International Journal of GEOMATE, Sept., 2021, Vol.21, Issue 85, pp.154-159
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2021.85.j2184
Geotechnique, Construction Materials and Environment

REVIEW OF THE FLEXURAL STRENGTH OF LIGHTWEIGHT CONCRETE BEAM USING PUMICE STONE AS OF SUBSTITUTION PARTIAL COARSE AGGREGATE

*Mufti Amir Sultan[1], Abdul Gaus[2], Raudha Hakim[3] and Imran[4]

[1,2,3,4]Faculty of Engineering , Universitas Khairun, Indonesia

*Corresponding Author, Received: 00 Dec. 2020, Revised: 00 Dec. 2020, Accepted: 00 Dec. 2020

ABSTRACT: This research was conducted to analyze the flexural behavior of unreinforced concrete beams produced by substituting coarse aggregate with pumice stones in order to reduce the weight. The specimens used were designed to be 15x15x70 cm in dimension while the coarse aggregate was replaced by the pumice stone at 25%, 50%, 75%, and 100%. Test object without pumice stone (0%) as control beams. The test was conducted at a two-point load with the beam loaded up to the period it failed. The results showed the partial substitution of a higher percentage of the coarse aggregate with pumice produced lower flexural capacity and the beams become lighter with the weight recorded to have reduced by 20.05%. This means the partial replacement of more coarse aggregate with pumice stone has the ability to reduce the weight of the beam and its flexural strength. The use of pumice as a substitute for coarse aggregate in unreinforced concrete beams against tensile strength is good because the tensile strength tends to be higher than the tensile strength of concrete in general.

Keywords: Beam, Deflection, Flexural, Pumice Stone

1. INTRODUCTION

Most of the areas in Indonesia are earthquake-prone, therefore, adequate attention needs to be placed on the materials to be used in constructing building structures. This is necessary due to the consideration that some of these structures such as the beams and walls provide the largest load because they are dead loads, thereby, contributing to the weight of the building. This large weight increases the impact of the earthquake impact by causing the collapse of the building. There is, therefore, the need to reduce the building weight to make it safer when exposed to earthquake loads. Moreover, the lightweight also has the ability to make the building foundation structure more efficient in accepting vertical loads. Several researchers have, however, conducted a lot of studies to produce lightweight concrete to be applied in constructing existing infrastructure, especially in the high earthquake zone. It is important to note that lightweight concrete usually has a specific gravity which is less than 1850 kg/m^3 [1], while normal concrete has 2400 kg/m^3.

One of the materials that can be used in the manufacture of lightweight concrete by utilizing pumice stone as coarse aggregate or light aggregate [2]. One of the methods to produce lightweight concrete is by using pumice stones as coarse or light aggregates. Pumice stone is a common material in Indonesia and observed to be distributed in Jambi, Lampung, West Java, Banten, Jogjakarta, West Nusa Tenggara, East Nusa Tenggara, and North Maluku [3].

Pumice has the same physical properties as concrete aggregates and can be used as lightweight aggregates due to their ability to also fulfill the requirements [4-5]. The concrete produced from this material is useable in earthquake-resistant buildings, those prioritizing thermal resistance as the main criterion, and in places where acid rain is more frequent [6]. Moreover, the use of pumice powder as a substitute for cement in the concrete mixture also has the ability to improve the compressive, tensile, and flexural strengths of concrete [7]. Meanwhile, pumice stone aggregated beams are usually coated with polymer to improve their behavior and this is reflected in the lower stiffness of the coated when compared with those without coats. This is due to the reduction in the adhesion between the cement and the aggregate. However, the coated specimen has the ability to increase the beam's flexural strength [8]. The use of pumice as coarse aggregate can significantly reduce the concrete volume weight and also has the ability to produce compressive strength which is included in the range of lightweight concrete [9-11]. It has also been reported to have produced a slightly lower compressive strength compared to normal concrete and this means there is a need for additional materials to maintain the compressive strength at a lighter weight [12]. Another study showed the partial replacement of up to 50% of coarse aggregate with pumice produced tensile, compressive, and flexural strengths considered to be comparable to the conventional concrete. Meanwhile, the strengths were observed to be reducing gradually when the aggregates replaced were > 50%. This means the effectiveness of this material is at a maximum of 50% replacement for structural purposes and 60% - 100% for non-structural purposes. This ability of the pumice aggregate to fulfill concrete properties, therefore, shows it can be used effectively as a lightweight aggregate based on SNI requirements [13-14]. It also indicates its ability to produce lightweight concretes with different strength grades and weight units due to the addition of a type of air-entraining agent. The concrete produced was, however, observed not to fulfill the strength requirements for load-bearing structural elements [15-18].

These descriptions showed the possibility of using pumice stones as aggregates to obtain lightweight concrete. This research was, therefore, conducted based on the consideration that North Maluku (Rum, Goto, and Tidore) is a pumice distribution area [3] included in the high earthquake zone [19].

2. RESEARCH SIGNIFICANCE

Pumice stone as a material is widely available in North Maluku, and its use is still limited as a material for embankment so that its economic value is relatively low. Efforts are needed to introduce the use of pumice stone with better economic value. One of the uses is to use it as coarse aggregate in the manufacturing process of lightweight concrete and lightweight bricks. So this research is very important to carry out so that the pumice stone material can be used to produce a lightweight structure.

3. RESEARCH METHOD

3.1 Test Specimens

This research was conducted through an experimental method. This involved testing the compressive and flexural strengths to identify the behavior of deflection loads in unreinforced concrete beams at several variations of light aggregate produced through pumice stone. The experiments were conducted at the Laboratory of Structures and Materials, Department of Civil Engineering, Khairun University, Ternate. Moreover, cylindrical specimens measuring 15x30 cm were designed to test for the compressive strength while other specimens measured 15x15x70 cm without reinforcement. It is important to note that the concrete mix was designed based on SNI 03-2834-2000 regarding the procedure for making normal concrete mix plans. This involved using normal fine sand aggregates from the Kalumata quarry of South Ternate City and coarse aggregates produced from crushed stones in the Togafo quarry of North Ternate City. Furthermore, the beam flexural strength was tested based on SNI [20], the procedure for making a normal concrete mix plan. Using normal fine sand aggregate originating from the Kalumata quarry of South Ternate City and coarse aggregate of crushed stone originating from the Togafo quarry of North Ternate City. The beam flexural strength test is carried out based on SNI [21]. Variations of beam-shaped test objects as shown in Fig. 1.

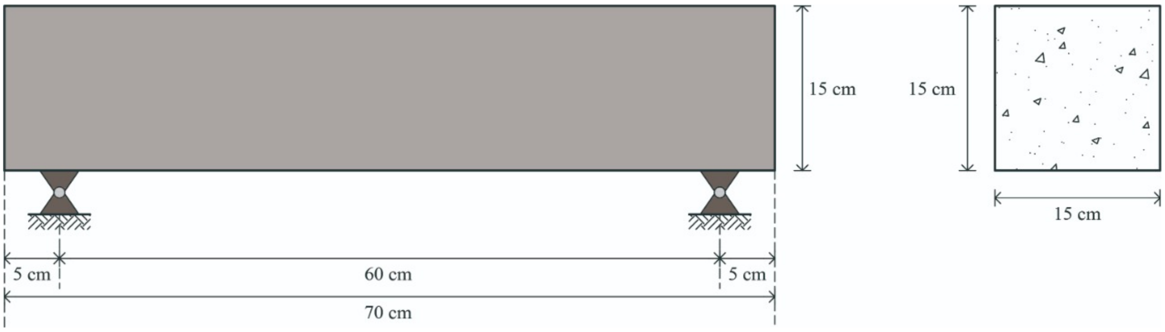

Fig. 1. Detail of the beam specimen

3.2 Test Set Up

Testing The concrete compressive strength test is carried out by giving a load to it. The surface of the concrete cylinder specimen until it cracks. The amount of concrete compressive strength of each test object uses the following Eq. (1). The cylindrical is loaded until breaks, the type of load is as shown in Fig. 2.

$$f'c = \frac{P_{max}}{A} \qquad (1)$$

where:

$f'c$ = compressive strength (N/mm^2),
Pmax = maximum compressive load (N)
A = cross-sectional area (mm^2)

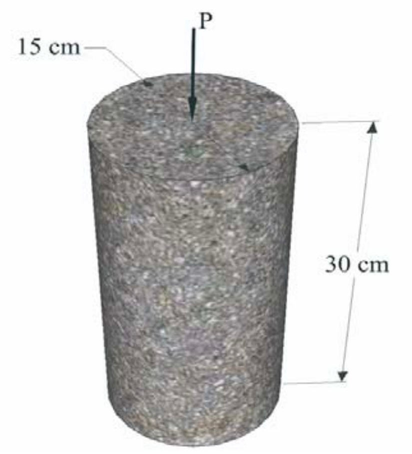

Fig. 2. Detail of the cylindrical specimens

Strength Flexural strength is the ability of concrete beams to withstand forces with the direction perpendicular to the axis given to it until the concrete beam breaks and is expressed in Mega Pascal (MPa). This flexural stress is known as the Modulus of Rupture. The equation for calculating the flexural stress or MOR is :

$$\boldsymbol{MOR} = \frac{\frac{1}{4}PL+\frac{1}{8}ql^2}{\frac{1}{6}bh^2} \qquad (2)$$

Where:
MOR = modulus of rupture (N/mm^2)
P = Maximum load (N)
q = Own weight of beam (N / mm)
b = width of object test (mm)
h = height of specimen (mm)

The beam is loaded until the concrete beams breaks, the type of load is as shown in Fig. 3.

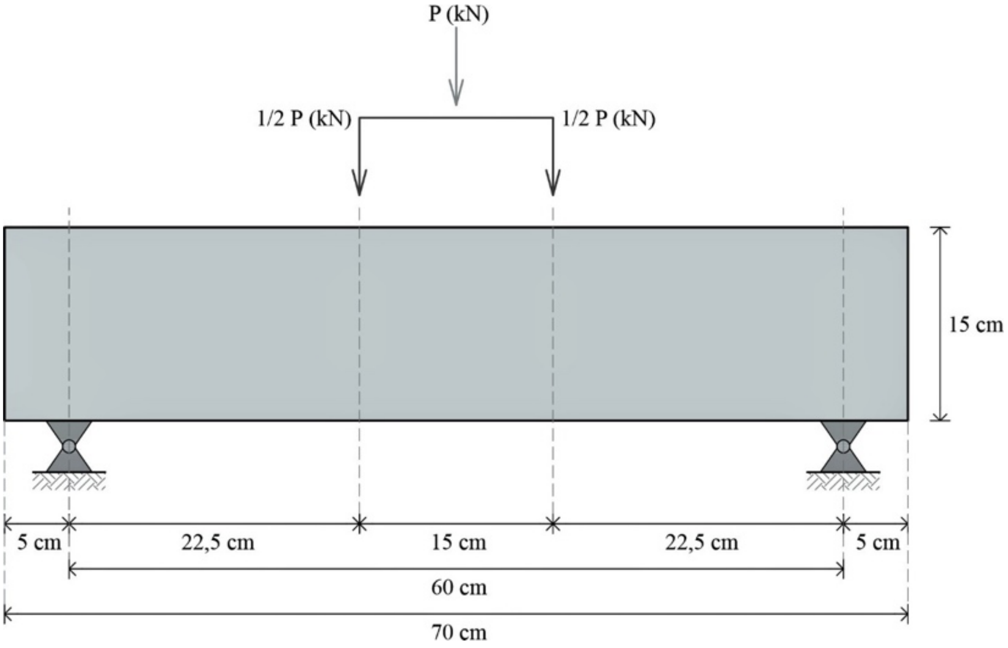

Fig. 3. Flexural strength test sketch

4. RESULT AND DISCUSSION

4.1 Relationship Between Load And Deflection

The load-deflection relationship of unreinforced beams is presented in the following Fig. 4 until Fig. 8.

Fig. 4 is the test result using unreinforced crushed stone aggregate. Sample 1 and sample 2 were able to receive a maximum load of 21.50 kN and 22.50 kN, or an average of 22.0 kN with a deviation of 9.80 mm and 9.40 mm, or an average of 9.60 mm, respectively. Initial cracks occurred at 17.15 kN and 18.75 kN loads, respectively, or an average of 17.95 kN.

Fig. 5 shows the result of the experiment conducted using 25% of pumice aggregate in the unreinforced beam. Samples 1 and 2 were observed to have been able to receive a maximum load of 13.75 kN and 19.00 kN respectively at an average of 16.38 kN. They also experienced a deflection of 12.40 mm and 11.40 mm at an average of 11.90 mm. Meanwhile, the initial cracks were discovered to have occurred at a load of 8.75 kN and 12.75 kN respectively with the average value found to be 10.75 kN.

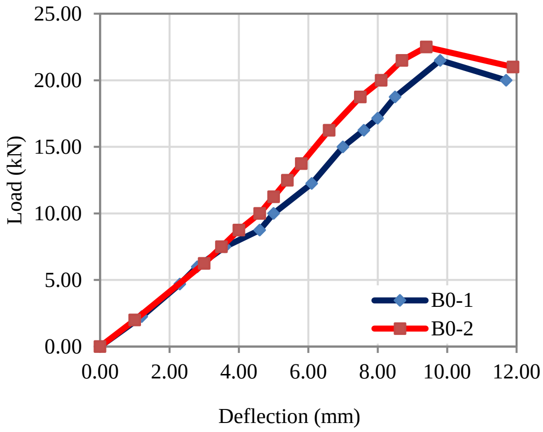

Fig. 4. Load-deflection B-0 relationship

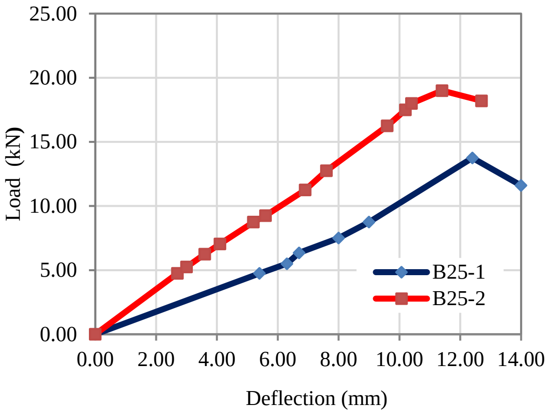

Fig. 5. Load-deflection B-25 relationship

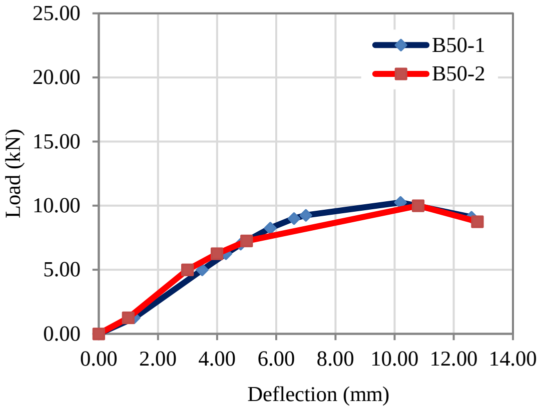

Fig. 6. Load-deflection B-50 relationship

Fig. 6 shows the result for the 50% pumice aggregate in the unreinforced beam. Sample 1 and 2 were able to accept a maximum load of 10.25 kN and 10.00 kN at an average of 10.13 kN with a deflection of 10.20 mm and 10.80 mm at an average of 10.50 mm respectively. Meanwhile, the initial cracks were recorded to have occurred at a load of 8.25 kN and 7.25 kN respectively with an average value of 7.75 kN.

Fig. 7 shows the result for 75% pumice aggregate in the unreinforced beam. Samples 1 and 2 were discovered to have accepted a maximum load of 7.50 kN and 8.75 kN respectively at an average value of 8.13 kN with a deflection of 9.20 mm and 10.20 mm at an average value of 9.70 mm. Meanwhile, the initial cracks were found to have occurred at 5.25 kN and 5.00 kN loads respectively at an average of 5.13 kN.

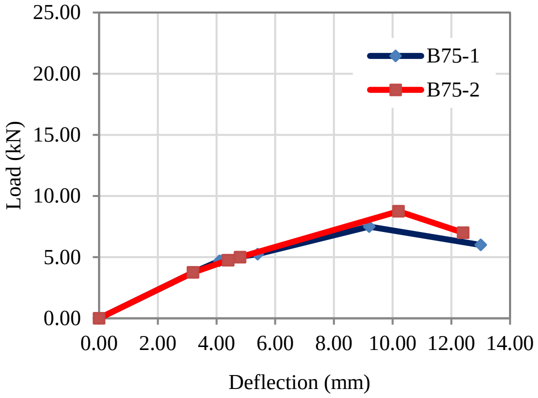

Fig. 7. Load-deflection B-75 relationship

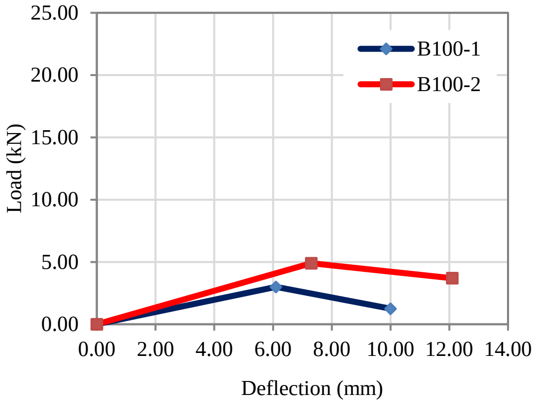

Fig. 8. Load-deflection B-100 relationship

Fig. 8 shows the result for 100% pumice aggregate in the unreinforced beam. Samples 1 and 2 were discovered to have accepted a maximum load of 3.00 kN and 4.90 kN respectively at an average value of 3.95 kN with a deflection of 6.10 mm and 7.30 mm at an average value of 6.70 mm. The test objects were, however, illegible at the beginning of the crack.

4.2 Volume Weight

Pumice was used as a substitute for coarse aggregate at a variation of 0%, 25%, 50%, 75%, and 100% to reduce the concrete volume weight. The beam used for the comparison had a volume weight of 2135.27 kg/m3 and the value was observed to have reduced to 2003.23 kg/m^3 due to the use of 25% pumice aggregate (B-25). The value was further decreased to 1944.76 kg/m^3 with 50% pumice aggregate (B-50), 1827.81 kg/m^3 with 75% pumice aggregate (B-75), and 1707.08 kg/m^3 with 100% pumice aggregate (B-100) as indicated in Fig. 9. This reduction was associated with the smaller volume weight of the pumice stone when compared with the normal aggregate.

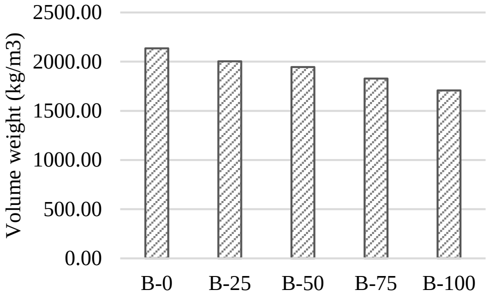

Fig. 9. Histogram of the combined weight and volume of specimens used for flexural strength test.

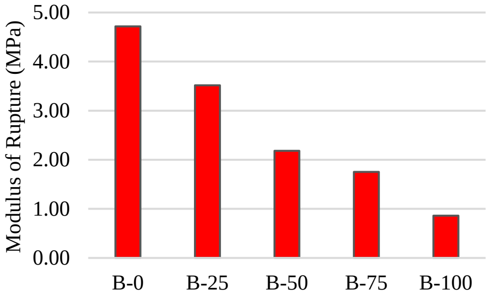

Fig. 10. Histogram of the modulus of rupture relationship with the type of test object

The flexural strength of the unreinforced concrete beams was tested using Universal Testing Machine (UTM). This was conducted after the dimensions of the test object have been measured and the compressive strength was determined at the maximum load when the object cracks or breaks. The results showed in Fig. 10 indicate the substitution of pumice for coarse aggregate was able to reduce the flexural strength of the concrete. This was due to the fact that the addition of more pumice to the concrete led to an increase in the cavities in the mixture. However, an inverse relationship was observed with the weight of the concrete volume.

From Table 1 it can be seen that, the percentage of tensile strength obtained from using pumice as coarse aggregate is greater when compared to the magnitude of 10% - 15% compressive strength it was generally recorded to have in previous studies. This, therefore, shows that the quality of lightweight concrete using pumice stones as coarse aggregates is good based on the high tensile strength of the material.

Table 1 The value of compressive strength, flexural strength and percentage of flexural strength to compressive strength

Specimen	Compressive strength (MPa)	Flexural strength (MPa)	Percentage of flexural strength to compressive strength
B-0	27.46	4.72	13.36%
B-25	14.72	3.52	13.68%
B-50	14.01	2.18	14.02%
B-75	11.74	1.75	15.32%
B-100	10.64	0.86	16.11%

5. CONCLUSION

The conclusions drawn from this research are as follows:

1. The use of pumice as a substitute for coarse aggregate in unreinforced concrete has an inversely proportional relationship with flexural strength. This was observed in the results which showed a greater percentage of pumice to have produced smaller flexural strength with the lowest value recorded to be 81.73% for the total replacement of the normal aggregates with pumice stones.
2. The use of pumice as a substitute for coarse aggregate in unreinforced concrete also has an inversely proportional relationship with the volume weight. This was observed in the results which showed a greater percentage of pumice stones to have produced a smaller volume weight, thereby, leading to lighter concrete. The largest weight reduction which was 20.05% of the normal concrete block was recorded with the use of 100% pumice stone.
3. The total replacement of the coarse aggregate in unreinforced concrete with pumice stoned produced a higher tensile strength than the normal concrete.

6. ACKNOWLEDGMENTS

The authors are grateful to the Khairun University for funding this research through the 2020 Higher Education Leading Research (PKUPT) scheme

7. REFERENCES

[1] SNI 03-3449, Tata Cara Rencana Pembuatan Campuran Beton Ringan Dengan Agregat

Ringan. 2002.

[2] Gaus A., Imran I., and Anwar C., Analysis of The Mechanical Properties of Concrete Beams That Use Pumice as a Partial Substitution of Concrete Mixtures, in International Conference on Science and Technology 2019, 2020, vol. 1569, pp. 1–6.

[3] Sukandarrumidi S., Bahan Galian Industri, Ke-3. Jogakarta: Gadjah Mada University Press, 2009.

[4] Geoffrey M., Raphael N.M., Walter O., and Silvester O.A., Properties of Pumice Lightweight Aggregate, Civ. Environ. Res., vol. 2, no. 10, pp. 58–68, 2012.

[5] Kabay N., and Aköz F., Effect of Prewetting Methods on Some Fresh and Hardened Properties of Concrete with Pumice Aggregate, Cem. Concr. Compos., vol. 34, no. 4, pp. 503–507, 2012.

[6] Muralitharan R.S., and Ramasamy V., Basic properties of pumice aggregate, Int. J. Earth Sci. Eng., vol. 8, no. 4, pp. 1845–1852, 2015.

[7] Reddy V., and Vasan S.G., Study on Behavior of Reinforcement Concrete Beam With Pumice Powder As a Partial Replacement, Int. J. Civ. Eng. Technol., vol. 9, no. 4, pp. 1689–1695, 2018.

[8] Wijatmiko I., Wibowo A., and Remayanti C,, The Effect of Polymer Coated Pumice to The Stiffness and Flexural Strength of Reinforce Concrete Beam, MATEC Web Conf., vol. 101, 2017.

[9] Venkatesh B., and Krishna B.V., A Study on The Mechanical Properties of Light Weight Concrete by Replacing Course Aggregate With (Pumice) and Cement With (Fly Ash), Int. J. Eng. Res. Technol., vol. 4, no. 08, pp. 331–336, 2015.

[10] Parmo P., Tavio T., Suriani E., Prianto K., and Haqi F.I., The Mechanical Properties of Lightweight Concrete Made with Lightweight Aggregate Volcanic Pumice, in Proceedings of the Built Environment, Science andTechnology International Conference (BEST ICON), 2018, pp. 167–171.

[11] Saravanakumar R., Veerakumar R., and Kumar G., Strength Behavior of Pumice Stone Lightweight Concrete Beam in Contrast With Reinforced Concrete Beam, Int. J. Recent Technol. Eng., vol. 8, no. 3, pp. 297–300, 2019.

[12] Idi M.A., Abdulazeez A.S., Usman S.A., and Justin T., Strength Properties of Concrete Using Pumice Aggregate As Partial Replacement of Coarse Aggregate, Int. J. Eng. Appl. Sci. Technol., vol. 04, no. 11, pp. 519–525, 2020.

[13] Numan H.A., Yaseen M.H., and Obed A.H., The Influence of Inclusion Volcanic Pumice on the Concrete Properties, Int. J. Civ. Eng. Technol., vol. 9, no. 13, pp. 1890–1904, 2018.

[14] Sangeetha S.P., Divahar R., Mawlong K., Lyngkhoi B., and Kurkalang A., Mechanical Characteristics of Pumice Stone as Light Weight Aggregate in Concrete, Int. J. Sci. Technol. Res., vol. 9, no. 1, pp. 3760–3762, 2020.

[15] Lakshmi A. S., Karthick S., Helden G., Boopathi M. D., and Pandian V. B., Experimental Investigation On Light Weight Concrete Using Pumice Aggregate, Int. J. Innov. Emerg. Res. Eng., vol. 4, no. 3, pp. 176–183, 2017.

[16] Manzoor M.M., Gupta A., Gani R., and Tanta A., Floating Concrete by Using Light Weight Aggregates and Air Entraining Agent, Int. J. Eng. Res., vol. 3, no. 6, pp. 99–104, 2018.

[17] Sultan M.A., Kusnadi K., and Yudasaputra M.T., Effect Of Pressure On Making Of Cemen Bricks from Pumice, Int. J. Civ. Eng. Technol., vol. 9, no. 5, pp. 1084–1091, 2018.

[18] Madlangbayan M.S. et al., Effect of Nanosilica on the Strength of Concrete With Volcanic Pumice As Coarse Aggregates, Int. J. GEOMATE, vol. 19, no. 75, pp. 50–57, 2020.

[19] SNI 1726, Tata Cara Perencanaan Ketahanan Gempa untuk Struktur Bangunan Gedung dan Non Gedung, in Badan Standardisasi Nasional, 2012, pp. 316–325.

[20] SNI 03-2834, Tata cara pembuatan rencana campuran beton normal, in Badan Standardisasi Indonesia, 2002.

[21] SNI 4431, Cara uji kuat lentur beton normal dengan dua titik pembebanan, Badan Stand. Indones., p. , 2011.