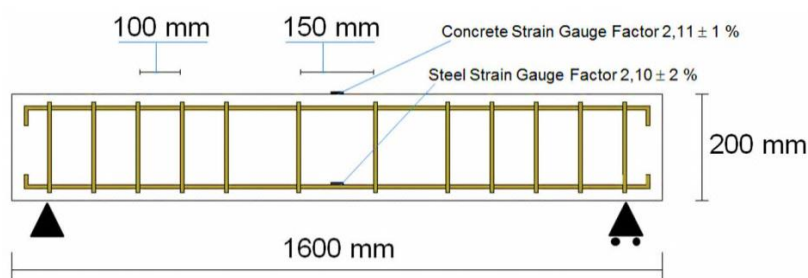


Figure 4. First variation of normal concrete beam (NCB)

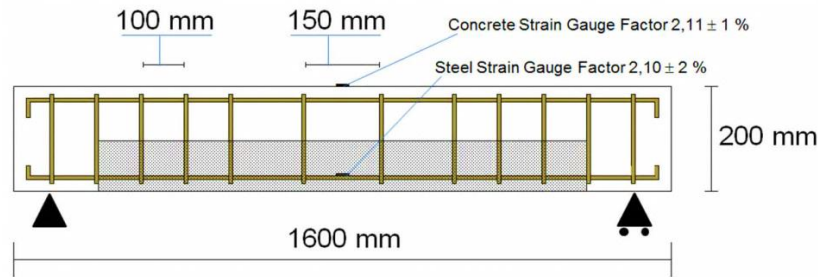


Figure 5. Second variation of composite beams with lightweight foamed concrete (CB)

2.6. Research Design

To facilitate the research to be carried out, it is necessary to plan the stages that will be used as guidelines in this study, the stages of the process are shown in Figure 6. Research Flow, used Ordinary Portland Cement Type 1 (OPC), sand, water, foam agent, sikament LN as a mixing agent for foamed concrete with a ratio of 1; 40 by volume. Nominal concrete mixing w/c 0.5.

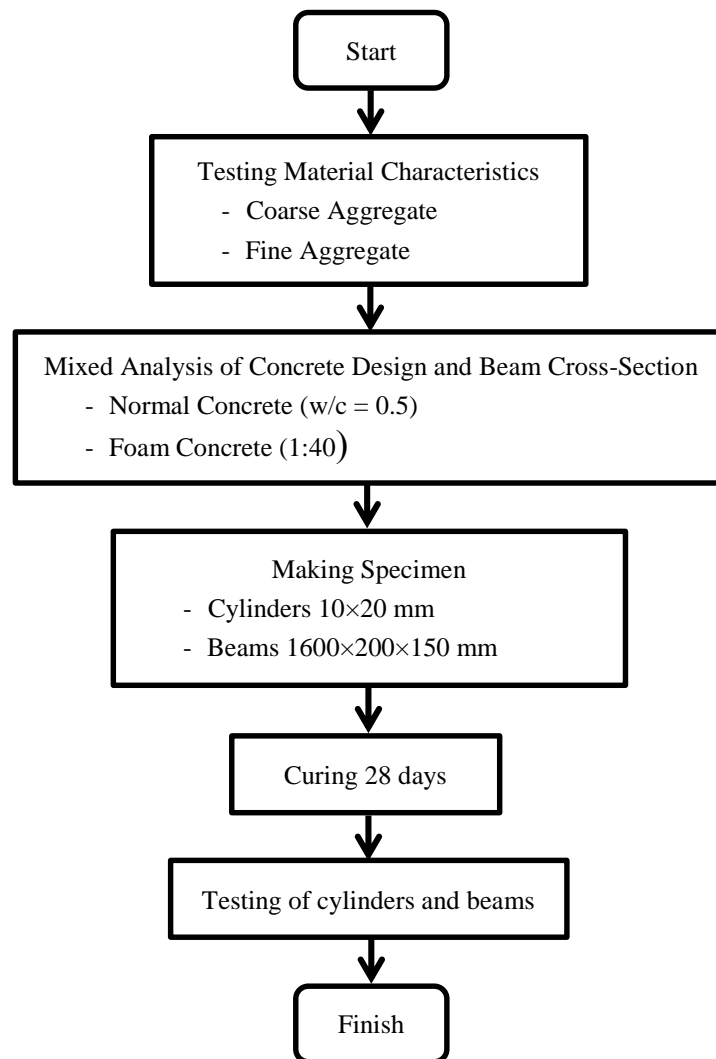


Figure 6. Flowchart of the research methodology

3. Results and Discussions

3.1. Load and Deflection Behavior

Two-point static load test at a speed of 0.1 mm/s until the beam capacity decreases and collapses. In order to produce a constant bending moment in the center region of the specimen, two equal and symmetrically placed weights are applied at a point 600 mm from the center span [19]. The load-deflection behavior of the specimen can be

observed in Figure 7 as a load-deflection relationship curve. Table 5 shows the results of the maximum beam deflection load

The first crack occurred in NCB-1 when the applied load reached 12,328 kN, on NCB-2 when the applied load reached 15,927 kN while the first crack occurred in CB-1 when the applied load reached 3,932 kN, on CB-2 when the applied load reached 4,398 kN. The first crack load on CB was lower than normal crack load, and had smaller first crack deflection, namely 0.30 and 0.43 mm, while in normal (NCB) beam it was 1.03 and 1.08 mm. This shows that the beams do not yet have ductility over the elastic span compared to normal beams. This may be due to the lower moment of inertia (I_g) of the entire beam section. The ratio of the moment of inertia of a normal beam (NCB) with a beam (CB) is about 0.52 or down to 52% compared to normal. This causes the load deflection slope to decrease.

The occurrence of the first crack indicates that the applied moment exceeds the crack moment capacity of the beam. The first crack causes a reduction in normal beam stiffness. Some new flexural cracks occur with increasing applied loads while the previous cracks are still so continues. Normal beam (NCB) is stiffer than beam (CB). This may be due to the effect of the absence of bonding between the steel reinforcement and concrete on the (CB) beam. seen a significant effect on the load-deflection slope at the crack stage.

When the load applied to the normal beam (NBC-1) reaches 99,959 kN, on beam (NBC-2) reaches 98,227 kN, the tensile reinforcement enters the plastic stage. The result after plastic stage is followed by crack of compressed-section concrete. This has an impact on reducing the flexural capacity of the beam. On beam (CB-1) the maximum capacity was 75,738 kN, on beam (CB-1) the maximum capacity was 77,902 kN, lower than the normal beam (NCB). The maximum capacity (CB) is preceded by compressive failure due to greater deflection than the result of tensile reinforcement. The beam deflection (CB) is greater due to reduced beam stiffness due to changes in the moment arm (z) from the tensile strength of the reinforcement to the compressive force. The moment arm (z) changes due to geometric conditions (CB), namely the steel reinforcement acts as a cable that tends to be straight at the time of deformation, steel reinforcement is driven by concrete to flexural following beam deformation. Whereas in beam (CB), the moment arm (z) between steel reinforcement and concrete compressive fibers changes when deformation occurs.

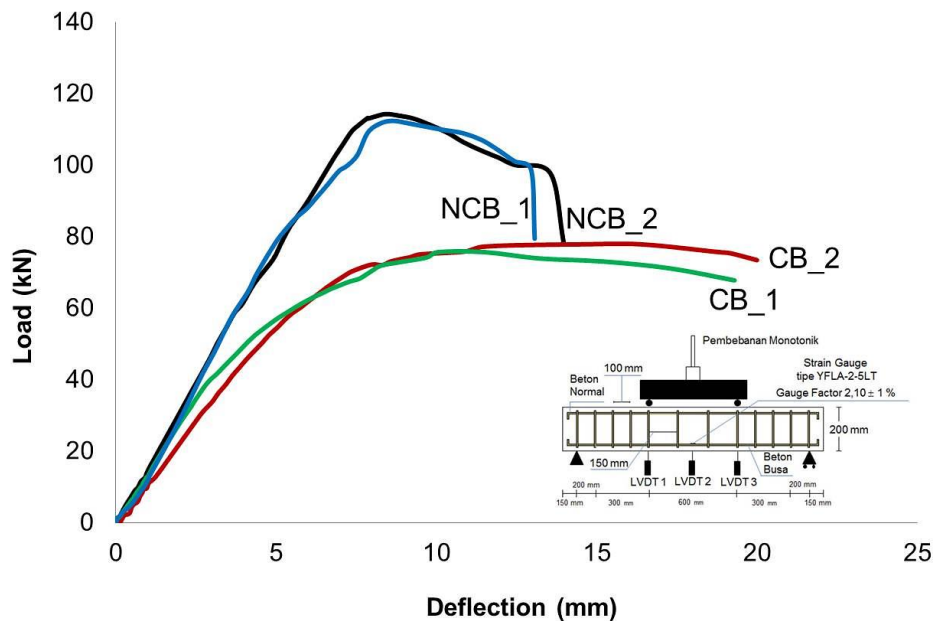


Figure 7. Correlation of load and deflection

Table 5. Result of load and deflections

No.	Sample	Initial crack (kN)	Load yield (kN)	Ultimate (kN)	Deflection		
					δ_{cr} (mm)	δ_y (mm)	δ_u (mm)
1	Normal concrete beam 1	12,328	99,959	112,458	1,03	7,23	8,63
2	Normal concrete beam 2	15,927	98,227	114,350	1,08	6,55	8,43
	Average	14,126	99,093	108,454	1,06	6,89	8,53
3	Composite beam 1	3,932	-	75,738	0,30	-	11,50
4	Composite beam 2	4,398	-	77,902	0,43	-	16,40
	Average	4,165	-	76,820	0,37	-	13,95

3.2. Strain of Concrete

Table 6 shows the results of the loading and strain of concrete, in the initial conditions of cracking, the strain of beams (CB) is quite large. these results indicate the beam capacity (CB) is very low. while in ultimate conditions, beams (NCB) and (CB) differ significantly, in relation to loads ($P_{ultimate}$) and ($M_{ultimate}$) where the values of P, M (NCB) are 1.445 times and 1.468 times greater than those of beams (CB). Figure 8 shows the concrete strain curve, it can be seen that the beam (NCB) has a better strain to the beam (CB).

Table 6. Result of load and strain of concrete

No.	Sample	Initial crack		Yield strength		Load ultimate	
		P_{cr}	ϵ_{ecr}	P_y	ϵ_{ey}	P_u	ϵ_{eu}
		N	μm	N	μm	N	μm
1	NCB 1	12328	149,8	99959	1624,6	112458	2274,1
2	NCB 2	15927	274,9	98227	1610,4	114350	2368,7
3	CB 1	3932	46,4	-	-	75738	1984,2
4	CB 2	4398	68,2	-	-	77902	2031,3

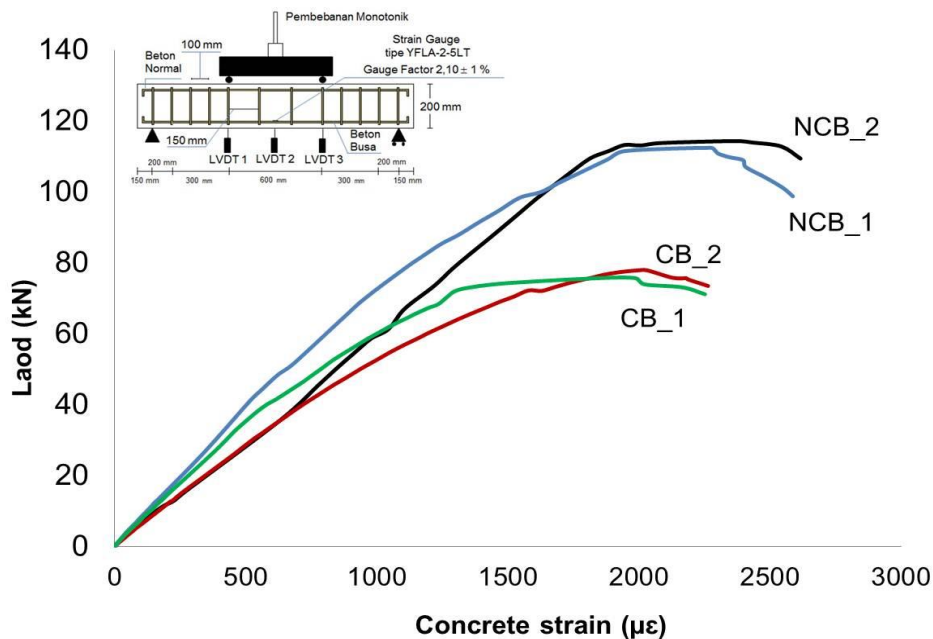


Figure 8. Strain of concrete

3.3. Strain of Steel

Tabel 7 shows on the normal beam (NBC-1), (NBC-2) the failure was initiated by the yielding of the steel reinforcement and followed by the compression failure on the concrete. The results show that composite beams (foamed concrete) has strength and very low stiffness. Concrete beams (NBC) and (CB) have significantly different ($P_{ultimate}$), moment ($M_{ultimate}$), where the P, M values are 1,455 times, 1,468 times greater than the beam (CB), it can be seen that the beam (CB) has additional strain small ones, and the yield stress does not occur. Figure 9 shows the strain curve of steel, in the sample (NBC) the load reaches 58.64 kN and the strain is 1258.1 $\mu\epsilon$, after reaching 114.35 kN the strain increases to 2505.7 $\mu\epsilon$ and the steel bar melts at 2086.7 $\mu\epsilon$. In the beam (CB), the linear strain of steel reached 41.18 kN and the capacity of the beam decreased at the strain value of 2004.76 $\mu\epsilon$. Ultimate load ratio of steel (CB) to (NBC) 1: 1,204.

Table 7. Result of load and strain of steel

No.	Sample	Initial crack		Yield strength		Load ultimate	
		P_{cr}	ϵ_{ecr}	P_y	ϵ_{ey}	P_u	ϵ_{eu}
		N	μm	N	μm	N	μm
1	NCB 1	12328	261,9	99959	1901,9	112458	2314,3
2	NCB 2	15927	339,0	98227	2086,7	114350	2505,7
3	CB 1	3932	65,7	-	-	75738	2002,9
4	CB 2	4398	54,3	-	-	77902	2080,9

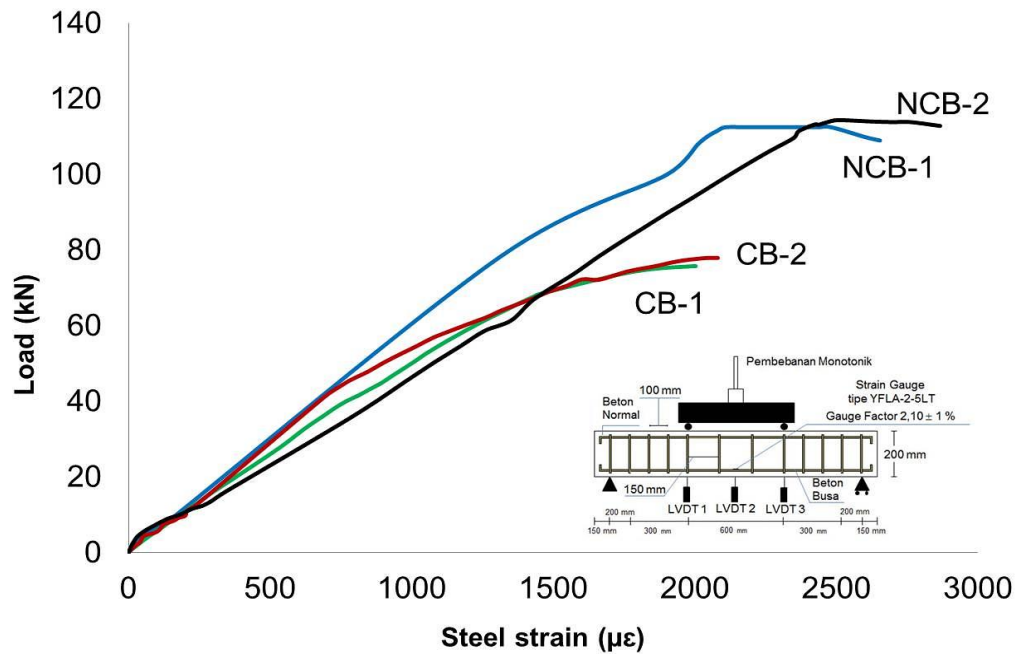


Figure 9. Strain of steel

3.4. Crack Pattern

Actual test results and visual observations of beam crack patterns. Figure 10 shows the beam crack pattern (NCB-1, NBC-2) in the middle span forming vertical cracks and 1/3 beam span forming vertical and diagonal propagation to the compressive section. The observations showed a dominant vertical crack pattern. Figure 11 shows the beam crack pattern (CB-1, CB-2) in the center span, forming a vertical crack. Increasing the load, the crack pattern increases at 1/3 to 1/6 of the beam span, forming a diagonal crack.

Observation of the cracks showed that the crack propagation was more progressive in blocks (CB-1, CB-2) than in beams (NBC-1, NBC-2). The number of cracks in (NBC) is much less than that of the beam (CB). Ultimate flexural capacity of normal beams (NBC-1) was 112.459 kN, and beam (NBC-2) was 114.350 kN, while the foamed concrete composite beams (CB-1, CB-2) are 75,738 kN and 77,902 kN, respectively. The ultimate flexural capacity of CB is only 29.23% compared to normal beam (BN).

On the normal beam, the failure was initiated by the yielding of the steel reinforcement and followed by the flexural failure on the concrete. Figures 12 and 13 shows photo of the beams damaged after being test. On normal beam (NBC) there is damage to the top of the concrete. Whereas in the foamed concrete composite beam there is damage due to crack propagation. Cause foamed concrete composite beam (CB), has lower flexural strength than normal concrete (NCB).

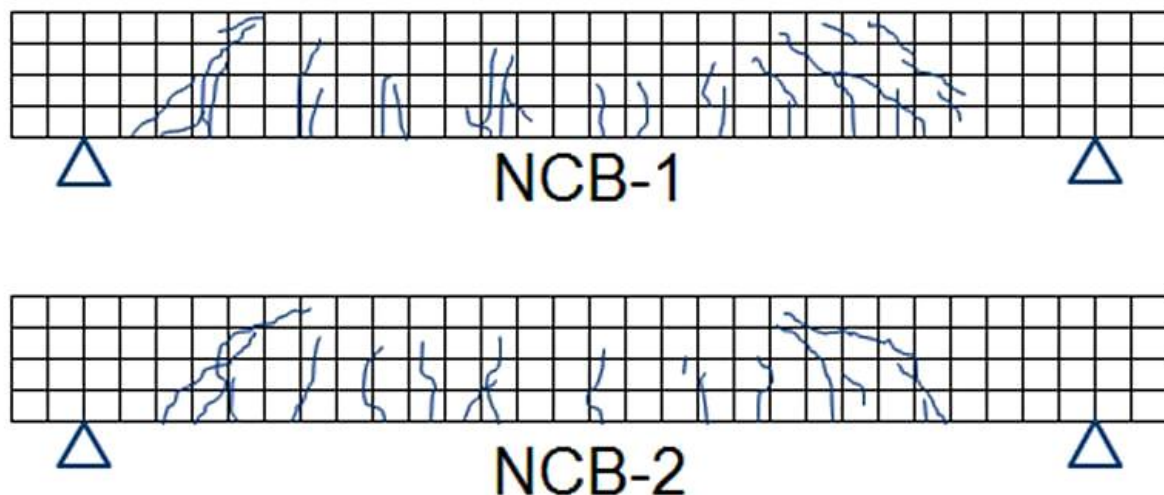


Figure 10. Normal concrete beam crack pattern

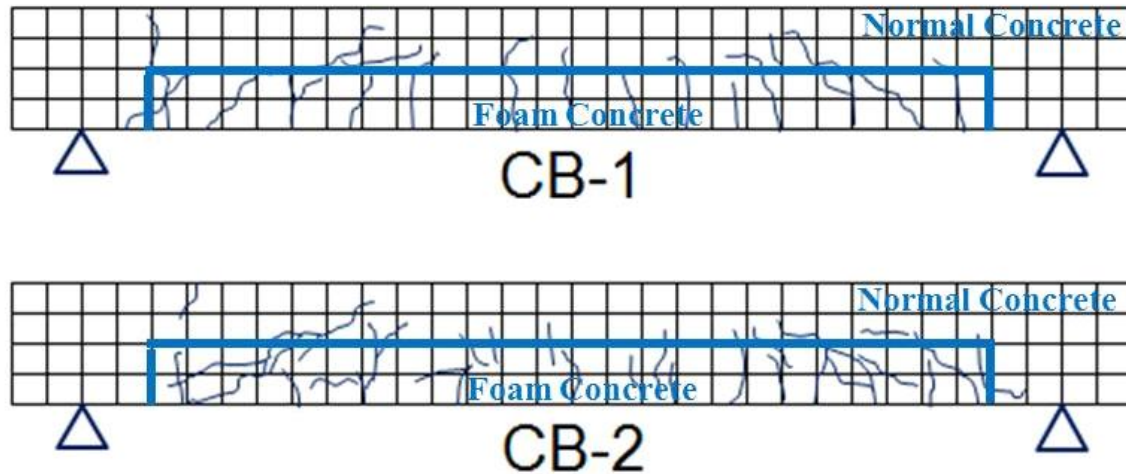


Figure 11. Composite beams with lightweight foamed concrete crack pattern



Figure 12. Normal concrete segment

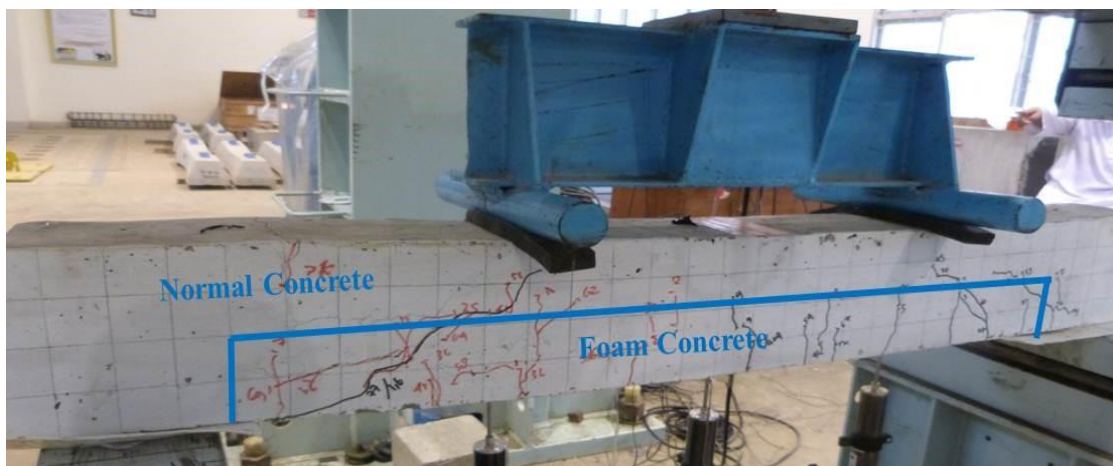


Figure 13. Composite beams with lightweight foamed concrete segment

4. Conclusion

The results showed that the maximum capacity of foamed concrete composite beams (CB-1) was 75,738 kN, and beam (CB-2) was 77,902 kN. whereas the normal beam (NCB-1) was 112,458 kN, and beam (NCB-2) was 114,350 kN. The initial crack load on the composite foam concrete beam (CB-1) and (CB-2) is lower than the normal beam load (NCB-1) and (NCB-2), the initial crack deflection is greater, on beam (CB) namely 0.43 mm, while the normal beam (NCB) is 1.08 mm. This shows that the beam does not have ductility to the elastic span compared to normal beams. This may be due to the lower moment of inertia (I_g) of the entire beam section. The ratio of moment of inertia of normal beam (NCB) to beam (CB) is about 0.52 or down to 52% compared to normal.

The weight of the beam decreased by 18.163% and the flexural capacity of the layered beam decreased by 32.260% compared to the normal beam. On the normal beam (NCB), the failure was initiated by the yielding of the steel reinforcement and followed by the flexural failure on the concrete and there is damage to the top of the beam. On the foamed concrete composite beam there is damage due to crack propagation, causes foamed concrete composite beams to have lower flexural strength than normal concrete. Crack propagation is much more progressive on composite beam (CB) than in normal concrete beam (NCB). The number of cracks in the beam (CB) is much more than the normal beam (NCB). Cracks in the beam (CB) tend to propagate in diagonal cracks due to the low elastic modulus of foamed concrete. Need to develop a method of strengthening the adhesiveness between two layers of foamed concrete composite to increase the flexural capacity, and stability of the foamed concrete beam.

5. Declarations

5.1. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

5.2. Funding and Acknowledgements

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5.3. Conflicts of Interest

The authors declare no conflict of interest.

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