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Mechanical properties of pervious concrete with slag and silica fume as cement substitution for highway shoulder

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Abstract. Nowadays, the rapid of road construction is not comparable to availability of cement materials. Meanwhile, there are cementitious materials from waste and by-product such as slag and silica fume that can replace the using of cements in concrete mixture. The high silica content in slag and silica fume can increasing the strength of concrete mixture. This study aims to obtain the mechanical properties of pervious concrete using slag and silica fume as cement substitution. The values of the mechanical properties are used for the design of highway shoulder. Two aggregate sizes were investigated in this paper. The binder materials for mixtures is a combination between cement, slag, silica fume and fly ash. Based on the research results, the highest compressive strength of 12.5 mm – 9.5 mm sample is 12.60 MPa, while the highest compressive strength of 9.5 mm – 4.75 mm sample is 13.25 MPa. The highest coefficient of permeability of 12.5 mm – 9.5 mm sample is 1.219 cm/sec and the highest coefficient of permeability of 9.5 mm – 4.75 mm sample is 0.865 cm/sec. The highest porosity of 12.5 mm – 9.5 mm sample is 24.41 % and the highest porosity of 9.5 mm – 4.75 mm sample is 23.04 %. Based on the data of the mechanical properties obtained, it can be concluded that using slag and silica fume as cement substitution for a pervious concrete are increasing compressive strength but decreasing coefficient of permeability and porosity.

1. Introduction

Infrastructure especially road constructions develop rapidly. This cause so many needs of cements materials in the future. But, someday the cement material will run out and can not be renewal. So the new cementitious materials that can replace cement in concrete mixture are needed. There is a need in concrete mixture innovation using another materials like cement. Pervious concrete is a new alternative to make a green infrastructure. Using pervious concrete as a highway shoulder expected to reduce a ponding in highway shoulder. Pervious concrete using waste product is a development in concrete technology that can reduce in dependence of using cement for green construction. Steel and iron waste industry that produces slag can used for a concrete mixture to replace partial cement as a binder material and as an aggregate. Slag is the waste material from casting iron (pig iron) where the process uses a kitchen (furnace) that the fuel is from the air that blown (blast) [1]. Slag contains silica, alumina, calcium oxyde and magnesium (95%). Silica content in slag can increase the strength of concrete mixture. Silica fume is a by-product resulting from the reduction of high purity quartz with coal or coke and wood chips in an electric arc furnace during the production of silicon metal or silicon alloys [2].

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 compressivestrength; 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 [3].

2. Method

2.1. Sample

The sample containing two different sizes of aggregate. The aggregate is single-size or uniform graded, that is 12.5 mm – 9.5 mm and 9.5 mm – 4.75 mm. Binder materials that is used in this paper is a combination between cement, slag, silica fume and fly ash. The coarse aggregate is natural aggregate and slag aggregate. Fine aggregate is used in this paper are stone ash. To increasing workability the mixture is added an additive Sika Mix PV 100. The water-cement ratio is 0.30 and 0.34.

Table 1. Materials for sample with aggregate size 12.5 mm – 9.5 mm

Mix	Cement	Fly Ash	Silica Fume	Slag	FAS	Water	Stone Ash	Coarse Agg.	
	56%	15%	3%	26%			Natural	Natural	Slag
	kg	kg	kg	kg			kg	kg	kg
C1.	4.84	1.62	0.33	2.13	0.30	2.59	0	26.20	0
C2.	4.69	1.57	0.32	2.07	0.34	2.85	0	26.20	0
C3.	4.84	1.62	0.33	2.13	0.30	2.59	0	20.96	5.24
C4.	4.84	1.62	0.33	2.13	0.30	2.59	1.57	19.39	5.24
C5.	4.69	1.57	0.32	2.07	0.34	2.85	0	20.96	5.24
C6.	4.69	1.57	0.32	2.07	0.34	2.85	1.57	19.39	5.24

Table 2. Materials for sample with aggregate size 9.5 mm – 4.75 mm

Mix	Cement	Fly Ash	Silica Fume	Slag	FAS	Water	Stone Ash	Coarse Agg.	
	56%	15%	3%	26%			Natural	Natural	Slag
	kg	kg	kg	kg			kg	kg	kg
C1.	4.84	1.62	0.33	1.81	0.30	2.59	0	26.20	0
C2.	4.69	1.57	0.32	1.76	0.34	2.85	0	26.20	0
C3.	4.84	1.62	0.33	1.81	0.30	2.59	0	20.96	5.24
C4.	4.84	1.62	0.33	1.81	0.30	2.59	1.57	19.39	5.24
C5.	4.69	1.57	0.32	1.76	0.34	2.85	0	20.96	5.24
C6.	4.69	1.57	0.32	1.76	0.34	2.85	1.57	19.39	5.24

2.2. Mechanical Properties Testing

Various mechanical properties of pervious concrete includes compressive strength, permeability and porosity. The sample for compressive strength test is cube with 10 x 10 x 10 cm according to ASTM C39 [4]. Permeability test sample is cylinder with diameter 10 cm with length 20 cm according to ASTM C1781 / C1781M – 15 [5]. The sample for porosity test is cube with 10 x 10 x 10 cm according to ASTM C1754 / C1754M – 12 [6].

3. Result and Discussion

3.1. Compressive Strength

Compressive strength test is a test to determine maximum loads that can be resist by concrete sample in sectional area. Compressive strength is calculated from the failure load divided by the cross-sectional area resisting the load and reported in units of megapascals (MPa).



Figure 1. Compressive strength

Table 3. Compressive strength test results for aggregates 12.5 mm – 9.5 mm

Mix	Compressive strength (MPa)		
	28 Days	60 Days	90 Days
C1.	10.40	11.38	12.60
C2.	5.43	5.95	4.19
C3.	5.81	5.90	4.90
C4.	8.58	9.80	11.15
C5.	4.60	6.83	5.89
C6.	4.04	5.96	6.86

Table 4. Compressive strength test results for aggregates 9.5 mm – 4.75 mm

Mix	Compressive strength (MPa)		
	28 Days	60 Days	90 Days
C1.	9.92	10.99	11.49
C2.	6.02	7.95	9.55
C3.	8.31	7.93	8.98
C4.	8.38	8.17	7.16
C5.	7.35	8.48	8.42
C6.	10.09	13.25	10.95

The compressive strength test of sample with aggregates 9.5 mm – 4.75 mm is higher than the compressive strength test of sample with aggregates 12.5 mm – 9.5 mm. This is occur because the density of sample with aggregates 9.5 mm – 4.75 mm is more dense than the sample with aggregates 12.5 mm – 9.5 mm.

3.2. Permeability

Permeability is a ability to flowing the fluids through the voids in a materials without breaking the materials. The aim of this test is to determine the waters that can flow. The value of permeability test is a coefficient of permeability in units of cm/sec.



Figure 2. Permeability test with *Falling Head Permeability*

Table 5. Result of permeability test

Mix	Coefficient of permeability (cm/sec)	
	12.5 mm – 9.5 mm	9.5 mm – 4.75 mm
C1.	1.196	0.861
C2.	1.207	0.855
C3.	1.183	0.858
C4.	1.207	0.862
C5.	1.219	0.849
C6.	1.184	0.865

Based on the result in Table 5, coefficient of permeability sample of aggregate 12.5 mm – 9.5 mm is higher than the sample of aggregate 9.5 mm – 4.75 mm. The voids in sample with aggregate 12.5 mm – 9.5 mm is much more, so the water flow quickly through the voids.

3.3. Porosity

Porosity test is a test to determine the total void in a mixture or sample. This test is comparing the sample in dry oven and sample in water. The porosity value is in percentage (%).

Table 6. Result of porosity test

Mix	Porosity (%)	
	12.5 mm – 9.5 mm	9.5 mm – 4.75 mm
C1.	19.65	19.32
C2.	17.45	23.04
C3.	24.24	15.30
C4.	19.23	19.45
C5.	24.41	15.65
C6.	21.24	18.44

According to the Table 6, the porosity sample with aggregate 12.5 mm – 9.5 mm is more higher than sample with aggregate 9.5 mm – 4.75 mm. The void content of sample with aggregate 12.5 mm – 9.5 mm is higher than sample with aggregate 9.5 mm – 4.75 mm.

3.4. Discussion

The highest compressive strength is 12.6 MPa in sample aggregate size 12.5 mm – 9.5 mm for mix C1 and 13.25 MPa in sample aggregate size 9.5 mm – 4.75 mm for mix C6. Sample with aggregate size 9.5 mm – 4.75 mm has a higher compressive strength than sample with aggregate size 12.5 mm – 9.5 mm cause sample with aggregate size 9.5 mm – 4.75 mm more dense. Compressive strength of pervious concrete with all cement as binder materials is 5.19 MPa [7].

This rising of compressive strength of pervious concrete are caused by high silica content in slag and silica fume. Silica is a pozzolanic materials that has good cementitious materials in increasing concrete compressive strength. Silica fume which is commonly used cement based systems, contain 85% to 98% silica [8]. When fine pozzolan particles are dissipated in the paste in cement hydration, they generate a large number of nucleation sites for the precipitation of the hydration products. Therefore, this mechanism makes paste more homogeneous. This is due to the reaction between the amorphous silica of the pozzolanic material and calcium hydroxide, produced during the cement hydration reactions [9] [10] [11]. When silica reacts with Ca(OH)_2 on hydration of cement produces the gel Calcium-Silicate-Hydrate (C-S-H). The gel C-S-H is the main chemical compound that has effect in concrete strength rising. When cement hydration process, there are Calcium Hydroxide compound by-product. When this compound reacts with slag there are more gel Calcium-Silicate-Hydrate (C-S-H).

Coefficient of permeability of the pervious concrete with all cement as binder is 1.363 cm/sec, whereas coefficient of permeability of the pervious concrete with slag dan silica fume is 1.219 cm/sec. From this comparison we can conclude that using slag and silica fume pervious concrete mixture decrease the coefficient of permeability. Using slag and silica fume for pervious concrete mixture can decreasing the porosity of mixture. Pervious concrete with all ceement as binder has porosity 27.69%, whereas the pervious concrete with slag and silica fume has porosity 24.41%.

Application of pervious concrete as a highway shoulder has a benefits include reducing the rate of runoff, filtering pollutants out of runoff, infiltrating runoff into the ground and maintaining the natural hydrologic function of the site [12].

Pervious concrete creates a drier surface during a storm event making these systems safer for drivers, produces less noise than traditional systems and a pervious concrete pavement could negate the need for other forms of stormwater treatment, such as retention ponds that can be both costly and impractical in many situations [13].

Pervious concrete pavement has advantages to recharge of local aquifer, water budget retention and pollution removal, less need for storm sewer, natural runoffallows rainwaterto drain directly to subbase course [14].

Pervious concrete have many impacts on the enviroentment including promotes infiltration, reduces peak flows and runoff volume, improves water quality and reduces thermal pollution [15].

And also, pervious concrete play a noticeable role in reducing noise, minimizing the heat isand effect in large cities and improving skid resistance [16].

4. Conclusion

Based on the mechanical properties data results of pervious concrete, compressive strength test result ranges 4.04 MPa – 13.25 MPa. Coefficient of permeability ranges 0.849 cm/sec – 1.219 cm/sec. Porosity ranges 15.3% – 24.41%. Pervious concrete with slag and silica fume as cement substitution increasing compressive strength. But then, the replacement of cement by slag and silica fume is decreasing coefficient of permeability and porosity. So that we can conclude that using slag and silica fume in pervious concrete mixture can replace cement partially.

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