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MECHANICAL AND HYDRAULIC PERFORMANCE OF PERVIOUS RECYCLED AGGREGATE GEOPOLYMER CONCRETE

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The widespread expansion of the global economy and the increase in human population have been major contributors to pollution and environmental complications. Construction and demolition wastes (CDW), impervious pavement surfaces, and industrial waste disposal sites have emerged as serious environmental challenges over the past decade. These challenges must be addressed through the synergic use of different sustainable practices, including pervious surfaces, CDW, and industrial wastes. Their combined utilization produces a pervious geopolymer concrete made with recycled concrete aggregates (RCA). This research aims to develop and assess the mechanical and hydraulic properties of pervious geopolymer recycled aggregate concrete (PGRAC) with a design porosity of 15%. The mixes were made with two binder blends of ground granulated blast furnace slag and fly ash (1:0 and 1:1) and RCA replacement of 0 and 100%. The mechanical and hydraulic performance were characterized by compressive strength and permeability, respectively. Results showed that pervious concrete made with natural aggregates and comprising a binder blend of slag:fly ash of 1:0 demonstrated 36% higher compressive strength than counterparts having a binder blend of 1:1. Meanwhile, the permeability was unaffected by the variation in the binder. At 100% RCA, the compressive strength of mixes having a binder blend of 1:0 was 192% higher than that of the equivalent mix having a binder blend of 1:1. Yet, the latter had 12% higher permeability than the former. These research findings demonstrate the ability to produce sustainable PGRAC for use in pavement applications.

Keywords: Permeable pavements, Sustainable environment, Compressive strength, Permeability.

1 INTRODUCTION

Global urbanization is driven by rural-to-urban migration due to economic development (Kuddus *et al.* 2020). Global population growth and development demand new infrastructure (Uratani and Griffiths 2023). Due to expansions and advancements, concrete will remain in high demand in building (Wangler *et al.* 2019). However, its production raises economic and environmental concerns. It depletes natural resources and uses a lot of energy, causing resource scarcity (Anwar *et al.* 2022). One ton of cement takes 1.6 tons of raw materials and 6.5 million BTUs, contributing to global greenhouse gas emissions and air pollution (Gupta *et al.* 2020). Thus, sustainable concrete alternatives are necessary to reduce cement consumption, energy, raw material, and greenhouse gas emissions. Various research have examined the effects of partial or total cement substitution by SCMs on concrete characteristics (Anwar *et al.* 2021). Complete cement replacement using single, binary, or ternary SCMs in the form of alkali-activated binders has been recommended to reduce cement's environmental effect (Adil *et al.* 2020, Lo *et al.* 2021). The possibility of alkali-activated binders as alternative construction materials has garnered interest. NA is scarce and in high demand, therefore finding alternatives is crucial (Santos *et al.* 2019). Due to its availability and good performance, recycled concrete aggregates (RCA) from construction and demolition wastes (CDW) are often utilized to replace NA (McNeil & Kang, 2013, Mehrabi *et al.* 2021).

Impermeable pavement systems, which encompass 3% of Earth's surface, are another environmental concern (Elizondo-Martínez *et al.* 2020). Stormwater runoff, floods, urban heat islands (UHI), lower groundwater recharge from precipitation, and non-skid surfaces owing to decreased friction are some of the issues (Elizondo-Martínez *et al.* 2020, Zhong *et al.* 2018). An effective permeable surface solution for pavement systems is needed to address these environmental issues. Pervious concrete (PC) is a porous pavement material with a unique permeable network of voids (Chandrappa and Biligiri 2016). PC pavement has interconnected pores with a diameter of 2-8 mm, porosity of 15-30%, and permeability of 1.3-12 mm/s (Elango *et al.* 2021). Indeed, PC made with geopolymers, and RCA would address the major environmental issues listed above. Several studies examined pervious geopolymer concrete's performance. The mechanical and hydraulic performance of metakaolin- and fly ash-based PGC was compared to cement-based PC. The former performed better mechanically and the latter better hydraulically than the cement-based equivalent. Geopolymers may make PGC with better performance than cement-based PC (Huang and Wang 2021, Hwalla *et al.* 2023). However, PGC integrating RCA (PGRAC) has not been tested.

This research evaluates the mechanical and hydraulic performance of pervious geopolymer recycled aggregate concrete (PGRAC) prepared by replacing NA with RCA and cement with GGBS/FA. Compressive strength and permeability were evaluated. This was done to address conventional materials problems related to environmental concerns. These include greenhouse gas emissions, impermeable surfaces, transportation noise, stormwater runoff that causes flooding, and hazardous pollutant taken to water bodies, which reduces water accessibility. Construction material manufacturing uses a lot of energy and natural resources, which strains the economy. The aim of this investigation is to develop and assess a sustainable, eco-friendly construction material that tackles global warming, water accessibility, greenhouse gas emissions, and natural resource usage.

2 MATERIALS AND METHODS

2.1 Materials and Sample Preparation

This research used Emirates Cement and Ashtech GGBS (ground granulated blast furnace slag) and class F FA fly ash binders. Dolomitic limestone natural aggregates (NA), satisfying ASTM C33 (ASTM C33 2023) specifications, were substituted with recycled concrete aggregate. The replacement levels were 0% and 100%. The NA and RCA have 4–10 mm particle sizes. NA/RCA had specific gravity, dry rodded density, fineness modulus, and surface area of 2.82/2.63, 1663/1563 kg/m3, 6.82/7.44, and 2.49/2.50 cm2/g. Table 1 shows 15% design porosity mixtures. As indicated in the table, 100% NA and ordinary Portland cement (OPC) were used to make the control mix (PC-NA) according to ASTM C150 (ASTM C150 2012). The geopolymer was produced with 0% and 100% RCA using a 10 M sodium hydroxide (NaOH) solution by dissolving NaOH granules in potable water. Sodium silicate (SS) was added to SH to make the alkaline solution and cooled for 24 hours. ACI 522R-10 was used to prepare the sample at ambient temperature and humidity (ACI Committee 522 2010). A pan mixer combined binder and aggregates for 4 minutes. After adding the alkaline solution gradually, the mixture was mixed for 3 more minutes. The concrete was manually compacted in two layers and hardened in the lab before testing. SG-0R and SG-100R were produced utilizing 0% and 100% RCA, respectively, with GGBS as the sole binding material. Similarly, SG+FA-0R and SG+FA-100R were prepared using a 1:1 ratio of GGBS and FA as the binding material.

Table 1. Mixture proportions of PC mixes.

Mix No.	Mix Designation	OPC (kg/m^3)	GGBS (kg/m^3)	FA (kg/m^3)	NA (kg/m^3)	RCA (kg/m^3)	SS (kg/m^3)	SH (kg/m^3)	Water (kg/m^3)
1	PC-NA	372	0	0	1541	0	0	0	149
2	SG-0R	0	370	0	1606	0	99	66	0
3	SG-100R	0	370	0	0	1537	99	66	0
4	SG+FA-0R	0	165	165	1606	0	89	59	0
5	SG+FA-100R	0	165	165	0	1538	89	59	0

2.2 Experimental Methods

The 1-, 7-, and 28-day compressive strength of PGC was evaluated using 100 mm (diameter) × 200 mm (height) cylindrical samples, as per ASTM C39-20 (ASTM C 39-20 2020), using Eq. (1).

$$\text{Compressive strength} = \frac{\text{Applied Load (kN)}}{\text{Area of Sample (mm}^2\text{)}} \tag{1}$$

The permeability coefficient, k, was evaluated using a 100 mm (diameter) × 50 mm (height) cylindrical sample following the modified falling head permeability in accordance with the procedure described in ACI 522R-10 (ACI Committee 522 2010). Eq. (2) below from Darcy's law was used to calculate the value of k.

$$k = \frac{A_p L}{A_s t} \ln \frac{h_o}{h_1} \tag{2}$$

Where: k = permeability coefficient (mm/s), A_p = Area of pipe (mm^2), A_s = Area of sample (mm^2), L = Length of sample (mm), t = time taken for water to move from h_o to h_1, h_o = Initial water level (mm), h_1 = Final water level (mm).

3 RESULTS AND DISCUSSION

3.1 Compressive Strength

Fig. 1 shows 15% porosity PGRA compressive strength. The NA-based control mix with OPC showed compressive strengths of 4.4, 11.0, and 13.9 MPa at 1, 7, and 28 days, respectively. SG-0R, made using GGBS as the only binder and 0% RCA, has better compressive strength of 18.1, 24.2, and 25.3 MPa, respectively. The geopolymeric binder may generate concrete with 82% better 28-day compressive strength than cementitious concrete. Faster geopolypolymerization at higher temperatures than cement hydration could account for geopolymer concrete's early strength enhancement relative to conventional concrete (Pilehvar *et al.* 2020). The strength increased somewhat between 7 and 28 days, indicating that geopolymer binders are strongest within 7 days after casting (Rao and Kumar 2020). FA replaced 50% GGBS at 1, 7, and 28 days, yielding 13.0, 21.8, and 21.5 MPa, respectively. Replacement of highly reactive GGBS with less reactive FA at ambient settings causes strength reduction which may be compensated by heat curing (Guan *et al.* 2023). The replacement of NA with 100% RCA in GGBS-based geopolymer mixes decreased compressive strengths by 35, 52, and 49% at 1, 7, and 28 days, respectively, primarily due to lower abrasion resistance and bulk density, performance of RCA (Amran *et al.* 2020). GGBS-FA mixed mixes with NA replaced with RA lost 74, 83, and 77% strength at the three ages. The porous FA and RCA and poor binding between the mixed geopolymer paste and RCA may explain this strength reduction (Sinsiri *et al.* 2010). However, with a 28-day strength over 3.5 MPa (ACI Committee 522 2010), all PGRAC mixes are suitable for pavement applications, while weaker mixes should only be used in shoulder lanes, walkways, and other light traffic roadways.

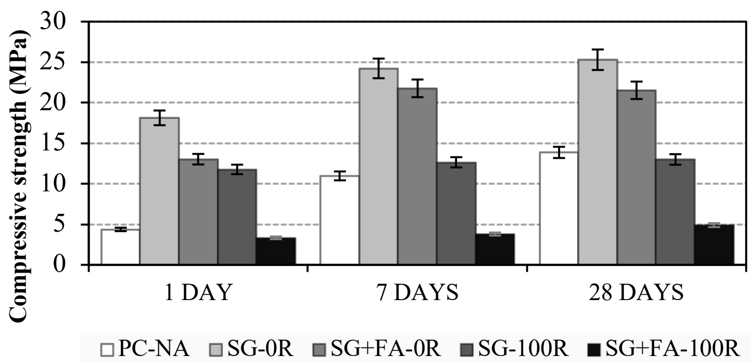

Fig. 1. Compressive strength of pervious geopolymer concrete mixes.

3.2 Permeability

The permeability results are shown in Fig. 2. All combinations had appropriate permeability for pavement applications with values between 2.8 and 4.1 mm/s (ACI Committee 522 2010). A control mix (PC-NA) showed identical permeability (<5% difference) to mixes produced with NA, independent of binder type. This suggests that cementitious or geopolymeric binder did not alter permeability. In pervious geopolymer concrete mixes built with GGBS alone, replacing NA with 100% RCA increased permeability by 30%. FA-containing peers had 40% higher permeability after RCA inclusion. This shows that RCA replacement was more noticeable with a combined binder of GGBS and FA than with GGBS alone. Porous RCA makes more porous concrete, which may explain the rise in 100% RCA mixtures (Aoki *et al.* 2012). This also explains why PGRAC created with GGBS and FA loses strength more than GGBS alone.

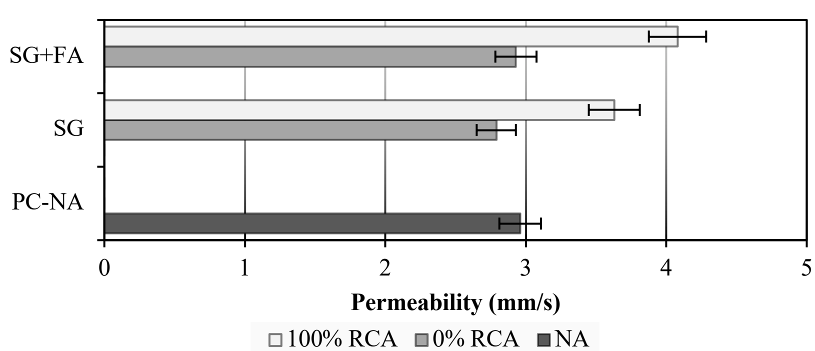

Fig. 2. Permeability of pervious geopolymer concrete mixes.

4 CONCLUSIONS

This research explored how binder type and RCA replacement affect pervious geopolymer concrete compressive strength and permeability where the following conclusions were drawn:

- All mixtures showed adequate strength for pavement applications, with compressive strengths ranging from 3.3 to 25.3 MPa. FA-based mixtures performed poorly compared to GGBS-based ones. The substitution of RCA reduced compressive strength at all ages.
- The permeability varied from 2.8 to 4.1 mm/s, satisfying pervious concrete hydraulic performance criteria. GGBS-FA blended mixtures were more permeable than GGBS-based ones. Pervious geopolymer concrete became more permeable when NA was replaced with RCA.

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