Physical And Mechanical Properties Of Lightweight Polymer Concrete With Epoxy Resin

By Anis Saggaff

Physical And Mechanical Properties Of Lightweight Polymer Concrete With Epoxy Resin

Octariza Juanda, Anis Saggaff, Saloma, Hanafiah

Abstract: Polymer concrete consists of polymer, hardener, and aggregate binders. The interaction between these materials depends on their physical characteristics and chemical reactions. However, it involves the use of epoxy and acrylic polymer instead of pure Portland cement. In other to conduct this research, the material used consisted of fine aggregates, epoxy resin, and foam. Furthermore, 4 ratios of fine aggregate to the epoxy resin used include 1:3, 1:2.75, 1:2.5, and 1:2 of the weight of the volume of the test object while the 3 ratios of foaming agent and water used include 1:30, 1:40, and 1:50 with 50% foam of the mixed volume. Moreover, the specimen was treated at an oven temperature of 60°C for 24 hours. From the experiment conducted, the most optimum diameter of the concrete mixture was found in LPC-1:3-1:50 of 25.28 cm while an increase in the speed of the initial and final bond time were found to be 60 and 120 minutes respectively in the mixture of LPC-1:2-1:30. In addition, the most optimum concrete pressure was found in LPC-1:2.75-1:30 to be 23.57 MPa with a specific gravity of 1,773.76 kg/m^3. The microstructure test conducted showed the greater foaming agent ratio and water has the ability to produce very large pores and non-dense polymers while smaller ones produce very small pores and increasingly dense polymer matrix. Therefore, it can be concluded that a smaller mixture ratio of foaming agent and water produces light polymer concrete with better characteristics.

Index Terms: Lightweight polymer concrete, epoxy resin, foam.

1 Introduction

Concrete is the most widely used construction material due to its production according to the compressive strength plan, ability to withstand high temperatures and easy availability of its production materials. However, it affects the weight of a building structure. Furthermore, the development of construction technology has led to the production of several modified concretes like foamed concrete which is lightweight and has many advantages such as reduced structural weight, savings in manufacturing costs, as well as faster and easier application compared to other materials such as steel and wood. The foamed concrete has a smaller compressive structure than conventional concrete and the water-binder ratio has been found to be one of the factors influencing the concrete since its value in the mixture is directly proportional to the compressive structure. Moreover, the foamed concrete mixture consists of cement, water, fine aggregates and admixtures like gas bubbles or foam-shaped air inserted into the mortar to form a pore in order to make the weight of the concrete become lighter. Furthermore, a concrete polymer is a monomer polymerized with other components through heat, catalyst, or radiation. The polymerized monomer has the ability to be used as a binding component and does not require water in the hardening process. Concrete polymers consist of polymer binders, hardeners, and aggregates and the interaction between these components depends entirely on chemical reactions and physics. However, since the 70s, concrete epoxy and acrylic polymers have been used to replace traditional materials because they have the better binding capacity and dry faster. Moreover, methyl property, methacrylate, unsaturated polyester resins, epoxy resins, resin furans, polyurethane resins, urea formaldehyde resins, and polyester or styrene blends are generally explored as the concrete polymer systems and they are developed as an effort to reduce the use of cement as well as to mitigate global warming. These polymers are used as cement replacement adhesives to make strong concrete polymer in a shorter time. Lightweight concrete has a density lower than 1,950 kg/m^3 and compressive strength less than 17 MPa and this makes it 25% lighter than the weight of ordinary concrete whose compressive structure reaches 60 MPa [1]. Foam or lightweight concrete cellular is the most lightweight material in construction and infrastructure today. It has a light density between 1,000 kg/m^3 and 1,600 kg/m^3, good durability, resists fire, and good thermal conductivity. The use of foamed concrete has encouraged several studies on the techniques of the nature, strength, and structural behavior of this material. Some have been conducted to determine the compressive, tensile and flexural strength while others have investigated the fracture energy attached to its ability to overcome certain structural cracks and failures. However, an extensive study of energy fractures showed the fracture energy of foamed concrete to be around 18 N/m to 25 N/m [2]. Furthermore, foam concrete is a mixture consisting of cement, fine aggregate, water, and special foam evenly distributed with uniform bubble sizes. It is made by adding foam to the mixture in order to produce air cavities inside the mortar. In general, the foam is produced by foam generator by dissolving foaming agents into the water, however, the quality of foamed concrete is determined by the quality of foam produced [3]. The parameters of this concrete include porosity as well as pore diameter and uniformity. In general, it has been found to have a large porosity with a low density (<500 kg/m^3) and 65% or more porosity. This means an increase in porosity reduces the pressure area of the material cross-section which consequently affects the mechanical properties of the foamed concrete [4]. According to Hilal et al. [5], the characteristics of this concrete are different from those of the conventional ones. However, the current technological advancements and needs in the construction sector have increased the use of foamed concrete, for example, in constructing soundproof and heat resistant building partition walls [6]. Moreover, the pre-formed foaming method is more economical and easier to process than others [7]. Based on ACI 523.3R [8], it is made by mixing foaming agents and water at a certain percentage and by

- *Octariza Juanda, is master student in Civil Engineering, Faculty of Engineering, Sriwijaya University, Indonesia.*
- *Anis Saggaff, Civil Engineering Department, Faculty of Engineering, Sriwijaya University, Indonesia.*
- *Saloma, Civil Engineering Department, Faculty of Engineering, Sriwijaya University, Indonesia. Corresponding Email: salomaunsri@gmail.com*
- *Hanafiah, Civil Engineering Department, Faculty of Engineering, Sriwijaya University, Indonesia.*

applying air pressure using a foam generator. Epoxy or polyepoxide is an epoxide thermosetting polymer whose quality is better when mixed with a catalyst or hardener agent. Thermosetting polymers only melt when first heated and harden permanently when cooled. Polymers are repetitive chains of long atoms, formed by binding identical molecules called monomers. They are, however, one of the non-metallic materials. Furthermore, bisphenol type resins are prepared as saturated acid components from a mixture of orthopthalic and isophthalic anhydride. The bisphenol contained makes this resin possess chemical resistance such as acid, alkaline chlorine, and at the same time heat resistance. There are many types of resins, such as natural oil, alkyd, nitrocellulose, polyester, melamine, epoxy, polyurethane, silicone, fluorocarbon, vinyl, cellulosic, etc. [9]. Moreover, based on the research conducted by Onprom et al. [10], foaming agents were dissolved in water at a concentration of 1:30 and poured into generator tubes to make foam with a density of 50 kg/m^3. However, the mixtures were produced based on the variations in the quantity of foam to have 30%, 40%, 50%, 60%, and 70% of the mixture volume and bottom ash substitution with 25% of the fine aggregate volume which was meant to pass the filter number 16. A foaming agent is a basic material needed to make foamed concrete. It is made of diffraction, which is a surface-active agent that can increase the ability of water to make foam [11]. In general, two diffraction materials have been identified and they include protein-based diffraction and synthesis. The protein-based fractures are made from processed animals such as horns, bones and animal skin, while synthesis-based diffraction is from chemicals. Therefore, this study discussed the physical and mechanical properties of lightweight polymer concrete with epoxy resin.

2 Experimental Procedures

2.1 Material

The material used in this study include epoxy resin, fine aggregate, and foam and the composition of the mixture was proportioned by volume to 1 m^3. This study used a mixed design based on the development of mixed compositions from previous studies as shown in Table 1. The ratio of fine aggregated epoxy resins includes 1:3, 1:2.75, 1:2.5, and 1:2 while those of foaming agent to water to produce foam were 1:30, 1:40, and 1:50 with foam percentage being 50% of the mixed volume. The specimen was treated at an oven temperature of 60°C for 24 hours.

Table 1. *Mixed design of lightweight polymer concrete with epoxy resin (0.014 m^3)*

Sample codes	Epoxy (1:0.5)		Fine aggregate (kg)	Foam (L)
	Resin (kg)	Hardener (kg)		
LPC-1:3.00-1:30	0.273	0.137	1.229	0.731
LPC-1:2.75-1:30	0.291	0.146	1.201	0.731
LPC-1:2.50-1:30	0.312	0.156	1.170	0.731
LPC-1:2.00-1:30	0.364	0.182	1.092	0.731
LPC-1:3.00-1:40	0.273	0.137	1.229	0.731
LPC-1:2.75-1:40	0.291	0.146	1.201	0.731
LPC-1:2.50-1:40	0.312	0.156	1.170	0.731
LPC-1:2.00-1:40	0.364	0.182	1.092	0.731
LPC-1:3.00-1:50	0.273	0.137	1.229	0.731
LPC-1:2.75-1:50	0.291	0.146	1.201	0.731
LPC-1:2.50-1:50	0.312	0.156	1.170	0.731
LPC-1:2.00-1:50	0.364	0.182	1.092	0.731

The process of producing the lightweight concrete polymer began with the preparation of the epoxy resin by mixing epoxy and hardener, added with fine aggregate, and stirred for 2 minutes. After that, the dry (solid) material formed a lightweight polymer concrete and the weighed fine aggregate was placed in a mixing bowl and mixed for about 3 minutes. However, before the liquid material mixing process stated above finished, the premixed-foam, produced through the pre-formed foaming method to be 33 mL, 25 mL, and 20 mL foaming agent in 1,000 mL of water representing 1:30, 1:40 and 1:50, was inserted into the foam making tube at an air pressure of 0.5 MPa. The time needed to make the foam was approximately 2 minutes and was added to the mixture according to the required volume and stirred again for 2 minutes. Therefore, the whole mixing process took approximately 5 minutes. This was followed by the conduct of a fresh concrete test including flow table test, and setting time. After these, the fresh concrete was poured into a 50 mm mold, cured at an oven temperature of 60°C for 24 hours and wrapped in plastic to minimize water evaporation.

2.2 Testing

A fresh concrete test was conducted based on ASTM C 143 [12] and ASTM C 191 [13] to include flow table and setting time tests while the hard-concrete testing includes density and compressive strength tests according to ASTM C 109 [14] using Automatic Compression Controls equipment. Each of the mixture composition was made for five cube specimens and the test was conducted on the 28th day. Samples that have undergone compressive concrete test were entered into microstructure testing through the use of small pieces of those with the highest compressive strength.

3 Results and Discussion

3.1 Flow Table

The results showed the diameter of the concrete mixture ranges from 17-25 cm and the most optimum was found in the mixture of LPC-1:3-1:50 to be 25.13 cm. The results of the flow table test are shown in Figs. 1 and 2.

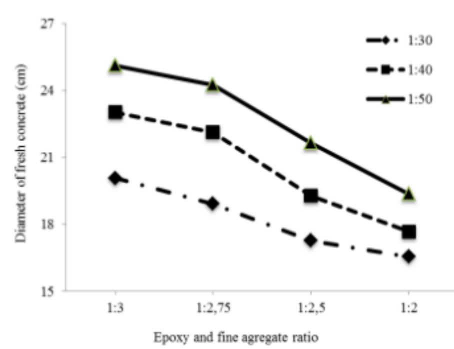

Fig. 1. *Effect of epoxy and fine aggregate ratio on the flow table*

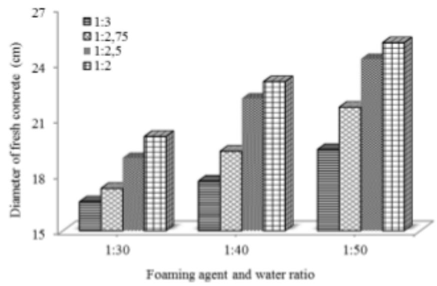

Fig. 2. *Effect of foaming agent and water ratio on the flow table*

Fig. 1 shows a smaller ratio of epoxy and fine aggregate led to a smaller diameter of the concrete mixture obtained as well as to have the ability to improve the workability on the polymer concrete. Fig. 2 also shows a greater ratio of foaming agents and water led to a higher diameter of the concrete mixture obtained. However, increased foam percentage was reported to have led to a decrease in workability of the foam concrete [15].

3.2 Setting Time

This test consisted of the initial and final setting time based on the ratio of epoxy and fine aggregate as shown in Figs. 3 and 4, and on the ratio of foaming agent and water as in Figs. 5 and 6. The initial time obtained ranged between 60-195 minutes while the final was between 120-300 minutes. However, the faster initial and final setting time were observed in the mixture of LPC-1:2-1:30 to be 60 and 120 minutes respectively.

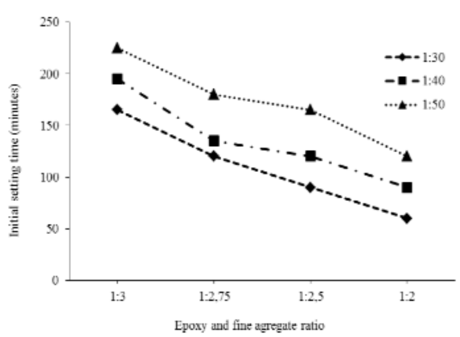

Fig. 3. *Effect of epoxy and fine aggregate ratio on initial setting time*

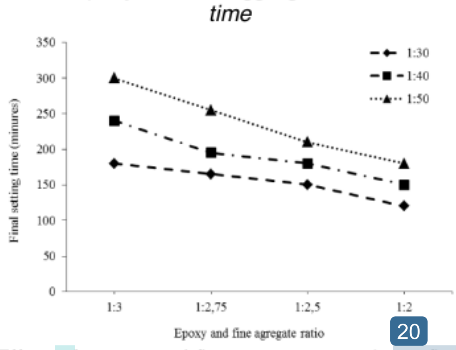

Fig. 4. *Effect of epoxy and fine aggregate ratio on final setting time*

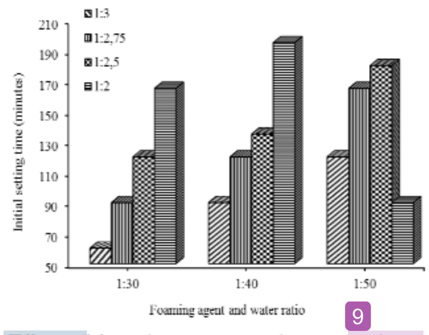

Fig. 5. *Effect of foaming agent and water ratio on the initial setting time*

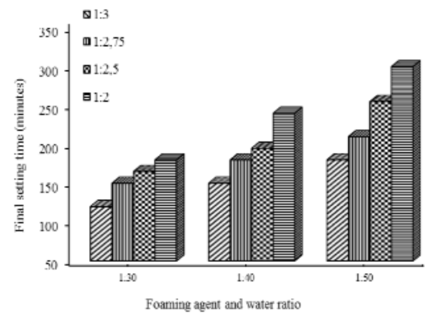

Fig. 6. *Effect of foaming agent and water ratio on the final setting time*

Variation in w/b values was found to have an effect on the setting time of foamed concrete such that an increment in the values of the w/b leads to a longer time [16].

3.3 Density

The test results showed the density obtained to have ranged between 1,600-1,800 kg/m^3 by weighing the 28-day 50-mm cube specimen as shown in Figs. 7 and 8.

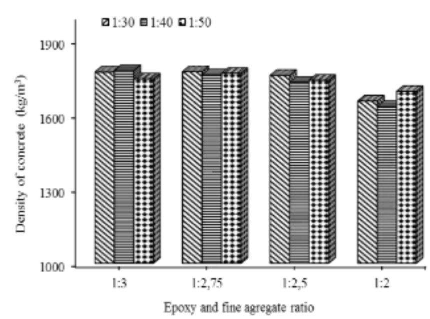

Fig. 7. *Effect of epoxy and fine aggregate ratio on density*

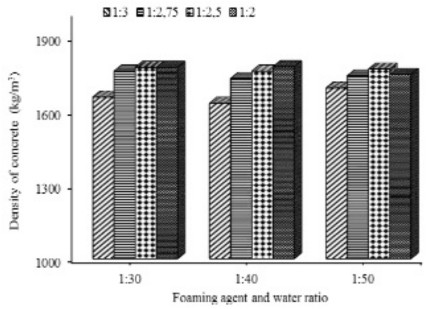

Fig. 8. *Effect of foaming agent and water ratio on density*

Fig. 7 shows all mixed compositions to have reached the targeted density, which ranged between 1,600-1,800 kg/m^3. This indicates the ratio of epoxy and fine aggregate is very influential on density such that the smaller the ratio of epoxy and fine aggregate, the smaller the density to be obtained. Fig. 8 shows foaming agents produce chemical reactions in stirred concrete mixtures leading to several scattered air bubbles and gradually hardened the concrete as a solid mixture. The air bubbles further form a stable vesicular structure [17]. In this study, the ratio of foaming agent and water greatly affected the density obtained. A greater ratio was found to be leading to a smaller density.

3.4 Compressive Strength

The results of the compressive strength on 28-day specimens are shown in Figs. 9 and 10 with the most optimum results found in the mixture of LPC-1:2.75-1:30 to be 23.57 MPa at a density of 1,773.76 kg/m^3.

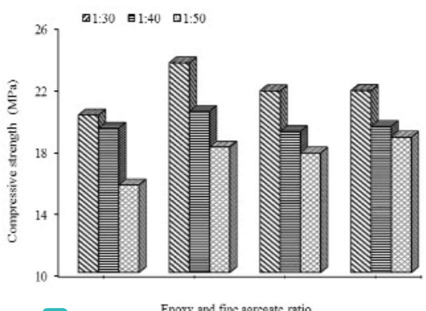

Fig. 9. *Effect of epoxy and fine aggregate ratio on compressive strength*

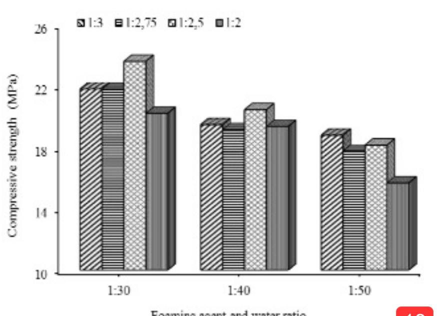

Fig. 10. *Effect of foaming agent and water ratio on compressive strength*

Fig. 9 shows the effect of the epoxy and fine aggregate ratio on compressive structure concrete. As a filler, a fine aggregate produces higher mechanical strength due to its high molecular compaction [18]. Fig. 10 shows the effect of the ratio of foaming agents and water on compressive reinforced concrete and a greater ration was found to be lowering the compressive strength [19].

3.5 Microstructure Test

The results of the microstructure test for each composition of lightweight polymer concrete mixture are presented in Figs. 11 to 22 at 1500x magnification and a less dense polymer matrix was discovered. In addition, the pores produced in each figure have different sizes (less than 10 µm) and fewer fine aggregates were observed to be producing more pores, thus affecting the density and compressive strength obtained.

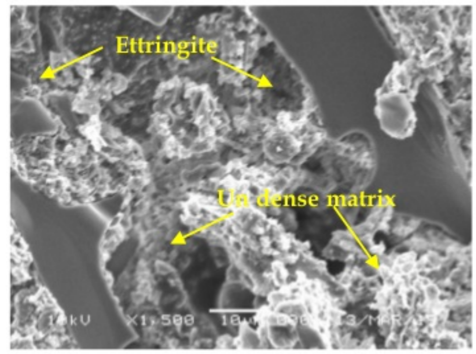

Fig. 11. *Microstructure test in LPC-1:3-1:30 mixture*

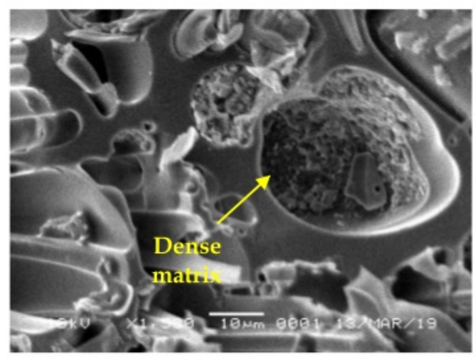

Fig. 12. *Microstructure test in LPC-1:2.75-1:30 mixture*

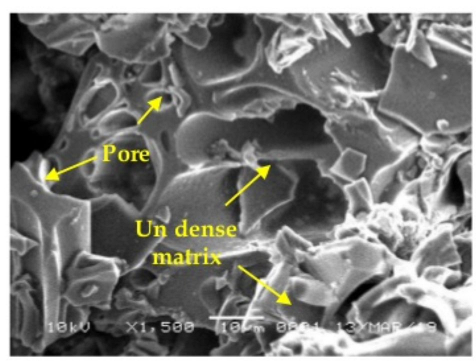

Fig. 13. *Microstructure test in the LPC-1:2.5-1:30 mixture*

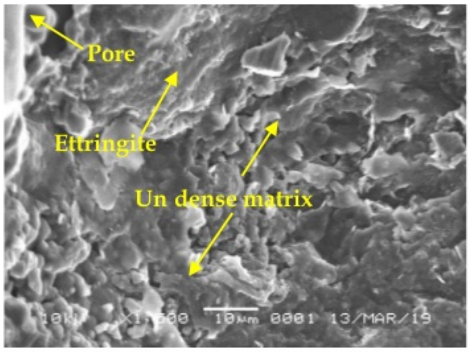

Fig. 14. *Microstructure test in the LPC-1:2-1:30 mixture*

Figs. 11 to 14 show a ratio of foaming agents and water of 1:30 produced very small pores and increased compressive strength. Fig. 13 shows a dense matrix polymer between epoxy and fine aggregate, thus increasing the compressive strength. Moreover, Figs. 11, 13, and 14 reveal bigger pores and un-dense-matrix lead to a decrease in density and compressive strength. In addition, the dehydration of concrete mixes during the curing process produced ettringite in small amounts.

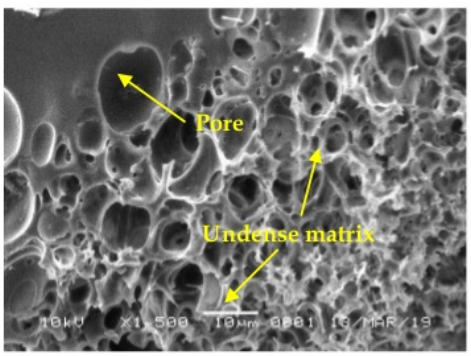

Fig. 15. *Microstructure test in the LPC-1:3-1:40 mixture*

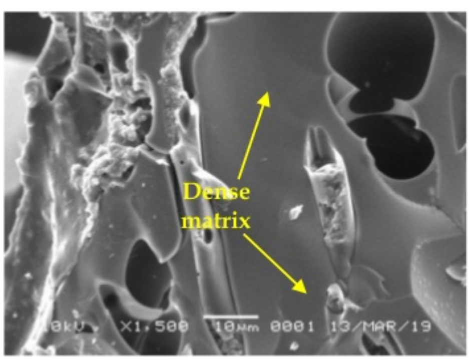

Fig. 16. *Microstructure test in the LPC-1:2.75-1:40 mixture*

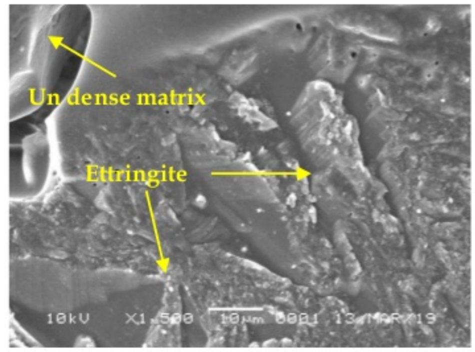

Fig. 17. *Microstructure test in the LPC-1:2.5-1:40 mixture*

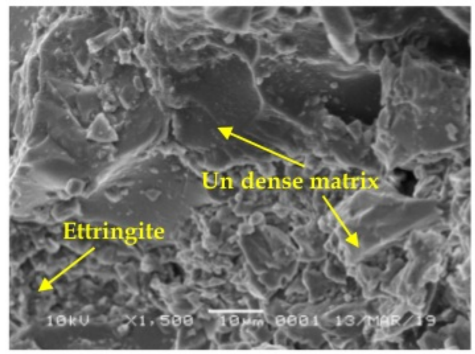

Fig. 18. *Microstructure test in the LPC-1:2-1:40 mixture*

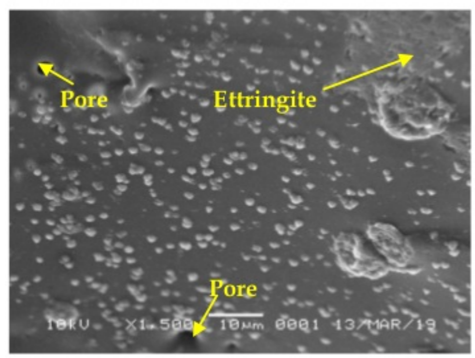

Fig. 19. *Microstructure test in the LPC-1:3-1:50 mixture*

Figs. 15 to 18 shows the ratio of foaming agent and water of 1:40 to produce very large pores while Figs. 19 to 22 with of 1:50 produced bigger pores. A greater ratio was observed to have led to a lower level of polymerization causing a decrease in compressive strength of the concrete. Figs. 16 and 20 reveal a dense matrix produces a compressive structure which is greater than other mixed compositions. However, the foaming agent and water ratio of 1:40 and 1:50 led to a decrease in compressive strength compared to 1:30. Furthermore, Figs. 15, 17, 18, 19, 21, and 22 show that larger pores and un-dense matrix causes a decrease in density and compressive strength. In addition, the concrete dehydration rate during the curing process and ettringite was high.

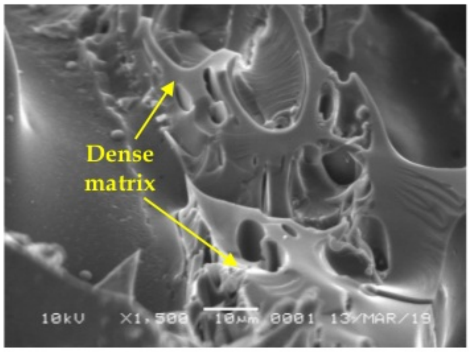

Fig. 20. *Microstructure test in the LPC-1:2.75-1:50 mixture*

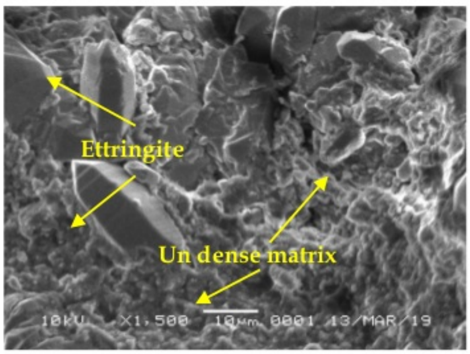

Fig. 21. *Microstructure test in the LPC-1:2.5-1:50 mixture*

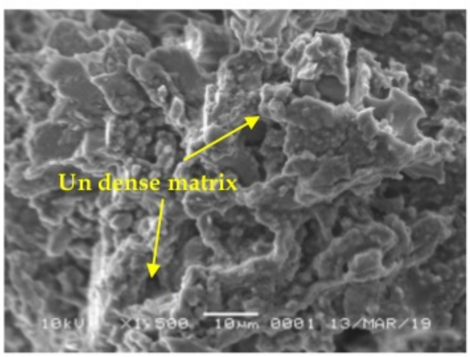

Fig. 22. *Microstructure test in the LPC-1:2-1:50 mixture*

4 CONCLUSION

The conclusions from the results of the study are as follows:

1. The maximum mixture composition of lightweight polymer concrete was found in the mixture ratio of the foaming agent and water at 1:30.
2. The most optimum result of the flow table test was observed in the mixture of LPC-1:3-1:50 to be a concrete stirring diameter of 25.13 cm. A higher ratio of foaming agent and water used and a greater ratio of epoxy and fine aggregate has the ability to lead to the greater diameter and smaller workability of the concrete mixture produced.
3. The setting time included the initial and final setting time and the fastest values were found at LPC-1:2-1:30 to be 60 and 120 minutes. Therefore, a greater ratio led to the more initial and final setting time needed.
4. The most optimum result for compressive concrete strength was found in the mixture of LPC-1:2.75-1:30 to be 23.57 MPa with a density of 1773.76 kg/m^3. Therefore, a greater ratio led to lower compressive strength.
5. The microstructure test showed the goodness of polymerization between epoxy and fine aggregate and the dense matrix observed in 1:30 increased compressive strength while the un-dense produced by the ratio of foaming agent and water at 1:40 and 1:50 decreased density and compressive strength. Therefore, a greater ratio of foaming agent and water affects the compressive structure and density of the concrete polymer.

ACKNOWLEDGMENTS

The research presented in this paper was supported by a grant from Unggulan Kompetitif Universitas Sriwijaya and PT. Semen Baturaja.

REFERENCES

[1] Dawood. E. T., dan Hamad. A. J.,2016. Proportioning of Lightweight Concrete by the Inclusions of Expanded PolystyreneBeads (EPS) and Foam Agent, Tikrit Journal of Engineering Sciences.

[2] Rahman. N. A., Jaini. Z. M., and Zahir. N. M., 2015. Fracture Energi Of Foamed Concrete By Means Of The Tree-Point Test On Notched Beam Specimens, ARPN Journal of Engineering and Applied Sciences.

[3] Thrakele, Maheshkumar, 2014. Expiremental Study on Foam Concrete, International Journal of Civil, Structural, Environmental and Infrastructure Engineering Research and Development.

[4] Yunfeng, L., Qijun, Y., Jiangxiong, W., Jie, H., dan Fangxian, Li, 2013. Characteristics of Pore Structure of Free-steaming Foamed Concrete and its Influence on the Compression Strength, Applied Mechanics and Materials.

[5] Hilal, A., Thom, N., dan Dawson, A. R., 2015. The Use of Additives to Enhance Properties of Pre-Foamed Foamed Concrete, International Journal of Engineering and Technology.

[6] Tan, X., Chen, W., Hao, Y., dan Wang, Xu, 2014. Experimental Study of Ultralight (<300 kg/m3) Foamed Concrete, Hindawi Publishing Corporation Advances in Material Science and Engineering.

[7] Saloma, Hanafiah, Urmila, D., 2017. The effect of water binder ratio and fly ash on the properties of foamed concrete, AIP Conference Proceedings.

[8] ACI 523.3R-93. Guide for Cellular Concrete above 800 kg/m^3. USA: American Concrete Institute.

[9] Syukroni. A, 2015. Physical and mechanical properties of polymer mortar with a variation of 5% resin; 10%; 15%; 20%; and 25% research, Gadjah Mada University.

[10] Onprom, P., Chaimoon, K., and Cheerarot, R., 2015. Influence of Bottom Ash Replacement as Fine Aggregate on the Property of Cellular Concrete with Various Foam Contents, Hindawi Publishing Corporation Advances in Material Science and Engineering.

[11] Thrakele, Maheshkumar, 2014. Expiremental Study on Foam Concrete, International Journal of Civil, Structural, Environmental and Infrastructure Engineering Research and Development.

[12] ASTM C 143, 2015. Standard Test Method forSlump of

Hydraulic-Cement Concrete, Annual Books of ASTM Standards. USA: Association of Standard Testing Materials.
[13] ASTM C 191, 2014. Standard Test Method forTime of Setting of Hydraulic Cement by Vicat Needle, Annual Books of ASTM Standards. USA: Association of Standard Testing Materials.
[14] ASTM C 109, 2015. Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens), Annual Books of ASTM Standards. USA: Association of Standard Testing Materials.
[15] Tiong, Hock Yong., Lim, Siong Kang., dan Lim, Jee Hock, 2016. Strength Properties of Foamed Concrete Containing Crushed Steel Slag as Partial Replacement of Sand with Specific Gradation, MATEC Web of Conferences.
[16] Yu, Xingang., Wei, Yurong., Luo, Shisong., Zeng, Kangyan., Li, Dejun., Wang, Hongfei., Li, Yuexiang., dan Wei, Xiaotie, 2011. Influence of Testing Methods on Setting Time of Foam Concrete, Advanced Materials Research.
[17] Tan, X., Chen, W., Hao, Y., dan Wang, Xu, 2014. Experimental Study of Ultralight (<300 kg/m3) Foamed Concrete, Hindawi Publishing Corporation Advances in Material Science and Engineering.
[18] Golestaneh, M., Amini, G., Najafpour,G,D., and Beygi, M, A. Evaluation of Mechanical Strength of Epoxy Polymer Concrete with Silica Powder as Filler.
[19] Tiong, Hock Yong., Lim, Siong Kang., dan Lim, Jee Hock, 2016. Strength Properties of Foamed Concrete Containing Crushed Steel Slag as Partial Replacement of Sand with Specific Gradation, MATEC Web of Conferences.

Physical And Mechanical Properties Of Lightweight Polymer Concrete With Epoxy Resin

ORIGINALITY REPORT

14%

SIMILARITY INDEX

PRIMARY SOURCES

1	www.ijstr.org Internet	146 words	4%
2	Saloma, Hanafiah, Dea Urmila. "The effect of water binder ratio and fly ash on the properties of foamed concrete", AIP Publishing, 2017 Crossref	60 words	2%
3	Rakesh Kumar. "A Review on Epoxy and Polyester Based Polymer Concrete and Exploration of Polyfurfuryl Alcohol as Polymer Concrete", Journal of Polymers, 2016 Crossref	36 words	1%
4	Ming-Yu Lee, Chun-Han Ko, Fang-Chih Chang, Shang-Lien Lo, Jyh-Dong Lin, Ming-Yang Shan, Jeng-Ching Lee. "Artificial stone slab production using waste glass, stone fragments and vacuum vibratory compaction", Cement and Concrete Composites, 2008 Crossref	35 words	1%
5	e-journal.uajy.ac.id Internet	35 words	1%
6	pt.scribd.com Internet	18 words	1%
7	www.ijedr.org Internet	17 words	< 1%
8	aip.scitation.org Internet		

16 words — < 1%

9 Saloma, Hanafiah, Debby Orjina Elysandi, Della Garnesia Meykan. "Effect of Na_2SiO_3/NaOH on mechanical properties and microstructure of geopolymer mortar using fly ash and rice husk ash as precursor", AIP Publishing, 2017
Crossref
14 words — < 1%

10 Yu, Xin Gang, Yu Rong Wei, Shi Song Luo, Kang Yan Zeng, De Jun Li, Hong Fei Wang, Yue Xiang Li, and Xiao Tie Wei. "Influence of Testing Methods on Setting Time of Foam Concrete", Advanced Materials Research, 2010.
Crossref
13 words — < 1%

11 Saloma, Hanafiah, Veriza Agistin. "Mechanical properties analysis of reactive powder concrete with curing temperature variation", IOP Conference Series: Materials Science and Engineering, 2019
Crossref
10 words — < 1%

12 FAlfuady, Saloma, Y Idris. "Characteristics Foam Concrete with Polypropylene Fiber and Styrofoam", Journal of Physics: Conference Series, 2019
Crossref
9 words — < 1%

13 Nattapong Makaratat, Chai Jaturapitakkul, Charin Namarak, Vanchai Sata. "Effects of binder and $CaCl_2$ contents on the strength of calcium carbide residue-fly ash concrete", Cement and Concrete Composites, 2011
Crossref
9 words — < 1%

14 K.-S. Wang. "Foamed lightweight materials made from mixed scrap metal waste powder and sewage sludge ash", Waste Management & Research, 10/01/2004
Crossref
9 words — < 1%

15 www.science.gov
Internet
9 words — < 1%

16 "ACMSM25", Springer Science and Business Media LLC, 2020
Crossref

8 words — < 1%

17 Margam Chandrasekaran, Paramanand Singh. "Sintered iron–copper–tin–lead antifriction materials — effect of temperature", Materials Science and Engineering: A, 2000
Crossref
8 words — < 1%

18 Abbas M. Abd, Suhad M. Abd. "Modelling the strength of lightweight foamed concrete using support vector machine (SVM)", Case Studies in Construction Materials, 2017
Crossref
8 words — < 1%

19 Patchara Onprom, Krit Chaimoon, Raungrut Cheerarot. "Influence of Bottom Ash Replacements as Fine Aggregate on the Property of Cellular Concrete with Various Foam Contents", Advances in Materials Science and Engineering, 2015
Crossref
8 words — < 1%

20 Christian Varhen, Shirley Carrillo, Gaby Ruiz. "Experimental investigation of Peruvian scallop used as fine aggregate in concrete", Construction and Building Materials, 2017
Crossref
7 words — < 1%

21 Wan Mastura Wan Ibrahim, Kamarudin Hussin, Mohd Mustafa Al Bakri Abdullah, Aeslina Abdul Kadir. "Geopolymer lightweight bricks manufactured from fly ash and foaming agent", AIP Publishing, 2017
Crossref
6 words — < 1%

22 InCIEC 2013, 2014.
Crossref
6 words — < 1%

EXCLUDE QUOTES	ON	EXCLUDE MATCHES	< 1%
EXCLUDE	ON		