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Influence of Expanded Clay Aggregate on the Engineering Properties of Lightweight Concrete

Influencia del agregado de arcilla expandida en las propiedades de ingeniería del hormigón ligero

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ABSTRACT

In seismically active locations, civil infrastructures, such as buildings, bridges, and dams, are frequently subjected to earthquakes. Using lightweight construction materials is one method for enhancing the seismic resistance of infrastructure. This study examined the engineering properties of lightweight concrete manufactured using expanded clay aggregate, with the purpose of developing sustainable and environmentally friendly building materials. Laboratory tests focused on the effects of the aggregate shape and the supplementary superplasticizer, as well as on the influence of the concrete age. Experimental studies were conducted to measure fresh (slump) and hardened properties (compressive strength, splitting tensile strength, and density). The expanded clay aggregate was produced by burning at a temperature of 800 to 1 200 °C. Cubic, oval, and round aggregate shapes with a maximum size of 20 mm were evaluated. This study also examined the effect of superplasticizers on the engineering properties of lightweight concrete. The composition of the superplasticizer varied from 0 to 2,5%. According to the experimental results, the engineering properties of lightweight concrete made with oval aggregates are advantageous in comparison with those using cubic and round shapes. It is also demonstrated that optimal amounts of superplasticizer are necessary to develop materials with adequate properties. It can be concluded that expanded clay aggregate can be used as an alternative material to produce lightweight concrete.

Keywords: expanded clay aggregate, lightweight concrete, compressive strength, splitting tensile strength, superplasticizer

RESUMEN

En lugares sísmicamente activos, las infraestructuras civiles, como edificios, puentes y represas, están frecuentemente sujetas a terremotos. El uso de materiales de construcción livianos es un método para mejorar la resistencia sísmica de la infraestructura. Este estudio examinó las propiedades de ingeniería del hormigón ligero fabricado con agregado de arcilla expandida, con el objetivo de desarrollar materiales de construcción sostenibles y respetuosos con el medio ambiente. Las pruebas de laboratorio se enfocaron en los efectos de la forma del agregado y el superplastificante suplementario, así como en la influencia de la edad del concreto. Se realizaron estudios experimentales para medir las propiedades en estado fresco (asentamiento) y endurecido (resistencia a la compresión, resistencia a la tracción por división y densidad). El agregado de arcilla expandida se produjo mediante incineración a una temperatura de 800 a 1 200 °C. Se evaluaron agregados de forma cúbica, ovalada y redonda, con un tamaño máximo de 20 mm. Este estudio también examinó el efecto de los superplastificantes en las propiedades de ingeniería del hormigón ligero. La composición del superplastificante varió de 0 a 2,5 %. De acuerdo con los resultados experimentales, las propiedades de ingeniería del hormigón ligero hecho con formas ovaladas son ventajosas en comparación con los que utilizan formas cúbicas y redondas. También se demuestra que se necesitan cantidades óptimas de superplastificante para desarrollar materiales con propiedades adecuadas. Se puede concluir que el agregado de arcilla expandida se puede utilizar como material alternativo para producir hormigón liviano.

Palabras clave: agregado de arcilla expandida, hormigón ligero, resistencia a la compresión, resistencia a la tracción por división, superplastificante

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Introduction

Concrete is one of the most used construction materials in the world. This is due to the fact that the components for producing concrete are accessible in a wide range of locations and relatively inexpensive compared to other materials. Concrete has several benefits as a construction material, including high resistance to compressive stress, fire resistance, low cost, and long-term serviceability. However, concrete also has several drawbacks, which have recently become the main concern of various countries, especially in terms of sustainability and its impact on the environment (Monika *et al.*, 2022; Saleh *et al.*, 2022).

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Concrete construction always generates waste and gas emissions. It starts with collecting constituent materials, extending through the construction stage, service life, the monitoring stage, and the demolition stage. In addition, producing concrete requires using natural resources, such as sand and rock, which may cause damage to the ecosystem, most notably the functional deterioration of river systems. According to the findings of previous studies, the yearly manufacture of concrete exceeds 10 billion metric tons, with aggregate consumption responsible for almost 70% (7,5 billion metric tons) and cement consumption accounting for roughly 1,2 billion metric tons (Bogas *et al*., 2015; Meyer, 2009; Bogas *et al*., 2014). Therefore, extensive innovation and the study of more sustainable and environmentally friendly alternative materials must be conducted in order to contribute to the development of the global construction industry.

In addition, the mass density of normal concrete is between 2 200 and 2 400 kg/m^3. This mass of concrete has also been widely studied by researchers and is still an open issue. Especially in earthquake-prone areas, the collapse of concrete structures with a high density might result in a fatal disaster. Several types of construction require a lighter structure to reduce density. The development of lightweight concrete is closely linked to the option of using lightweight materials as a substitute for aggregate, especially considering that coarse aggregate has the most significant proportion in concrete composition. Various innovations to produce lighter concrete have been explored over the years, such as using coarse aggregate replacement material with waste from the agriculture industry (Shafigh *et al*., 2011; Shafigh *et al*., 2014; Aslam *et al*., 2016; Mannan *et al*., 2006), using aggregate from plastic waste (Alqahtani *et al*., 2017; Akcaozoglu *et al*., 2010; Castillo *et al*., 2020), using pumice aggregate (Pujianto and Prayuda, 2021; Rashad, 2019; Karthika *et al*., 2021), using recycled aggregate (Hassan *et al*., 2015; Posi *et al*., 2013; Saha *et al*., 2021), and using expanded clay aggregate (Ahmad *et al*., 2019; Ahmad and Chen, 2019; Rumsys *et al*., 2017).

Lightweight cement-based materials have recently been the focus of research on lightweight materials for concrete production. This project aims to develop cement substitutes that can provide lightweight concrete and reduce the consumption of Portland cement, whose production process emits excessive amounts of carbon dioxide (Liu *et al*., 2021; Pelisser *et al*., 2012). There are several studies on lightweight cement-based materials, some of which use cenosphere and fly ash (Arunachalam *et al*., 2023; Kavinkumar *et al*., 2023; Souza *et al*., 2019; Chen and Huang, 2019; Shi *et al*., 2022; Hanif *et al*., 2017; Brooks *et al*., 2021; Aungatichart *et al*., 2022), pumice powder (Hossain, 2004; Kurt *et al*., 2016), nano-silica materials (Sikora *et al*., 2020; Du *et al*., 2015; Adhikary *et al*., 2021; Elrahman *et al*., 2019; Adhikary *et al*., 2020; Gayathiri and Praveenkumar, 2022; Zhang *et al*., 2018). Using cement-based materials can produce lightweight concrete that is environmentally friendly, of high quality, and similar to normal concrete. However, when compared to conventional concrete or lightweight concrete using coarse aggregate replacement, the manufacturing process for lightweight concrete employing cement-based material replacement requires skills, a high level of accuracy, and higher production costs.

Each alternative material for lightweight concrete has different advantages and disadvantages. Producing lightweight concrete from plastic waste requires a long process to produce aggregates that can be used as lightweight raw material. Additionally, the utilization of agricultural waste is still debatable due to its durability and resistance to fire. This research aims to utilize expanded clay aggregate as a lightweight artificial aggregate to produce more sustainable and environmentally friendly lightweight concrete. There is research on expanded clay aggregate for light concrete, focusing on physical and mechanical properties (Campione *et al*., 2001; Kulkarni and Muthadhi, 2020; Dabbaghi *et al*., 2021) and durability (Hubertova and Hela, 2013; Nahhab and Ketab, 2020; Nawel *et al*., 2017). Based on the results of said research, it can be concluded that this expanded clay aggregate material is suitable for use in the production of lightweight concrete. In addition, using this material can improve thermal performance, which may reduce energy consumption in civil infrastructures (Vijayalakshmi and Ramanagopal, 2018). However, the compressive strength obtained is always lower than that of normal concrete. Some research has been conducted on utilizing the combination of expanded clay aggregate and other light materials, such as expanded glass aggregate (Rumsys *et al*., 2018; Adhikary *et al*., 2020; Augonis *et al*., 2022), metakaolin, silica fume, and fly ash (Tawfik *et al*., 2021; Vivek *et al*., 2022; Mohammed *et al*., 2022). It has also been determined that expanded clay aggregate could be combined with other materials, but several studies have found that the clay source and processing method significantly affect the performance of lightweight concrete.

Although expanded clay aggregate has been widely accepted by the research community as one of the materials for producing lightweight concrete, its effectiveness is significantly affected by various factors, with the manufacturing method being the most important. In addition, it is suspected that the shape and size of expanded clay aggregate influence the engineering properties of lightweight concrete, and admixtures are frequently used to improve the properties of concrete by enhancing workability and accelerating performance. The effect of admixtures on the properties of lightweight concrete made with expanded clay aggregate has not been thoroughly investigated. Due to this lack of information, it is necessary to conduct additional research on the effect of the aggregate shape and the effect of admixtures on the engineering properties of lightweight concrete made from expanded clay aggregate.

This research consists of three series based on several mix proportions. The first series focuses on the effect of the three different clay aggregate shapes: cubic, oval, and round. It should be noted that the manufacturing method is identical for all shapes, with grain distributions ranging from 5 to 20 mm. In addition, the source of the clay employed in this research is Yogyakarta, Indonesia. It should be emphasized that the location from which the clay is collected, as well as its type, significantly affects the aggregate production process and the properties of concrete. Thus, the novelty of this study is the use of three shape variations of expanded clay aggregate from the Yogyakarta area.

The second series evaluates the effects of superplasticizers on the properties of lightweight concrete. The studied variations were 0, 1, 1,5, 2, and 2,5%. Compressive and split tensile strength testing constituted the majority of the tests conducted in this research. In addition, a slump test was carried out to determine workability and mass density. This, in order to manage the index level of the lightweight concrete produced.

Series III focuses on the index corresponding to the development of split tensile and compressive strength in relation to the age of concrete. Here, a compressive strength conversion factor is generated for a specific age. The conversion factor of concrete properties to age has been commonly utilized for normal concrete, but it has not been studied for lightweight concrete made from expanded clay aggregate. Therefore, this study aims to establish a correlation between the age and the properties of lightweight concrete, such as compressive and split tensile strength, as there is no previous research in this regard. Given the relationship between the age of concrete and its properties, it is expected that it will no longer be necessary to conduct compressive strength tests with various ages in the future. Thus, it is possible to reduce the number of specimens in order to evaluate, based on age, the compressive and split tensile strength of lightweight concrete including expanded clay aggregate.

Experimental program

Materials

The materials used in this study were cement, water, fine aggregate, coarse aggregate, and superplasticizer. The cement used in this study was in line with the ASTM C150 standard, *i.e.*, type 1 cement (ordinary Portland cement) (ASTM International, 2015). The fine aggregate used in this study was river sand from Kali Progo, Yogyakarta, Indonesia. Its physical and mechanical properties were examined before use as a constituent material of concrete. The evaluated mechanical parameters were water content, absorption, specific gravity, and mud content. The results are summarized in Table 1. In addition, the fine aggregate's grain particle size distribution was measured (Figure 1). These measurements were taken based on ASTM C136 (ASTM International, 2019a).

Table 1. Properties of the fine aggregate

Properties	Value
Specific gravity	2,45
Water absorption (%)	2,57
Water content (%)	2,22
Mud content (%)	2,00
Mass density (g/cm^3)	1,52
Fineness modulus	2,38

Source: Authors

Lightweight expanded clay aggregate (LECA) was the coarse aggregate employed in this study. The source of this clay is Sleman, Yogyakarta, Indonesia. As mentioned before, our research comprised three series. The first was focused on coarse aggregate shapes, *i.e.*, cubic, oval, and round. Meanwhile, series II and III only employed round coarse aggregate. Figure 2 shows the shape of each aggregate. The production process of expanded clay aggregate began by mixing clay with sufficient water. The same amount of water was used for each aggregate shape. The dough was then molded into the desired size, with the aggregate size distribution ranging between 5 and 20 mm. The aggregate was then burned at temperatures between 800 and 1 200 °C. Subsequently, the properties of the coarse aggregate were evaluated, *i.e.*, specific gravity, water content, water absorption, density, mud content, and roughness level. The results regarding these properties are displayed in Table 2 for all shapes.

In addition, the effect of admixtures was explored in this study. The superplasticizer used was either Viscocrete 3115N from SIKA or type D superplasticizer for water reduction and retarding, in accordance with ASTM C494 (ASTM International, 2019b).

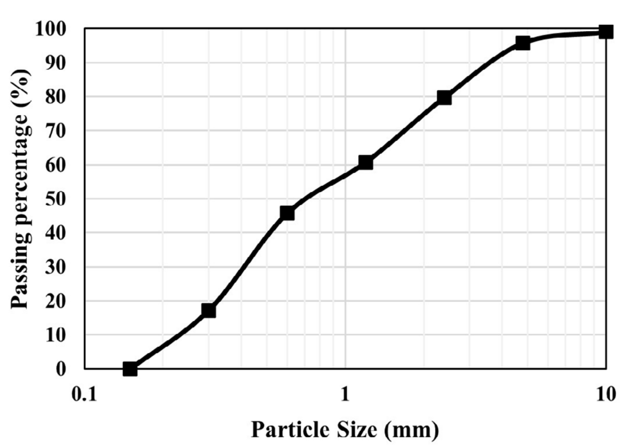

Figure 1. Size distribution of the fine aggregate
Source: Authors

Figure 2. Shape of the coarse aggregates
Source: Authors

Table 2. Properties of the coarse aggregate

Properties	Value
Specific gravity	1,98
Water absorption (%)	18,91
Water content (%)	1,67
Mud content (%)	2,00
Mass density (g/cm^3)	0,98
Roughness (%)	94,00

Source: Authors

Mix proportions

This research aimed to evaluate the effect of aggregate shape, admixtures, and age on concrete. Table 3 shows the mix proportions for series I. Table 4 presents the mix proportions for series II, which corresponds to the amount of superplasticizer used. The superplasticizer percentage was derived from the total binder used to cast the specimen.

Table 3. Mix proportions for series I

ID	SI.A	SI.B	SI.C
Aggregate shape	Cubic	Oval	Round
Cement (kg/m^3)	342,41	342,41	342,41
Fine aggregate (kg/m^3)	679,02	679,02	679,02
Coarse aggregate (kg/m^3)	918,67	918,67	918,67
Water (l)	184,90	184,90	184,90

Source: Authors

Table 4. Mix proportions for series II

ID	SII.A	SII.B	SII.C	SII.D	SII.E
Superplasticizer (%)	0	1	1,5	2	2,5
Cement (kg/m^3)	342,41	342,41	342,41	342,41	342,41
Fine aggregate (kg/m^3)	679,02	679,02	679,02	679,02	679,02
Coarse aggregate (kg/m^3)	918,67	918,67	918,67	918,67	918,67
Water (l)	184,90	147,92	147,92	147,92	147,92

Source: Authors

Table 5 shows the mix proportions used in examining the development of concrete's mechanical properties with age. In series II and III, expanded round clay aggregate was employed. It should be noted that all test objects were cured with water before testing.

Table 5. Mix proportion for Series III

ID	SIII.A
Superplasticizer (%)	0
Cement (kg/m^3)	342,41
Fine aggregate (kg/m^3)	679,02
Coarse aggregate (kg/m^3)	918,67
Water (l)	184,90
Aggregate shape	Round

Source: Authors

Test method

This study included four tests: a fresh properties (workability) test, a density test, a compressive strength test, and a splitting tensile strength test. The slump test was performed in series I and II, but not in series III, since it utilized the same proportion of materials as the ID SII.A specimens. The slump test followed ASTM C143 (ASTM International, 2020), the standard test procedure for slump testing in hydraulic cement concrete. Moreover, a density test was conducted on 28-day-old concrete that had already solidified and aimed to determine whether the concrete mass met the requirements for lightweight concrete. This test followed ASTM C642 (ASTM International, 2021) and was only performed on series I and II specimens.

In this study, compressive and splitting tensile strength tests were conducted for all series. They were carried out with 28-day-old concrete in series I and II, whereas, in series III, age variations of 3, 7, 14, 21, and 28 days were examined. The dimensions of the cylindrical specimen for compressive strength testing were 10 x 20 cm, while that for split tensile strength had dimensions of 15 x 30 cm. The average of the three specimens is obtained from each variation in compressive and splitting tensile strength. There are 18 specimens in series I, 30 in series II, and 30 in series III.

Thus, a total of 78 specimens were used in this study, out of which 39 were used to measure compressive strength and the other half to measure splitting tensile strength. This study followed the ASTM C39 standard for compressive strength testing (ASTM International, 2021), with a constant loading rate of 0,15 MPa/sec, as well as ASTM C496 for splitting tensile strength testing (ASTM International, 2017b), with a constant loading rate of 0,7 MPa/sec. To preserve the hydration process, all cast specimens underwent water curing for 28 days. Additionally, all specimens were placed in a controlled room with a fixed temperature and relative humidity during the curing process.

Results and discussion

Influence of the coarse aggregate shape

Various studies regarding the effect of expanded clay aggregate size have been carried out by several researchers (Ozguven and Gunduz, 2012; Rashad, 2018). However, there is limited information regarding the effect of LECA shapes on the engineering properties of concrete. As previously mentioned, this study examines this effect on the properties of lightweight concrete. These experiments were conducted since expanded clay aggregate is typically produced with a uniform shape but with different sizes.

Four types of tests were carried out in this regard: a slump test, density test, a compressive strength test, and a splitting tensile strength test. Figure 3 shows the fresh concrete slump test results for series I, indicating that the aggregate shape does not affect the slump value. This is due to the fact that the three mix proportions used are identical, except for the aggregate shape. The specimens in series I (with a round coarse aggregate, SI.C) yield lower slump values compared to other shapes (cubic and oval), but the difference is insignificant. Therefore, it can be concluded that the shape of the expanded clay aggregate has no significant effect on the slump value of fresh concrete.

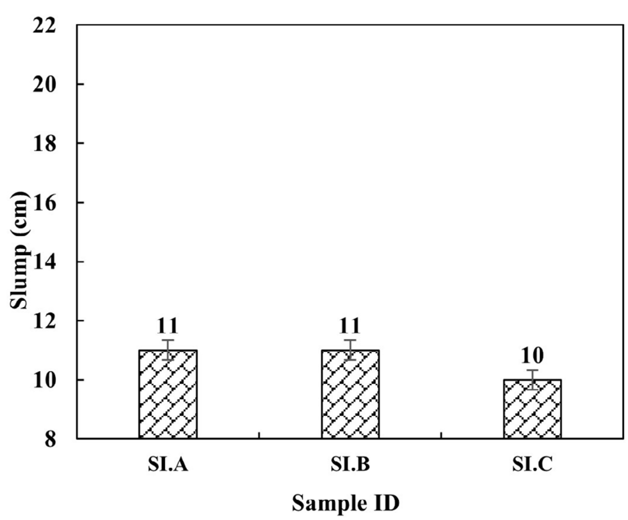

Figure 3. Slump results for series I
Source: Authors

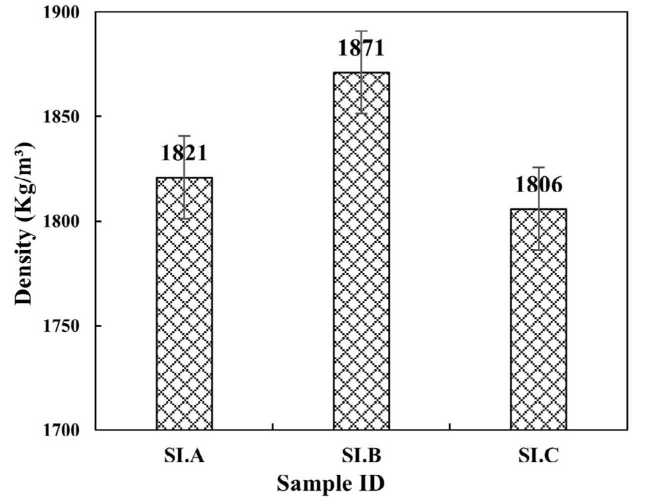

Figure 4. Density results for series I
Source: Authors

Density is a key aspect in determining the classification of concrete. Lightweight concrete corresponds to density values ranging from 320 to 1 920 kg/m^3. This, according to ACI 213 and ASTM C330 (ACI Committee, 2014; ASTM International, 2017a). The results of the laboratory tests indicate that all specimens in series I correspond to lightweight concrete (Figure 4). The SI.B specimens (utilizing oval expanded clay aggregates) reported the highest density compared to other specimens. Nonetheless, the density of SI.B does not exceed 1 900 kg/m^3. In contrast, SI.C specimens (with round expanded clay aggregate) showed the lowest density: only 1 806 kg/m^3. The difference in hardened density between these samples may be due to the influence of the expanded clay aggregate's size and shape. However, these differences are not significant, and all specimens can be classified as lightweight concrete.

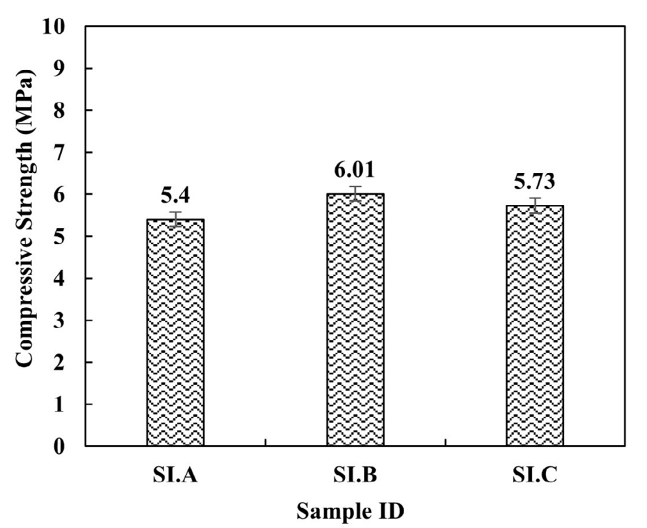

Figure 5. Compressive strength for series I
Source: Authors

Figure 5 shows the compressive strength of concrete after 28 days, with a comparison regarding the coarse aggregate shape. These values range between 5 and 6 MPa. Series I used the same mix proportions for all specimens, but a different aggregate shape. No additional superplasticizer was used in this series. This demonstrates that the aggregate shape has no significant effect on the compressive strength of 28-day-old concrete. Th oval expanded clay aggregate provided the specimens with the highest compressive strength, while the round coarse aggregate reported the specimens with the lowest values. This is because round coarse aggregates have a weaker compressive stress resistance compared to those with cubic and oval shapes, which are more stable in withstanding compressive forces.

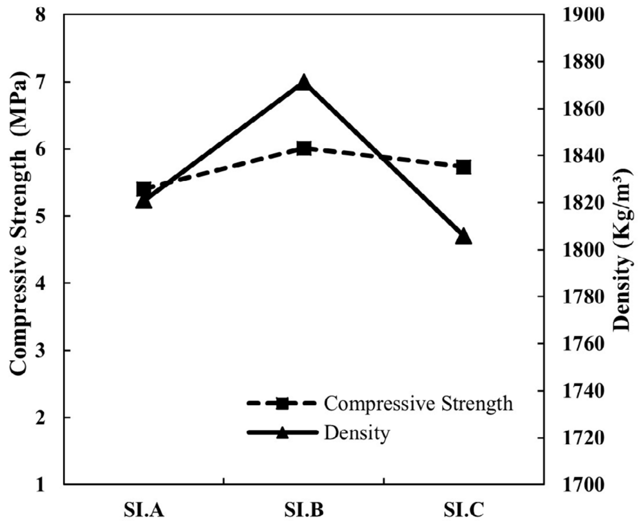

Figure 6. Comparison between compressive strength and density for series I
Source: Authors

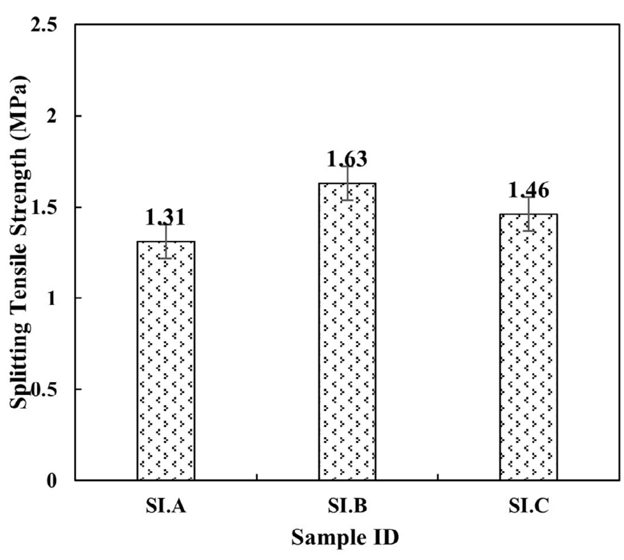

Figure 7. Splitting tensile strength for series I
Source: Authors

This study also evaluated the relationship between compressive strength and concrete density. Figure 6 shows a comparison between compressive strength and density with different coarse aggregate shapes. At the age of 28 days, a high density provides a higher compressive strength, specifically in specimens with oval coarse aggregates. This is due to the influence of concrete density. Consequently, the greater the density, the smaller the pore volume, and *vice versa*. Thus, higher density concrete has higher compressive strength, even with the same mix proportions. Figure 7 provides information about another test regarding hardened qualities, which involved the splitting tensile strength after 28 days. The results show a linear trend comparable to that of the compressive strength, with the highest values obtained by concrete with oval particles. This indicates that the oval aggregate is more resistant to load deformation than the other shapes evaluated.

Influence of chemical admixture

This research also studied the effect of admixture addition on lightweight concrete's fresh and hardened properties. The corresponding experiments used a homogeneous spherical aggregate with dimensions ranging from 5 to 20 mm. After 28 days, concrete was subjected to testing with regard to its hardened properties. Figure 8 shows results of the slump test for series II concrete, which was conducted to examine the influence of chemical admixture. These results indicate a significantly increased slump value due to the additional superplasticizer. It should be noted that, in this variation, the water content was reduced by 20% when compared to normal concrete without a superplasticizer. However, this test demonstrates that superplasticizers can improve the performance of fresh concrete by increasing workability. Previous studies have shown similar results, even with different types of superplasticizers. According to them, increasing the amount of superplasticizer increases the fluidity of fresh concrete (Nahhab and Ketab, 2020; Nepomuceno *et al.*, 2018; Tang *et al.*, 2020).

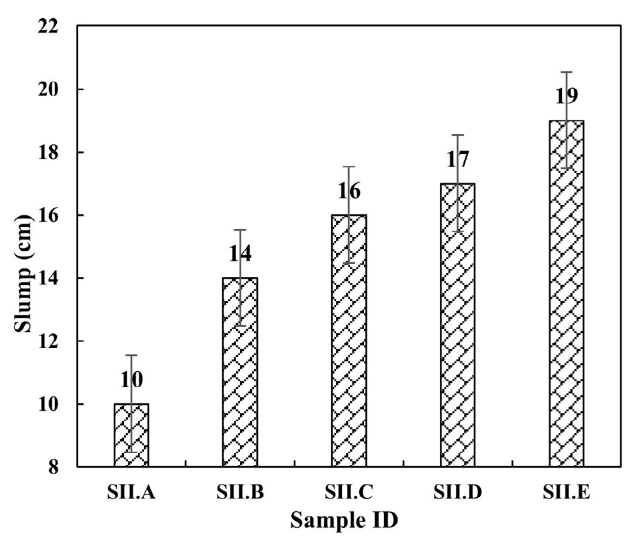

Figure 8. Slump results for series II
Source: Authors

The results of the density examination carried out for each specimen in series II are shown in Figure 9. Here, the density of hardened concrete with chemical admixture ranges from 1 750 to 1 850 kg/m³. This shows no significant differences in the density of each specimen when compared to normal concrete without admixture (SII.A). However, with respect to concrete made with oval and cubic coarse aggregate, the density of concrete made with this superplasticizer is significantly lower. In addition, all specimens containing this superplasticizer were classified under the lightweight concrete category. The relationship between the compressive strength of concrete and the amount of admixture after 28 days can be seen in Figure 10.

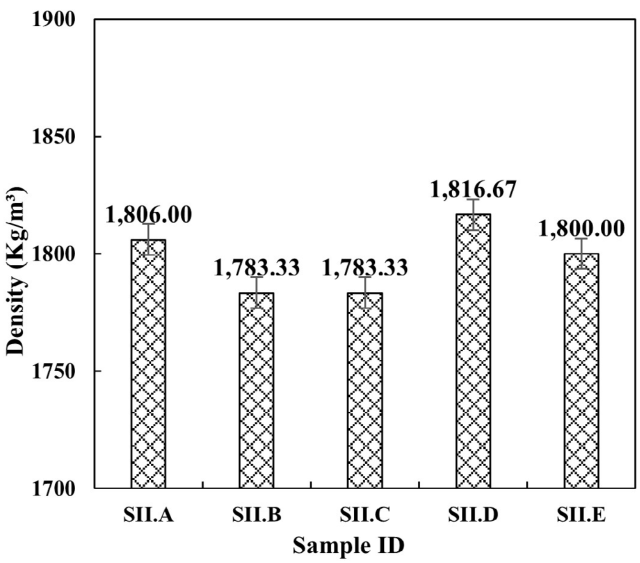

Figure 9. Density results for series II
Source: Authors

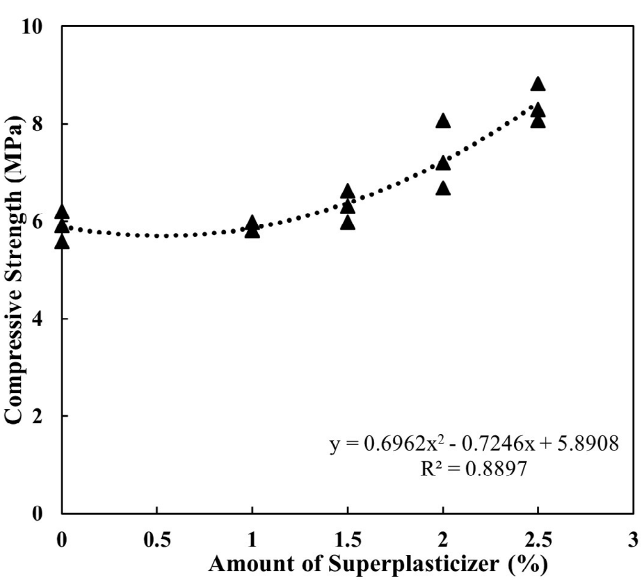

Figure 10. Compressive strength after 28 days for series II
Source: Authors

Curve fitting with polynomial regression is an efficient and simple method to study the relationship between the engineering properties of concrete, its age, and the amount of superplasticizer used. This approach has also been used in previous research to evaluate the effects of superplasticizers on the compressive and split tensile strength of concrete (Gu *et al.*, 2021; Faraj *et al.*, 2022a, 2022b, 2022c), as well as the effects of age on these properties (Varga *et al.*, 2012; Elaty, 2014). Our analysis determined a polynomial relationship with a correlation coefficient of 0,8897 (88,97%). This value indicates a significant relationship between the compressive strength of concrete and the amount of superplasticizer used. The test findings indicate that compressive strength increased along with the amount of superplasticizer. One of the factors contributing to this trend is the decreased proportion of water in the mixture (due to the use of a superplasticizer). Note that reducing the water content of concrete decreases the water-to-binder ratio, and cement requires a minimal amount of water to react. Due to evaporation during the hydration process, water is retained in the concrete when a sufficient volume is used. This allows it to expand the pores upon evaporation, resulting in a decreased compressive strength. However, water is required for the processing of fresh concrete. With the aid of this additive ingredient, the amount of water can be reduced significantly, and fresh concrete can become more plastic.

Figure 11 illustrates the results obtained regarding the splitting tensile strength of 28-day-old concrete with various concentrations of superplasticizer. The correlation coefficient between the splitting tensile strength and the amount of admixture is relatively high, reaching 95,10%. The trend identified in our study indicates that tensile strength increases along with the amount of superplasticizer. This pattern closely resembles the compressive strength testing results. It is important to recall that the addition of superplasticizers can help to reduce the water content: even though the density of concrete decreases, its compressive and splitting tensile strength increase, as less water is trapped in it and the volume of the pores is reduced. Increasing the amount of superplasticizer also increases the workability of the concrete, resulting in a more uniform aggregate distribution. This is extremely helpful for the production of lightweight, high-performance concrete. It should be noted that the resulting compressive strength is still lower than that of conventional concrete made with coarse aggregate from natural resources such as rock. However, this lightweight aggregate can also be utilized in various non-structural concrete constructions.

Influence of the age of concrete

According to our results, compressive strength increases with age (Figure 12). This resembles the patterns shown by concrete with typical aggregate.

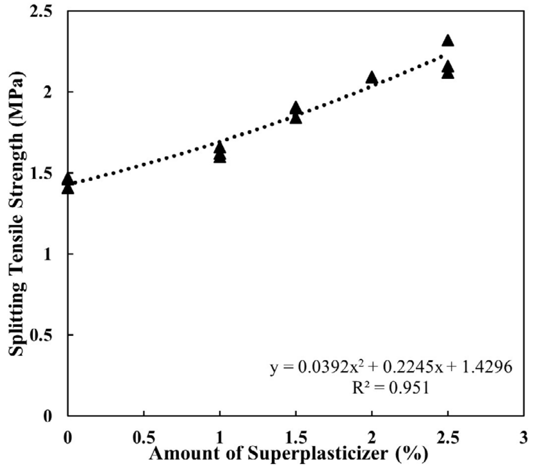

Figure 11. Splitting tensile strength after 28 days for series II
Source: Authors

Table 6. Strength increase rate

Concrete age (Days)	3 to 7	7 to 14	14 to 21	21 to 28
Compressive strength (%)	59,24	23,14	15,99	10,51
Splitting tensile strength (%)	71,42	21,12	17,44	5,49

Source: Authors

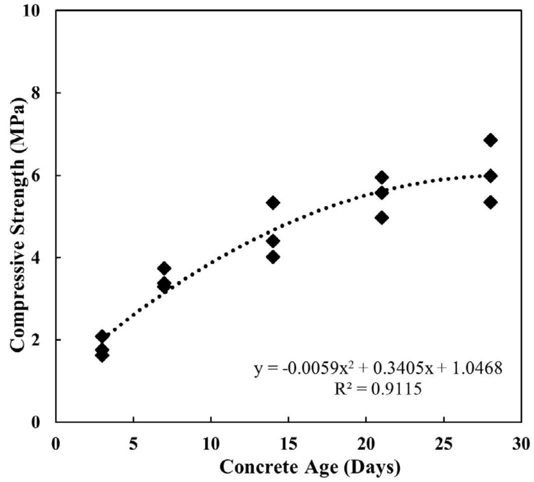

Figure 12. Relationship between age and compressive strength (series III)
Source: Authors

The relationship between age and splitting tensile strength is presented in Figure 13, and the evolution of compressive and splitting tensile strength is shown in Table 6. These findings indicate that the splitting tensile strength of concrete increases with age. Furthermore, the strength increase rate decreases with age, which is caused by the nearly complete hydration of the concrete, whose strength approaches ideal conditions. The conversion factor for the compressive and splitting tensile strength at a given age is presented in Table 7. With this factor, there will be no need to test for age differences, thus reducing the number of required samples during experimentation. This conversion factor applies to three shapes of expanded clay aggregate: cubic, oval, and round. There is a need for additional study on a more effective formula for producing improved hardened properties, such as compressive and splitting tensile strength. In addition, future studies aiming to use this aggregate for structural components must also conduct another types of experiments, such as flexural strength testing.

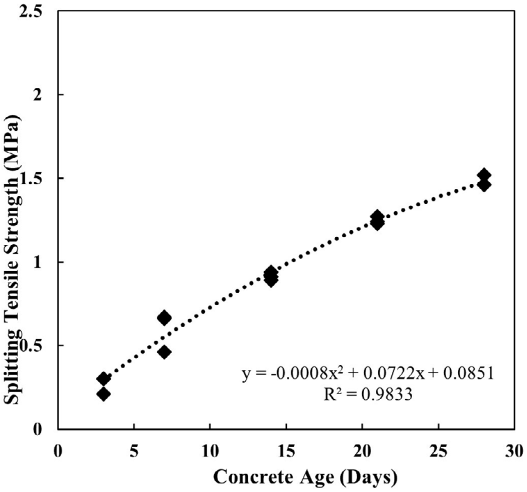

Figure 13. Relationship between age and splitting tensile strength (series III)
Source: Authors

Table 7. Conversion factor regarding compressive and splitting tensile strength

Concrete age (Days)	3	7	14	21	28
Compressive strength	0,30	0,57	0,76	0,91	1,00
Splitting tensile strength	0,18	0,40	0,62	0,84	1,00

Source: Authors

Several specimens are shown in Figure 14 after testing. It is evident that the expanded clay aggregate component of the specimen can fail, alongside the surface mortar area. As a result, a compressive strength that is often lower than that of normal concrete is reported.

Figure 14. Specimens after testing
Source: Authors

Conclusions

Based on the results and discussion, the following conclusions can be drawn.

1. The shape of expanded clay aggregate affects the qualities of hardened concrete. However, the obtained difference is insignificant. An oval aggregate improves the compressive and splitting tensile strength.

2. The incorporation of superplasticizers can lower the amount of water required for the casting of concrete. This reduces the amount of water consumed while improving the workability of fresh properties. In addition, the decrease in water content increases the compressive and flexural strength of lightweight concrete and decreases its density.

3. This study presents a conversion factor for predicting the compressive and splitting tensile strength of lightweight concrete made with expanded clay aggregate.

4. Using expanded clay aggregate as the coarse aggregate in concrete can result in the production of lightweight concrete.

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CRediT author statement

As'at Pujianto: conceptualization, data curation, funding acquisition, methodology, supervision, writing (review and editing). *Hakas Prayuda*: data curation, project administration, writing (review and editing). *Farrel Asani*: data curation, investigation, writing (original draft). *Muji Basuki Santoso*: data curation, investigation, writing (original draft). *Fahriza Wirawan*: data curation, investigation, writing (original draft).

Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Not applicable.

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