Crack Patterns Analysis on Structural Beam with Slag Cement

Rahmi Karolina*, Syahrizal, R.Inanda, Baskara Hutahean, and M.A.P Handana
Universitas Sumatera Utara, Medan, Indonesia

*rahmi.karolina@usu.ac.id

Abstract. The more widespread use of concrete and the increasing development shows that there is a greater demand for concrete so a new innovation for concrete is needed in an alternative use of basic materials. Slag cement is the result of fine grinding of steel slag which has the properties of cement which can function as an aggregate adhesive in concrete mixtures and has a fineness level that is either equal or more than type I portland cement. This research aims to compare high quality concrete made from slag cement and conventional concrete mixtures. Concrete beam samples with the size of 20 cm x 30 cm x 240 cm, with 2D10 compressive reinforcement and 3D10 tensile reinforcement. The number of samples are 6 with a variation of 3 high quality reinforced concrete with type I portland cement and 3 using slag cement. Flexture test is by analyzing the behavior of beams due to loading, crack patterns, and visual results of the beam with slag cement. From the results of the research, at the same load of 8 tons obtained a maximum deflection value of 9.52 mm on structural beams with slag cement and 13.30 mm on normal structural beams, thus structural beams with slag cement have better rigidity. The crack patterns that occur is the flextural crack patterns that occur in 1/3 of the middle span with a number of 5 cracks and a maximum crack width of 0.218 mm that occurs in structural beams with slag cement.

1. Introduction
In the world of building construction, development is an ongoing effort to improve the standard of living and welfare of the community. Many research has been done to get better and more environmentally friendly construction products. Concrete is an option as a structural material in building construction. The more widespread use of concrete and the increasing development shows that there is a greater demand for concrete so a new innovation for concrete is needed in an alternative use of basic materials. The more widespread use of concrete and the increasing development also shows that there is a greater demand for concrete, so we need a new innovation for concrete in the alternative use of basic materials. This innovation includes the use of steel slag waste as a fine aggregate substitution materials and slag that can be used for raw materials for making cement (Keputusan Menteri Negara Lingkungan Hidup Nomor: 231 Tahun 2010). Slag is waste produced from the by-products of the metal ore smelting process. Iron ore is reduced to iron and the remaining material from the slag that floats on the iron. This slag is periodically tapped as a liquid and it will be used for the manufacture of GGBS that must be quickly extinguished in large volumes of water, optimizing the properties of cement and produce granules similar to coarse sand. The granulated pulp is then dried and ground into a fine powder. Although usually designated as "GGBS" in the UK, it can also be referred to as "GGBS" or "Cement Slag" Concrete which is basically a mixture of fine aggregate, coarse aggregate and cement. The content of the dominant chemical composition in slag contains iron oxide and silicate. Physically and the chemical composition of the slag is similar to
clinker so that slag can be added in the final grinding of cement at the finish mill as an additional substitute material.  

In Indonesia, there are many industries engaged in steel smelting and refining, including PT Krakatau Steel which is located in West Java that produces at least 150 tons of slag every day. Every ton of steel production produces 20 percent of slag waste. Slag byproducts produced from steel smelting and refining companies can be utilized as material with more value through waste co processing. If it's not utilized, the waste is included in the category of toxic and hazardous waste (B3). (Puslitbang Jalan dan Jembatan, 2011). In good fineness, slag cement shows the same or higher quality compared to Portland cement (type I) and has the characteristic of "Low Heat Hydration" which is producing a low hydration heat and CO2 emissions which are produced when production is very low. Therefore, it can replace portland cement function with certain mass ratio. Various substitution levels are starting from 30% - 70%. (Semen Indonesia, 2017). From the content of the chemical composition, it can be expected that slag can be reused for various applications in the field of Civil Engineering. Currently, the steel mill has developed the use of slag as a mixture for structural concrete in order to reduce the cost of construction or repairs to existing facilities and infrastructures. So it is expected that later, slag has a high economic value besides the negative impact due to the slag on environmental damage can be minimized so that the environment becomes clean, free of solid waste and constantly maintained.

2. Research Method
2.1 Concrete
Concrete is a mixture of coarse aggregate, fine aggregate, water and cement with or without additives which then hardened. In a concrete, there is a set of mechanical and chemical interactions of the forming materials. The diversity of concrete-forming materials are made from various types of cement, aggregate and also pozzolanic material, fly ash, high furnace slag, fiber, and others. (Neville and Brooks 1987). Concrete is also a mixture of Portland cement or other hydraulic cement, fine aggregate, coarse aggregate and water with or without additives that forms a solid mass. (SNI 02 2847 2002).

2.2 Reinforced Concrete Beams
To hold a great tensile strength on the bottom edge beam fibers, it needs to be given reinforcing steel so that it is called as reinforced concrete in this reinforced concrete beam section. Steel reinforcement is planted in the concrete in such a way so that the tensile force needed to hold the torque on the cross section of the crack can be held by the reinforced steel. Due to the nature of the concrete which is not strong enough against tensile, then the part of the beam which holds the tensile (under the neutral line) will be held by the reinforcement while the part that holds the pressure (above the neutral line) is still retained by concrete.

2.3 Constituent Materials of Concrete Beams
a. Portland Cement
According to ASTM C-150 1985, Portland cement is defined as a hydraulic cement produced by grinding a clinker consisting of hydraulic calcium silicate which generally contains one or more forms of Calcium Sulfate as an added material which is milled together with its main ingredient. The process of making portland cement begins by putting the main raw material from the quarry in the form of 70% limestone, 15% clay, Silica and Iron Oxide mashed until it can be stirred evenly according to the proportions. Then heated up to 800-9000C and put into a rotary clin to be burned at a temperature of 14500C. When the clinker is cooled, grinding is conducted along with the addition of gypsum until it becomes fine.

b. Slag Cement
Slag cement is the result of the addition of Granulated Blast Furnace Slag which has clinker-like properties into the final grinding of cement at the finish mill as an additional substitute material. The content of the dominant chemical composition in the slag contains Iron Oxides and Silicates. Physically and the chemical composition of slag is similar to clinker.
Blast Furnace Slag is a slag, a waste material from pig iron casting, where the process uses a furnace whose fuel is from a blown air (blast). Slag constituent materials are limestone, silica and alumina which react at temperatures of 1600°C and in a form of liquid. Liquid slag floating on molten iron ore, separated and granulated. Liquid slag has a composition of about 30% to 40% SiO₂ and about 40% CaO which is close to the chemical composition of Portland cement. If this liquid is cooled slowly, there will be a useless crystal as a mixture of cement and can be used as a substitute for aggregates that commonly known as slag steel. However, if the liquid is cooled quickly and suddenly, it will form a granulated glass which is very reactive for making slag cement. This granulated glass is dried and grinded with a granulator until it is fine or to the required size and can be used as a substitute for cement in the making of concrete. (Paul Nugraha, 2007).

Figure 2.1. The Making Process of Slag

Based on SK.SNI T-15-1991-03, aggregates are granular materials such as sand, gravel, split, and iron furnace crust that is used together with a binder to form hydraulic or mixed cement concrete. Aggregates content in concrete ranges from 60-70% of the volume of concrete. A large proportion of aggregates in concrete indicates an important role of aggregates. Aggregates must be graded in such a way that the entire mass of concrete can function as a whole, homogeneous, and dense object in which small aggregates function as filling gaps between large aggregates. (Nawy, 1998) The selection of aggregates is important because it will affect the quality of concrete. Therefore, the aggregates used must have the following conditions:

a. The aggregate is clean.
b. Hard.
c. Free of absorption properties.
d. Does not mix with clay or mud.
e. Distribution / gradation of the aggregate size meets the requirements

d. Water
Water is needed in the making of concrete to trigger the chemical process of cement, soaking aggregates and providing ease in concrete work. Water containing hazardous compounds, which are contaminated with salt, oil, sugar, or other chemicals when used in concrete mixtures will reduce the quality of concrete and can even change the properties of the concrete produced. The water used can be in the form of fresh water (from rivers, lakes, ponds, etc.), sea water or waste water, as long as it meets the specified quality requirements (Trimulyono, 2003). The value of the ratio between the weight of water and cement for a concrete stir is called the water cement ratio (w / c). In order to make the perfect hydration process in the concrete mix, general w / c values used are from 0.40 to 0.65 depending on the quality of the concrete to be achieved. To increase workability (ease of workmanship) a higher w / c value is needed. (Dipohusodo, 1994). Generally, the strength and quality of concrete is strongly influenced by the water used.
e. Superplasticizer Master Ease 3029
Superplasticizer is greatly increases workability. Mixtures with a slump of 7.5 cm will become 20 cm. Used primarily for high quality concrete because it can reduce water by up to 30%. High flowability in concrete mixtures containing superplasticizers generally lasts around 30-60 minutes and after that it decreases rapidly. (Paul Nugraha, 2007). Superplasticizer used in this high quality concrete mixture is the type of Master Ease 3029. Master Ease 3029 is a type of high range water reduce superplasticizer produced by BASF. The Master Ease is designed to provide high rheological properties in fresh concrete thereby increasing the ease of placement and completion of concrete as well as pumping concrete for all construction activities.

f. Reinforcing Steel
Concrete-reinforcing steel is steel in the form of a circular cross-section rod used for reinforcement of concrete, which is produced from billet raw material by hot rolling. Based on the shape of the concrete, concrete-reinforcing steel can be divided into 2 (types) i.e. plain concrete-reinforcing steel and fin concrete-reinforcing steel. Plain concrete-reinforcing steel has a circular cross section with non-finned flat surfaces and fin concrete-reinforcing steel is a special-shaped concrete reinforcement whose surface has a cross and longitudinal ribs that are intended to increase adhesion and resist longitudinal motion from the bar relatively against the concrete.

2.4 Test Samples
The making of concrete samples in this research used a block mold with a size of (20 x 30 x 240) cm. There are 2 variations of materials for the samples.

| Table 2.1 Beams Sample |
|------------------------|
| Code | Type of Cement | Number of Samples |
| BN   | Type I Portland Cement | 3 |
| BS   | Slag Cement | 3 |
| Total of Samples | 6 |

2.5 Mix Design of Concrete
Mix design of concrete is intended to determine the composition or proportion of the constituent materials. The proportion of these constituent ingredients is determined through a concrete design (mix design). This is done so that the mixture proportion can meet the technical requirements economically. In determining the proportion of mixtures, the American Concrete Institute (ACI) method is used in this research based on SNI 2847: 2013.

| Table 2.2 Normal Beams Mixtures |
|---------------------------------|
| Portland Cement | Split | Sand | Water | HRWR |
|-----------------|-------|------|-------|------|
| 95,65714 kg     | 155,5476 kg | 139,7012 kg | 26784 ml | 1147,886 ml |

| Table 2.3 Slag Beams Mixtures |
|--------------------------------|
| Slag Cement | Split | Sand | Water | HRWR |
|--------------|-------|------|-------|------|
| 95,65714 kg  | 155,5476 kg | 139,7012 kg | 26784 ml | 1147,886 ml |

2.6 Tensile Strength Test of Structural Beams
The concrete beam test refers to ASTM C-78 conducted at the Structure Laboratory of FT USU. The test steps are as follows:
1. Preparation of testing equipment: Dial Gauge, Hydraulic jack pump, hydraulic jack.
2. In the beam, a grid line with a distance of 5 cm is made first so that the crack pattern lines at the time of testing are easily seen and marked.
3. The beam is placed on top of the Static Loading Frame that has been provided. The support of the sample is located 15 cm from the right and bottom left of the sample.
Figure 2.2 Beam Dimension

4. Dial Gauge (deflection / decrease gauge equipment) is placed under the beam with a 3-point position, i.e. 1/4 L-L, center line and 1/4 L-R.

5. Profile I with a length of 70 cm is placed right in the middle of the beam, in order to divide the centralized force loading with a large of P.

Figure 2.3 Beam Loading

6. The vertical examination of the hydraulic load and jacking equipment above the profile I was carried out in order to obtain pure vertical force.

g. After all equipment are installed, the testing phase is carried out by pumping the hydraulic jack with a constant load multiples. Load multiples that occur is read through the manometer. Hydraulic jack is pumped, the end of the hydraulic jack will press the top profile I frame and automatically the base of the hydraulic jack presses the profile I steel which is given 2 solid iron supports as a 2 point load. Every time the load is added, the mechanical dial gauge will spin and read the deflection that occurs.

h. Load and deflection is recorded when adding a load of 0.5 tons. In addition to recording the load and deflection, each additional load is observed on the sample whether cracks occur or not.

i. Loading is stopped after the beam has a maximum crack and deflection.

Figure 2.4 Beam Loading
3. Results and Discussion

3.1 Tensile Strength Test of Rebar

The tensile strength test of steel reinforcement, by using the equipment "Tensile Machine Test" is carried out at Politeknik Negeri Medan.

![Tensile Test of Rebar](image)

**Figure 3.1 Tensile Test of Rebar**

Plain rebar Ø 6
- yield stress value (fy) = 337.93 N/mm²
- breakdown stress value (fu) = 518.40 N/mm²

Thread rebar D 10
- yield stress value (fy) = 364.75 N/mm²
- breakdown stress value (fu) = 527.64 N/mm²

3.2 Compressive Strength Test of Concrete

From the results of previous experiments, obtained the results of the average compressive strength test of concrete:
Normal concrete = 73.75 Mpa
Slag concrete = 74.63 Mpa

3.3 Theoretical Results of Structural Beams

| Pu (KN) | Deflection | Pu (KN) | Deflection |
|---------|------------|---------|------------|
| 1/4L-L  | 1/4L-R     | CL      | 1/4L-L     | 1/4L-R     | CL       |
| mm      | mm         | Mm      | mm         | mm         | mm       |
| 81.9    | 8.051      | 9.975   | 83.3       | 8.188      | 10.146   |

3.4 Test Results of Deflection
### Table 3.2 Results of Theoretical Calculation

| Beban (Kg) | C-L (Balok Normal) Lendutan (mm) | C-L (Balok Slag) Lendutan (mm) | 1/4L-L(Balok Normal) Lendutan (mm) | 1/4L-L(Balok Slag) Lendutan (mm) | 1/4L-R(Balok Normal) Lendutan (mm) | 1/4L-R(Balok Slag) Lendutan (mm) |
|------------|-----------------------------------|-----------------------------------|-----------------------------------|-----------------------------------|-----------------------------------|-----------------------------------|
| 0          | 0.00                              | 0.00                              | 0.00                              | 0.00                              | 0.00                              | 0.00                              |
| 500        | 0.25                              | 0.20                              | 0.17                              | 0.15                              | 0.18                              | 0.16                              |
| 1000       | 0.33                              | 0.38                              | 0.35                              | 0.26                              | 0.36                              | 0.28                              |
| 1500       | 0.43                              | 0.74                              | 0.50                              | 0.43                              | 0.54                              | 0.45                              |
| 2000       | 1.34                              | 1.21                              | 0.81                              | 0.75                              | 0.85                              | 0.77                              |
| 2500       | 1.76                              | 1.57                              | 1.21                              | 0.91                              | 1.26                              | 0.93                              |
| 3000       | 2.24                              | 2.02                              | 1.75                              | 1.36                              | 1.79                              | 1.39                              |
| 3500       | 2.77                              | 2.49                              | 2.27                              | 1.70                              | 2.32                              | 1.80                              |
| 4000       | 3.32                              | 2.99                              | 2.75                              | 2.14                              | 2.79                              | 2.17                              |
| 4500       | 3.96                              | 3.51                              | 3.30                              | 2.65                              | 3.34                              | 2.68                              |
| 5000       | 4.96                              | 4.09                              | 3.83                              | 3.47                              | 3.89                              | 3.51                              |
| 5500       | 5.65                              | 4.76                              | 4.51                              | 4.19                              | 4.56                              | 4.20                              |
| 6000       | 6.56                              | 5.65                              | 5.21                              | 4.80                              | 5.26                              | 4.82                              |
| 6500       | 7.82                              | 6.64                              | 6.01                              | 5.25                              | 6.08                              | 5.27                              |
| 7000       | 9.21                              | 7.83                              | 7.11                              | 5.83                              | 7.15                              | 5.86                              |
| 7500       | 10.30                             | 9.52                              | 8.39                              | 6.37                              | 8.42                              | 6.40                              |
| 8000       | 11.00                             | 10.30                             | 9.52                              | 8.39                              | 10.30                             | 9.52                              |

**Figure 3.2** Graph of Load-Deflection Ratio (BN and BS)
3.5 Crack Patterns Occurred on the Beam

Figure 3.3 (a) Crack Pattern of Normal Structural Beam 1
In Figure 3.3 (a), (b), (c) and figure 3.4 (a), (b), (c) it can be seen that the crack patterns that occur is almost the same, which is flexure. In this test, cracks that occur in the samples are generally begin with a subtle crack on the underside of the samples, i.e. the tensile side of the cross section, followed by flexural cracks on the side where the previous subtle cracks occurred. Flexural cracks occur in areas that have a maximum flexure torque value, that is, in the area around the center span which is exactly located in the area of two given point loads. The direction of the perpendicular crack is almost perpendicular to the axis of the beam.

3.6 Maximum Crack Width

![Microscope Crack](image)

Table 3.3 Maximum Crack Width

| No | Sample | Maximum Crack Width (cm) |
|----|--------|--------------------------|
| 1  | BN 1   | 0.219                    |
| 2  | BN 2   | 0.220                    |
| 3  | BN 3   | 0.221                    |
| 4  | BS 1   | 0.217                    |
| 5  | BS 2   | 0.216                    |
| 6  | BS 3   | 0.218                    |

4. Conclusions
Based on the test results that have been carried out on the structural beams with slag cement, the following conclusions are obtained.
1. From the test results, structural beams using slag cement experienced initial cracks at an average load of 4.2 tons and for normal structural beams experienced initial cracks at an average load of 4 tons.
2. At the same load of 8 tons, it is obtained the maximum average deflection value in the middle of the span which is on the structural beam with a slag cement of 9.52 mm and on the normal structural beam of 10.30 mm. Thus structural beams with slag cement have better rigidity.
3. The crack patterns that occur in all samples are the flexural crack patterns. This is indicated by the direction of the vertical crack towards the main axis of the beam and occurs in the 1/3 middle span region.
4. From the test results, the number of cracks that occur in the structural beam using slag cement is less than the normal structural beam. And for the maximum average crack width that occurs on the structural beam with slag cement is 0.217 cm and on the normal structural beam is 0.220 cm.
5. Structural beam with slag cement produces brighter colors compared to the normal structural beam.
References
[1] ASTM C 1611. Standard Test Method for Slump Flow of Self Consolidating
Concrete.
[2] ASTM C 642-97. Standard Test Method for Density, Absorption, and Voids in
Hardened Concrete.
[3] ASTM C 78-02. Standard Test Method for Flexural Strength of Concrete (Using Sample Beam
with Third-Point Loading).
[4] Badan Standarisasi Nasional. SNI 4431 : 2011
[5] Suresh, D. & Nagaraju, K., 2015. e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 12, Issue 4
Ver. VI (Jul. - Aug. 2015), PP 76-82. Kuppam: IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE).
[6] Turuallo, G., 2013. s.l.:www. researchgate.net.
[7] Departemen Pekerjaan Umum, 1990. SK. SNI S -18-1990-03. Bandung: Yayasan LPMB.
[8] Wegian, M. F., 2010. Vo.3, No.4, 235-243 November 2010. s.l.:The IES Journal Part.A Civil
and Structural Engineering.
[9] Pandey, R. K., Kumar, A. & Khan, M. A., 2016.Volume: 03 Issue: 02. India: International
Research Journal of Engineering and Technology (IRJET)
[10] Pandiangan, J., 2016. Medan: Universitas Sumatera Utara.
[11] Sundaramoorthy, G. & VimalBalaji, K., 2017. M.I.E.T Engineering College, Tirchirappalli:
SSRG International Journal of Civil Engineering.
[12] Suresh, D. & Nagaraju, K., 2015. e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 12, Issue 4
Ver. VI (Jul. - Aug. 2015), PP 76-82. Kuppam: IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE).
[13] Turuallo, G., 2013. s.l.:www. researchgate.net.
[14] Dipohusodo, Istimawan, 1994, Jakarta : Gramedia Pustaka Umum
[15] McCormac, C. , Jack, 2004, Edisi Kelima Jilid 1, Jakarta : Erlangga.
[16] Suresh, D. & Nagaraju, K., 2015. e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 12, Issue 4
Ver. VI (Jul. - Aug. 2015), PP 76-82. Kuppam: IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE).
[17] Nawy, G. , Edward, 2008, Bandung : PT. Refika Aditama