Effectiveness of Glass Powder as a Partial Replacement of Sand in Concrete Mixtures

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Abstract. Concrete is commonly used as the main component in a building. Concrete is obtained by mixing Portland cement, water, aggregates, and sometimes added ingredients at certain comparisons in the form of chemicals, fibrous materials, and non-chemical materials. Utilization of glass powder waste for concrete mixtures is now being developed. This research was conducted to determine the optimum composition of glass powder as a partial replacement of sand against the compressive strength of concrete. The content of the glass powder mixture used is 10%, 15%, 20%, and 30% of the weight of sand in the concrete mixture. Slump test results showed that in the variation of coarse glass powder concrete slump decreased due to lack of bonding capacity between the aggregates. In concrete with a variation of fine glass powder the slump slightly decreases because the fine glass powder absorbs too much water. Concrete compressive strength testing is carried out at 28 days. The results of concrete compressive strength test showed the optimum value can be achieved by 22.8 MPa with 15% variation in glass powder content. The use of glass powder is effective as a substitute for partial sand at 15% of coarse glass powder.

Keywords: compressive strength, concrete, effectiveness, glass powder, sand.

1. Introduction
Concrete is a material commonly used as the main component in a building structure. Concrete is obtained by mixing Portland cement, water, aggregates, and sometimes added ingredients at certain comparisons in the form of chemicals, fibrous materials, and non-chemical building materials. The development of concrete innovation in the current era continues to experience improvements. Utilization of glass powder waste for concrete mixtures is now being developed.

Glass is principally composed of silica. Use of milled (ground) waste glass in concrete as partial replacement of cement could be an important step toward development of sustainable (environmentally friendly, energy-efficient and economical) infrastructure systems. When waste glass is milled down to micro size particles, it is expected to undergo pozzolanic reactions with cement hydrates, forming secondary Calcium Silicate Hydrate (C–S–H) [1]. Experimental results revealed that additional compressive strength of 40 MPa can be gained with combination of glass powder and silica fume [2].

The use of glass powder is an alternative that can be used as a partial substitution of cement in a concrete mixture because the chemical elements contained in glass powder are almost the same as the chemical elements contained in cement [3].

The use of glass powder in concrete will affect the compressive strength. Compressive strength of concrete with glass powder substitution is higher than the design compressive strength, and continues to increase with the addition of glass powder content. At 28 days, the compressive strength of specimens
with various amount of glass sand replacement were all higher than that of the design strength when soaked in sulphate solution [4]. Beyond 10% glass powder the strength of concrete reduces and is lower than that of the control [5]. When glass powder was used as an aggregate replacement material, the compressive strength of concrete depended on the type containing crushed glass aggregate increased while the compressive strength of concrete containing natural mineral aggregate decreased [6].

Glass powder can be used as a filler because it has potential as a pozzolan material. Concrete with the highest compressive strength value was achieved at 10% glass powder composition while the lowest compressive strength can be at 15% glass composition [7]. Beyond a replacement of 30%, calcium hydroxide became insufficient for the pozzolanic reaction of glass powder [8,9]. Glass particles well encapsulated into dense and mature gel observed by SEM, may help explaining enhanced durability results and thus confirming that waste glass powder can further contribute to sustainability in construction [10].

The purpose of this research is to analyze the use of glass powder as a substitute for sand on concrete compressive strength, and the analysis of the percentage of glass powder to achieve optimal compressive strength.

2. Material And Method
The percentage of glass powder addition to sand weight of 0%, 10%, 15%, 20% and 30% in each mixed plan. The test object used in the form of a concrete cylinder diameter of 15 cm height 30 cm. Concrete compressive strength values are obtained through standard testing procedures using a testing machine by providing multilevel compressive loads with a certain rate of increase in load with cylindrical specimens with a diameter of 150 mm and a height of 300 mm. Then the test object is pressed with the test equipment until it breaks. Maximum compressive load when the specimens are broken divided by the cross-sectional area of the test specimens is the value of the concrete force strength expressed in MPa or kg/cm².

The test procedure commonly used is the ASTM C 39 standard. The formula used for the calculation of the compressive strength of concrete is:

\[ f'c = \frac{P}{A} \]  

where \( f'c \) is strength of concrete (MPa), \( P \) is maximum load (N), and \( A \) is test object cross-sectional area (mm²)

Coarse aggregate and fine aggregate that is split and sand are examined first before being used as a material for making concrete mix. Material testing for fine aggregate includes examination of aggregate gradation, organic sludge content, water content, specific gravity and absorption. Normal concrete mix plans (mix designs) are made using concrete designs according to SNI 03-2834-2000. The test object used is cylindrical with height 300 mm, diameter 150 mm for compressive strength test.

The composition of the concrete mix material in this study was determined through a mix design calculation in advance from the results of the fine and rough aggregate test graphs. Determination of the weight of the cement demand is determined by a comparison of the cement water factor and the maximum cement demand. Sand and gravel requirements are calculated using grading zone graphs from the results of specific gravity measurements. The use of glass powder in a concrete mixture is determined by using a comparison of the volume of sand in the mix design.

Furthermore, the normal concrete is given a code BK of glass concrete, for concrete with a mixture of coarse glass powder given the code BK.K, concrete with a mixture of fine glass powder is given the code BK.H and the code for concrete with a mixture of glass powder mixture is BK.C.

3. Result and Discussion

3.1. Slump Test
Slump test is carried out to determine the thickness of a mixture of fresh concrete in order to meet the specified requirements. The value of the slump is checked by testing the fresh concrete before pouring it, by taking it directly from the mixer using a bucket or a device that does not absorb water. Slump
testing is carried out using a cone with a diameter of 10 cm, a bottom diameter of 20 cm and a height of 30 cm.

Concrete with a variation of coarse glass decreases in slump due to lack of bonding capacity between the aggregates. In concrete, the variation of fine glass has decreased slightly because the fine glass powder absorbs too much water. Value of the complete test results as in table 1.

| No | Variation | Slump (cm) |
|----|-----------|------------|
| 1  | 10% Rough Glass | 3.5 cm |
|    | Smooth Glass   | 2 cm      |
|    | Mixed Glass    | 3 cm      |
| 2  | 15% Rough Glass | 5 cm      |
|    | Smooth Glass   | 1.5 cm    |
|    | Mixed Glass    | 4.5 cm    |
| 3  | 20% Rough Glass | 2.8 cm    |
|    | Smooth Glass   | 1 cm      |
|    | Mixed Glass    | 2.5 cm    |
| 4  | 30% Rough Glass | 3 cm      |
|    | Smooth Glass   | 0 cm      |
|    | Mixed Glass    | 1.5 cm    |

3.2. Compressive Strength Test Results

Concrete compressive strength testing is performed on 28-day-old concrete using Compression Testing Machine (CTM) to determine the maximum compressive strength that can be held by concrete until the concrete cracks or breaks. Test material is cylindrical with a diameter of 15 × 30 cm. Recapitulation of compressive strength test results can be seen in Table 2.

In the 28-day test it can be seen the average compressive strength of concrete with 0% addition variation results in compressive strength of concrete which is 20.82 MPa. Concrete compressive strength test results as shown in Figure 1. Graph of concrete compressive strength test results of the variation of coarse glass powder, Figure 2. Graph of concrete compressive strength test results of the variation of fine glass powder, Figure 3. Graph of concrete compressive strength test results of mixed glass powder variations.

| No | Addition of glass powder | Concrete Cylinder Weight (Kg) | Test Object Code | Concrete Age | Compressive Strength (MPa) |
|----|--------------------------|-------------------------------|-----------------|--------------|----------------------------|
| 1  | 0%                       | 13.2                          | BK. 0%          | 28           | 21.97                      |
|    |                          | 13.3                          | BK. 0%          | 28           | 19.65                      |
|    |                          | 12.9                          | BK. 0%          | 28           | 20.84                      |
|    |                          | 12.9                          | BK.K. 10%       | 28           | 13.08                      |
| 2  | 10%                      | 12.9                          | BK.H. 10%       | 28           | 15.97                      |
|    |                          | 13                            | BK.C. 10%       | 28           | 19.53                      |
|    |                          | 12.9                          | BK.K. 15%       | 28           | 22.8                       |
| 3  | 15%                      | 13.1                          | BK.H. 15%       | 28           | 17.7                       |
|    |                          | 12.8                          | BK.C. 15%       | 28           | 19.7                       |
|    |                          | 12.8                          | BK.K. 20%       | 28           | 10.9                       |
| 4  | 20%                      | 12.8                          | BK.H. 20%       | 28           | 16.2                       |
|    |                          | 13                            | BK.C. 20%       | 28           | 16.19                      |
|    |                          | 13.1                          | BK.K. 30%       | 28           | 15.34                      |
| 5  | 30%                      | 12.9                          | BK.H. 30%       | 28           | 20.44                      |
|    |                          | 13                            | BK.C. 30%       | 28           | 21.12                      |
3.3. Concrete samples after being tested

Concrete test specimens after being tested for compressive strength will certainly be damaged. The damage that occurs is then visually analysed. Normal concrete samples are damaged as in general, in the form of fine cracks as in Figure 4.

Figures 5 through 7 show damage that occurs in concrete samples with variations of coarse glass powder, fine glass powder, and mixed glass powder. The damage shows that the concrete sample has the same damage type, which is a large crack and shattered.
4. Conclusion

The addition of glass powder variations to the weight of the sand increases the compressive strength of the concrete. The increase occurred at 15% variation in coarse glass powder by 22.8 MPa and 30% in mixed glass powder by 21.12 MPa.

In the 10% mixture of coarse aggregate, fine glass powder, and the mixture experienced a decrease respectively 13.08 MPa, 15.97 MPa, and 19.53 MPa. In the mixture of 15% smooth and the mixture has decreased namely 17.7 MPa, and 19.7 MPa. In a mixture of 20% coarse, fine glass powder, the mixture has decreased respectively 10.9 MPa, 16.2 MPa and 16.9 MPa. In the 30% mixture of coarse and fine glass powders decreased by 15.34 MPa and 20.4 MPa.

The optimum compressive strength of concrete that can be achieved is 22.8 MPa with a variation of 15% glass powder content. The use of glass powder is effective as a substitute for partial sand in a variation of 15% rough glass and 30% mixed glass with an increase of 2.01% and 1.44%.

Damage that occurs in concrete with glass powder when it reaches optimal compressive strength will be broken apart into small debris, different from normal concrete in general what if exposed to high
pressure will suffer damage in the form of large chunks. Based on the form of damage from concrete with glass powder during compressive strength test it can be said that concrete with glass powder if used in a structure is safer than conventional concrete. Further research is needed on the use of glass powder in concrete based on gradations of sand associated with the compressive strength and the shape of the damage that occurs in concrete with glass powder.

5. References
[1] Islam GMS, Rahman MH and Kazi N 2017 Waste glass powder as partial replacement of cement for sustainable concrete practice Int J Sustain Built Environ 6 37–44
[2] Vaitkevičius V, Šerelis E and Hilbig H 2014 The effect of glass powder on the microstructure of ultra high performance concrete Constr Build Mater 68 102–9
[3] Purnomo H and Hisyam ES 2014 Pemanfaatan serbuk kaca sebagai substitusi parsial semen pada campuran beton ditinjau dari kekuatan tekan dan kekuatan tarik belah beton J Fropil 2 45–55.
[4] Nety and Tanzil G 2013 Pengaruh sulfat terhadap kuat tekan beton dengan variasi bubuk kaca substitusi sebagian pasir dengan W/C 0,4 dan 0,5 J Tek Sipil Dan Lingkung 1 63–7.
[5] Khatib JM, Negim EM, Sohl HS and Chileshe N 2012 Glass powder utilisation in concrete production Eur J Appl Sci 4 173–6.
[6] Afshinnia K and Rangaraju PR 2016 Impact of combined use of ground glass powder and crushed glass aggregate on selected properties of Portland cement concrete Constr Build Mater 117 263–72.
[7] Karwur HY, R. Tenda SE, Wallah and Windah RS 2013 Kuat tekan beton dengan bahan tambah serbuk kaca sebagai substitusi parsial semen J Sipil Statik 1 276–81.
[8] Du H and Tan KH 2017 Properties of high volume glass powder concrete Cem Concr Compos 75 22–9.
[9] Du H and Tan KH 2014 Waste glass powder as cement replacement in concrete J Adv Concr Technol 12 468–77.
[10] Matos AM and Sousa-Coutinho J 2012 Durability of mortar using waste glass powder as cement replacement Constr Build Material 36 205–15.