The Influence of Steel Slag as Alternative Aggregate in Permeable Concrete Pavement

A A G Nadiatul Adilah[1], S Y Ayman Mohammed[1], P J Ramadhansyah[1], O Rokiah[1] and M R Hainin[2]

[1]Faculty of Civil Engineering Technology, Universiti Malaysia Pahang, 26300 Kuantan, Pahang, Malaysia
[2]Faculty of Engineering, School of Civil Engineering, Universiti Teknologi Malaysia, 81310 Johor Bahru, Malaysia

Abstract. This study identifies the pervious concrete with a high direct runoff on the pavement incorporating steel slag. This study is progressing in two stages i.e. 1ststage is obtaining the best mix design by using cubic concrete samples with dimension of 100mm height based on 7 days compressive strength test. Indeed, different proportion of aggregate and ratio were tested in order to select the highest compressive strength which has reached 10.9 MPa in the first 7 days of curing. The cylindrical concrete sample with the dimension of 200 x 100 mm was used in the 2nd stage. In addition, steel slag was used in the 2nd stage besides the granite aggregate. In fact, three different percentages of steel slag are involved; 50% Steel Slag and 50% Granite; 30% Steel Slag and 70% Granite; and 70% Steel Slag and 30% Granite. Hydrologically, 13.8 mm/s is the highest Infiltration rate that pervious concrete has reached which has been recorded throughout permeability test. The rainfall intensity which plays an important role on the pavement was identified. Thus, intensity distribution frequency curve was developed using MSMA and compared within filtration rate results of pervious concrete. Mix design ten (M10) has the ability to perform efficiently during highest rainfall intensity meanwhile strength needed to be increased since 10.9 MPa in the first 7 days of curing is not sufficient.

1. Introduction

Nowadays, flood is the most significant disaster in Malaysia that effects to the social and economic of the population. Pahang River is one of the rivers that contributes flood problem. Heavy rainfall can cause the excess of runoff rise to the high-water levels and causing the area to be flooded. Floods are the most significant natural disasters, which affect 4.9 million people and inflict damage worth of several million every year in Malaysia. About 29,720 km^{2}or 9% of the land area of the country is prone to flooding [1]. Pekan town is located on the banks of the Pahang River, regularly suffers both economic damages and physical destructions caused by the floods [2]. Flood occurs in Pekan due to drainage problem since it cannot cattle the quantity of water when storm-water runoff increases [3]. Pervious concrete or (thirsty concrete) is commonly used as an initially drainage tool to soak up most of runoff. This relieves the intensity of storm water drains and can minimize the expansive storm water from structures. Also, it assists to decrease storm water infrastructure costs. By infiltrating water, porous concrete can absorb nearby floor water sources and water surround root structures for timber and vegetation, which would not have obtained any water from an impermeable floor [4]. The use of porous concrete can be used in water sensitive urban sketch and structure to assist size the quantity of city runoff and pollutants flowing into natural waters [5]. Transportation is playing an essential position in any development of a community seeing that the rate motion made via either vehicle or humans represents energetic and active in the community. However, the presence of high depth direct runoff on roads is performing as boundaries against vehicles. Indeed, this direct runoff is paralyzing the mobility of any vehicle especially throughout evacuation time during flood session[6]. This study focused on investigation of the mechanical and hydrological properties of pervious concrete by compressive strength and permeability tests respectively. Indeed, it consists of 2 stages; 1st stage is obtaining preliminary results via 48 cubic concrete samples in dimensions of 100mm height based on 7 days compressive strength test. Indeed, various ratios of aggregate size are tested to select the highest compressive strength to be used in 2ndstage that consist of 12 cylindrical concrete samples in dimension of 200mm height and 100mm in diameter. In this stage, steel slag was use in 3 percentages as following:

a) 30% Steel Slag and 70% Granite
b) 50% Steel Slag and 50% Granite
c) 70% Steel Slag and 30% Granite

Infiltration rate is obtained through out permeability test. Oppositely, the Intensity Distribution Frequency IDF curve is performing by using MSMA 2nd edition for Rumah Pam Pahang Tua Station at site 3533102.

2. Materials

2.1. Cement

The cement manufactured according to the standards ASTM CI50. The physical and chemical properties of Portland cement are illustrated in Table1.

Table 1. Cement Properties [5]

Property	Test Result	Product Data	ASTM C 150	Standard
Physical & Mechanical Properties				
Normal Consistency	23.10 %	-		ASTM C 187
Blaine Fineness	361.3 m^2/kg	-	280 m^2/kg	ASTM C 204
Setting Time				ASTM C 191
Initial Set	1 hrs., 29 min	≥ 60 min	> 45 min	
Final Set	2 hrs., 15 min	-	< 6 hrs., 15 min	
Specific Gravity	3.15	-	3.14 - 3.16	ASTM C 188
Soundness	-	≤ 10		
Chemical Properties				
Loss on Ignition	-	≤ 5%		
Insoluble Residue	-	≤ 5%		
Sulphate (SO_3)	-	≤ 4%		
Chloride Content	-	≤ 0.1%		

2.2. Granite Aggregate

In this research, Granite Aggregates was collected from the Civil Engineering laboratory at Universiti Malaysia Pahang- Gambang campus.

2.2 *Steel slag*

Steel slag is produced as a by-product during the oxidation of steel pellets in an electric arc furnace. This by-product that mainly consists of calcium carbonate is broken down to smaller sizes to be used as aggregates in asphalt and concrete. They are particularly useful in areas where good-quality aggregate is scarce [7].

3. Sample Preparation

Sieving were performed for granite and steel slag aggregates in order to separated them into different groups which are 20,14,12.5,9.5 and 4.75mm.This study has been carried out on 60 samples as stated in Table 2.

Table 2. Sample Distribution

Sample Type	Mould Type	No. of samples	Dimension
Cube	Plastic	48	100*100
Cylindrical	Steel	12	200*100

3.1 Testing Procedures

In 1st stage, the 16 mixtures were casted in plastic cubic moulds meanwhile in 2nd stage the 4 mixtures casted in cylindrical steel moulds. All mixtures were demoulded after 24 h, labelled and weighted for various testing. Then the samples were cured in a bath at room temperature, according to AS1012.8.1-2000 as shown in Figure 2. In 1st stage, all 3 samples of each mixture were prepared for 7 days compressive strength test. In 2nd stage, from each batch, 6 samples were prepared for permeability testing and compressive strength test.

3.2 Compressive Strength

Compressive strength of the pervious concrete was determined on cube and cylinder specimens that were cured in water curing and tested for 7 days as per ASTM C39M-18 as shown in Figure 1 and 2. All the specimens for compressive strength test have been stored in the curing tank until the testing day. 3 specimens have been tested for each curing age to obtain the average compressive strength. It was performed by using 2000kN UTM machine. The compressive strength test has been conducted according to the standard steps. The value of Compressive strength was calculated from the maximum loading acting on cross sectional area of cubes and cylinder by using this equation 1.

$$\text{Compressive Strength } \sigma = \frac{P}{A} \qquad (1)$$

Figure 1. Seven (7) Days curing

Figure 2. Compressive Strength Test

3.3. Permeability Test

One of the hydrological properties for the pervious concrete is the infiltration rate which is the speed of water passing through the porous concrete. The interconnected void of pervious concrete allows water to penetrate to hardened concrete. The relationship between strength and porosity is inversely proportional where highly porous combinations commonly yields decrease strength and vice versa. According to Abu Bakar et al. [8] PCPC with void ratios between 15% and 25% produce strength values greater than 13.8 MPa (2000 psi) with a permeability of about 200 L/m²/min (480 in./hr.). Permeability values up to 600 L/m²/min (1440 in./hr.) were reported for PCPC mixtures with a void ratio exceeding 20%. In terms of the permeability ability, the falling head test implemented based on the standard BS 1377-5:1990 and ASTM D2435–04. The falling head equipment test will be constructing in the University Malaysia Pahang laboratory for the pervious concrete. As shown in the Figure 3.

Figure 3. Permeability Test Instrument

3.4 Intensity Duration Frequency (IDF)

The data obtained is analysed with by using Equation 2. Intensity Duration Frequency (IDF) curves is developed. This study selects Rumah Pam Pahang Tua Station since it is located nearby Pahang River in Pekan which has experienced flood event during the past years located in Figure 5.

$$i = \frac{\lambda T^{\kappa}}{(d+\theta)} \qquad (2)$$

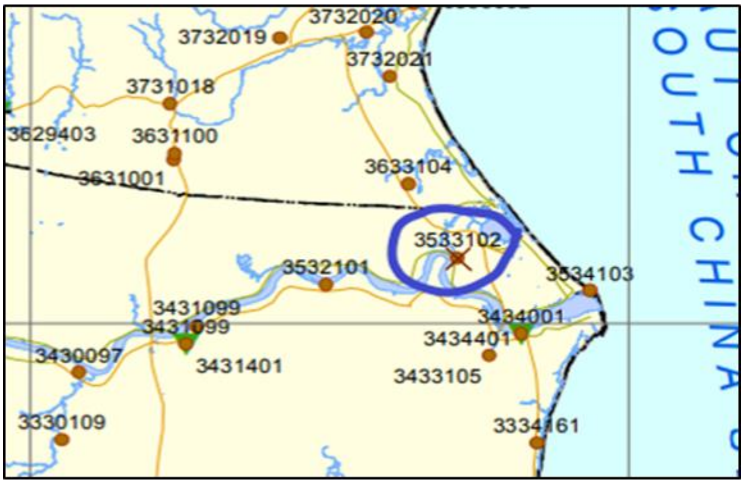

Figure 4. Location of 3533102 Rainfalls

Intensity Duration Frequency (IDF) curve is graphical representation gives the expected rainfall intensity of a given duration. Rainfall Intensity (mm/hr), Rainfall Duration (how many hours it rained at that intensity) and Rainfall Frequency (how often that rain storm repeats itself) are the parameters that make up the axes of the graph of IDF curve. An IDF curve is created with long term rainfall records and collected at a rainfall station [9]. All calculations are by MSMA 2nd Edition through Average Recurrence Interval (ARI) of 5, 10, 20, 50and 100.

4. Result and discussions

4.1. Preliminary Result

The effect of various coarse aggregate sizes on the compressive strength of pervious concrete was investigated. In the 1st stage, 20, 14 12.5, 9.5 and 4.75mm of granite aggregate were used. Based on Figure 6, the preliminary result which consists of 16 mixtures is illustrated. There are two mix design categories on basis of granite aggregate size which are single-sized aggregate and multi-sized aggregate. Average results of this stage are tabulated in Table 3 and 4. As noticed in table 4, ratio C: A of the PC is constant for all mixtures except M10 and M12 were 1:3.6 and 1:4.5 respectively. Also, mixtures 13, 14, 15 and 16 have an average granite aggregate density of 1333 kg/m^3 with 20mm and 14mm granite aggregate size. Also, the average weight of PC sample is ranged 1.7-2.1 Kg. Although all mentioned identical features, the compressive strength results are various Thus, the proportions of granite aggregate sizes dosage have an impact on the mechanical properties. However, upon a closer inspection of the results in Figure 6, it is observed that 16 mixtures of pervious concrete have different value of compressive strength due to various sizes and volume of aggregate 7 days compressive strength for pervious concrete mixtures ranged from 0.602 MPa to 10.9 MPa. Indeed, 10th mix has achieved the highest strength compression after 7 days curing in water at room temperature compared to the 16 mixtures. As known, 10.9 MPa is 2 thirds of the ultimate compressive strength which is indicated to be almost 17 MPa. Meanwhile, the previous studies of the control mix have reached the maximum 7 days compressive strength of 6.45 MPa [10].

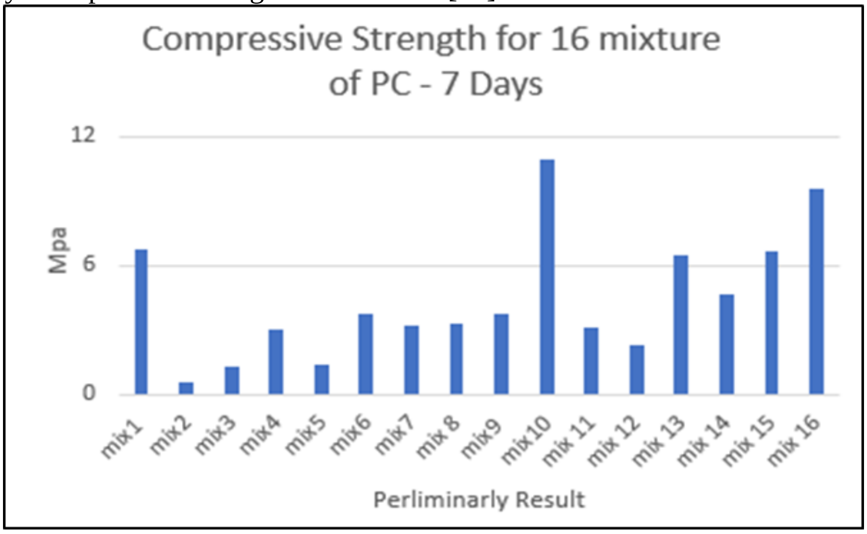

Figure 5. Compressive Strength for 16 mixtures

Table 3. Compression Strength Single-Sized Aggregate

Mix	Density Kg/m^3			Ratio		Compressive Strength (MPa)
	Cement	Aggregate	Water	Cement Aggregate ratio	w/c	
M1	347	1438	101	1:3.2	0.29	6.701
M2	270	1003	84	1:3.7	0.31	0.602
M3	355	1046	115	1:3	0.32	1.275
M4	359	1661	102	1:4.6	0.28	3
M5	355	1084	113	1:3.1	0.31	1.4

Table 4. Compressive Strength Multi-Sized Aggregate

Mix	Density Kg/m^3			Ratio		Compressive Strength (MPa)
	Cement	Aggregate	Water	Cement Aggregate ratio	w/c	
M6	311	1245	126	1:4	0.41	3.7
M7	312	1245	84	1:4	0.27	3.2
M8	311	1244	102	1:4	0.33	3.257
M9	310	1238	97	1:4	0.31	3.8
M10	440	1600	133	1:3.6	0.30	10.9
M11	440	1760	132	1:4	0.3	3.102
M12	360	1620	108	1:4.5	0.3	2.322
M13	334	1338	118	1:4	0.35	6.48
M14	334	1335	105	1:4	0.31	4.7
M15	334	1333	105	1:4	0.31	6.7
M16	334	1333	105	1:4	0.31	9.6

4.2. Mechanical and Hydrological Properties

The permeability results are various in the value of the infiltration rate since the range from 5 mm/s to 14 mm/s. Furthermore, 7 days compressive strength results were different due to different ingredients involved. Indeed, the first bar is representing the control mix for permeability which has achieved the lowest infiltration rate as 5 mm/s which because of using granite aggregate with no presence of steel slag; meanwhile, the highest permeability infiltration has reached the maximum of infiltration rate of 14 mm/s while the percentage of steel has reached 70 percentage of the mixture. It is also worth mentioning that even compressive strength results of the control mix have reached 10.9 MPa; meanwhile, with the first existing steel slag in the pervious the strength has increased to 11.8 MPa due to the high resistance that steel slag possesses. Indeed, the moderated permeable concrete has achieved in terms of the speed of water pass through the sample has occurred while the mixture consists of equivalent values of steel slag and granite on the basis of weight.

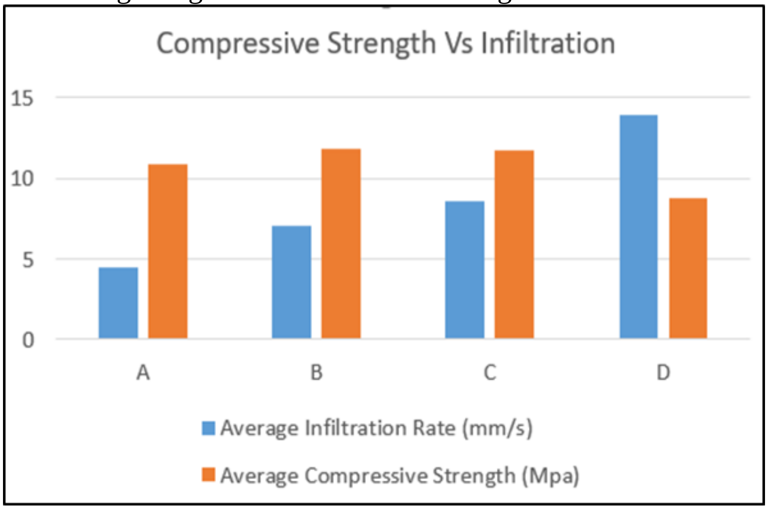

Figure 6. Compressive Strength vs Infiltration Rate

4.3. IDF Curve Developed

Referring to Table 5 and Figure 8, It is noticeable that the data collected from Rumah Pam Pahang Tua Station site 3533102 has been identified in the range of duration of 5 to 4320 minutes. Indeed, results were various; however, it is observed that while the duration of rainfall is shorter the higher value obtained. For example, in 5 ARI, for 5 minutes the value obtained is 173.3 mm/hr meanwhile for 4320 the value of intensity has decreased to 6.7 mm/hr. It is worthy to be highlighted that the maximum value of rainfallintensity gained is for 100 ARI is 327.11 mm/hr. Based on MSMA 2nd edition, 327.11 mm/hr considered as heavy rain.

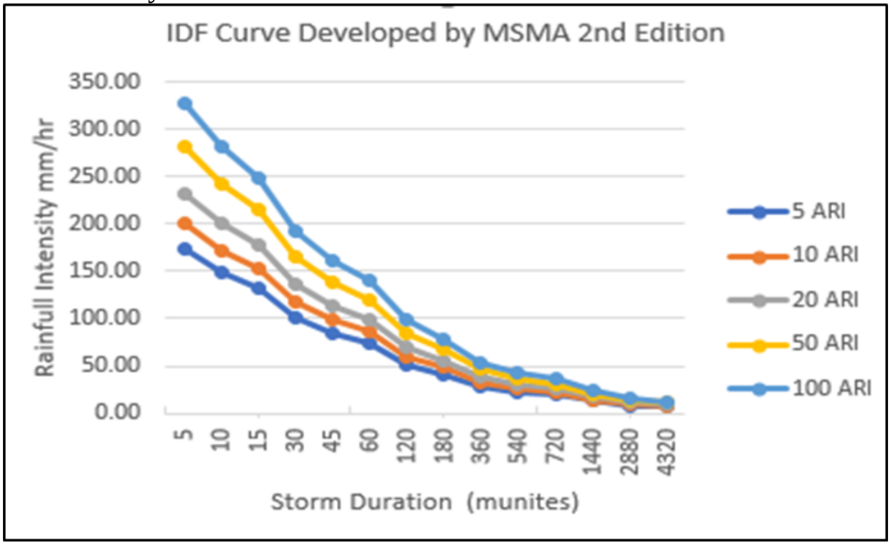

Figure 7. IDF Curve

Table 5. Intensity value by MSMA 2012

Duration	Average Recurrence Interval ARI (mm/hr)				
(minutes)	**5**	**10**	**20**	**50**	**100**
5	173.3	200.8	232.6	282.4	327.1
10	148.8	172.4	199.7	242.5	280.8
15	131.9	152.7	176.9	214.9	248.9
30	101.6	117.7	136.4	165.6	191.8
45	84.93	98.38	114	138.4	160.3
60	74.04	85.76	99.33	120.6	139.7
120	51.87	60.08	69.59	84.51	97.89
180	41.63	48.22	55.86	67.83	78.57
360	28.25	32.72	37.90	46.02	53.31
540	22.41	25.96	30.07	36.52	42.30
720	19.00	22.00	25.49	30.95	35.85
1440	12.72	14.73	17.06	20.72	24.00
2880	8.49	9.84	11.39	13.83	16.02
4320	6.70	7.76	8.99	10.92	12.65

5. Conclusions

To sum up, there are 3 outcomes which are stated clearly below regarding the compressive strength and permeability of the pervious concrete. Result of the IDF curve developed as well as the necessary comparison between intensity of rainfall and infiltration rate. Based on the preliminary result, the mix control has reached 10.9 MPa; meanwhile, with the first existing steel slag in the pervious the strength has increased to 11.8 MPa due to the high resistance that steel slag possesses. However, the more up to 50% of steel slag aggregate involved in the mixture much more strength obtained since 30% and 50% of steel slag have increased the strength of pervious concrete compared to mix control. The permeability results are various in the value of the infiltration rate since the range from 5 - 14 mm/s. The highest permeability infiltration rate has achieved the maximum of infiltration rate of 14 mm/s while the percentage of steel has reached 70 percentage of the mixture. It is worth to be said that the critical value of the rainfall intensity for 100 ARI obtained from the IDF curve is almost 1.1 mm/sec. Meanwhile, the lowest infiltration rate obtained in this study is 4.5 mm/s which is adequate to full fill the requirement of the rainfall intensity obtained from MSMA 2nd edition regarding at site 3533102 critical zone during flood session in Pekan.

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