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EVALUATION OF FLY ASH AS SUPPLEMENTARY CEMENTITIOUS MATERIAL TO THE MECHANICAL PROPERTIES OF RECYCLED AGGREGATE PERVIOUS CONCRETE

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ABSTRACT: Pervious concrete is a type of pavement made with minimal fine aggregate and high void ratio that allows stormwater to infiltrate into the soil and overcomes surface runoff problems. In this paper, the utilization of fly ash as supplementary cementitious material to the mechanical properties of pervious concrete made with recycled aggregate was investigated. Recycled aggregate was reclaimed from concrete waste to make pervious concrete. 0%, 50%, and 100% of recycled aggregate were used to replace natural coarse aggregate; while 0%, 15% and 25% of fly ash were used as cement replacement. The mechanical properties of pervious concrete were evaluated by determining the compressive strength, splitting tensile strength and flexural strength at 28 days. The results revealed that the use of recycled aggregate significantly affected the strength of pervious concrete. Further, the experimental results show that fly ash as supplementary cementitious material improved the compressive strength, splitting tensile strength and flexural strength of pervious concrete.

Keywords: Pervious concrete, Recycled aggregate, Fly ash, Strength

1. INTRODUCTION

The increasing population in urban areas brings a significant impact on the environment. The change of land use into a residential area and industrial area has increased surface runoff problem. With the concept of concrete that has many pores made with minimal sand or without sand, pervious concrete is an alternative solution to tackle surface runoff problems and contribute to groundwater recharge. Although it is one solution to solve the problem of surface runoff and can support groundwater recharge, pervious concrete has a low strength, therefore its application is limited to the light traffic load. Its characteristics that have many pores cause pervious concrete has low strength and have different properties compares to normal concrete [1,2]

The world's attention to environmental issues nowadays continues to increase, especially in the re-utilization of waste to avoid increasingly polluting the environment. As one of the most widely used building materials in the world, the concrete has been produced more than 20 billion tons annually, also causes environmental problems. The depletion of natural resources due to aggregate use and CO2 emissions due to cement production is made concrete to be environmentally damaging material [3,4]. By recycling concrete waste as an aggregate it is expected to be one of the alternative environmental problem solving and reducing the use of natural resources up to 40% [5].

Experiments on the use of the aggregate recycling obtained from concrete waste as concrete aggregate has been widely conducted by researchers. The results explained that the recycled aggregate concrete has a mortar attached to the original aggregate, thus leading to more absorptive and lower concrete strength [6-15]. This weakness causes the utilization of recycled aggregate is very limited in concrete, such as a sub-base road, landfill, or non-structural concrete [16,17].

The recycled coarse aggregate has been used as a concrete porous constituent material to support sustainable construction. A similar trend to the application in normal concrete, the use of recycled aggregate reduces the strength of pervious concrete. Several attempts were made to increase the strength of pervious concrete. Reducing the ratio of aggregate to concrete can increase strength, however, it reduces the permeability of pervious concrete [18], while reducing the W/C ratio and using graded size aggregate can provide good strength without significantly reducing the void ratio [19].

As the amount of fly ash generated each year as an environmental pollutant continues to increase, the utilization of fly ash has drawn the researcher's interests. It is proved the utilization of fly ash in concrete and cement is the most effective one [20,21]. Fly ash as cement replacement improves durability and workability of concrete [22]-[25], and reduces drying shrinkage of concrete, especially when uses in recycled aggregate concrete [26]. Therefore, the evaluation of fly ash as supplementary cementitious material to the mechanical properties of recycled aggregate pervious concrete is needed to be conducted.

2. EXPERIMENTAL PROCEDURES

2.1 Materials

Pervious concrete is a type of pavement that has a high void ratio due to minimal fine aggregate uses in the mix proportion that allows stormwater to infiltrate in the soil. Natural coarse aggregate and recycled coarse aggregate with no fine aggregate were used in making pervious concrete.

2.1.1 Recycled Aggregate

Recycled coarse aggregate was reclaimed from crushed cylinder concrete specimens with 225 kg/cm2 as parent concrete average compression strength. The natural coarse aggregate and recycled coarse aggregate appearance are presented in Fig. 1.

Table 1 Physical Properties of recycled coarse aggregate and natural aggregate

Properties	RCA	NCA
Bulk Specific Gravity SSD	2.47	2.30
Absorption (%)	5.15	14.33
Oven-dry density (gr/cc)	1.46	1.51

Note: RCA= Recycled coarse aggregate; NCA= Natural coarse aggregate.

Table 2 Grain size distribution of recycled coarse aggregate

Sieve size (mm)	Cumulative Percent Passing (%)
25.4	100.00
19.1	100.00
12.7	100.00
9.5	100.00
4.75	52.28
2.38	10.66
1.19	0.00

The physical properties of natural coarse aggregate and recycled coarse aggregate used in the experiment are described in Table 1. It indicated that the natural coarse aggregate used in the experiment has higher oven-dry density compared to recycled coarse aggregate. However, the water absorption of natural coarse aggregate indicated more porous compared to recycled coarse aggregate.

Furthermore, the grain size distribution of recycled coarse aggregate was also examined and listed in Table 2 then illustrated in Fig. 2.

(a) (b)
recycled coarse aggregate

(c) natural coarse aggregate

(d) natural coarse aggregate

Fig.1Appearance of aggregate

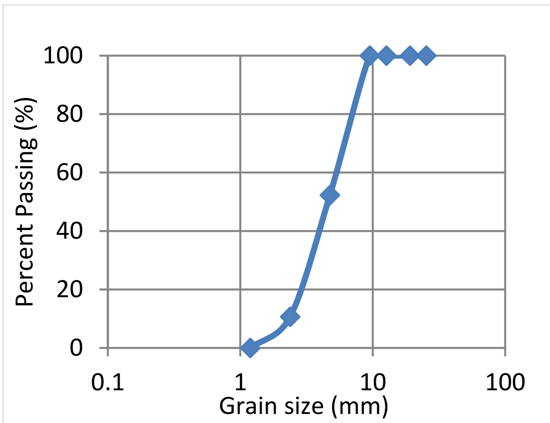

Fig.2 Grain size distribution of recycled aggregate

2.1.2 Binder

Portland pozzolan cement was used in the experiment with water-to-cement ratio was set to 0.3 for all mixtures.

Table 3 Physical Properties of Portland Pozzolan Cement (PPC)

Properties	Value
Density (gr/cm3)	2.97
Specific surface area m^2/kg	325
Setting time :	
- Beginning	153 min
- End	249 min
Compressive strength (kg/cm2)	
- 3 days	205
- 7 days	290
- 28 days	385
Density (gr/cm3)	2.97

Table 4 Chemical Properties of Portland Pozzolan Cement (PPC)

Properties	Mass (%)
Ig loss	1.69
SiO_2	23.13
Al_2O3	8.76
Fe2O3	4.62
CaO	58.66
MgO	0.9
SO3	2.18
FL	0.69
Insol	8.82

The physical properties and chemical properties of Portland Pozzolan Cement met the requirements of ASTM C 595M-1995 type IP used in the mix proportion are described in Table 3 and Table 4, respectively.

Fly ash Type C also used in the experiment as a supplementary of portland pozzolan cement. The chemical properties of fly ash are listed in Table 5.

Table 5 Chemical properties of fly ash (XRF)

Properties	Mass (%)
SiO_2	20.4
Al_2O3	7.5
Fe2O3	37.77
CaO	25.8
MgO	0.69
SO3	1.6

2.2 Mix proportion

The mix proportions of pervious concrete in this study are described in Table 6. The cement-to-aggregate ratio of pervious concrete was set to 1:4 with 0% of fine aggregate used in the experiment. The recycled coarse aggregate replaced 0 %, 50% and 100% of natural aggregate while 0%, 15% and 25% of fly ash were used to replaced Portland pozzolan cement by weight.

Table 6 Mix proportion of pervious concrete

Mix ID	Aggregate (%)		Binder (%)	
	NCA	RCA	C	FA
NF0	100	0	100	0
NF1	100	0	85	15
NF2	100	0	75	25
NRF0	50	50	100	0
NRF1	50	50	85	15
NRF2	50	50	75	25
RF0	0	100	100	0
RF1	0	100	85	15
RF2	0	100	75	25

Note: RCA= Recycled coarse aggregate; NCA= Natural coarse aggregate; C= Cement; FA= Fly ash.

2.3 Testing Procedures

To evaluate the mechanical properties of hardened pervious concrete, compressive strength test, splitting tensile strength, and flexural strength test was conducted at age 28days. For compressive strength and splitting tensile strength tests, cylinder specimens with a diameter of 15 cm and 30 cm height were made and tested according to ASTM C39 and ASTM C496, respectively. Standard test method for flexural strength of concrete using simple beam 53 cm x 15 cm x 15 cm specimens with third-point load according to ASTM C78 was also conducted to determine the flexural strength of pervious concrete.

3. RESULTS AND DISCUSSION

The mechanical properties of recycled aggregate pervious concrete using fly ash as supplementary cementitious material were evaluated. The density, compressive strength, splitting tensile strength and flexural strength of pervious concrete are discussed below.

3.1 Density of pervious concrete

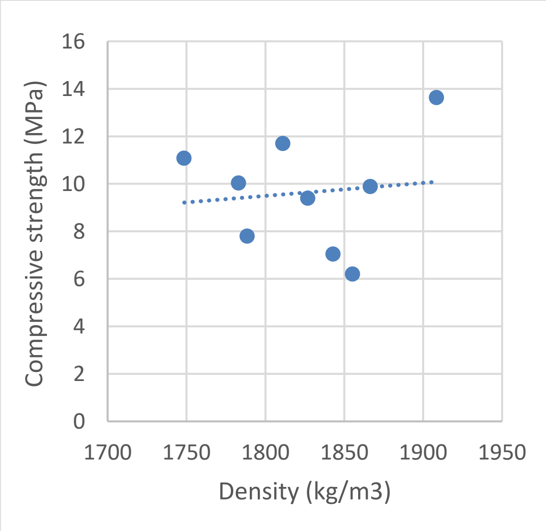

Fig.3 Density and compressive strength of pervious concrete

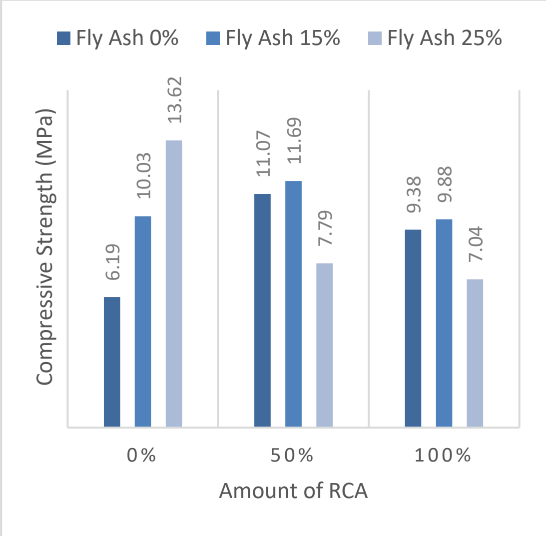

Fig.4 Compressive strength of pervious concrete

Fig. 3 illustrates the effect of density on the compressive strength of pervious concrete. It is indicated that the compressive strength of pervious concrete increased with an increase in density. It proves that higher strength is generally provided by denser concrete, which influences its mechanical properties. Furthermore, the compressive strength of pervious concrete is generally increased linearly to its density [27-29]. Nevertheless, the utilization of recycled aggregate in pervious concrete causes the variability in density so that the accurate comparison is difficult to be drawn due to differing aggregate densities and angularities [29]. Moreover, varying degree of compaction affects the variations of density in pervious concrete [30].

3.2 Compressive Strength

The effect fly ash as partial replacement of cement on compressive strength of pervious concrete using recycled aggregate is illustrated in Fig. 4. It indicated that the utilization of fly ash in pervious concrete using natural coarse aggregate significantly improved the compressive strength. 15 % of fly ash increased the compressive strength of pervious concrete using natural aggregate up to 83.65%, while 25% of fly ash increased 149.49% of compressive strength compared to natural aggregate pervious concrete with 0% of fly ash.

Figure 4 also illustrates the effect of the utilization of recycled coarse aggregate to replace specific natural coarse aggregate. It shown that 50% and 100% recycled coarse aggregate to replace specific natural aggregate with 0% of fly ash indicated to improve compressive strength up to 76.18% and 71.88%, respectively.

However, in 15% of fly ash to replace cement, 50% of recycled coarse aggregate to replace specific natural coarse aggregate the compressive strength increased 16.62% the compressive strength of pervious concrete, while 100% recycled coarse aggregate lower the compressive strength of pervious concrete instead. In contrary to the 0% of fly ash that recycled coarse aggregate to replace specific natural coarse aggregate tends to improve its compressive strength, 25% of fly ash significantly decreased pervious concrete compressive strength when the percentage of recycled coarse aggregate was increased.

3.3 Splitting Tensile Strength

The result of splitting tensile strength test of pervious concrete with the effect of utilization of fly ash and recycled coarse aggregate to the strength of previous concrete are presented in Fig. 5. It indicated that the utilization of fly ash in pervious concrete using natural coarse aggregate significantly improved the splitting tensile strength. 15 % of fly ash increased splitting tensile strength of pervious concrete using natural aggregate up to 57.035%, while 25% of fly ash increased 94.93% of splitting tensile strength compared to natural aggregate pervious concrete with 0% of fly ash.

Figure 5 also illustrates the effect of the utilization of recycled coarse aggregate to replace specific natural coarse aggregate to its splitting tensile strength. It showed that 50% and 100% recycled coarse aggregate to replace specific natural aggregate with 0% of fly ash indicated to improve splitting tensile strength up to 101.21% and 61.78%, respectively.

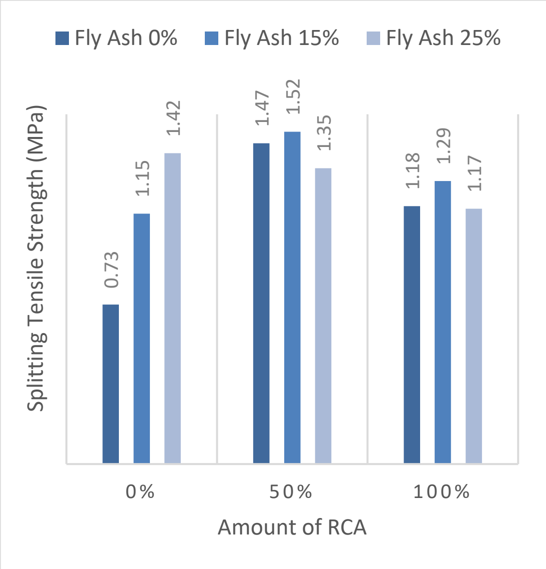

Fig.5. Splitting tensile strength of pervious concrete

However, in 15% of fly ash to replace cement, 50% of recycled coarse aggregate to replace specific natural coarse aggregate the splitting tensile strength increased 32.7% the splitting tensile strength of pervious concrete, while 100% recycled coarse aggregate increased the splitting tensile strength of pervious concrete 13.01%. Instead, 25% of fly ash significantly decreased pervious concrete splitting tensile strength when the percentage of recycled coarse aggregate was increased compared to 0% of fly ash.

3.4 Flexural Strength

Fig. 6. Illustrates the flexural strength of pervious concrete. Previous discussions on compressive strength and splitting tensile strength indicated a similar trend due to the utilization of fly ash on the strength of recycled aggregate pervious concrete. However, the flexural strength of pervious concrete demonstrated no significant influence on the utilization of recycled aggregate and fly ash.

4. CONCLUSIONS

Compressive strength test, splitting tensile strength test, and flexural strength test of pervious concrete was examined to investigate the effect of utilization of fly ash on the mechanical properties of recycled aggregate pervious concrete. The following conclusions are drawn from the test result:

1. The compressive strength of pervious concrete increased with an increase in density. However, the variability of recycled aggregate density and degree of compaction also influence the density of recycled aggregate pervious.
2. The utilization of recycled coarse aggregate to replace selected natural coarse aggregate increases compressive strength and splitting tensile strength of pervious concrete.
3. Utilization of fly ash up to 25 % to replace cement improves compressive strength and splitting tensile strength of pervious concrete using natural coarse aggregate. However, replacing natural coarse aggregate with recycled coarse aggregate up to 50% improves the strength of pervious concrete, particularly in 15% of fly ash to replace cement.
4. The utilization of recycled aggregate and fly ash in pervious concrete indicated less significant effect on the flexural strength of pervious concrete.

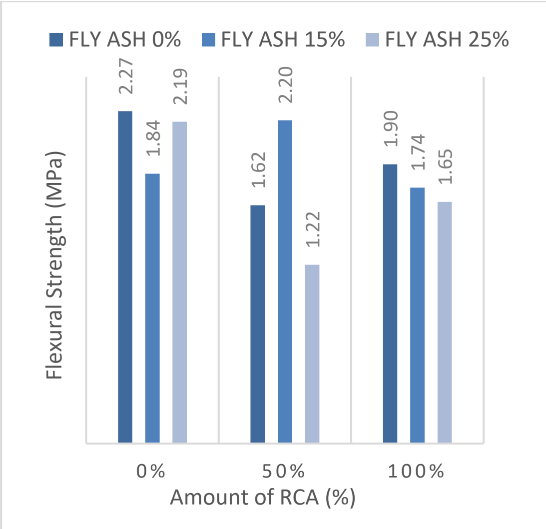

Fig.6 Flexural strength of pervious concrete

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