The analysis of tensile strength and elasticity in slag concrete with curing variations at 90 days age

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Abstract. Cement is a concrete constituent material that has a great influence on concrete quality, both normal and high-quality concrete. High quality concrete in SNI 03-6468-2000 is defined as concrete which has compressive strength characteristics above 41.4 MPa. During the process, cement produces gas emissions obtained from combustion, calcination of limestone, and the use of electrical energy. The purpose of using cement in the preparation of concrete itself is as a binder between aggregates. Nowadays, commonly used cement (OPC cement) can be replaced with slag cement. Slag cement is the result of the addition of Granulated Blast Furnace Slag into the final grinding of cement which is a waste product from the steel ore smelting process. This research is comparing the magnitude of the tensile strength and the modulus of elasticity of the samples with 100% OPC cement and those with 100% slag cement. The samples used were cylinders with 15 cm diameter and 30 cm height. The tests were carried out when the concrete reaches 90 days age. The curing of the samples was carried out with four variations which is by submerging those in tap water, Kuala Tanjung sea water, Sulphuric Acid water, and compound curing. The results of this test were obtained if the slag cement-used concrete is able to have a tensile strength that is almost the same as OPC cement-used concrete which is 4.341 MPa for normal concrete and 4.293 MPa for slag concrete and its modulus of elasticity of 46103.67 MPa for normal concrete and 46892.82 MPa for slag concrete.

1. Introduction
High quality concrete in SNI 03-6468-2000 is stated as concrete which has compressive strength characteristics above 41.4 MPa. In its preparation, cement becomes the most influential material with its function as a binding material. The most commonly used cement is type I Portland cement. Cement in its own manufacturing process produces 7% of CO$_2$ emissions from the total emission gas produced [1]. Besides cement, in the world of construction, steel is also one of the materials which in its manufacturing process has an unfavourable impact on environment. During the process of making steel, steel slag waste is produced. This waste was categorized as B3 waste by the Research and Development Center for Roads and Bridges in 2011 [2].

In 2017, one of the largest cement companies in Indonesia has launched a product called slag cement. Slag cement is the result of steel ore smelting in the form of Granulated Blast Furnace Slag addition into the final milling of cement. This research is the result of the development of slag cement usage as a substitute for Portland cement in concrete preparation which is expected to be more environmentally friendly.

2. Methods
2.1 Materials
The use of slag cement in this research was carried out as a substitute for Portland cement. Concrete
with 100% use of slag cement is called slag concrete, and concrete with 100% use of Portland cement is called normal concrete [3]. Materials used in the preparation of slag concrete and normal concrete are coarse aggregate, fine aggregate, cement, water, and the addition of superplasticizer to improve workability at execution.

1. Cement
   a. Portland cement
   Portland cement in SNI 15-2049-2004 is a hydraulic cement produced by grinding cement slag which mainly consists of calcium silicate which is hydraulic and ground together with additives in the form of one or more crystalline forms of calcium sulphate compounds and may be added with other additive materials [3].

   The cement used in making slag concrete and normal concrete is type I Padang cement.

   b. Slag cement
   Slag cement is the result of Granulated Blast Furnace Slag addition which has a nature like clinker into the final grinding of cement at the finish mill as an additional substitution material. The most dominant chemical composition in the slag is Iron Oxide (CaO) and Silicate (SiO$_2$)[4].

   The cementious nature of slag is influenced by several factors such as its chemical composition, alkali concentration, reaction to the system, glass content, fineness and temperature caused during the hydration process. Slag cement has several advantages compared to Portland cement such as less energy needed, more resistance to abrasion, low hydration heat so that the initial crack can be as minimal as possible. However, the initial strength of the concrete is lower and the setting time is longer compared to ordinary cement [5].

   Table 1. Chemical composition contents of slag.

   | Oxide  | % of Weight |
   |--------|-------------|
   | CaO    | 51.68       |
   | SiO$_2$| 29.59       |
   | Al$_2$O$_3$ | 10.05       |
   | Fe$_2$O$_3$ | 2.59        |
   | MgO    | 2.11        |
   | S$^2-$ | 0.22        |
   | as Na$_2$O | 0.44        |
   | SO$_3$ | 2.31        |
   | LOI    | 0.21        |
   | IR     | 0.95        |
   | If Cao | 0.18        |
   | Cr$^{6+}$ | 0.52       |

   Physically, the fineness of slag cement is more refined than type I Portland cement. Slag cement also has a whiter color than type I Portland cement.

2. Aggregates
   Aggregates are granular materials such as sand, gravel, split, and iron furnace crust mixed with binding material (cement) to form a stir. The aggregate content alone in concrete is 60% -70% of the concrete volume.

   a. Fine aggregate
   Sand or aggregate must have a good gradation. This is because the aggregate will fill the empty spaces that cannot be filled by other materials, resulting a solid concrete.

   b. Coarse aggregate
   Coarse aggregate is in the form of gravels or split that comes from natural disintegration of natural rocks. Coarse aggregate has a grain size of about 5-40 mm. The gravels used in this research are gravels
with 1-1 split. The size of the gravels affects the quality of the concrete strength itself where the smaller the size of the gravels, the cavity in the concrete will be more filled than the use of gravels in larger size.

3. **Superplasticizer**

Superplasticizer is a type of admixture which is commonly used to help improve the workability of concrete. Superplasticizer used in this research is type F which is High Range Water Reducer with Master Ease 3029 type. This type serves to reduce the amount of water of the mixture by 12% and help improve workability when working on concrete which is also designed to provide high rheological properties in fresh concrete with the aim to facilitate the placement and completion of concrete as well as concrete pumping for all construction activities. The following are the characteristics of the Master Ease 3029.

| Description                  | Information                          |
|------------------------------|--------------------------------------|
| Shape                        | Solution                             |
| Color                        | Yellowish                            |
| Relative density, 25°C       | 1.090±0.03 gr/cm²                    |
| pH                           | 6.1±2.0                              |
| Contents of Chlorine         | < 0.1%                               |
| Density                      | 41.5-1.5%                            |

4. **Water**

The strength and quality of concrete are generally influenced by the water used in the mixture. Good water is the one that can be drunk and does not contain hazardous materials such as oil, sugar, salt or other chemical substances.

2.2. **Curing**

The curing that was carried out in this research consisted of four types which is by submerging the samples with tap water, Sea water, Acid water, and curing with compound.

a. Submersion with tap water

According to Neville (2004), the concrete hydration process runs well in water immersion. This hydration process affects the concrete pores which get smaller as the age of the concrete increases and causes the bond between the aggregates within to be increasingly tight. If the pores get smaller, it will produce a higher strength of concrete.

b. Submersion with sea water

Sea water used in this immersion is taken from Kuala Tanjung. Sea water that has the potential for active alkaline aggregates should not be used for concrete, this can be dangerous if it's mixed or combined with Sodium salts present in sea water. Calcium Chloride and Magnesium Chloride will react chemically with cement so as to reduce the setting time.

c. Submersion with Sulfuric Acid water

Sulfuric acid is a naturally formed acid compound on the surface of soil and ground water. Sulfuric acid also has a high aggressiveness compared to other acids. An acidic environment that contains acidic chemical elements will slowly damage the concrete starting from the edges and corners of the concrete by releasing the particles of concrete so that the concrete becomes porous [6].

If the concrete structure has a direct contact with Sulfuric acid compounds, the strength quality of the concrete will be affected by the corrosion that caused. The occurred corrosion can be influenced by several factors, i.e. temperature, dissolved salts, and microorganism activity.

2.3. **Cylinder samples**

The samples used in this research were cylinders with 15 cm diameter and 30 cm height. The process of making these samples was done by casting for each specimen with the concrete of 100% Portland cement.
and concrete of 100% slag cement.

2.4. Tests

Tests that were carried out are tensile and elasticity test where the tests were carried out on each type of concrete with four variations of curing.

a. Tensile strength test

The capability of concrete in terms of tensile is related to the behavior of brittle concrete material. This brittle nature occurred due to the concrete crushed strain which only reaches values between 0.001 and 0.005. The tensile strength of concrete is around 9% to 15% of the compressive strength. Each increase in compressive strength given is only have a small effect on the increase in the tensile strength [7]. The tensile strength of small concrete is caused by fine cracks that occur in concrete. This crack does not have a big effect if the concrete receives pressure. This is due to the pressure that occurs in the concrete causing the crack to close so that the possibility of pressure distribution. The tensile strength obtained through split cylinders test with the cylinder samples is usually produces tensile strength values that reflect the actual strength. At the time of testing, the sample is placed on the test tool in the longitudinal direction and is given a compressive load throughout the length or height of the cylinder. The sample will be split and divided into two parts.

![Figure 1. Tensile strength test.](image)

b. Elasticity test

The comparison of strain and stress in concrete is called modulus of elasticity. Modulus of elasticity in concrete has a connection with other concrete properties, the most important is the compressive strength of concrete. The value of modulus of elasticity is known as a parameter to measure whether the load can be carried without damaging the concrete or not, especially in a plastic state [8].

![Figure 2(a). Ring and dial are mounted to the sample.](image)

Figure 2(b). The dial is moving due to loading.
The sample before being put into the compress machine must first be fitted with the elasticity test ring and its ring. Once mounted, the new sample is tested by doing loading.

3. Results and discussion

3.1. Test results of split tensile strength

The results of the tensile strength test for normal concrete with 100% Portland cement and with 100% slag cement can be seen in Table 3.

**Table 3.** Split tensile strength test results of normal concrete.

| Age and Variation | Type of Curing     | Tap water | Sea water | Acid water | Compound |
|------------------|--------------------|-----------|-----------|------------|----------|
| 90 Days BN       |                    | 4.341 MPa | 3.680 MPa | 3.822 MPa  | 3.916 MPa|
| 90 Days BS       |                    | 4.290 MPa | 4.293 MPa | 4.199 MPa  | 3.609 MPa|

From the test results, it can be concluded that the greatest value of the two tests is on Tap water curing for normal concrete and sea water curing for slag concrete. This condition supports the function of the slag itself which is used in offshore buildings and water construction.

![Graph of split tensile strength test of normal concrete and slag concrete.](image3)

3.2. Test results of modulus elasticity

In the modulus of elasticity test, the modulus values for both concrete, normal and slag concrete can be seen in Table 5.

![Test result of SEM from slag concrete.](image4)
### Table 4. Test results of modulus of elasticity.

| Age and Variation | Type of Curing | Tap water | Sea water | Acid water | Compound |
|-------------------|----------------|-----------|-----------|------------|----------|
| 90 Days BN        |                | 46103.67  | 41463.07  | 39773.06   | 34410.37 |
| 90 Days BS        |                | 40054.41  | 46892.82  | 40152.09   | 35646.37 |

Normal concrete has a modulus of elasticity of 46,103.67 MPa. Slag concrete has a modulus of elasticity of 46892.82 MPa. The highest strength is in normal concrete with Tap water immersion curing, while the maximum strength for slag concrete is in concrete with sea water curing. The higher the modulus of elasticity of concrete, the better the concrete. This is because if the concrete is given a certain strength to be able to withstand the strain as small as possible, then it means that the strength of concrete is quite good.

### 4. Conclusions

From the results of research on the magnitude of tensile strength of non-slag normal concrete and concrete with 100% slag and the modulus of elasticity can be concluded as below.

1. The highest tensile strength value for normal concrete is 4,341 MPa with Tap water curing and slag concrete is 4,293 MPa with sea water curing.
2. Slag concrete can be used in construction such as docks or dams that have a high pH.
3. The greatest modulus of elasticity for normal concrete is 46103.67 MPa, and for slag concrete is 46892.82 MPa.

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