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# THE USE OF GLASS POWDER WASTE AS A PARTIAL SUBSTITUTE FOR CEMENT ON THE COMPRESSIVE STRENGTH OF CONCRETE

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ABSTRACT: Excessive use of cement can cause damage to the environment. Using materials that have similar properties to cement as a concrete mixture can reduce the use of cement. Because the silica content in glass is quite large, glass has the potential to be used as a partial substitute for cement in concrete. This study aims to determine the effect of glass powder used as a partial cement substitute on the compressive strength of normal concrete. This study uses cylindrical specimens with 15 cm in diameter and 30 cm in height according to SNI 03-2834-2002. They were tested at seventh, fourteenth, and twenty-eighth day. The variations of the glass powder are 0%, 4%, 8%, 12%, and 16%. Based on the results of the testing at the twenty eighth days, the concrete's compressive strength at 0% variation is 22.8 MPa, at 4% variation is 24.0 MPa, at 8% variation is 17.5 MPa, at 12% variation is 17.6 MPa, and at 16% variation is 7.9 MPa. Thus, using glass powder as a partial substitute for cement in concrete mixtures affects the compressive strength of normal concrete. At the twenty-eighth day, the compressive strength of the concrete has increased by 5% to 24.0 MPa.

*Keywords: Concrete, Waste Glass Powder, Cement, Compressive Strength*

## 1. INTRODUCTION

Amid the current development of construction technology, many innovations in tools and materials are used to support infrastructure development. Concrete is still one of the most widely used construction materials [1]. However, the manufacture of concrete contributes significantly to environmental problems because using cement as one of its constituent materials negatively impacts the environment [1-3].

Excessive use of cement can cause damage to the environment [2], [4-5]. This is because the manufacturing process as a whole produces approximately 5% carbon dioxide ($CO_2$) emissions [4], [6-7]. In addition, using materials containing cement will undergo a process of carbonation that occurs during the service life until dismantling [6]. The use of cement can be reduced by replacing some of its use in concrete mixtures with materials that have similar properties to it.

One of the materials that can be used as a partial substitute for cement in concrete mixtures is glass powder. Glass powder was chosen because the main constituent material is silica ($SiO_2$), a pozzolanic material whose use can increase the compressive strength of concrete [8-11], [13–15]. Previous researchers have argued that the best use of glass in concrete is by grinding it into finer grains, because the fine particles in the glass powder can fill the air voids in the concrete to reduce the number of fine cracks, which eventually can increase the compressive strength of concrete [16-20]. In addition, the use of waste glass as a substitute has been believed to increase workability, thank to the material's smooth surface and low water absorption [21].

The use of glass powder as a partial substitute for cement in concrete is expected to reduce environmental impact. Ibrahim, in his study; aimed at determininge the effect of glass powder on the compressive strength and tensile strength, found that the use of glass waste at a variation of 5% increases the compressive strength and tensile strength of normal concrete for about 8% and 13%, these figures were obtained from calculations of 0% variation [21].

This study aims to obtain the effect of the use of glass powder waste as a partial substitute for cement on the compressive strength of normal concrete. The use of glass powder waste as a partial substitute for cement in concrete mixtures is expected to reduce environmental pollution caused by the use of the said substance.

## 2. RESEARCH SIGNIFICANCE

This study discusses the use of glass powder waste as a substitute for cement in concrete. The utilization of glass powder waste is expected to reduce the waste of glass powder in the environment and help reduce $CO_2$ emissions caused by cement production, which negatively impacts the environment. Hopefully, this research can be helpful for public society, academia, and the industry as additional insight and reference for library materials in developing science.

## 3. METHODS

This experimental study was conducted at the Jakarta State Polytechnic in 2022. This study uses cylindrical specimens with 15 cm in diameter and 30 cm in height, with three samples for each variation, based on SNI 03-2834-2002 [22]. The variations of glass powder used in this study are 0%, 4%, 8%, 12%, and 16%, from which the most optimum use of glass powder in concrete testing at seventh, fourteenth, and twenty-eighth day was selected.

The coarse aggregate used in this study is crushed stone with the maximum size of 20 mm, and the fine aggregate is natural sand. The aggregates were tested for specific gravity and water absorption, bulk density and air voids, sieve analysis, sludge levels, and moisture content.

The cement to be used is PCC cement. The glass powder used as the partial substitute for cement is glass powder that passes pan No. 200. Since the powder serves as the partial substitute of cement, it must have a fineness similar to cement. The glass powder used in this research is light bulbs waste.

### 3.1 Material Test

The material testing in this study are summarized in the following sections:

#### *3.1.1 Specific gravity and water absorption*

The tests of specific gravity and water absorption of coarse and fine aggregates in this study refer to ASTM 127 and ASTM C128 [23-24]. This test aims to get the specific gravity and water absorption in coarse aggregate and classify the aggregate.

#### *3.1.2 Bulk density and voids*

The tests of bulk density and voids of the coarse and fine aggregates in this study refer to ASTM C 29/29M [25]. This test aims to get the weight of the contents and voids in the aggregate and to compare the test results with the specifications.

#### *3.1.3 Sieve analysis*

The tests of sieve analysis of the coarse and fine aggregates in this study refer to ASTM C136 [26]. This test aims to get the aggregate fineness number and the maximum diameter of the aggregate.

#### *3.1.4 Sludge levels*

The tests of sludge levels of the coarse and fine aggregates in this study refer to ASTM C117 [27]. This test aims to get the mud content and compare the value of the mud content of the test results with the aggregate specifications.

#### *3.1.5 Moisture content*

The tests of moisture content of the coarse and fine aggregates in this study refer to ASTM C566 [28]. This test aims to get the moisture content of the aggregate.

#### *3.1.6 X-ray fluorescence test on cement and glass powder*

The focus of the XRF test on glass powder,is obtaining pozzolanic chemical compounds.

### 3.2 Concrete Test

The test for the fresh concrete was carried out by conducting slump test, bulk density test, and setting time test, while the mechanic properties was assessed using compressive strength test.

#### *3.2.1 Compressive strength*

The compressive strength of concrete is a test where the concrete is given an axial load using a compressive strength machine,from which the value of the maximum load it can withstand is obtained. Than, the obtained maximum load is divided by the cross-sectional area of the test concrete to get the load per unit area in MPa.

The compressive strength test of concrete can be calculated using Equation 1 below.

$$f'c = \frac{P}{A} \quad (1)$$

$f'c$ = compressive strength of concrete (MPa)
$P$ = maximum load (kN)
$A$ = area ($mm^2$)

## 4. RESULT AND DISCUSSION

### 4.1 Result

The results of the experiment are described in the following explanation.

#### *4.1.1 Result of x-ray fluorescence testing on cement and glass powder*

Based on (Table 1) glass powder and cement contain similar elements, they are; MgO, $SiO_2$, $K_2O$, CaO, and $TiO_2$.

Table 1. Data of X-Ray Fluorescence Test on Cement and Glass Powder

| Chemical Elements | Glass Powder (%) | Cement (%) |
|---|---|---|
| MgO | 0.82 | 0.57 |
| $SiO_2$ | 72.80 | 10.20 |
| $K_2O$ | 1.55 | 0.60 |
| CaO | 13.70 | 79.52 |
| $TiO_2$ | 0.01 | 0.31 |
| $Cr_2O_3$ | 0.79 | - |
| MnO | 2.50 | - |
| BaO | 2.50 | - |
| $Nd_2O_3$ | 5.30 | - |
| $Al_2O_3$ | - | 2.00 |

*4.1.2 Aggregate testing result*

The results of the aggregate testing in this study are shown in (Table 2) below.

Table 2. Data of Aggregate Testing Result

| Aggregate Testing | Fine Aggregate | Coarse Aggregate |
|---|---|---|
| Spesific Gravity | 2.56 | 2.54 |
| SSD | 2.60 | 2.57 |
| Apparent Density | 2.67 | 2.62 |
| Abs. (%) | 1.70 | 1.24 |
| Bulk density ($Kg/m^3$) | 1610.41 | 1214.15 |
| Voids (%) | 36.89 | 52.10 |
| Sludge Levels (%) | 2.55 | 0.35 |

The data signifies that the specific gravities of the fine and coarse aggregates SSD used to design the concrete mixture are 2.60 and 2.57, respectively, and the bulk densities.are 1610.41 $kg/m^3$ and 1214.15 $kg/m^3$.

*4.1.3 Specific gravity testing result on cement and glass powder*

The specific gravity of the cement and glass powder can be calculated using Equation 2 below.

$$SG = \frac{W}{(V_2 - V_1)d} \quad (2)$$

SG = Specific Gravity of cement or glass powder (gram/ml)
W = Weight of cement or glass powder (gram)
$V_1$ = Initial volume (ml)
$V_2$ = Final volume (ml)
d = Bulk density of water (1 gram/ml)

Table 1 Data of the Specific Gravity of cement

| Sample | Weight of Cement (gram) | V1 | V2 | Specific Gravity |
|---|---|---|---|---|
| 1 | 64 | 0.50 | 21.10 | 3.10 |
| 2 | 64 | 0.40 | 20.70 | 3.15 |
| | mean | | | 3.12 |

Based on (Table 3), the specific gravity of the cement is 3.12. According to SNI 15-2531-1991, the specific gravity of portland cement ranges from 3.05-3.25, so the tested portland cement meets the requirements, and the test object can be used in the concrete mixture.

The table below contains the results of the specific gravity test on glass powder.

Table 2. Data of the Specific Gravity of glass powder

| Sample | Weight of Glass Powder (gram) | V1 | V2 | Specific Gravity |
|---|---|---|---|---|
| 1 | 50 | 0.50 | 21.20 | 2.42 |
| 2 | 50 | 0.80 | 21.40 | 2.43 |
| | mean | | | 2.42 |

Based on (Table 4), the specific gravity of the glass powder (2.42) is smaller than that of the cement(3.12).

*4.1.4 Mix design*

(Table 5) below is the result of the concrete design calculation based on SNI 03-2834-2002.

Table 3. Mix Design Concrete

| Materials | Var. 0% (kg) | Var. 4% (kg) | Var. 8% (kg) | Var. 12% (kg) | Var. 16% (kg) |
|---|---|---|---|---|---|
| Cement | 37.5 | 35.9 | 34.5 | 32.9 | 31.5 |
| Glass Powder | 0 | 1.5 | 3.0 | 4.5 | 6.0 |
| Course Agr. | 95.0 | 95.0 | 95.0 | 95.0 | 95.0 |
| Fine Agr. | 67.0 | 67.0 | 67.0 | 67.0 | 67.0 |
| Water | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 |

From the percentage of cement weight at 0% variation, which is 37.50 kg, the weight of glass powder was obtained. The 4% variation used 1.50 kg of glass powder, the 8% variation used 3 kg of glass powder, the 12% variation used 4.50 kg of glass powder, and the 16% variation used 6 kg of glass powder. Any addition of glass powder reduces the cement's weight.

*4.1.5 Slump test result*

The result of the slump test is shows in (Fig. 1) below

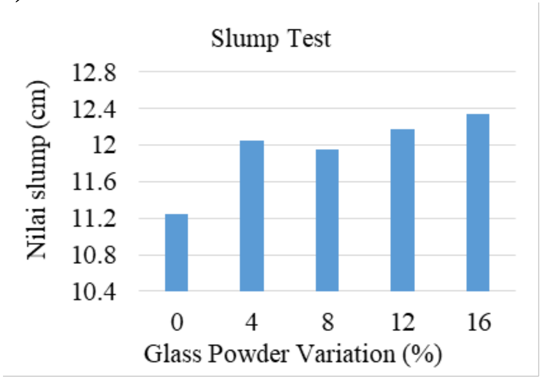


Fig. 1 Slump Test Result

As shown in (Fig. 1) above, the use of glass powder tends to increase the slump value in fresh concrete. This can happen because one of the properties of glass powder is that it does not absorb water. Hence the higher the usage, the lower the concrete mixture's adhesiveness to water.

*4.1.6 Bulk density test result*

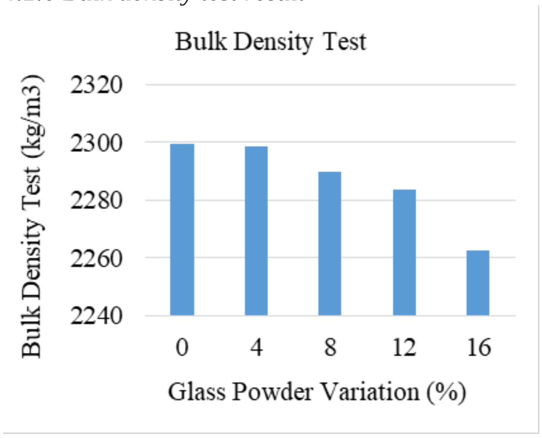


Fig. 2 Bulk Density Test Result

Based on (Fig. 2) above, the use of glass powder tends to lower the density of the fresh concrete. This can happen because the specific gravity of the glass powder is much smaller than the density of the cement. Thus, more addition of glass powder reduces the concrete's weight even lower.

*4.1.7 Setting time test result*

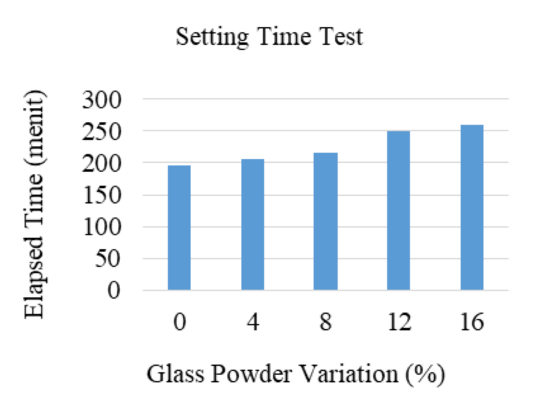


Fig. 3 Setting Time Test Result

Based on (Fig. 3) above, the use of glass powder tends to increase the setting time. This happens because one of the properties of glass powder is that it does not absorb water, so higher content of glass powder slows the binding of other ingredients with water, leading to a longer concrete setting time.

*4.1.8 Compressive strength of concrete*

The comparasion of the compressive strengths of each variation of glass powder as a substitute for cement is shown in (Fig. 4) below.

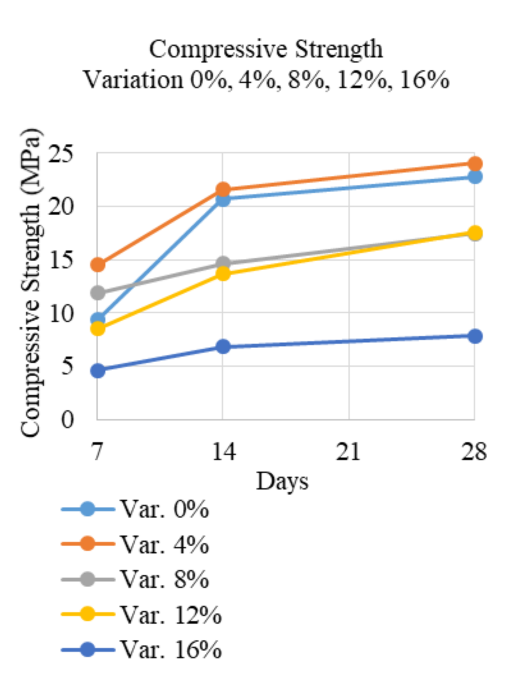


Fig. 4 Compressive Strength of Concrete in Each Variation.

Based on (Fig. 4), the use of glass powder as a partial substitute for cement in 7-day-old concrete fluctuated its compressive strength. The compressive strength of concretes with the variations of 0%, 4%, 8%, 12%, and 16%, are 9.37 MPa, 14.50 MPa, 11.85 MPa, 8.49 MPa, and 4.58 MPa. respectively The maximum compressive strength value is on the concrete with the variation of 4%.

Based on (Fig. 4), the use of glass powder as a partial substitute for cement in 14-day-old concrete fluctuated its compressive strength. The compressive strengths of concretes with the variations of 0%, 4%, 8%, 12%, and 16%, are 20.67 MPa, 21.58 MPa, 14.60 MPa, 13.64 MPa, and 6.85 MPa. respectively The maximum compressive strength value is on the concrete with the variation of 4%.

Based on (Fig. 4), the use of glass powder as a partial substitute for cement in 28-day-old concrete fluctuated its compressive strength. The compressive strengths of concretes with the variations of 0%, 4%, 8%, 12%, and 16%, are 22.81 MPa, 24.03 MPa, 17.47 MPa, 17.58 MPa, and 7.87 MPa respectively. The maximum compressive strength value is on the concrete with the variation of 4%.

To obtain the effect of using glass powder on the compressive strength of concrete, the acquired data were then analysed using simple linear regression method in SPSS. The results is shown in the following table.

Table 6. Coefficients of Each Variation of Concretes

| | Unstandardized Coef. | | Standardized coef. | t | Sig. |
|---|---|---|---|---|---|
| | B | Std Error | Beta | | |
| 7 | 12.9 | 2.5 | -0.7 | 5.1 | 0.1 |
| | -0.4 | 0.26 | | -2 | 0.2 |
| 14 | 22.6 | 1.8 | -0.9 | 13 | 0 |
| | -0.9 | 0.18 | | -5 | 0 |
| 28 | 25.6 | 2.92 | -0.9 | 8.8 | 0 |
| | -1 | 0.3 | | -3 | 0 |

The results of the simple linear regression are shown in (Table 6). The significance of the 7-day-old concrete is 0.26, greater than 0.05. It indicates that the use of glass powder as a partial cement replacement material does not significantly affect the compressive strength of the concrete. In addition, the constant value (a) is 12.857, while the regression coefficient (b) is -0.388. Hence, the regression equation can be written as Y = 12.857 – 0.388X. Based on this equation, the compressive strength of concrete at the age of 7 days without the addition of glass powder as the partial substitute of cement is 12.857, and for every branch of 1 unit of glass powder, the compressive strength of concrete decreases by 0.388.

According to (Table 6), the significance of the 14-day-old concrete is 0.017, smaller than 0.05. It indicates that the use of glass powder as a partial cement replacement material significantly affects the compressive strength of the concrete. In addition, the constant value (a) is 22.587, while the regression coefficient (b) is -0.890. Thus, the regression equation can be written as Y = 22,587 – 0.89X. Based on this equation, it is known that the compressive strength of the concrete at the age of 14 days without the addition of glass powder as the partial substitute of cement is 22.587, and for every branch of 1 unit of glass powder, the compressive strength of concrete decreases by 0.890.

According to (Table 6), the significance of the 28-day-old concrete is 0.044, smaller than 0.05. It indicates that the use of glass powder as a partial cement replacement material significantly affects the compressive strength of the concrete. In addition, the constant value (a) is 25.593, while the regression coefficient (b) is -1.003. Therefore, the regression equation can be written as Y = 25,593 – 1,003X. Based on this equation, it is known that the compressive strength of the concrete at the age of 28 days without the addition of glass powder as the partial substitute of cement is 25.593, and for every branch of 1 unit of glass powder, the compressive strength of concrete decreases by 1.003

Table 7. Model Summary of Each Concrete Variation.

| Days | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| 7 | 0.66 | 0.435 | 0.2 | 3.2 |
| 14 | 0.94 | 0.887 | 0.8 | 2.3 |
| 28 | 0.89 | 0.79 | 0.7 | 3.8 |

It is shown in (Table 7) that the coefficient of determination ($R^2$) is 0.435. This means that 43.5% of the compressive strength of the 7-day-old concrete is determined by the use of glass powder as the partial cement substitute through the regression equation of Y = 12.857 – 0.388X. Meanwhile, 56.5% of the concrete's compressive strength is determined by other factors.

It is shown in (Table 7) that, the coefficient of determination ($R^2$) is 0.887. This means that 88,7% of the compressive strength of the 14-day-old concrete is determined by the use of glass powder as the partial cement substitute through the regression equation of Y = 22,587 – 0.89X.

Meanwhile, 11.3% of the concrete's compressive strength is determined by other factors.

It is shown in (Table 7) that, the coefficient of determination ($R^2$) is 0.79. This, means that 79% of the compressive strength of 28-day-old concrete is determined by the use of glass powder as the partial cement substitute through the regression equation Y = 25,593 – 1,003X. Meanwhile, 21% of the concrete's compressive strength is determined by other factors.

### 4.2 Discussion

Table 8. Percentage of Changes in Compressive Strength

| Age of Concrete (days) | Variation of Light Brick (%) | Compressive Strength (MPa) | Increases/ Decreases (%) |
|---|---|---|---|
| 7 | 0 | 9.34 | 0 |
| | 4 | 14.51 | 55 |
| | 8 | 11.85 | 27 |
| | 12 | 8.49 | -9 |
| | 16 | 4.58 | -51 |
| 14 | 0 | 20.67 | 0 |
| | 4 | 21.58 | 4 |
| | 8 | 14.60 | -29 |
| | 12 | 13.64 | -34 |
| | 16 | 6.85 | -67 |
| 28 | 0 | 22.81 | 0 |
| | 4 | 24.03 | 5 |
| | 8 | 17.47 | -23 |
| | 12 | 17.58 | -23 |
| | 16 | 7.87 | -66 |

As shown in (Table 8) above, the compressive strengths of the 7, 14, and 28-day-old concrete is increased by adding 4% of glass powder The compressive strength at day 7 is 14.51 MPa, at day 14 is 21.58 MPa, and at day 28 is 24.03 MPa. It is also shown in the table that the 4% variation increased the strength of the 0% variation. At day 7, the increase reached 55%; at day 14, the increase reached 4%; and at day 28, the increase reached 5%.

In previous study by Ibrahim, the optimum value of the use of glass waste as a cement substitute was 5%. In this study, the optimum value was obtained at the 4% variation. The results are different, but the difference is not too far because the variations that were used are not the same. In addition, the optimum value in each test can vary due to the use of different types of glass powder, which make the composition of the constituent compounds different as well.

The increase in compressive strength in concrete can occur due to the addition of $SiO_2$. The fine particles in the glass powder can fill the air voids in the concrete to reduce the number of fine cracks, so its use can increase the compressive strength of concrete.

Meanwhile, the decrease in the compressive strength of concrete after treated with the 4% variation was caused by the decrease in CaO content along with the increase in $SiO_2$ content in the concrete. Because CaO is also a pozzolanic material that is also important in concrete, the decrease in CaO content in concrete also affects the strength of the concrete.

## 5. CONCLUSION

Based on this research, the use of glass powder as a substitute for cement in concrete mixtures effects the compressive strength of concrete. In the use of glass powder with variation of 4%, there was an increase in the compressive strength of concrete aged 7, 14, and 28 days. The strengths of the concrete increasesby 55% to 14.51 MPa after seven days, by 4% to 21.58 MPa after fourteen days, and by 5% to 24.03 MPa after 28 days. The variations of 8%,12%, and 16% decrease the concrete's compressive strength.

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