

The effect of steel slag as a coarse aggregate and Sinabung volcanic ash a filler on high strength concrete

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Abstract. The Development of concrete technology is continues to grow. The requisite for efficient constructions that are often viewed in terms of concrete mechanical behavior, application on the field , and cost estimation of implementation increasingly require engineers to optimize construction materials, especially for concrete materials. Various types of concrete have now been developed according to their needs, such as high strength concrete. On high strength concrete design, it is necessary to consider several factors that will affect the reach of the quality strength, Those are cement, water cement ratio (w/c), aggregates, and proper admixture. In the use of natural mineral, it is important for an engineer to keep an eye on the natural conditions that have been explored. So the selection of aggregates as possible is a material that is not causing nature destruction. On this experiment the use of steel slag from PT.Growth Sumatra Industry as a substitute of coarse and fine aggregate, and volcanic ash of mount Sinabung as microsilika in concrete mixture substituted to create high strength concrete that is harmless for the environment. The use of mount sinabung volcanic ash as microsilika coupled with the use of Master Glenium Sky 8614 superplasticizer. This experiment intend to compare high strength concrete based slag steel as the main constituent aggregates and high strength concrete with a conventional mixture. The research result for 28 days old concrete shows that conventional concrete compressive strength is 67.567 MPa, slag concrete 75.958 Mpa, conventional tensile strength 5.435 Mpa while slag concrete 5.053 Mpa, conventional concrete bending strength 44064.96 kgcm while concrete slag 51473.94 kgcm and modulus of conventional concrete fracture 124.978 kg / cm² while slag concrete 145.956 kg / cm². Both concrete slump values shows similar results due to the use of superplasticizer.

1. Introduction

High Quality Concrete is a concrete that has characteristics as a very solid unity of material with a compressive strength ranging from 55.5 to 200 Mpa. This concrete allows the creation of a sleek, lightweight concrete structure that can also save energy and natural materials. High Strength Concrete Density also gives the advantage that it has high resistance to dangerous attack of liquids or gases.

High Quality Concrete is generally used in high-rise buildings and bridges. In high buildings, High Strength Concrete is used to conserve dimensions of columns and beams so that wider space is available between columns to columns, as well as between beams that affect the elevation of each floor. The reduction of the structure component dimension itself will reduce the weight of the structure so that the load on the foundation becomes lighter. On long bridges that generally use pre-cast concrete, High Strength Concrete is required to support larger span loads due to bridge spans and also



to overcome the possibility of precast concrete damage that often occurs in the mobilization of precast concrete itself.

The need for these structural components leads to the use of high strength concrete which includes strength, durability, service life and efficiency. High strength concrete is greatly influenced by the constituent material on the concrete. There are several factors that influence the achievement of high quality concrete compressive strength in its design. The preparation of eligible materials is one of the factors that can influence in the manufacture of high quality concrete. Factors affecting the quality of a concrete are cement factors, cement water factor, aggregate factor, microsilica usage and usage of admixture materials.

One material that meets as an alternative material in the achievement of high quality concrete is Steel Slag. Steel Slag is a by-product of steelmaking produced during the separation of molten steel from dirt in a blast furnace (enclosure for metal heating or fireworks). Steel Slag is a substance that remains when the steel has been extracted from its seeds. Steel Slag is also a nonmetallic material in which the main constituent components are calcium, magnesium, and aluminum silicate in several combinations (Burge, T.A, 2004).

Steel slag waste, included in the category of hazardous and toxic waste materials (B3). In 2010, slag production in Indonesia is only about 800 thousand tons per year. Every ton of steel production produces 20 percent of slag waste. PT Krakatau Steel in Cilegon, Banten is one of the steel manufacturer companies in Indonesia that produces at least 150 tons of slag every day. In order not to cause pollution, the steel association asked the government to use steel waste (slag waste). This utilization can be used for infrastructure projects. If not utilized, the waste is included in the category of toxic and hazardous waste (B3). (Puslitbang Jalan and Jembatan, 2011).

The use of steel slag as a coarse aggregate in a concrete mixture is an effort to utilize B3 waste that can cause environmental pollution. Besides, steel slag as a coarse aggregate of concrete mix is expected to be a solution in achieving high quality concrete that is environmentally friendly and economical. This is because the steel slag itself has a rough surface texture and perforated which caused due to gas trapping when the hot slag cooling process, the gas holes are not mutually dependent and not porous, if the slag is split because of the breaking process, then the hardness is not lost even the smallest grains.

Steel slag wastes that normally produced by the Indonesian steel industry are still in the form of chunks. So it still needed other stages before being processed into another product. Slag with a large lump size is through the collision process first to get the size of the aggregate in need. From the crushing process, the slag can be used as a rough aggregate or fine aggregate that is safe to use and have economic value.

Currently in Indonesia the utilization of steel slag has started to be developed and applied in the field of pavement. Specification of pavement design by using slag as its constituent material also being enforced by Pusjatan. Through this research, it is expected the optimization of steel slag can be developed in the field of construction of concrete especially high quality concrete.

Utilizing waste materials for useful things is one of the best ways to tackle environmental problems. Not only reducing the damage to environmental impacts but also become an alternative use of materials that are still commonly used. Various research and experiments in the field of concrete is done as an effort to improve the quality of concrete. Materials technology and implementation techniques obtained from the results of these experiments and the experiments are intended to answer the increasing demands on the use of concrete and overcome the problems that often occur during field work. In the construction of high-rise buildings and other buildings, it needs concrete with high strength, high quality concrete is the most appropriate choice.

The advantages of using slag in a concrete mix are as follows: enhancing the compressive strength of concrete due to the tendency of slow increase in compressive strength; increasing the ratio between flexibility and compressive strength of concrete; reducing the variation of compressive strength of concrete; increasing the resistance to sulfate in seawater; reducing alkali-silica attack; reducing the heat of hydration and lowering the temperature; fixing the final solution and giving a bright color to

the concrete; enhancing the durability due to changes in the volume; reducing porosity and chloride attack.

2. Literature Review

Slag is the waste material from casting iron (pig iron), where the process uses a furnace (blast) that the fuel is from the air that is blown (blast) (Paul Nugraha and Antoni, 2007). A mixture of calcium, aluminum, silicon and phosphorus forms (slag) that acting at a temperature of 1600°C and forming a liquid, when the liquid is cooled it will occur crystals resembling aggregate shapes. Slag waste has porous particle granules on its surface, has a good gradient, with varying particle size variations. In the smelting of steel, ore or scrap metal is liquefied with a combination of limestone, dolomite or lime, the manufacture of steel is initiated by removing the impurity ions of steel, including aluminum, silicon and phosphorus. To remove the impurity ions, calcium is required in the limestone. A mixture of calcium, aluminum, silicon and phosphorus forms (slag) which reacts at a temperature of 1600 °C and forms a liquid, when the liquid is cooled there will be crystals, that can be used as mixture of cement and may also be a substitute for aggregate. Factors to determine the cementitious properties in slag are chemical composition, alkali concentration and reaction to the system, the glass content in slag, subtlety, and temperature that generated during the hydration process takes place.

Slag is the result of a high blast furnace residue, produced by steel smelting industries that physically resemble rough aggregates. When the liquid is cooled slowly there will be useless crystals as a cement mixture and can be used instead of aggregates. However it forms a highly reactive granulated glass, suitable for the manufacture of slag cement. The slag is then ground to fine, it can be used as a substitute for cement in the manufacture of concrete.



Figure 1. Coarse and fine steel slag of PT. Growth Sumatera Industries

According to Cain (1994: 505) Factors to determine the cementitious properties in slag are chemical composition, alkali concentration and reaction to the system, glass content in slag, subtlety and generated temperature during the hydration process. ASTM (1995,494) Slag is a non-metallic product that is a finely shaped to large blocks material, from a cooled combustion product.

Table 1. The chemical element content in steel slag

No.	Parameter	Unit	Result	Method
1	Lead (Pb)	Mg/kg	26.6	AAS
2	Cadmium (Cd)	Mg/kg	<0.003	AAS
3	Copper (Cu)	Mg/kg	97.5	AAS
4	Chromium (Cr)	Mg/kg	5353	AAS
5	Silver (Ag)	Mg/kg	<0.001	AAS
6	Selenium (Se)	Mg/kg	<0.01	AAS
7	Barium (Ba)	Mg/kg	817	AAS
8	Mercury (Hg)	Mg/kg	0.38	AAS
9	Arsenic (As)	Mg/kg	0.21	AAS

Source: Test Laboratory of Research and Industrial Standardization Council, Medan 2016

2.1 Stone Ash

Stone ash is an aggregate of filler minerals, obtained from byproducts of cement factories or stone crushing machines. This type of material is much needed as a mix in the process of asphaltting and can be used as a substitute for sand. Currently the stone ash is not so good for sale because the usage in the pavement construction industry has very little use of pavement construction with Lapen and has been switched to concrete asphalt layer. On the other hand the use of sand for concrete mixture continues to increase. The similarity of physical properties between stone ash and sand makes the use of sand can be reduced by the use of stone ash.

Here is the usage advantages of a mixture of stone and sand ash in fine aggregates:

- Stone ash generally has excellent grain size, it is very influential to reduce the gap of grain size in the concrete mixing material.
- Stone ash can also reduce air content caused by concrete aggregates. This is caused by the fine size of the stone that fills the cavities between the aggregate granules.
- With the addition of stone ash on the sand used in the concrete mixture, it will reduce the bleeding in the concretemixture. This is in because the better arrangement of gradation of sand that can hold water, so that water to the surface of the concrete can be reduced.

With the advantages, the use of cement can be reduced because the resulting concrete will be more solid and improve its quality. In high quality concrete planning according to ASTM, the fine aggregate used must have a greater modulus of fineness equal to 2.5. Therefore, stone ash can increase the sand modulus of non-compliant sand by substituting sand for a certain amount of sand.

2.2 Sinabung Ash

Volcanic dust is a mineral volcanic rock including glass material that has a size of sand and gravel with a diameter of approximately 2 mm (1/2 inch) which is the result of volcanic eruption. Such very small ash particles can have a cross section smaller than 0.001 mm (1 / 25,000th of an inch).

Volcanic ash has a very hard and insoluble nature in the water so it is often very abrasive and slightly corrosive and capable of conducting electricity when in a wet state.

Table 2 Content of Characteristic Elements of Sinabung Ash

No.	Parameter	Result	Unit	Method
1	Silica as SiO ₂	79.7	%	Gravimetry
2	Aluminium as AL ₂ O ₃	3.88	%	Calculation
3	Calcium as CaO	12.10	%	Titrimetry
4	Magnesium as MgO	0.14	%	Gravimetry

Source: Test Laboratory of Research and Industrial Standardization Council, Medan 2016

From the results of examination of chemical content above, it is seen that sinabung ash has a very high content of silica. This percentage of content indicates that the ash of sinabung can be made as a mirosilika in high quality concrete mixing. Thus it is possible to use the volcanic ash of Mount Sinabung as a filler and become a cement substitution so as to reduce the use of cement in concrete mixture.

3. Research Method

Research method and research flow can be seen in Figure 2.

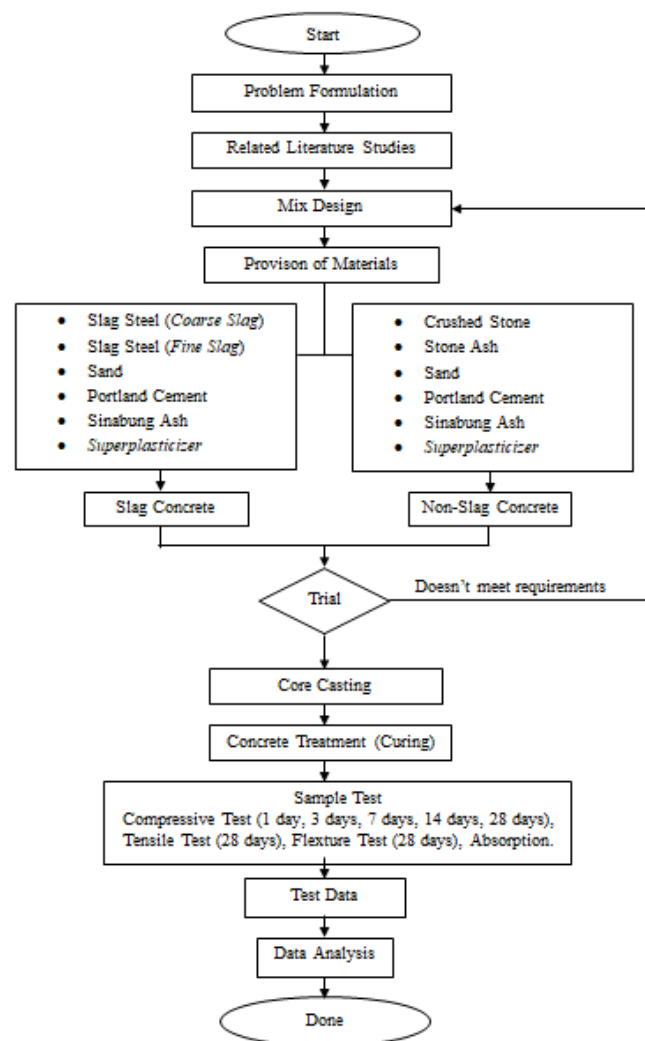


Figure 2. Research flow

4. Result and Discussion

4.1 Slump Test

Test results of slump value for concrete with steel slag and without steel slag can be seen in table.

Table 3. Slump value test results

Mix Variation	Slump Value (cm)
Non-Slag	25
Slag	25

Table 3 shows that the slump values of the two concretes do not show any significant differences. High Slump value is caused by the use of Superplasticizer which serves to improve the workability of fresh concrete.

4.2 Compressive Strength of Cylinder Concrete

Tests were performed at 1, 3, 7, 14, and 28 days old. Testing is done based on SNI 1974: 2011, The test method of compressive strength of concrete is with cylindrical test object. The results of the compressive strength test for both concrete variations can be seen in the table below.

Table 4 Compressive Strength Test Results of Slag Steel Concrete

No	Sample	Age of Concrete (Days)	Test Weight (kg)	Actual Compressive Load (kN)	Cross-Sectional Area (cm ²)	Actual Compressive Strength (Mpa)	Average Com. Strength (Mpa)
1	Slag 01	1	4.938	278	78.5	36.831	43.896
2	Slag 02		4.886	348	78.5	46.104	
3	Slag 03		4.879	368	78.5	48.754	
4	Slag 04	3	4.750	490	78.5	64.917	71.541
5	Slag 05		4.819	560	78.5	74.191	
6	Slag 06		4.842	570	78.5	75.516	
7	Slag 07	7	4.849	650	78.5	86.115	77.282
8	Slag 08		4.861	550	78.5	72.866	
9	Slag 09		4.783	550	78.5	72.866	
10	Slag 10	14	4.967	600	78.5	79.490	70.658
11	Slag 11		4.929	580	78.5	76.841	
12	Slag 12		4.976	420	78.5	55.643	
13	Slag 13	28	4.792	600	78.5	79.490	75.958
14	Slag 14		5.017	560	78.5	74.191	
15	Slag 15		4.983	560	78.5	74.191	

From the table of test results, the compressive strength above shows that within 1 day the concrete has reached high compressive strength, and continues to increase until the age of 7 days concrete, then the compressive strength growth of the press begin to slow down afterwards.

Table 5 Compressive Strength Test Results of Concrete Without Slag Steel

No	Sample	Age of Concrete (Days)	Test Weight (kg)	Actual Compressive Load (kN)	Cross-Sectional Area (cm ²)	Actual Comp. Strength (Mpa)	Average Comp. Strength (Mpa)
1	Non-Slag 01	1	3.923	260	78.5	33.121	33.651
2	Non-Slag 02		3.874	266	78.5	33.885	
3	Non-Slag 03		3.828	236	78.5	30.064	
4	Non-Slag 04	3	3.863	392	78.5	49.936	47.871
5	Non-Slag 05		3.919	314	78.5	40.000	
6	Non-Slag 06		3.923	378	78.5	48.153	
7	Non-Slag 07	7	3.915	440	78.5	56.051	57.321
8	Non-Slag 08		3.966	444	78.5	56.561	
9	Non-Slag 09		4.023	414	78.5	52.739	
10	Non-Slag 10	14	4.061	338	78.5	43.057	53.170
11	Non-Slag 11		3.953	370	78.5	47.134	
12	Non-Slag 12		4.058	496	78.5	63.185	
13	Non-Slag 13	28	4.077	510	78.5	64.968	67.567
14	Non-Slag 14		4.031	520	78.5	66.242	
15	Non-Slag 15		4.097	500	78.5	63.694	

From the table of compressive strength test results above, it is seen that within 1 day the concrete has reached high compressive strength, and continues to increase until the age of 7 days concrete, then go down at day 14 and reach maximum strength at age 28 days. From the results of both compressive strength of steel slag concrete samples and the non-steel slag samples against the age of the test, then both test results of compressive strength can be compared through the following graph

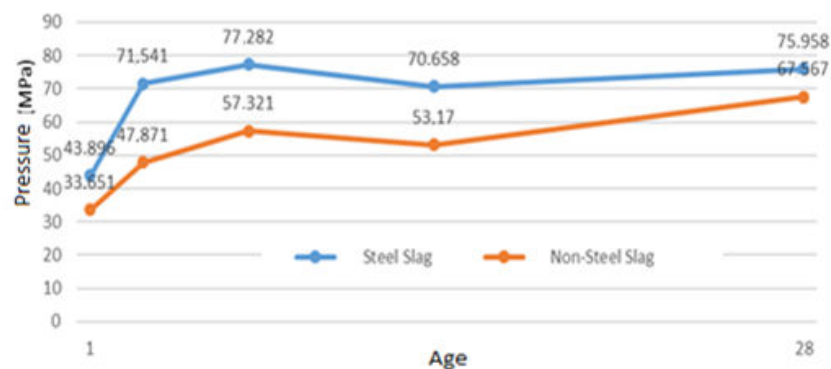


Figure 3. Compressive Strength Comparison of Steel Slag Concrete and Conventional

From the test results of compressive strength of both types of specimens it can be concluded that high quality concrete with main aggregate of slag steel has higher compressive strength than the compressive strength of high quality concrete with main aggregate of crushed stone. With compressive strength of slag concrete at age 28 days is 75.958 Mpa and compressive strength of non slag concrete is 67.567 Mpa. Increasing compressive strength of concrete with the main aggregate of steel slag is between 12 -15% of the concrete with crushed stone aggregate as the main constituent aggregate.

4.3 Tensile Strength of Concrete Cylinders

This test aims to determine the value of compressive strength of high quality concrete with rough aggregate replacement by steel slag compared with high quality concrete without rough aggregate replacement

Table 6 Tensile Strength Test Results of Slag Steel Concrete

No	Sample	Age of Concrete (Days)	Test Weight (kg)	Actual Tensile Load (kN)	Tensile Strength (Mpa)	Average Compressive Strength (Mpa)
1	Slag Concrete 01	28	4.887	162	5.159	5.053
2	Slag Concrete 02		1.911	154	4.904	
3	Slag Concrete 03		4.881	160	5.096	

Table 7 Tensile Strength Test Results of Concrete Without Slag Steel

No	Sample	Age of Concrete (Days)	Test Weight (kg)	Actual Tensile Load (kN)	Tensile Strength (Mpa)	Average Comp.Strength (Mpa)
1	Non-Slag 01	28	3.830	168	5.350	5.435
2	Non-Slag 02		3.931	180	5.732	
3	Non-Slag 03		3.881	164	5.223	

From the comparison of concrete tensile strength it can be seen that the concrete without slag provides greater tensile resistance compared to the concrete with the use of slag steel as its main aggregate.

4.4 Flexure Strength of Concrete Beam (15 x 15 x 60)

The calculation data of flexure capacity based on strain data for reinforced concrete beams can be seen in the table below.

Table 8 Test Results of Fracture Modulus of Steel Slag Concrete

No	Sample	Age of Concrete (Days)	Test Weight (kg)	Actual Tensile Load (kN)	Fracture Modulus (kg/cm ²)	Average Frac. Modulus (kg/cm ²)
1	Slag Concrete 01	28	43.100	81.8	145.422	145.956
2	Slag Concrete 02		42.900	82.4	146.489	

Table 9 Test Results of Fracture Modulus of Concrete Without Steel Slag

No	Sample	Age of Concrete (Days)	Test Weight (kg)	Actual Tensile Load (kN)	Fracture Modulus (kg/cm ²)	Average Frac. Modulus (kg/cm ²)
1	Non-Slag 01	28	34.200	70.2	124.800	124.978
2	Non-Slag 02		32.800	70.4	125.156	

Table 10 Flexure Moment Of Slag Concrete

No.	Sample	Maximum Moment (kgcm)	Average Maximum Moment (kgcm)
1	Slag Flexure Concrete 01	51287.000	51473.938
2	Slag Flexure Concrete 02	51660.875	

Table 11 Flexure Moment Of Non-Slag Concrete

No.	Sample	Maximum Moment (kgcm)	Average Maximum Moment (kgcm)
1	Non-Slag Flexure Concrete 01	44003.250	44064.965
2	Non-Slag Flexure Concrete 02	44126.680	

From the table above it can be concluded that Steel Slag Concrete has a fracture modulus and a higher flexure moment of resistance than the concrete without aggregate replacement.

5. Conclusion

Based on the research that has been done, it can be concluded that:

1. Normal compressive strength of high quality concrete at age 1,3,7,14, and 28 days respectively are 33.651 Mpa. 47.871 Mpa. 57.321 Mpa. 53.170 Mpa and 67.567 Mpa. While compressive strength of concrete with slag substitution at age 1,3,7,14 and 28 days respectively are 43.896 MPa. 71.541 MPa. 77.282 MPa. 70.658Mpa and 75.958. Thus it shows that high quality concrete made of steel slag as the main constituent aggregate has a compressive strength greater than that of conventional high-quality concrete.
2. The average tensile strength of high quality slag concrete with 28 days of concrete is 5.053 MPa. While the average tensile strength of conventional high quality concrete with 28 days of concrete is 5,435 Mpa. It shows that the tensile strength of conventional high quality concrete is stronger than the tensile strength of high quality concrete with slag steel replacement.
3. Fracture Modulus on high quality slag concrete is 145.956 kg / cm² while the fracture modulus on conventional high quality concrete is 124.978 kg / cm². So it can be concluded that the fracture modulus of slag concrete is higher than the conventional concrete.
4. The flexure moment on high quality slag concrete is 51473.938 kgcm while the flexure moment on conventional high quality concrete is 44064.965 kgcm. So it can be concluded that the flexure moment of slag concrete is higher than the conventional concrete

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