Enhancing Tensile Strength and Porosity of Self Compacting Concrete (SCC) with Glass Waste Powder

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Abstract. Utilization of glass waste powder is an alternative material as a substitute for some cement in SCC concrete because the element contained in the glass waste powder has similarities with cement. Research on glass waste powder as a substitute for some cement using percentage variation that is 5%, 10%, 15%, 20%, 25%, and 30%, with the age of SCC concrete 28 days. The study uses quantitative methods to obtain data on the tensile strength and porosity of the SCC concrete with glass waste powder as a partial substitute for cement. A tensile strength using a cylinder-shaped sample of 150 mm diameter and 300 mm in height with a sample amount per percentage of 4 pieces. The porosity test uses a cylinder-shaped sample of 150 mm in diameter and 300 mm in height with a sample number of each 4 pieces. The results of the study acquired a significant influence of the addition of glass waste powder to strong tensile and porosity of the SCC. Besides, it also obtained the optimal percentage value of the addition of glass waste powder to tensile strength concrete of 5.5% with a maximum value of tensile strength 3.422 MPa. For porosity obtained the optimal percentage value of glass waste powder at 8.583% with a porosity value of at least 9.806%.

Keywords: SCC concrete, glass waste powder, tensile strength, and porosity.

1. Introduction
Construction technology advances more and more rapidly along with the development of the times. Similarly, the development of concrete technology to meet the challenges of today's industry. Nowadays the World needs concrete with performance, durability, and high workability, where the conventional way of compaction may not always work well under the condition of the content of different situations [1]. Self-Compacting Concrete is a solution to answer that question. Self-Compacting Concrete (SCC) is a high-performance concrete manufacturing technology that was originally developed in Japan in the year 1988. SCC concrete is a solution to the ability of the durability concrete and the need for skilled workers. SCC Innovation affirmed by a very short time between the formulation of its property concept and its application in the concrete construction industry. The wide range of SCC applications that are currently being observed is the consequence of favorable economic effects. The SCC is defined as a concrete whose composition and components are chosen mainly due to the specific rheological properties of the mixture, ensuring its ability to properly fill the mold, to cover the reinforcement and compaction under its weight without mechanical compaction [2].
Considering the SCC concrete production requires a lot of cement where when the cement production process causes a negative effect on the environment. The amount of material that is carried out from production activities will negatively impact the environment such as acid rain, respiratory disorders and to add a crust to the roof of buildings or housing [3]. Based on the problem it is necessary for alternative material substitute cement. One of the solutions is utilizing glass waste powder as a substitute for some cement in the SCC concrete mixture. Based on data of the Ministry of Life, Glass waste contributed 1.3% of 817,026.68 tons of garbage [4]. Glass powder is expected to be a substitute for some cement because the elements contained in the powder waste glass resembles cement and its pozzolanic nature. In the powder waste glass, many contain SiO2, and when the waste glass drops into micro-sized particles glass waste powder experiences a reaction with cement hydrate, forming secondary calcium silicate hydrate (C-S-H) [5].

Based on the problem, research with the purpose of (1) To know the influence of replacement of glass waste powder variations on a portion of cement in the SCC concrete against tensile strength and porosity of the SCC age 28 days. (2) To determine the value of the optimal percentage of glass waste powder variation as a substitute for some cement in the SCC concrete so that obtained maximal tensile strength and minimal porosity of the SCC concrete at the age of 28 days.

2. **Theoretical Foundation**

2.1. **Glass Powder**

Glass is the result of crystallization of inorganic compounds that unravel. Glass powder has its advantages and can be a material of concrete, one of which is glass powder. Glass powder has some advantages over other pore fillers [6], namely: (1) Zero water absorption (2) The hard glass properties make the concrete resistant to abrasion that can only be achieved by a little natural aggregate, (3) glass powder improve the element of the fresh concrete to increase strength without the use of Superplasticizer, (4) The glass Powder is pozzolan so that it can be a The following compounds are contained in the glass powder [7]

| Composition | Crushed Glass | Glass Powder |
|-------------|---------------|--------------|
| Al₂O₃       | 1.38          | 1.54         |
| CaO         | 11.70         | 11.42        |
| Fe₂O₃       | 0.48          | 0.48         |
| K₂O         | 0.38          | 0.43         |
| L.O.I.      | 0.22          | 0.36         |
| MgO         | 0.56          | 0.79         |
| Na₂O        | 13.12         | 12.85        |
| SiO₂        | 72.61         | 72.20        |
| SO          | 0.09          | 0.09         |

2.2. **Glass Powder**

Self-Compacting Concrete (SCC) is concrete with high flowability with low segregation levels that can spread the flat of formwork and solidification itself reinforcement without a manual compaction process [8]. The settings of aggregate size, aggregate comparison, and admixture solid are the factors that make the SCC concrete capable of compacted independently [9].

According to Okamura & Ouchi [10], the SCC offers some advantages among others:

- The implementation does not cause air pollution.
- Concrete compaction problems can be overcome.
- The amount of manpower can be reduced.
● Faster construction.
● Can be obtained with high concrete strength.

2.3. **Portland Cement**
The Portland cement is a hydraulic cement resulting from a deposed clinker. The clinker consists of hydraulic silicate calcium which is generally composed of one or more forms of calcium sulfate. Where calcium sulfate as added material is milled together with its main ingredient [11].

Cement function is to paste the aggregate grains so that there is a dense mass also cement also serves to fill the cavity between the aggregate grains in concrete [12]. Portland cement consists of the 4 most important elements:

- Tricalcium silicate (C3S) or 3CaO. SiO2
- Dicalcium Silicate (C2S) or 2CaO.SiO2
- Tricalcium Aluminate (C3A) or 3CaO.A12O3
- Tetracalcium Aluminoferit (C4AF) or 4CaO.A12O3.Fe2O3

2.4. **Aggregate**
Aggregate is a natural mineral granule used as a mixture of concrete or mortar. In concrete 70% volume consists of aggregate [13]. Depending on the large size of the grain, the aggregate is divided into two types, namely the fine aggregate and the coarse aggregate. There are several differences in criteria from one source to another. The criteria expressed by ASTM indicate that the fine aggregate is granular that is less than 4.8 mm and 4.75 mm in diameter. While the coarse aggregate of the grain is over 4.8 mm and 4.75 mm [14].

2.4.1. **Fine Aggregate.** The terms of the subtle aggregate are as follows [15]: (a) It has a sharp and hard grain with a hardness index < 2.2. (b) remain, not broken or destroyed by the influence of the weather. The sodium sulfate salt part is crushed maximum 12%, if with magnesium sulfate maximum 18%. (c) does not contain mud (fine-grained by 0.06 mm) more than 5%. (d) does not contain too much organic substance, which is evidenced by color experiments with a solution of NaOH 3%, i.e. fluid color above the fine aggregate deposits should not be darker than standard color/competition. (e) fine Modulus of grain between 1.50 – 3.80 and with grain variation according to the gradation standard. (f) Specifically, for concrete with a high durability rate, the fine aggregate should be unreactive to alkali. (g) The fine aggregate of the sea or coast may be used provided that with instructions from the approved Material inspection Agency.

2.4.2. **Coarse Aggregate.** The following rough aggregate terms [15] : (a) The imposition is loud and not porous. The hardness index is less than equal to 5% (tested with copper stem scratches). (b) remains or is not destroyed by the influence of the weather. If tested with a solution of sodium sulfate salt, the part is destroyed by a maximum of 12%, and if tested using magnesium sulfate, the part that is destroyed has a maximum of 18%. (c) does not contain mud more than 1% (fine-grained through 0.006 mm sieve). (d) Flat and oblong aggregate details should not be more than 20%. (e) The maximum grain size should not exceed 1/5 the smallest distance between the mold fields, the 1/3 thick concrete plate, 3/4 net distance between the reinforcement.

2.5. **Superplasticizer**
Superplasticizer is an added ingredient (admixture). Admixture is an added ingredient in concrete. In addition to the basic material of concrete that is aggregate, cement, and water. The admixture serves as a natural concrete trait modifier according to the desired planner, this material is commonly added to the concrete mixture before or during the concrete stirring process [16].

Console SS-74 N is a solid type F (High Range Water Reducer) which serves to reduce the use of water in the concrete. Water usage can be reduced ranging from 12-35% of the planned water amount. The SS-74 N Console is a solid product of BASF Indonesia, developed to add to the workability [17].
2.6. The Mix Design Planning Method

Method of mix design self-compacting concrete is a modification of the method of mix design in general that is mixed with simple mix design from Okamura [18]. Specifying the first comparison of rough aggregate amounts with fine aggregates. Self-compaction can be obtained through the control of a binder water factor as well as a dose of solid. Planning solid concrete mix design was implemented using EFNARC (The European Federation of Specialist Construction Chemicals and Concrete Systems) in 2005.

The specification of concrete self-compacting (SCC [19]: (a) The gross aggregate used is a maximum of 50% of the aggregate solid volume. (b) The fine aggregate Volume is set to only 40%-55% of the total volume of mortar. (c) The ratio of water volume and binder is set between 0.85 – 1.1 depending on the properties of its binders. (d) The dose of solid and water factor-binder is determined afterward to obtain compaction independently.

| Table 2. Standard EFNARC composition of constituent materials |
|-------------------------------------------------------------|
| Materials                  | Rate of weight (Kg/m3) | Rate of Volume(L/m3) |
| ---------------------------|------------------------|----------------------|
| Binder                     | 380 – 600              |                      |
| Water                      | 150 – 210              | 150 – 210            |
| Coarse aggregate           | 750 – 1000             | 270 – 360            |
| Fine aggregate             |                        | 45% – 55% of mass    |
| Cement water factor        | 0.30 – 0.55            | 0.85 – 1.10          |


2.7. Tensile Strength

Tensile strength is a strong value pull indirectly from a cylinder-shaped concrete sample tested by laying a flat sample

Strong pull-out is calculated as follows:

\[
F_{ct} = \frac{2P}{\pi LD}
\]

Description:
FCT = Tensile Strength (kg/cm2)
P = Maximum test load (kg)
L = Length of the test object (CM)
D = Diameter or width of the test object (cm)

2.8. Porosity

Porosity is the percentage of cavity or pore levels in concrete that become one of the factors that affect concrete strength. This cavity or pores are usually filled by interconnected air or water and are called concrete capillaries.

The formula to calculate the value of porosity in the mortar is as follows:

\[
\text{Porosity} = \frac{B - C}{B - A} \times 100
\]

With
A: The weight of the samples in water (gram)
B: SSD condition sample weight (gram)
C: Dry Sample weight oven (gram)

3. Research Methodology

The study uses quantitative methods to obtain data on the tensile strength and porosity of the SCC concrete with the glass waste powder as a partial substitute for cement. The Implementation of research is divided into several phases, beginning with preparation, implementation, and analysis of data.
3.1. **Ingredients Preparation**

3.1.1. **Glass.** The glass used in this study is a glass waste that is already unused. The process of manufacturing waste glass into powders as follows:

- The glass bottles that have been collected are cleaned using clean water so that other substances that stick not to be mixed in the waste powder glass, after cleaning bottles dried glass.
- The dried glass bottles were then inserted into the Los Angeles machine as many as 1 small bucket, then entered 12 balls of the Los Angeles machine and then closed the machine tightly.
- Turn on the Los Angeles machine in 5 x 12 minutes with 5 minutes time lag to clean and prepare the machine for playback.
- After smoothed out using the Los Angeles machine, gently remove the iron ball, then the glass waste powders are ejected and put on the tray.
- Glass waste powder that has been smooth enough then filtered using a sieve No. 100.
- Repeat all the steps above until the glass waste powder needs are met.

**Figure 1.** Research Flowchart
3.1.2. Research Stage at Laboratory

- Fine aggregate inspection, including water content test, mud level, specific gravity, organic substance content, and granular gradations.

| Table 3. Fine Aggregate Testing Standard |
|-----------------------------------------|
| Test materials                      | Standard used     |
|--------------------------------------|--------------------|
| Mud content                         | SNI-1970-2008      |
| Water content                       | SNI-03-1968-1990   |
| Organic substances Content          | SNI-1970-1992      |
| Bulk Specific Gravity (SSD)         | SNI-1970-2008      |
| Absorption                          | SNI-1970-2008      |
| Gradations                          | SNI-03-1968-1990   |
| Modulus of smoothness               | SNI-03-1968-1990   |

- Coarse aggregate inspection, including granular gradations, specific gravity, and abrasion testing.

| Table 4. Coarse Aggregate Testing Standard |
|--------------------------------------------|
| Test materials                             | Standard used     |
|--------------------------------------------|--------------------|
| Bulk Specific Gravity (SSD)                | SNI-1970-2008      |
| Absorption                                 | SNI-1970-2008      |
| Gradation                                  | SNI-03-1968-1990   |
| Modulus of smoothness                      | SNI-03-1968-1990   |

- The creation of tensile strength test object, cylinder-shaped (diameter 150 mm height 300 mm) and for cylindrical porosity (diameter 50.8 mm and height 50 mm)
- Percentage of glass waste powder used is 5%, 10%, 15%, 20%, 25% and 30%.
- Percentage of use of Superplasticizer from any variation of glass waste powder.

| Table 5. Percentage of use of Superplasticizer |
|-----------------------------------------------|
| Glass waste powder percentage (%) | Percentage Superplasticizer (L) |
|--------------------------------------|-------------------------------|
| 0%                                   | 0.125                         |
| 5%                                   | 0.119                         |
| 10%                                  | 0.112                         |
| 15%                                  | 0.106                         |
| 20%                                  | 0.1                           |
| 25%                                  | 0.094                         |
| 30%                                  | 0.087                         |

- Treatment (curing) by soaking in water for 28 days.
- Tensile strength testing of the SCC concrete and porosity at the age of 28 days.

3.1.3. Mix Design. Calculation results of material needs for 4 strong test samples of pull-down and SCC concrete porosity.

| Table 6. Mix Design Calculation |
|---------------------------------|
| Glass waste powder percentage (%) | Glass waste powder percentage (%) | Portland Cement (kg) | Fine Aggregate (kg) | Coarse Aggregate (kg) | Water (L) | Admixture (L) |
|----------------------------------|----------------------------------|----------------------|---------------------|-----------------------|-----------|---------------|
| 0%                               | 0                                | 12.492               | 21.823              | 18.445                | 4.327     | 0.125         |
| 5%                               | 0.625                            | 11.867               | 21.733              | 18.370                | 4.372     | 0.119         |
| 10%                              | 1.249                            | 11.243               | 21.643              | 18.294                | 4.372     | 0.112         |
3.1.4. **Testing standards Tensile Strength and Porosity.** Tensile strength testing using Standard regulation SNI 03-2491-2002. Porosity testing using Standard rules ASTM C 642-90.

### 4. Result and Discussion

#### 4.1. **Fine Aggregate Testing Results**
Tests carried out are tests of mud content, water content, organic substance levels, specific gravity, and gradations. The test results are presented in the following table 7.

**Table 7. Result of Fine Aggregate Testing**

| Test materials                  | Result       |
|--------------------------------|--------------|
| Mud content                    | 5.28%        |
| Water content                  | 2.86%        |
| Organic substances Content     | Light Yellow |
| Bulk Specific Gravity (SSD)    | 2.5          |
| Absorption                     | 2.9%         |
| Gradation                      | Zone II      |
| Modulus of smoothness          | 3.67         |

#### 4.2. **Coarse Aggregate testing results**
Tests conducted are specific gravity testing and gradation. The test results are presented in the following table 8.

**Table 8. Coarse Aggregate Testing Result**

| Test materials                  | Result       |
|--------------------------------|--------------|
| Bulk Specific Gravity (SSD)    | 2.45         |
| Absorption                     | 2.2%         |
| Gradation                      | 20mm Zone    |
| Modulus of smoothness          | 7.7          |

#### 4.3. **Tensile Strength Testing Results**
Data analysis results obtained a significance value of $0.000 < 0.05$ and F count $84.893 > F$ Table then it can be concluded that a significant change occurred. The robust R Square value of the attraction is 0.890. With Yc's regression equation $= -0.003X2 + 0.033x + 3.331$ obtained the optimal variation of 5.5% with a strong pull-off Value of 3.422 MPa. The following table results in the strong value of the SCC concrete.

**Table 9. Tensile Strength Testing Result**

| Glass waste powder percentage (%) | Average Tensile Strength (MPa) |
|-----------------------------------|--------------------------------|
| 5%                                | 3.421                          |
| **5.5%**                          | **3.422**                      |
| 10%                               | 3.361                          |
| 15%                               | 3.151                          |
| 20%                               | 2.791                          |
| 25%                               | 2.281                          |
| 30%                               | 1.621                          |
Data results of the tensile strength of concrete control of 2.75 MPa, in concrete with a 5% glass waste powder percentage acquired a strong value of average pull of 3.421 MPa. For the glass waste powder variation of 5.5% obtained the optimal value of glass waste powder variation and obtained a strong value of the maximum tensile of 3.422 MPa. There is a strong increase in drag because of the Pozzolan glass waste powder is a material containing silica and alumina, the compound will react chemically with calcium hydroxide at room temperature and form compounds that have properties like cement [20].

On a variation of glass waste powder 25% and 30%, the tensile strength of concrete decreased. There is a strong decline in the withdrawal due to too much powder waste glass of cement percentage decreased much, so that the connective power between aggregates decreases. This is due to glass waste powder being a pozzolan material that contains silica and alumina, but has no binding properties such as cement [21]. With decreased inter-aggregate bonding leads to strength pulldowns.

4.4. Porosity testing Results
Data analysis results obtained a significance value of 0.000 < 0.05 and F count 73.753 > F Table 3.47 then it can be concluded that a significant change occurred. The value of R Square porosity is 0.875. With Yc's regression equation = 0.006X2 – 0.103x + 10.248 obtained the optimal variation of 8.583% with a porosity value of 9.806%. Here is the result table of SCC concrete porosity value.

| Glass waste powder percentage (%) | Average porosity (%) |
|-----------------------------------|----------------------|
| 5%                                | 9.820                |
| 8.583%                            | 9.806                |
| 10%                               | 9.810                |
| 15%                               | 9.816                |
| 20%                               | 9.835                |
| 25%                               | 9.855                |
| 30%                               | 9.883                |

Figure 2. Graph of Tensile Strength Testing Result
From the research result data, concrete control porosity value of 10.675%, in concrete with a percentage of glass waste powder 5% obtained an average porosity value 9.820 (Decrease percentage 8.01%). For variations of glass waste powder of 8.583% obtained the optimal value of glass waste powder variation and the value of minimum porosity which is at 9.806% (decrease percentage of 8.14%). In the variation of glass waste powder 10%, 15%, 20%, 25% and 30% concrete porosity also decreased from concrete control.

From the graph in Figure 3 occurs two conditions of change. First when the SCC concrete with all the percentage of glass waste powder shows the results of porosity under the control concrete. The effect of being seen in table 1 powder waste glass that is pozzolanic can be a substitute for cement. In powdered waste glass much contains SiO2. The chemical reaction is between the silica particles of the glass grain and the alkali matter of the cement grain. This reaction is often called alkali-silica reaction (ASR), this reaction creates a "gel" agar, which can swell and cause concrete cracks early if precautions are not enforced in the formulation of concrete mixture [22]. So, the "gel" was able to fill the pores of the SCC concrete. The second condition is when the rise of porosity. The effect caused by glass waste powder is not absorbing water (zero water absorption) [6]. Water is one of the big causes of porosity value in concrete, this is because the water element is composed of hydrogen and oxygen. Moreover, the size of the glass waste powder grain is greater than cement, so that the surface area is smaller and needs less water. Its nature does not absorb water and the surface area is smaller than the moisture content in fresh concrete becomes much left so after the dry concrete causes the pore.

5. Conclusion
- Glass Waste powder variations in replacement of some cement has a significant effect on the tensile strength and porosity of the SCC concrete.
- The optimal rate of addition of glass waste powder resulting in maximum tensile strength of the SCC concrete is at a percentage of 5.5% at 3.422 MPa. The optimum addition of glass waste powder resulting in minimal porosity of SCC concrete is at a percentage of 8.583% at 9.806%.

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