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Research Article

# ANALYSIS OF THE EFFECT OF ADDING GLASS POWDER WASTE AS A CEMENT SUBSTITUTION AND THE USE OF PUMICE AGGREGATE ON THE COMPRESSIVE STRENGTH OF LIGHT CONCRETE

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## Abstract

Along with the increasing demand for building materials and the high cost of cement, innovation in the use of environmentally friendly and economical alternative materials is essential. Glass powder waste, which is difficult to decompose and potentially pollutes the environment, has potential as a cement substitute due to its favorable physical and chemical properties. Additionally, pumice, as a lightweight aggregate, can reduce the structure's dead load and improve construction efficiency. This study aims to analyze the effect of adding glass powder waste as a cement substitute and using pumice aggregate on the compressive strength of lightweight concrete. Glass waste sourced from industrial and household origins was used as a partial replacement for cement, while pumice served as a substitute for coarse aggregate. The study employed an experimental method, with laboratory testing focused on compressive strength measurements. The results showed that the addition of glass powder at a certain percentage resulted in higher compressive strength compared to concrete without glass powder This suggests that the combination of glass powder and pumice stone can significantly increase the compressive strength of light concrete, although the efficiency of the mixture decreases at higher percentages. This research offers a practical alternative for utilizing local waste and natural aggregates in the development of concrete that is both environmentally sustainable and economically efficient.

**Keywords**: light concrete, glass powder, pumice, compressive strength, cement substitution.



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## INTRODUCTION

Concrete is a building material formed from a mixture of several main components, namely cement, fine aggregate, coarse aggregate, water, and can also contain additional materials (admixture) (Ndububa, 2022). Nowadays, the development of material technology continues to experience significant progress. This is driven by the demand for materials that have specific properties and characteristics as needed. Along with the increasing pace of development, the public's demand for building materials, including cement, the main component in construction work, continues to grow. The increase in cement consumption led to a rise in market prices. This condition encourages researchers to seek alternative materials to replace cement that are more affordable yet maintain quality, one of which is the utilization of glass waste (Claisse, 2016).

Glass waste is a type of waste from household and industrial activities that is difficult to decompose naturally. If the number continues to increase without proper management, this waste can lead to environmental pollution. However, glass has the potential to be reused, one of which is as an additional material in the manufacture of concrete. This is due to the properties of glass that is resistant to extreme weather and chemical attacks so that it can make a positive contribution to the durability of concrete (Ani, 2022).

On the other hand, the use of concrete with lightweight aggregates in modern construction is increasingly in demand because it offers a variety of advantages. However, in Indonesia, the use of pumice stone as a lightweight aggregate is still relatively limited and has not been fully developed. Replacing conventional coarse aggregate with light aggregate, such as pumice stone, in concrete mixtures can reduce dead loads, improve construction execution efficiency, and maintain economical costs. Additionally, pumice exhibits good thermal properties due to its relatively low thermal conductivity, (Widodo, 2014). One alternative to using a pumice stone is to use it as a partial substitute for coarse aggregate in the manufacture of concrete.

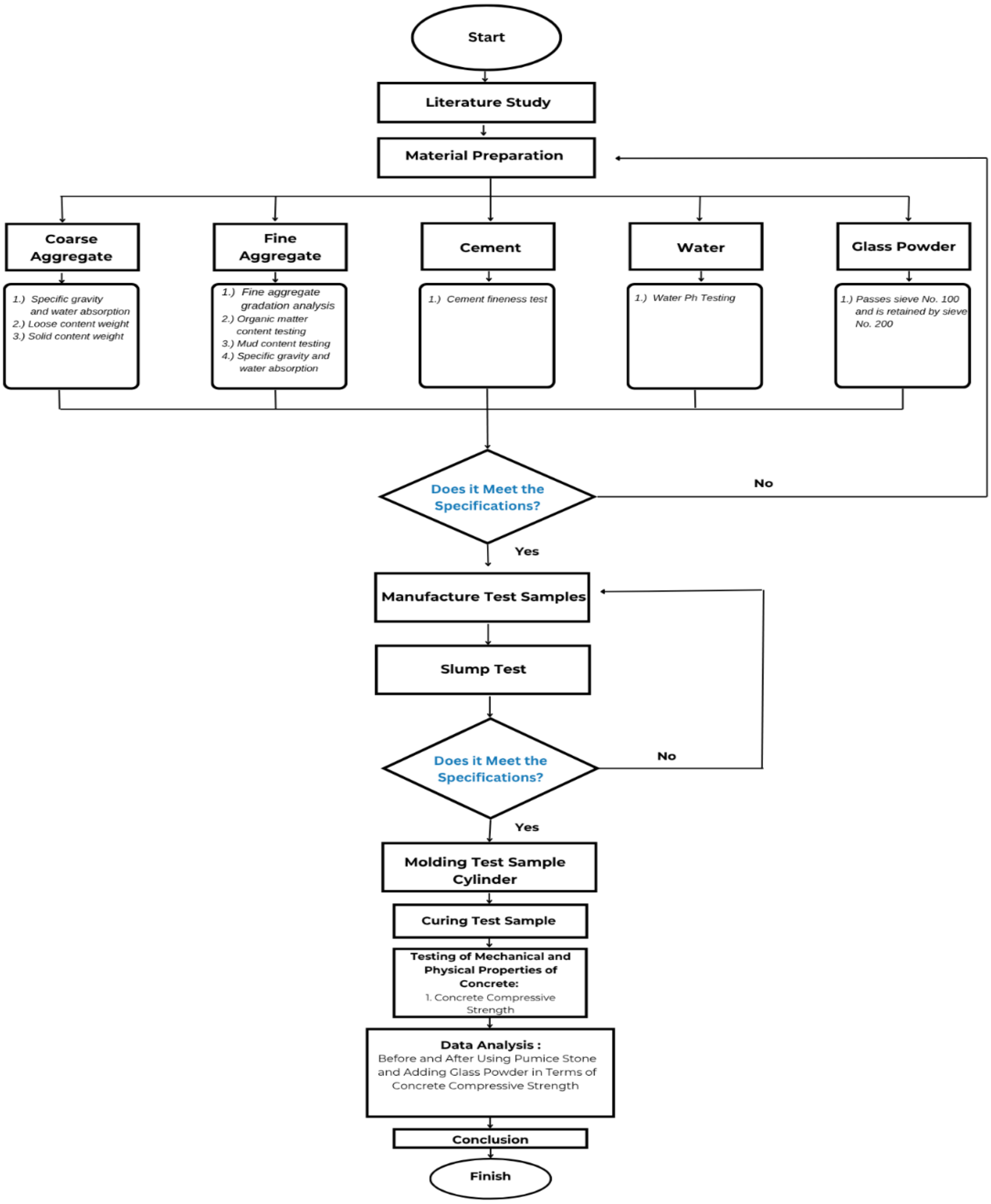
Based on this background, this study will investigate the use of pumice stone as a substitute for some of the coarse aggregate used in making concrete, as well as the addition of glass as a cement substitute with varying percentages of use (0%, 5%, 10%, and 15%). This study aims to analyze the effect of using glass powder as a cement substitute on the compressive strength of lightweight concrete using pumice aggregate, and to determine the optimal composition that yields the highest strength. In addition, the research compares the compressive strength of lightweight concrete with and without glass powder to comprehensively evaluate its effectiveness. Therefore, this study can be applied within the construction industry as a potential solution to the challenges encountered in the development of modern infrastructure.

## RESEARCH METHOD

The research method for producing lightweight concrete using pumice stone with added glass powder is an experimental method (Teng, 2023) , where testing is carried out directly at the Material Technology Laboratory of Swadaya Gunung Jati University. The subjects analyzed in this study are concrete mixed materials which include water, cement, coarse aggregate of pumice, fine aggregate and additional variables in the form of glass powder as a cement substitution with variations of 0%, 5%, 10%, and 15%. The research consists of 3 stages of testing. In the initial stage, main material testing was carried out. The second stage involved mix design for the manufacture of 24 test pieces using K125 light concrete. The third stage entailed testing the compressive strength of the light concrete.

Determine sampling was carried out using a purposive sampling technique, where the concrete mix variations were deliberately chosen based on the research objectives, which were to observe the effect of glass powder percentage on the compressive strength of concrete. The data collection techniques involved laboratory testing, including compressive strength tests, slump tests, and unit weight measurements. All tests were conducted in accordance with applicable national standards. Meanwhile, the SNI uses SNI 03-3449-2002, concerning Procedures for the Preparation of Lightweight Concrete Mixtures with Light Aggregates, and SNI 03-3402-2008, concerning Methods of Testing the Weight of Structural Lightweight Concrete Contents (Xia, 2020). The stages of research implementation in the following flowchart and explanation:

Figure 1. Research flow diagram




**Preparation of Lightweight Concrete Materials**

During the material preparation phase, all essential components of the concrete mixture must be carefully selected and prepared. These include fine aggregate, coarse aggregate, cement, water, and supplementary materials if applicable. In this study, pumice and glass powder are employed as alternative materials due to their potential to enhance concrete properties through a sustainable substitution approach.

**Characterization of Concrete Materials**

Prior to the mixing process, the raw materials are subjected to standardized laboratory tests to ensure their suitability and compliance with relevant specifications. For the coarse aggregate (pumice), tests are conducted to determine specific gravity, water absorption, loose bulk density, and compacted bulk density. For the fine aggregates (cement and sand), tests include cement fineness, particle size distribution of sand, specific gravity, water absorption, organic impurities, and silt content. The glass powder is sieved to ensure it passes through the No. 100 sieve and is retained on the No. 200 sieve, thereby maintaining consistency in particle size.

**Fabrication of Test Specimens**

In the preparation of concrete test specimens, the required materials include water, cement, sand, pumice, and glass powder as an additive. Following the completion of material characterization, the specimen fabrication process begins by preparing all necessary equipment and weighing each material according to the predetermined concrete mix design.

Initially, pumice, cement, and sand are dry-mixed until a uniform blend is achieved. Water is then gradually introduced into the mixer while mixing continues until a homogeneous mixture is formed. Once thoroughly mixed, the fresh concrete is removed from the mixer for workability testing using the slump test method. The mixture is placed into the slump cone in three equal layers, each compacted using a tamping rod and lightly tapped along the sides of the cone to reduce entrapped air. After filling, the cone is carefully lifted, and the slump value is measured using a straightedge.

Once the slump value has been recorded, the fresh concrete is placed into cylindrical molds in three equal layers. Each layer is compacted using a tamping rod and the mold's outer surface is tapped gently with a rubber mallet to eliminate air voids and ensure full compaction. Each specimen is labeled with a date or identification code. After 24 hours, the specimens are demolded and weighed to determine their individual masses before being placed in the curing tank.

**Curing of Specimens**

Curing is performed by submerging the test specimens in a water tank located at the Materials Technology Laboratory, Civil Engineering Study Program, Faculty of Engineering, Swadaya Gunung Jati University. Immersion begins once the specimens reach their final set. The curing process is critical for promoting optimal hydration, which directly contributes to the development of compressive strength and the durability of the concrete.

**Compressive Strength Testing**

The objective of the compressive strength test is to determine the concrete's ability to resist compressive loads at the ages of 14 and 28 days. This property serves as the primary parameter in evaluating concrete performance. The testing procedure begins by removing the test specimens from the curing tank one day prior to testing. The following day, the specimens are surface dried, weighed, and capped. After capping, the specimens are placed in the compressive strength testing machine. The machine is then operated until the specimen fails, and the maximum load applied is recorded. The compressive strength is calculated based on the recorded load, and all results are documented for analysis.

In this study, three specimens were prepared for each glass powder mixture variation at two curing ages, 14 and 28 days. The identification codes for each specimen are presented in the following table :

Table 1. Test band code

| No. | Percentage subs. Glass Powder (%) | Age (Days) | Sample Test Code | Total Samples |
|---|---|---|---|---|
| 1 | 0% | 14 | A1-0, A2-0 | 3 |
| | | 28 | A11-0, A12-0, A13-0 | 3 |
| 2 | 5% | 14 | A3-5, A4-5, A5-5 | 3 |
| | | 28 | A14-5, A15-5, A16-5 | 3 |
| 3 | 10% | 14 | A6-10, A7-10 | 3 |
| | | 28 | A17-10, A18-10, A19-10 | 3 |
| 4 | 15% | 14 | A8-15, A9-15, A10-15 | 3 |
| | | 28 | A20-15, A21-15, A15-15 | 3 |

## RESULTS AND DISCUSSION

This research was carried out carefully and systematically, by conducting a series of tests in the laboratory of Gunung Jati Swadaya University. Each test will produce data that is used as the basis for the analysis, which will be described in the following section to determine the compressive strength value of concrete.

### *Material testing*

Inspection of Rough Aggregate (Pumice)

Testing of aggregates in the form of pumice stone is carried out in the laboratory to determine its physical and mechanical characteristics as a substitute material for coarse aggregates in concrete mixtures. Pumice stone has a crucial role in determining the strength of concrete, so a comprehensive series of tests are required, including tests of specific gravity, water absorption, loose fill weight, and solid content weight. The results of the coarse aggregate testing of pumice are presented in the following description.

Table 2. Pumice rock rough aggregate test results

| Description | Requirement | | Result | Unit | Specification |
|---|---|---|---|---|---|
| | Standard Value | Standard Requirement | | | |
| Specific Gravity (B/B-Ba) | 1.0 - 1.8 | SNI 03-4804-1998 | 1.09 | gram/cm$^3$. | Accepted |
| Water Absorption ((B-A)/AX100%) | ≤ 3 | SNI 03-1970-2008 (BS 8007) | 1.91 | % | Accepted |
| Loose Fill Weight | ≤ 1.10 | SNI 03-2847-2002 | 0.349 | gram/cm$^3$. | Accepted |
| Solid Fill Weight | ≤ 1.10 | | 0.419 | gram/cm$^3$. | Accepted |

Fine Aggregate Inspection (Cement and Sand)

Testing of fine aggregates includes gradation analysis with a sieve, cement fineness, organic matter content, sludge content, as well as specific gravity and water absorption testing. The results of each fine aggregate test are presented as follows.

Table 3. Fine aggregate testing results of cement and sand

| Description | Requirement | | Result | Unit | Specification |
|---|---|---|---|---|---|
| | Standard Value | Standard Requirement | | | |
| Fine Modulus of Sand Grains | 1.5 - 3.8 | SNI 03-1990 | 3.32 | % | Accepted |
| Organic Matter Levels of Sand | ≤ 0.5 | SNI 03-2816-1992 | 0.0 | % | Accepted |
| Sand Sludge Substance Levels | ≤ 5 | SKNI S- 04-1989 | 4.04 | % | Accepted |
| Smoothness of Sieve Cement No.100 | 0 | ASTM C184-66 | 0.0 | % | Accepted |
| Smoothness of Sieve Cement No.100 | ≤ 22 | | 0.038 | % | Accepted |
| Specific Gravity (B/B-Ba) | 2.5 - 2.7 | SNI 03-1970-1990 | 2.513 | $gram/cm^3$. | Accepted |
| Water Absorption ((B-A)/AX100%) | ≤ 3 | SNI 03-1970-2008 | 0.24 | % | Accepted |

**Glass Powder Inspection**

Glass powder used In this study, it comes from crushed glass bottle waste. The examination of the results of the smoothness of the glass powder is carried out by filtering using filters No. 100 and No. 200 where the glass powder used in the concrete mixture uses glass powder that is retained in filter No. 200.

***Mix design***

**Planning of Light Concrete Mix**

After going through the testing stages of the material to be used, the next step is to design the composition of the concrete mixture with reference to SNI 03-3449-2002. The concrete designed in this study is Lightweight Structural Concrete with a target compressive strength of 9.8 MPa, which is equivalent to the quality of K-125. The preparation of the concrete mixture is carried out systematically through calculation stages that follow applicable technical standards, in order to ensure optimal concrete performance.

Table 3. Mix design light concrete

| No | Description | Value | Unit |
|---|---|---|---|
| 1 | Compressive Strength Plan (f'c) | 9.8 | MPa |
| 2 | Standard Deviation (S) | 5.6 | MPa |
| 3 | Added Value (M) | 9.184 | MPa |
| 4 | Average Compressive Strength (f'cr) | 18.98 | MPa |
| 5 | Types of Cement | Portland Type I | |
| 6 | Water Cement Factor (FAS) | 0,60 | |
| 7 | Slump Value | 60-180 | mm |
| 8 | Maximum Aggregate Size | 30 | mm |
| 9 | Wh | 175 | |
| 10 | Wk | 225 | |
| 11 | Free Moisture Content | 191.67 | kg |
| 12 | Quantity of Cement | 319.44 | kg |
| 13 | Minimum Cement Quantity | 275 | kg |
| 14 | Specific Gravity of Fine Aggregate | 2.513 | kg/m3 |
| 15 | Specific Gravity of Coarse Aggregate | 1.09 | kg/m3 |
| 16 | Specific Gravity of Combined Aggregate | 1.645 | kg/m3 |
| 17 | Fine Aggregate Percentage | 39 | % |
| 18 | Coarse Aggregate Percentage | 61 | % |
| 19 | Bulk Density | 1440 | kg/m3 |
| 20 | Combined Aggregate Quantity | 928.89 | kg/m3 |
| 21 | Fine Aggregate Quantity | 362 | kg/m3 |
| 22 | Coarse Aggregate Quantity | 566.62 | kg/m3 |

Composition of Light Concrete Mixture Per m3

Table 4. Light concrete mix per m3

| Volume | Water | Cement | Fine Aggregate | Coarse Aggregate | Total Weight |
|---|---|---|---|---|---|
| 1m3 (kg) | 191.67 | 319.444 | 362.2667 | 566.62 | 1440.003 |

Composition of Light Concrete Mixture 3 Silenderra Test Strips

Table 5. Light concrete mix 3 cylindrical test strip

| Test Sample | Water | Cement | Fine Aggregate | Coarse Aggregate | Total Weight |
|---|---|---|---|---|---|
| 1 | 1.02 | 1.69 | 1.92 | 3.00 | 7.63 |
| 3 | 3.05 | 5.08 | 5.76 | 9.01 | 22.90 |

**Composition of Glass Powder Requirements**

Glass powder used as a cement substitute uses a percentage of 0%, 5%, 10%, and 15% of the weight of cement. The following are the results and recapitulation of the need for glass powder.

Table 6. Glass powder requirements

| Variasi | Number of Samples | Cement (Kg) | Glass Powder (Kg) |
|---|---|---|---|
| A1-0 | 3 | 5.08 | 0 |
| A2-5 | 3 | 5.08 | 0.254 |
| A3-10 | 3 | 5.08 | 0.508 |
| A4-15 | 3 | 5.08 | 0.762 |
| A5-0 | 3 | 5.08 | 0 |
| A6-5 | 3 | 5.08 | 0.254 |
| A7-10 | 3 | 5.08 | 0.508 |
| A8-15 | 3 | 5.08 | 0.762 |
| | **Total** | | 3.048 |

**Cylindrical Specimen Testing**

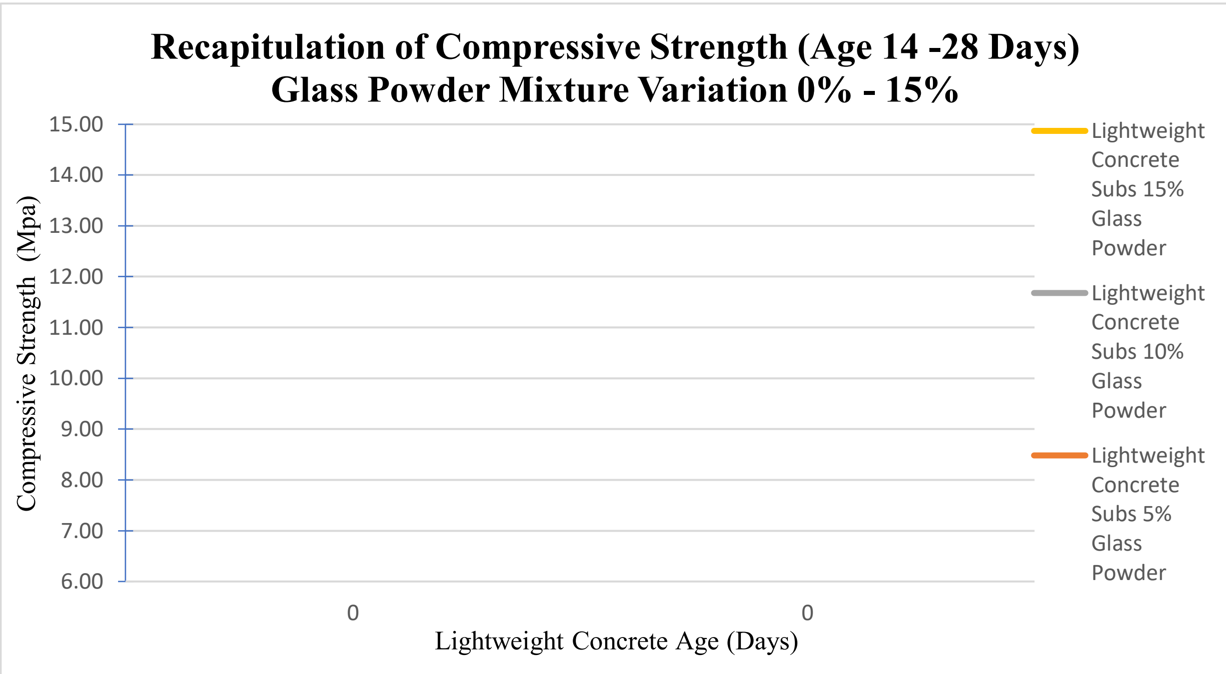
This test is carried out to determine the actual compressive strength of the concrete. The test is carried out by gradually applying maximum load to the test specimen until it is damaged or destroyed, which is when the concrete is no longer able to withstand the load. The planned compressive strength (f'c) in this study was set at 9.8 MPa. The test pieces used were 14 days and 28 days old, with a total of 24 concrete cylinders. The sample consisted of four variations of glass powder content, namely 0%, 5%, 10%, and 15% of the weight of cement, and used pumice stone instead of coarse aggregate. The results of the test value of the average compressive strength of lightweight concrete are presented as follows.

Table 7. Compressive strength value of light concrete age 14 days

| No. | Age | W | Field Area | Load | Weight | Specific Gravity | Compressive Strength | | Mpa | Slump | Sample Code |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | n days | (gr) | cm2 | (kN) | (kg) | | N days (kg/cm2) | 14 days (kg/cm2) | | cm | |
| 1 | 14 | 7,304 | 176.62 | 105 | 10707 | 1,378 | 60.61 | 82.99 | 8.14 | 10 | A1-0 |
| 2 | 14 | 7,334 | 176.62 | 141.66 | 14446 | 1,384 | 81.78 | 111.97 | 10.98 | 9 | A2-5 |
| 3 | 14 | 7,357 | 176.62 | 120 | 12236 | 1,388 | 69.27 | 94.85 | 9.30 | 8 | A3-10 |
| 4 | 14 | 7,354 | 176.62 | 138.33 | 14106 | 1,388 | 79.86 | 109.34 | 10.72 | 9 | A4-15 |

Table 8. Compressive strength value of light concrete age 28 days

| No. | Age | W | Field Area | Load | Weight | Specific Gravity | Compressive Strength | | Mpa | Slump | Sample Code |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | n days | (gr) | cm2 | (kN) | (kg) | | N days (kg/cm2) | 14 days (kg/cm2) | | cm | |
| 1 | 28 | 7,268 | 176.62 | 143 | 14,61 | 1,371 | 82.75 | 113.29 | 11.11 | 10 | A5-0 |
| 2 | 28 | 7,382 | 176.62 | 160 | 6,31 | 1,393 | 92.37 | 126.46 | 12.40 | 8 | A6-5 |
| 3 | 28 | 7,324 | 176.62 | 150 | 15,29 | 1,382 | 86.59 | 118.56 | 11.63 | 9 | A7-10 |
| 4 | 28 | 7,293 | 176.62 | 147 | 14,95 | 1,376 | 84.67 | 115.92 | 11.37 | 8 | A8-15 |




Graph 1. Results of recapitulation of compressive strength of concrete age 14 and 28 days

Based on the table and graph, the compressive strength of light concrete by using pumice aggregate and glass powder as cement substitutes has increased compressive strength when compared to the compressive strength of light concrete without the addition of glass powder. The compressive strength values of light concrete percentages of 5%, 10%, 10%, 10.30 Mpa, and 10.72 Mpa respectively are 10.98 Mpa, 9.30 Mpa, and 10.72 Mpa at 14 days of concrete age and at 28 days of concrete the compressive strength values are 12.40 Mpa, 11.63 Mpa, and 11.37 Mpa respectively. Meanwhile, the normal compressive strength values of lightweight concrete at the age of 14 and 28 days are 8.14 Mpa and 11.11 Mpa.

## CONCLUSION

Based on the results of the data, this study was discussed on the use of Pumice Stone as a substitute for coarse aggregate and the addition of glass powder to the substitution of light concrete cement for compressive strength testing. So the following conclusions are obtained.

The test results of the compressive strength of 14-day concrete with 0% glass powder substitution worth 8.14 Mpa, 5% worth 10.98 Mpa, 10% worth 9.30 Mpa, 15% worth 10.72 Mpa. As for the results of the 28-day compressive strength test of concrete with 0% glass powder substitution worth 11.11 Mpa, 5% worth 12.40 Mpa, 10% worth 11.63 Mpa, 15% worth 11.37 Mpa. The optimal compressive strength value of light concrete with the addition of glass powder as a cement substitute is found at the percentage value of 5% glass powder with a compressive strength value of 10.98 Mpa at the concrete age of 14 days and a value of 12.40 Mpa at the concrete age of 28 days. The use of glass powder as a cement substitute in light concrete can increase the compressive strength value by 5%, 10% and 15% when compared to the compressive strength value of light concrete without the addition of glass powder. However, the pressure value decreased as the percentage value increased. This can be caused by the uneven distribution of glass powder in the concrete mix, and the imperfect compaction process and lack of further testing of the glass powder content that affects the quality of the glass powder.

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