Components of steel slag in acid-contaminated porous concrete

S R Tonapa, L Febriani and D Sandy

Department of Civil Engineering, Universitas Kristen Indonesia Paulus, Makassar, Indonesia
Email: tonapa.27rv.bubble@gmail.com

Abstract. The presence of slag as a result of waste from steel production annually increases. Researchers and environmentalists are very concerned to overcome this problem. Currently steel slag has been studied as a substitute for concrete compilers. The focus of this research is to utilize steel slag as a constituent of porous concrete in direct contact with acidic regions, in this case sulfuric acid and chloride. This test was carried out using 243 samples in testing the compressive strength, tensile strength and pore volume of concrete. Content of steel slag used is 0%, 50% and 80%. In the compressive strength test results for normal curing, sulfate curing and chloride curing showed an increase of 6.49%, 5.71%, 8.28% in the 50% slag content and 10.81%, 10.29%, 17.20% in the 80% slag content. Then in the tensile strength test showed an increase of 7% to 11% in the 50% slag content and 16% to 17% in the 80% slag content. As for the pore volume, the value is in range from 17% to 19%. These results indicate that slag can be used as a substitute for aggregate on porous concrete with compressive strength ranging from 10 MPa to 19 MPa.

1. Introduction
Pervious concrete is a special type of concrete that generally has an internal structure of interconnected macro-pores. This is closely related to its function as fast water drainage, reducing noise caused by interactions between tires and sidewalks, as well as material that can reduce the heat of urban areas. According to ACI 522R-10, the range of aggregate sizes used is aggregate sizes of 7 (1/2 in. To No.4), 8 (3/8 in. To No. 8), 67 (3/4 in. To No. .4) and 89 (3/8 in. To No. 16), with void content from 15 to 35% and typical compressive strength from 2.8 to 28 MPa. A good water-cementitious material ratio for pervious concrete is 0.26 to 0.45. Meanwhile, steel slag waste is reported to have increased every year. Waste management includes reduction, storage, collection, transportation, utilization, processing and stockpiling [1,2]. In this research, it will be managed by using slag waste as aggregate substitution material in pervious concrete.

2. Methods
The use of electric furnace slag (FEA) as a total pervious concrete substitution material. In his research three different grain variations were used, namely 6-10 mm, 10-20 mm and a mixture of the two previous grain sizes with each proportion of 30% -70%. Mechanical property tests performed are compressive strength and flexural strength, while the hydraulic properties testing performed is porosity and constant head permeability. From the results of the compressive strength test, the resulting value varies from 19 to 31 MPa and 3 to 4 MPa for the flexural test. As for the porosity test
the resulting value is 15-20% and the permeability coefficient is 10-12mm / s. From the results of this test, the use of FEA as a substitute material for porous concrete has met the applicable standards [3,4].

Hua Peng, et al. (2018) have conducted research using fly ash (FA) and blast furnace slag (BFS) as cement substitution material in pervious concrete. Coarse aggregate used is gravel with a size of 16-19 mm. Comparison of the mixture for the paste itself is 100% cement (M1), 70% cement + 30% BFS (M2), 70% cement + 10% FA + 20% BFS (M3), 70% cement + 15% FA + 15% BFS (M4), 70% cement + 20% FA + 10% BFS (M5), and 70% cement + 30% FA (M6). Tests carried out were mortar compressive strength tests at 28 days, compressive strength tests at 28 days and 60 days, porosity tests and permeability tests. In the results of the compressive strength test showed that there was a decrease in strength at 28 days while there was an insignificant increase in strength at 60 days. Compressive strength and permeability decrease with increasing porosity. These results provide clues for sustainable research in mechanical properties and hydraulic properties in pervious concrete [5].

Lei Lang, et al. (2019), conducted research on pervious concrete with constituents of slag and magnesium phosphate cement (MPC). Slag is used as a rough aggregate in this study. Several different aggregate sizes and different molding methods are used and the compressive strength test, flexural strength test, porosity test and permeability test are used. From the test results show that the specimen with vibration molding has a higher compressive strength with a maximum strength reaching 41.5 MPa in samples with steel slag pervious concrete (MSPC). Likewise, the flexural strength at 28 days reaches a maximum of 8 MPa. Porosity increased with increasing aggregate dimensions with a range of values of 23.8% -26.5% for all MSPC mixtures. The results of this test show that steel slag combined with MPC is pervious concrete which is eco-friendly [6].

2.1. Materials and mix design

The coarse aggregate used in this study is a local aggregate with a maximum dimension of 20 mm and the slag used is steel production waste from PT. Barawaja Makassar.

All aggregates has done through the examination of characteristics in accordance with the Indonesian National Standard (SNI). The results of the examination of aggregate characteristics that have met this standard are then used to determine the design mix based on the ACI 522R-10 standard shown in the following table:
Table 1. Mix design pervious concrete.

| Description                                      | Value  |
|--------------------------------------------------|--------|
| Void content                                     | 17.0%  |
| Volume design                                    | 1 m³   |

**Determine aggregate weight (lihat ukuran agregat)**

a. Weight of coarse aggregate in unit of coarse aggregate volume, (loose)  
   (b)                                                                 | 1415 kg/m³ |

b. Weight of coarse aggregate in unit of concrete volume (compacted), (b₀)  
   (b)                                                                 | 1535 kg/m³ |

c. Ratio value b/b₀                                                                      | 0.92      |

d. Ratio value b/b₀ based on table 6.1                                                  | 0.99      |

**Aggregate weight in saturated surface dry condition**

a. Absorpsi                                                                            | 1.194%    |

b. Weight of coarse aggregate in unit of concrete volume (SSD condition)               | 1446 kg/m³|

**Determine paste volume**

Paste Content                                                                        | 25.00%    |

Paste volume in mix concrete (Vp)                                                    | 0.250 m³  |

**Determine eight of cement ,**

Water cement ratio (w/c)                                                              | 0.26      |

Weight of cement (c)  
   (c)                                                                 | 434.78 kg/m³ |

**Determine weight of water**

Weight of water (w),  
   (w)                                                                 | 113.04 kg/m³ |

**Determine of compact volume**

Aggregate volume (Va),  
   (V_a)                                                              | 0.578 m³  |

Cement volume                                                                        | 0.138 m³  |

Water volume (Vw)                                                                    | 0.113 m³  |

Total of solid volume (Vs)                                                           | 0.830 m³  |

**Check void**

void amount                                                                           | 20.55%    |

**Permeability check**

Void actual                                                                          | 20.55%    |

Permeability                                                                         | 3.19 in/mm \*min                                    |

|                           |         |
|---------------------------|---------|
|                            |         |
|                            |         |

**Mix Design Compositions in 1 m³**

Weight of cement                                                              | 434.8 kg |

Weight of water                                                               | 113.0 kg |

Weight of coarse aggregate                                                  | 1446.4 kg |

Total Weight                                                                  | 1994.2 kg |

Used sample as many as 243 by the test cylinder compressive strength, split tensile strength and testing void (porosity) in each sample. In this study substitution of coarse aggregate of 50% and 80% of the weight of the aggregate was carried out and treatment of the specimens was treated...
with water, sulfuric acid solution and hydrochloric acid. Following are the aggregate requirements for each substitution.

| Materials       | Sub. 50% Slag (kg) | Sub. 80% Slag (kg) |
|-----------------|--------------------|--------------------|
| Cement          | 434.8              | 434.8              |
| Coarse aggregate| 723.2              | 1289.3             |
| Slag            | 723.2              | 1157.1             |

Table 2. Composition variation.

2.2. Pervious Concrete Testing
Pervious concrete testing standards are based on SNI 1974: 2011 (compressive strength), SNI 2491: 2014 (split tensile strength test) and voids (porosity).

Figure 2. Compressive strength test
Figure 3. Split strength test

3. Results and Discussion
3.1. Void content (Porosity)
From the porosity test results, the porosity value decreased by 5.59% in PC50% S specimens and 4.88% in PC80% S specimens with sulfate curing. Also in chloride curing decreased by 4.24% in PC50% S specimens and 3.22% in PC80% S specimens. The test results can be seen in the following table and graph:

| Age of concrete (days) | Void content (%) |
|------------------------|------------------|
|                        | 0% Slag | 50% Slag | 80% Slag |
| Normal curing          | 19.20    | 18.54    | 18.15    |
| Sulfate curing         | 18.46    | 17.51    | 17.27    |
| Chloride curing        | 18.20    | 17.76    | 17.57    |

Table 3. Result of void content.
5.00
5.50
6.00
6.50
7.00
7.50
8.00
8.50
9.00
9.50
10.00
11.00
12.00
13.00
14.00
15.00
16.00
17.00
18.00
19.00
20.00

PC0%S
PC50%S
PC80%S

Void content (%)
Sample code

Normal curing
Sulfate curing
Chloride curing

Figure 4. Column chart of void content.

3.2. Split Tensile Strength
Test the split tensile strength of the cylinder resulted in a decrease in the value of sulfate curing and chloride curing values 11.46% and 18.60% respectively in the PC50% S specimens and 12.20% and 16.25% in the PC80% S specimens. The test results can be seen in the following table and graph:

| Age of concrete (days) | Spilt Strength (MPa) |
|------------------------|-----------------------|
|                        | 0% Slag  | 50% Slag | 80% Slag |
| Normal curing          | 1.49     | 1.65     | 1.74     |
| Sulfate curing         | 1.34     | 1.46     | 1.53     |
| Chloride curing        | 1.25     | 1.34     | 1.46     |

Figure 5. Column chart of split strength on 28 days.

3.3. Compressive Strength
The compressive strength test results in PCS50 specimens decreased by 6.09% in sulfate curing and 13.71% in chloride curing, while in PCS80 specimens decreased by 5.85% in sulfate curing and 10.24% in chloride curing.
Table 5. Result of compressive strength for normal curing

| Age of concrete (days) | Compressive Strength (MPa) for Normal curing |
|------------------------|---------------------------------------------|
|                        | 0% Slag | 50% Slag | 80% Slag |
| 7                      | 11.41   | 12.26    | 12.36    |
| 14                     | 14.62   | 15.28    | 15.75    |
| 21                     | 16.03   | 16.32    | 17.07    |
| 28                     | 17.45   | 18.58    | 19.33    |

Figure 6. Graph of compressive strength for normal curing.

Table 6. Result of compressive strength for sulfate curing.

| Age of concrete (days) | Compressive Strength (MPa) for Sulfate curing |
|------------------------|---------------------------------------------|
|                        | 0% Slag | 50% Slag | 80% Slag |
| 7                      | 10.56   | 11.51    | 11.79    |
| 14                     | 14.05   | 14.62    | 15.18    |
| 21                     | 15.37   | 15.94    | 16.50    |
| 28                     | 16.50   | 17.45    | 18.20    |

Figure 7. Graph of compressive strength for sulfate curing.
Table 7. Result of compressive strength for chloride curing

| Age of concrete (days) | Compressive Strength (MPa) for Chloride curing |
|-----------------------|-----------------------------------------------|
|                       | 0% Slag  | 50% Slag  | 80% Slag  |
| 7                     | 9.62     | 10.47     | 10.94     |
| 14                    | 12.64    | 13.58     | 14.15     |
| 21                    | 14.05    | 14.90     | 15.37     |
| 28                    | 14.81    | 16.03     | 17.35     |

Figure 8. Graph of compressive strength for chloride curing

4. Conclusion

In this research, pervious concrete containing steel slag in sulfate curing and chloride curing has been tested. Based on the results of tests in the laboratory, it can be concluded that there was an increase in strength in the immersion of water with specimens containing steel slag. However, there was a decrease in strength in both acid immersion (sulfate and chloride) but in sulfate curing it was not so significant. The porosity test value on the two immersions did not differ much by only a difference of 1.36%. Although there is a decrease in strength in both immersion, the strength value still fulfills the strength range of pervious concrete as well as the porosity value. The use of steel slag as a constituent of pervious concrete requires continuous research of durability by considering mechanical properties and hydraulic properties.

Reference

[1] Ćosić K, Korat L, Ducman V and Netinger I 2015 Influence of aggregate type and size on properties of pervious concrete *Constr. Build. Mater.* **78** 69–76
[2] Hariyanto S, Rachmayani H N, Citrasari N, Zalika Z A and Faruqi H M 2019 The planning of non-medical solid waste management at Universitas Airlangga Hospital *IOP Conf. Ser. Earth Environ. Sci.* **245** 1–6
[3] Sandoval G F B, Reyes I G, Cavalheiro C D, Moura A C and Toralles B M 2019 Pervious concrete made with electric furnace slag (FEA): mechanical and hydraulic properties *RIEM-IBRACON Struct. Mater. J.* **12**
[4] Chen X, Wang H, Najm H, Venkiteela G and Hencken J 2019 Evaluating engineering properties and environmental impact of pervious concrete with fly ash and slag *J. Clean. Prod.* **237** 117714
[5] Peng H, Yin J and Song W 2018 Mechanical and hydraulic behaviors of eco-friendly pervious concrete incorporating fly ash and blast furnace slag *Appl. Sci.* **8** 859
[6] Lang L, Duan H and Chen B 2019 Properties of pervious concrete made from steel slag and magnesium phosphate cement *Constr. Build. Mater.* **209** 95–104