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# Mechanical properties of powder concrete with a geopolymer bond

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# Mechanical properties of powder concrete with a geopolymer bond

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**Abstract** *Commonly, the manufacturing of Reactive Powder Concrete (RPC) uses a portlant cement as a binder. This research introduce a powder based concrete with an eco- friendly geopolymer binder. The production of geopolymer-powder concrete is believed as an alternative to reduce large amounts of* $CO_2$ *released into the air. A geopolymer is obtained by mixing a fly ash as residual of coal burning waste with lye which is the mixture of sodium hidroxide and sodium silicate. Apart from that, glass powder is used to replace quartz powder (with similar quantity) in the manufacturing of this concrete . In producing of geopolymer-powder concrete, 4 mixed variations have been used based on the volume ratio between geopolymer and glass powder. To investigate the mechanical characteristic of geopolymer-powder concrete, several tests include compressive-, flexural-, and split-tensile strength test were conducted using a 20 cm x 10 cm cylindrical speciment and a cube of 40 cm x 10 cm x 10 cm. The test results prove that using 20% of geopolymer mixture, the specimen can achieve the compressive strength of 15,97 MPa, flexural strength of 5,49 MPa, and split-tensile strength of 2,90 MPa.*

## 1. Introduction

Concrete is one of the most popular building material in the construction because the product is easy to find, with a relatively cheap price, less effort to make, and the manufacturing technology is relatively simple.

Concrete is one of the most popular construction material since its raw material is relatively easy to find and the manufacturing techniques are relatively simple and less effort so it yields generally cheap production cost.

A new breakthrough from concrete technology is *Reactive Powder Concrete* (RPC). RPC performance is a way higher than conventional concrete, where it is composed from cement, sand, silica fume, quartz powder, superplasticizer, and steel fiber. The relatively high strength of RPC is achieved by using a very

low ratio of cement water factor 0.15 - 0.26. The size of the granule is very fine and internal reactions occur between its constituent components [1], [2], [3].
Basically, both RPC and conventional concrete may have he same binder ingridient which is portland cement. However, the cement manufacturing process creates a problem for nature conservation. The first environment problem is the emission of greenhouse gas (carbon dioxide) which is produced during the production process. This substance is released into the atmosphere and then rises freely to deplete the ozone layer causing a greenhouse effect. The production of portland cement accounts for 7% of the total CO2 produced on earth [4], [5], [6].

The use of Geopolymers as concrete binders is one alternative that can be used to replace cement. Geopolymers are inorganic polymers that use aluminosilic mineral materials ($SiO_2$ and $Al_2O_3$) to replace the C-chain. Geopolymers are also a synthesis of secondary products such as fly ash and other ingredients which contain a lot of silica and alumina that forms an inorganic alumina silica compound [7]. Geopolymer concrete is formed from chemical reactions consists of alkali compounds that can react compounds of (Si) and (Al) which exists in materials such as fly ash, this reaction is called polymerization which produces Si-O –Al-O structural bonds that are consistent with the term polysialate as the chemical name of geopolymer concrete that is made from Silico-Aluminate based on structural structure as shown in figure 1 [8], [9], [10], [11], [12], [13].

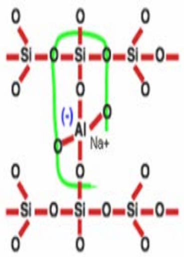

**Figure 1.** Bonds that occur in Geopolymers

Geopolymers are friendly to the environment. The manufacturing process uses raw materials of fly ash which is the residual combustion of coal and doesn't require too much energy. The process of making geopolymer is quite simple. With a maximum heating of 90$^{o}$C, it can produce geopolymer concrete with high strength [7], [14].

The limits of natural raw materials and the release of high carbon dioxide into the air in the process of cement production has an impact on deteriorating environmental conditions [8]. Therefore, it is necessary to replace cement, concrete binding materials, which should be more environmental friendly. Many research have been done on the mechanical properties of geopolymer concrete in normal concrete [7], [14], but no research has been done on the use of geopolymers as reactive powder conrete binders. This study provides significant results on the use of geopolymers as reactive powder concrete binders.

## 2. Material

### *2.1. Fine aggregate*

Fine aggregate as the base material for concrete production plays an important role in determining the quality of concrete. Fine aggregate quality is influenced by grains, hardness, sludge content and organic content, thus fine aggregate quality has a very big influence on concrete quality. In this research, the fine aggregate used was silica sand with a maximum grain size of 600 micrometers.

*2.2 Fly ash*

Fly ash is the remnants of coal combustion. According to the ACI Committee 226, it is explained that fly ash has fairly fine grain quality, which passes sieve No. 325 (45 milli microns) 5-27% with *specific gravity* between 2.15 - 2.8 and has the color of blackish gray. In general, the chemical elements of fly ash consists of silica ($SiO_2$), alumunia ($Al_2O_3$), ferrous oxide ($Fe_2O_3$), and calcium oxide (CaO) and also contains other additional elements named magnesium oxide (MgO), titanium oxide ($TIO_2$) , alkaline ($Na_2O$ and $K_2O$), sulfur trioxide ($SO_3$), phosphorus oxide ($P_2O_5$) and carbon. This study uses recycled fly ash obtained from the remaining coal combustion of the Suralaya power plant included in the F category.

*2.3 Sodium silicate*

Sodium silicate is an alkaline solution which plays an important role in the polymerization process. Sodium silicate has a function to speed up the polymerization reaction. Reactions occur very quickly when many alkaline solutions contain silicate solutions such as sodium silicate or potassium silicate compared to the reaction that occur due to alkaline solutions which contain lots of hydroxide solutions.

*2.4. Sodium hidroxide*

NaOH is an inorganic mixture formed from the formula $Na^+ + OH^-$. The NaOH itself is solid white and has a very high base level, with the pH of 14. In geopolymer, NaOH is a strong reactor in the form of *flake* with the content of 98% to react with sodium silicate and mixed with fly ash so that fly ash can function as a substitute for cement which has the binding ability.

*2.5 Glass powder*

Glass waste is one of the recycled materials that can be used in the construction industry since the raw materials are available and cheap. Moreover, glass has resistance from abrasion and weather or chemical attacks because it has a fairly high amount of silica. Hence, glass can be used as an alternative to concrete materials. The compositions contained in glass are: $SiO_2$, $Al_2O_3$, $FeO_3$, CaO, MgO, $Na_2O$, $K_2O$, and $SO_3$. In this study, the glass that is used was taken from a glass factory and then processed with the help of a *Los Angeles* machine to the size of passing a 250 mm filter.

## 3. Research method

To make concrete powder with a geopolymer binder, an activator solution is prepared, specifically sodium hydroxide (NaOH) in solid form (flake) is dissolved in water suitable to the concentration that is planned on the table. Then store until the temperature drops. Another activator, sodium silicate ($Na_2SO_3$), already in the form of a solution mixed with sodium hydroxide which is already cold, then stir evenly. The weighed fly ash is first mixed into the activator solution and evenly stirred. 2. After stirring, a concrete binder is formed, named geopolymers which is then poured into a mixing machine with other materials, such as fine aggregates, glass powder, and silica fume.

To make geopolymer-powder concrete, some activators were prepared. A solid-form Sodium hydroxide (NaOH) was initially dissolved in the water at certain concentration as mentioned in the Table 1. The solution was then stored until the temperature dropped. Another activator, sodium silicate

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($Na_2SO_3$) solvent, was mixed with the NaOH and stirred evenly. It was followed by additional fly ash proportionally to the activator solutions such that a concrete binder had been formed. Finally, the geopolymer concrete was produced by mixing a former concrete binder together with other materials such as fine aggregates, glass powder, and silica fume.

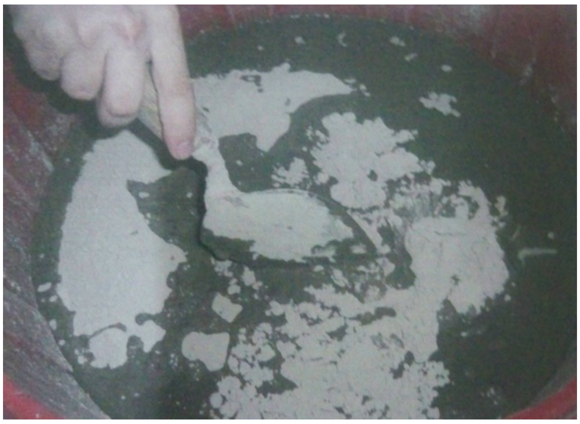

Figure 2. Mixing fly ash with activator solution

The mixed design materials are shown in the table 1 and table 2. After the mixing process, the concrete would become a paste after certain of time and it was ready to be casted into the mold which had been lubricated by the oil. Mold sizes used on the tests were consist of 10x20 cm cylinder and 10x10x40 cm cube. Each variation of mixture comprised of 10 cylinders and 5 cubes. After the concrete was formed into a specimen and cured at the room temperature, the specimens were treated at 95$^o$C temperature. The heating process was carried out for 24 hours and the specimens were stored at room temperature until the testing day. The testing day was 7 days afterwards. The tests involved compressive-, flexural-, and split tensile test.

Design of mixture of the material are shown in the table 1 and table 2. After the mixing process, wait until it becomes concrete paste, then pour it into formwork which has been lubricated by oil. Size of the formwork is in accordance with the size of the test object i.e., for 10 X 20 cm cylinder and 10 X 10 X 40 cm block as shown. Every variation of the mixture requires 10 cylinders and 5 blocks. Leave the concrete at room temperature after it is formed then treat the mixture by raising its temperature to 95$^0$C. The heating process is carried out for only 24 hours then store the concrete until the testing day, which is 7 days after this process. Test that will be performed on the object covers compressive strength, flexural strength, and split tensile strength.

Table 1. Percentage of mixture weight in powder concrete

| Parameter | Amount |
|---|---|
| Concentration of NaOH (molar) | 9,00 |
| $\frac{\text{sodium silicate}}{\text{fly ash}}$ (weight) | 0,25 |
| $\frac{\text{sodium silicate}}{\text{sodium hydroxide}}$ (weight) | 0,50 |

Table 2. Variation of geopolymer powder concrete mixture

| Material | Percentage of Mixture | | |
|---|---|---|---|
| Silica fume | 15% | | |
| Glass powder | 30% | | |
| Geopolymer | 20% | 30% | 40% |
| Variation | mix-1 | mix-2 | mix-3 |

## 4. Result and Discussions

The test results of all specimens are presented in Figure 3. It is showed that mixture mix-1 has the highest compressive strength. The quantity of geopolymer used in this mixture is 20%. The result also indicates that the additional proportion geopolymer into the mixture does not increase the strength but it decreases the strength.

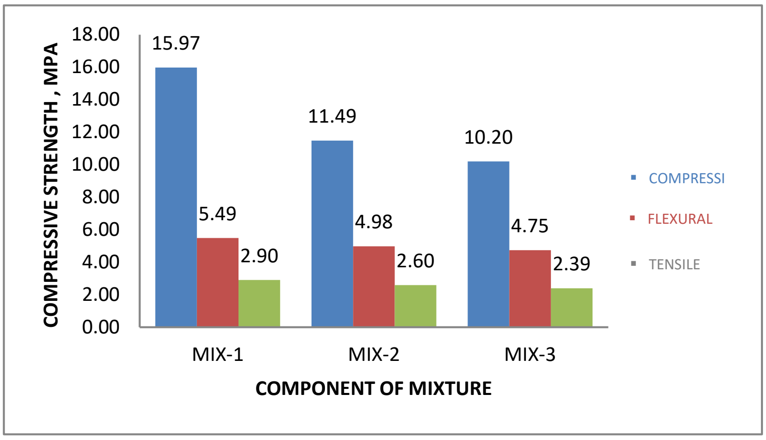


Figure 3. Mechanical properties of geopolymer concrete powder.

The trend of flexural test and split-tensile test results are consistent with the compressive test. It means that if the compressive strength increases, the flexural strength and split-tensile strength will also increase. In contrast, if the compressive strength decreases, the flexural strength and split-tensile strength will also decrease.

The highest test value is obtained if the amount of geopolymers used is 20%. This is because all geopolymer materials can cover silica fume and glass powder granules such that there is no excessive reaction in the geopolymer chain to become a binder. The main composition of silica fume and glass powder is silica or Si, which is also one of the basic elements in the geopolymer chain as shown in Figure 1. However, if the amount of geopolymer increase, the compressive strength will decrease. It is because the excessive reaction between silica fume and glass powder with geopolymers that are used. This reaction inflicts formation of large pores and has impact on the volume of geopolymer as shown in Figure 4. Larger volume of pores will reduce the value of concrete compressive strength.

Figure 4. Volume alteration of geopolymer concrete

The value of compressive strength, flexural strength and split tensile strength of geopolymer powder concrete are lower compared to geopolymer concrete which produced by using coarse aggregates worked by Ecaputri [12]. This is because geopolymers in concrete powder have a large amount of pores which reduce value of compressive strength, flexural strength and split tensile strength.

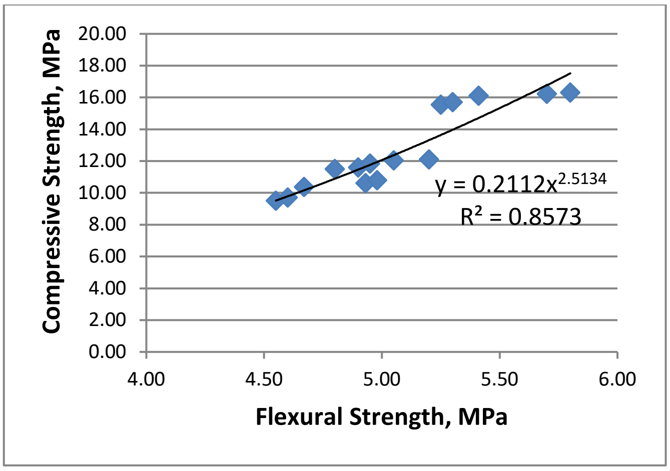


Figure 5. The relation between compressive strength and flexural strength with geopolymer binders

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As a structural element, reinforced concrete beam has a significant role to carry the load. If the load exceeds the flexural capacity of the reinforced concrete beam, the beam will collapse [13]. The relationship of flexural strength and concrete compressive strength according to SNI 03-2487-2002 yields a modulus of flexure failure for normal concrete (without reinforcement) as follows :

$$f_r = 0{,}7\sqrt{f_c'} \quad (1)$$

$f_r$= flexural strength
$f_c'$ = compressive strength

In this research, correlation between flexural strength and compressive strength of concrete powder with geopolymer as binder is shown in Figure 5.

$$f_r = 0{,}2112(f_c')^{2{,}5134} \quad (2)$$

Equation (1) and equation (2) signify the same tendency, that the greater the compressive strength of concrete, the greater flexural strength will be.

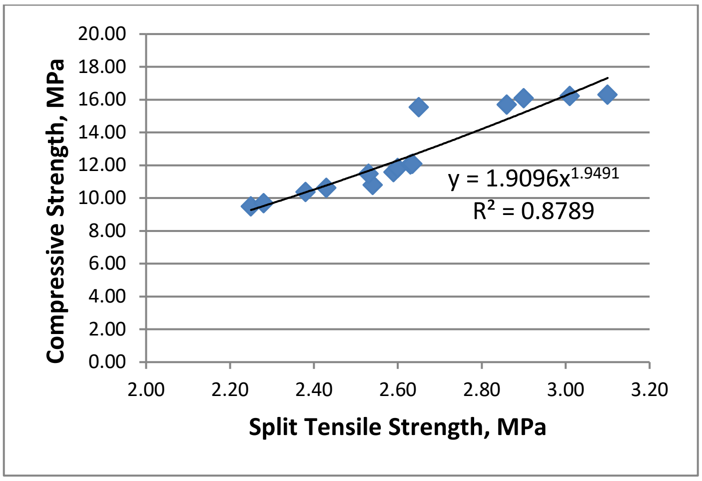


Figure 6. Correlation of compressive strength and split tensile strength with geopolymer binders.

Correlation of compressive strength and split tensile strength with geopolymer binders in this research is shown in Figure 6.

$$f_{sp} = 1{,}9096(f_c')^{1{,}9491} \quad (3)$$

Equation (3) indicates that the greater the value of compressive strength of concrete, the greater the value of split tensile strength.

## Conclusion

Based on on this research, the following conclusion are obtained:
1. The value of compressive strength, flexure strength and split tensile strength of concrete powder with geopolymer binders depend on the amount of geopolymer used. The higher amount of geopolymers used, the smaller compressive strength, flexure strength and tensile strength will be.
2. Excessive geopolymers in concrete powder can increase the volume of pores that appear and it will reduce the value of the concrete strength.
3. The greater the value of compressive strength of powder concrete with geopolymer binders, the greater the value of flexural strength and split tensile strength

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