Effects of the FRP Layer and Concrete Strength on Fiber-Reinforced Polymer-Confined Artificial Lightweight Aggregate Concrete

Butje Alfonsius Louk Fanggi(✉), Ambros Raha Lelang Wayan, Obed. Oktafianus Nego Nenobais, Matelda Christiana Mauta, Yosefus Conterius

Civil Engineering Department, Politeknik Negeri Kupang, Kupang 85001, Indonesia
butje.loukfanggi@pnk.ac.id

Abstract. The characteristics of lightweight concrete are distinct from those of the many other types of concrete. On the other hand, there has been relatively little investigation into the performance of such concrete when it is wrapped in fiber-reinforced polymer. This study investigates effect of fiber reinforced polymer layer and concrete strength on the stress-strain behaviour of fiber reinforced polymer-confined lightweight aggregate concrete columns. Twelve specimens, each comprised of one of two distinct concrete strengths and one of three distinct fiber reinforced polymer layers, were cast and examined. It is known that increasing the concrete's strength causes the column's strength and strain improving ratios to decrease. Also, it has been confirmed that increasing the number of fiber reinforced polymer layers increases the ultimate axial strength and strain of fiber reinforced polymer-confined lightweight aggregate concrete columns. This was done by using a test specimen.

Keywords: Lightweight Aggregate concrete; Stress-strain Behavior; Glass fiber

1 Introduction

The density of lightweight concrete is less than 1950 kg/m3 [1,2]. Lightweight concrete is also renowned for its ability to insulate against temperature extremes, withstand fire, insulate against sound, and anti-earthquake capabilities [2]. The construction industry may benefit from lightweight concrete's superior properties as compared to ordinary concrete, which could lead to increased application of the material. [2]. Nonetheless, it has a number of disadvantages, including low compressive strength and ductility [2]. Consequently, these drawbacks restrict the use of such concrete for columns, beams, and other load-bearing constructions [2].

Fiber-reinforced polymer, more often known as FRP, is currently among the many common materials that are used to repair or enhance the capacity of structural parts. It has a lower overall weight, a better strength, a resistance to corrosion, and it is very durable. These are only some of its many advantages. There have been a large number of studies conducted on the effectiveness of FRP to confine conventional concrete [3–

M. Setiyo et al. (eds.), *Proceedings of the 4th Borobudur International Symposium on Science and Technology 2022 (BIS-STE 2022)*, Advances in Engineering Research 225,
https://doi.org/10.2991/978-94-6463-284-2_8

12]. They came to the conclusion that the incorporation of FRP jacketing into concrete improved both the material's ultimate strength and its strain. However, there has been relatively little research done on FRP-confined lightweight concrete. The authors Zhou et al. [1] examine the influence that the concrete strength and the number of FRP layers have on the stress-strain behavior of lightweight carbon fiber-reinforced concrete columns. It was discovered that increasing the strength of the concrete brought about a reduction in the strength improvement ratio of lightweight FRP-confined concrete columns. The ultimate strength and strain of FRP-confined lightweight concrete columns grow in direct proportion to the number of FRP layers that make up the column. On lightweight concrete columns wrapped in FRP, Li et al. [2] study how the amount of carbon FRP layers affects the columns. According to the findings described in [2], it is possible to draw the conclusion that the ultimate strength and strain of FRP-confined lightweight concrete columns are improved when a greater number of FRP layers are used. In their study [13], Louk Fanggi et al. report the results of their test on lightweight concrete columns encased in glass FRP. They came to the conclusion that increasing the thickness of the FRP layer resulted in an increase in both the ultimate strength and strain.

On the basis of the past restricted experiments that were conducted on FRP-confined lightweight concrete columns, it is evident that the results of the test on the effect of concrete strength on glass FRP-confined lightweight concrete columns has not yet been explored. This is due to the fact that these experiments have been conducted in the past but have been limited. Consequently, the purpose of this work is to report the findings of an ongoing experimental study on lightweight concrete columns that are limited by glass fiber reinforced plastic (FRP). The discussion focuses on the effects that the strength of the concrete and the number of FRP layers have on the stress-strain behavior of glass FRP wrapped lightweight aggregate concrete columns.

2 Method

In total, twelve different specimens were analyzed after they were produced. The specimens had a height of 200 mm and a diameter of 100 mm. During the testing, the specimens were made using two different mixes, which resulted in an average unconfined concrete compressive strength of either 18.26 or 38.01 MPa. The coarse aggregate in the mixtures consisted of lightweight artificial aggregate with a minimal maximum allowed size of 10 mm. This allowed maximum size was the nominal maximum size. Glass fiber reinforced plastic (FRP) was used because of its 1.30 mm nominal ply thickness and 3.24 GPa ultimate tensile strength. Notably, Louk Fanggi et al. [13] had previously reported specimens with concrete strengths of 18.26 MPa. in order to evaluate the effect of the number of FRP layers. These specimens are also included in this paper in order to investigate the effect of concrete strength on the stress-strain behavior of glass FRP-confined lightweight aggregate concrete columns. The specimens are described in great detail in Table 1.

Table 1. Details of the specimens tested

Specimen	f'_{co} (MPa)	ε_{co} (%)	Number of layers	Number of Specimen
G38-1-1	38.01	0.21	1	1
G38-1-2			1	1
G38-2-1			2	1
G38-2-2			2	1
G38-3-1			3	1
G38-3-2			3	1
G18-1-1	18.26	0.16	1	1
G18-1-2			1	1
G18-2-1			2	1
G18-2-2			2	1
G18-3-1			3	1
G18-3-2			3	1

It is important to point out that the value of εco is not calculated based on the control specimens themselves; rather, it is estimated with the use of an equation that was published by Tasdemir [14].

All specimens underwent a grinding process at one end to guarantee uniform distribution of the applied load. The specimens were tested in axial compression using a universal testing equipment powered by a servo-hydraulic computer with a capacity of 1000 kN. The Displacement control was given at a rate that was approximately 0.003 mm/s until all specimens failed.

3 Results And Discussion

3.1 Failure Condition

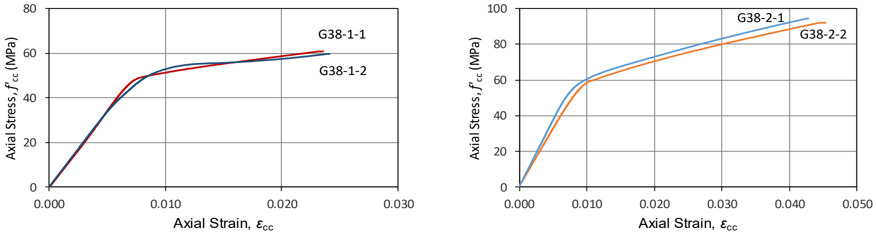
The condition of failure for each specimen is illustrated in Fig. 1. The failure of each specimen was due to the FRP rupture along the hoop's axis, and this was the primary cause of the failure. According to the findings presented in Fig. 1, the rupture was found to be more severe in specimens that contained a greater number of FRP layers. In addition to this, it was discovered that specimens that contained a greater number of FRP layers resulted in a more audible explosion when they broke down.


G38-1-1&2 G38-2-1&2 G38-3-1

Fig. 1. Failure Condition

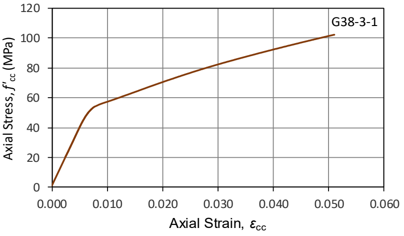
3.2 Stress-strain Behavior

Fig.2 depicts the stress-strain relationship of the twelve specimens. The curves can be seen to practically monotonically climb, indicating that the concrete was well restrained.



a) G38-1-1&2

b) G38-1-1&2



c) G38-3-1&2

Fig. 2. Stress-strain behavior of the tested specimens

3.3 Influence of the concrete's strength and of the number of FRP layers

The stress-strain relationship of concrete is depicted in the third figure. This relationship can be seen for all specimens, regardless of the amount of FRP layers present. The graph demonstrates that an increase in the number of FRP layers causes a corresponding increase in the ultimate stress (f'cu) and also strain (cu). This finding has also been validated in other investigations [1, 2, 3], focusing on carbon and glass FRP-confined lightweight concrete columns, respectively.

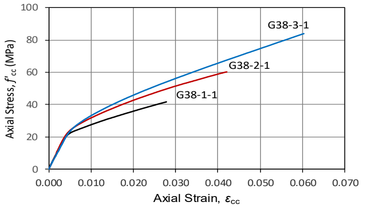


Fig. 3. Effect of number of FRP layers

The same finding is also evident when comparing the typical values of f'cu and εcu for specimen G18, as indicated in Table 2.

Table 2. Compressive behavior of tested specimens

Specimen	f'_{cu} (MPa)	Ave. f'_{cu} (MPa)	Ave. f'_{cu}/f'_{c}	ε_{cu} (%)	Ave. ε_{cu} (%)	Ave. $\varepsilon_{cu}/\varepsilon_{co}$
G38-1-1	60.88	60.29	1.59	2.36	2.39	11.13
G38-1-2	59.69			2.41		
G38-2-1	92.23	93.25	2.45	4.54	4.41	20.58
G38-2-2	94.27			4.28		
G38-3-1	102.35	102.35	2.69	5.11	5.11	23.85
G38-3-2	-			-		
G18-1-1	41.49	43.62	2.39	3.77		
G18-1-2	45.75			4.94	4.36	27.26
G18-2-1	75.37	74.25	4.07	6.90	6.91	
G18-2-2	73.13			6.91		43.22
G18-3-1	94.12	94.12	5.16	8.29	8.29	51.88
G18-3-2	-			-		

Table 2 illustrates how concrete strength affects the stress-strain characteristics of lightweight concrete wrapped with FRP. It can be seen that when concrete strength increases, the ratios of strength (f'cu/f'co) and strain improvement ratios (εcu/(εco) drop. Zhou et al. [2] have also reported this phenomena.

4 Conclusion

The findings of a recent study into the axial compression behaviour of FRP-confined aggregate in lightweight concrete are presented here. The investigation was carried out in order to better understand how this material behaves. The following are some of the conclusions that can be drawn from the findings that were presented:

1. The ultimate axial strength (f'cu) and strain (cu) of FRP-confined concrete columns both increase in proportion to the number of FRP layers that are present in the column.
2. Both the ratios of strength (f'cu/f'co) and strain improvement (cu/(co)) get lower as the strength of the concrete gets higher.

Acknowledgements. The authors are grateful to Politeknik Negeri Kupang and would want to express their appreciation for the financial support that was provided for the work that was discussed in this publication. In addition, the authors would like to take this opportunity to thank PT Fyfe Fibrwrap Indonesia for supplying the fibers that were utilized in the current experiment.

References

1. Li P, Sui L, Xing F, Huang X, Zhou Y, Yun Y. (2018), Effects of Aggregate Types on the Stress-strain Behavior of Fiber Reinforced Polymer (FRP)-Confined Lightweight Concrete. Sensors, 18(3525):1-18.
2. Zhou Y, Liu X, Xing F, Hongzhi C, Sui L. (2016), Axial compressive behavior of FRP-confined lightweight aggregate concrete: An experimental study and stress-strain relation model. ASCE J Compos Constr 119:1–15.
3. Stanton JF, Owen LM. (2006), The Influence of concrete strength and confinement type on the response of FRP-confined concrete cylinders, vol. 238. ACI Special Publication; October p. 347–62.
4. Tamuzs V, Tepfers R, Zile E, Ladnova O. (2006), behavior of concrete cylinders confined by a carbon composite III: deformability and the ultimate axial strain. Mech Compos Mater 42(4):303–14
5. Wu G, Lu ZT, Wu ZS. (2006), Strength and ductility of concrete cylinders confined with FRP composites. Constr Build Mater 20(3):134–48.
6. Almusallam, T. H. (2007), behavior of normal and high-strength concrete cylinders confined with e-glass/epoxy composite laminates. Compos. Part B, 38(5–6), 629–639.
7. Wu G, Wu ZS, Lu ZT, Ando YB. (2008), Structural performance of concrete confined with hybrid FRP composites. J Reinf Plas Compos 27(12):1323–48.
8. Cui C, Sheikh A. (2010), Experimental study of normal- and high-strength concrete confined with fiber-reinforced polymers. ASCE J Compos Constr 14(5):553–61.
9. Park JH, Jo BW, Yoon SJ, Park SK. (2011), Experimental investigation on the structural behavior of concrete-filled FRP tubes with/without steel rebar. KSCE J Civ Eng 15(2):337–45.
10. Vincent T, Ozbakkaloglu T. (2013), Influence of fiber orientation and specimen end condition on axial compressive Behavior of FRP-confined concrete. Constr Build Mater 47:814–26.
11. Vincent T, Ozbakkaloglu T. (2013), Influence of concrete strength and confinement method on axial compressive Behavior of FRP confined high- and ultrahigh strength concrete. Compos Part B-Eng 50:413–28.
12. Louk Fanggi, B.A, Moata, M, Wayan, A, Mata, A, dan Benu, M. (2019), Influence of Number of FRP layer on Compressive Behavior of FRP-Confined Lightweight Concrete, Proceeding on ICESC-2019, Labuan Bajo-Indonesia, 18-19 October 2019.
13. Tasdemir, M. A., Tasdemir, C., Jefferson, A. D.,m Lydon, F. D., Barr, B. I. G. (1998)., Evaluation of Strains at peak stresses in concrete: A three-phase composite model approach. Cement Concr. Res., 20(4): 301-318.