

Fabrication of Geo-polymer Concrete using Rice Husk, Crumb Rubber and GGBFS

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Abstract

This study examines the production of geo-polymer concrete utilizing ground granulated blast-furnace slag (GGBS), rice husk ash, and crumb rubber. The characteristics of Geo-polymer concrete were evaluated by compressive and tensile strength tests, sorptivity assessments, and chloride permeability investigations. The compressive strength of GPC diminishes after 28 and 56 days, even with 15 percent and 25 percent GGBS substitution by RHA, particularly when compared to GPC consisting solely of 100 percent GGBS. The minimal proportion of crumb rubber in various GPC formulations improves the compressive strength of GPC at all curing ages. The split tensile strength of GPC typically diminishes with an increase in RHA content; however, the incorporation of crumb rubber significantly enhances the resistance in all GPCC mixes. The effectiveness of the RHA-infused GPC is now contingent upon the size of the RHA particles. RHA with a particle size of 75 microns reveals a compressive strength of 35.2 MPa after 28 days, whereas RHA with a particle size of 125 microns shows a compressive strength of 29.8 MPa within the same timeframe. The compressive strength of GPC diminishes with an increase in the particle size of RHA, and vice versa. Testing results demonstrate a sorptivity reduction of approximately 23.72% at 28 days and 50.42% at 56 days, both resulting from the incorporation of crumb rubber in the mix fraction. GPC has enhanced performance in strength, sorptivity, and chloride permeability, achieving around 15%, indicating its potential as a substitute for OPC-based concrete.

Keywords: *Geo-polymer concrete; compressive strength; RPCT; crumb rubber; GGBS; RHA.*

Introduction

Cement is the most prevalent construction material worldwide, due to its numerous advantages, such as cost-effectiveness, simplicity of handling, adaptation to desired shapes, high strength, maintainability, and longevity. In the course of developing human community services Concrete is regarded as one of the fundamental constituents. The principal components of concrete are Ordinary Portland Cements (OPCs), employed to bind coarse and fine particles. Moreover, OPC often has an adverse impact on the climate. It is widely acknowledged that Ordinary Portland Cement (OPC) is produced from raw materials such as lime, clay, and minerals, and the extraction of these natural resources often results in detrimental environmental effects. The widespread use of

OPC is associated with major environmental concerns (Davidavits, 1994). 1.5 tons of earth mineral resources are consumed to produce one ton of cement, leading to the emission of approximately 1.0 ton of carbon dioxide into the atmosphere (Mehta, 2001). The production of OPC generates substantial CO₂ emissions that exacerbate global climate change. Roughly 7% of global climate change is ascribed to the cement industry owing to CO₂ emissions (Mehta, 1999). Carbon dioxide (CO₂) accounts for approximately 64% of global warming among other greenhouse gas emissions (Caffery, 2002). Global cement consumption rises annually by 2.7 billion tons and is anticipated to surge by 4 billion tons per year by 2020 (Chana, 2011). In 2013, the cement industry in Australia emitted approximately 36 billion tons of carbon dioxide. These challenges can be mitigated by incorporating supplemental cementitious materials such as Ground Granulated Blast Furnace Slag (GGBS), Fly Ash (FA), Rice Husk Ash (RHA), and Metakaolin. GGBS is the primary waste generated by steel manufacturers, while RHA is an agricultural byproduct derived from the incineration of rice husks in industrial processes. Relevant keywords suggest that by-products from numerous factories are significantly accumulated at disposal sites in India. Utilizing these by-products as supplemental cement components presents various advantages, including environmental preservation and the reduction of soil erosion by resolving the waste issues connected with these by-products. The rising demand for concrete has driven researchers to create eco-friendly alternatives by incorporating waste materials from several industries as substitutes for conventional concrete constituents. External cement components may be wholly or partially substituted by cement, contingent upon necessity. Concrete produced from a silica-rich waste product used as a raw material for alkaline solutions is referred to as Geopolymer concrete.

The fundamental principles of that theme were established by Glukhovsky in 1957, known as soil cement, although the Geopolymer concept was first proposed by Davidovits in 1978. Geopolymer functions as an eco-friendly substitute for Ordinary Portland Cement (OPC). A Geopolymer is an organic polymer formed from aluminum silicate compounds and an alkaline liquid (Komnitsas and Zaharaki, 2007; Cheng and Chiu, 2003; He et al., 2011). The polymerization interactions of the raw elements aluminum (Al), silicon (Si), and alkaline liquids now demonstrate a chemical structure identical to that of zeolite. The enhancement of GPC is essential, yielding inherent advantages, such as a decrease in carbon dioxide emissions. Materials including both silica and alumina are extensively acknowledged as a precursor in the manufacture of GPC. Fly ash, a byproduct of electricity generation, has emerged as the primary material employed in the fabrication of geopolymer concrete. FA is a byproduct containing aluminum and silica, found at numerous locations around. Global FA output has surpassed 380 million tons annually. Pozzolana has been primarily employed as a key resource in several investigations. Pozzolana is a substance distinguished by a significant amount of crystalline silica and alumina. Specific alkaline chemicals, such as NaOH and Na₂SiO₃, are essential in the synthesis of GPC. Alkaline substances activate the precursor and create an aluminosilicate matrix; geopolymer concrete will be employed

for many applications, including repairs and sculpture creation. The compressive strength of a GPC depends on the Si/Al ratio and the type of material used.

The existing OPC situation clearly produces various detrimental environmental issues, intensifying climate change via greenhouse gas emissions, particularly CO₂, in addition to significant energy consumption and the usage of natural or pure resources for all outputs. This research seeks to identify an alternative method to OPC to resolve the concerns.

Materials and Methodology

A literature review indicates that limited research has been undertaken on geo-polymer concrete including RHA and CR. A comparison study between conventional and geo-polymer concrete has not been undertaken. The materials utilized in this investigation are as follows:

- GGBS (Ground granulated blast slag)
- RHA (Rice husk ash)
- CR (Crumb rubber)
- Aggregates (Coarse and fine)
- Super plasticiser

Mix proportions used in this study Due to the unavailability of an Indian standard for the GPC mix design, the mixture proportions have been determined based on pertinent literature and prior research findings. The entire aggregate quantity was determined to be 80% of the total concrete volume. CA has been selected to withdraw 60 percent of the total. This research has selected a substitution of GGBS with RHA at 15% and 25%, with or without the inclusion of crumb rubber. Alkaline solution for binding, i.e. In this research, GGBS and RHA were utilized at a ratio of 0.4. The ratios of sodium silicate and hydroxide were selected to be 3. The concentration of sodium hydroxide was utilized at 12 M for specific types of combinations. The RHA examined in this study was categorized into two distinct particle size distributions: one at 125 microns and the other at 75 microns, to evaluate the GPC output based on the scale of the RHA particles. An alkaline solution was prepared one day before to casting to get a uniform mixture and to complete the polymerization reaction between the two components. The mixing process is finalized in the pan mixer by incorporating the specified quantities of all additions. Water has been incorporated according to the requirements for the preparatory work of concrete mixtures.

Casting Procedure

The procedure for casting is detailed below: - All components were removed, and any dust or debris was rinsed away in the initial phase. All components calculated according to the selected mix proportions. Subsequently, GGBS and RHA were incorporated into the plate and thoroughly mixed by hand to achieve a uniform combination. The FA and CA were added to a pan mixer, which was then spun for 2-3 minutes to achieve a homogenous concrete mix. GGBS and RHA were incorporated into a pan mixer and agitated for approximately 4-5 minutes to achieve a homogenous mixture. Alkaline liquids were subsequently injected, and the pan mixture was swirled for two minutes. In accordance with the durability requirement, W and SP were incorporated into the reaction mixture and subsequently distributed across three layers within the mold on the vibrating table. The final completion of a mold has been executed with the assistance of the trowel. • Moulds have been placed on a level base to prevent any undulation.

Results and Discussion

Compressive strength The analysis of compressive strength for GGBS-based GPC, incorporating 125 micron and 75 micron RHA, is documented in Tables 1 and 2. Utilizing that average to determine outcomes, three specimens were examined, leading to the selection of the final sample. Four mixtures were formulated with a particle size of 75 microns for RHA, while an equal number of blends were created with a particle size of 125 microns for RHA. The compressive strength at approximately 100% GGBS was calculated to be 47.8 MPa; however, it has been observed to reach roughly 49.7 MPa at 28 days with the incorporation of crumb rubber. It indicates an enhancement in the compressive strength of GPC mostly due to the incorporation of crumb rubber. The samples were prepared by substituting GGBS with RHA (particle size 75 microns), resulting in increases in two rubber types, with observed strengths of 35.2 MPa, 13.6 MPa, and 15.3 MPa at a replacement ratio of 25%, ranging from 15% to 25%, with or without crumb rubber. This signifies a decline in compressive strength as the particle size of RHA increases. Similarly, after 56 days of GPC with 100% GGBS, 15% RHA, and 25% RHA, the compressive strengths recorded were 51.5 MPa, 37.5 MPa, and 22.4 MPa, respectively, excluding crumb rubber. When crumb rubber was included, the strengths were observed to be 54.3 MPa, 31.7 MPa, and 17.6 MPa for RHA particle sizes of 75 microns, respectively. RHA with a particle size of 125 microns, both with and without crumb rubber, has compressive strengths of 13.7 MPa and 16.1 MPa, respectively.

The reduction in compressive strength with the incorporation of RHA may primarily result from insufficient bonding between the aggregate and RHA, which could also lead to an increase in voids within the concrete due to the elevated RHA concentration. However, the use of crumb rubber enhances strength due to its high elasticity, which mitigates concrete cracking and plugs the pores created by the addition of RHA.

Table 1: Compressive strength at 28 and 56 days with RHA particle size of 75 microns

Mix Design Proportions	28 days (MPa)	56 days (MPa)
GGBS100%	47.8	51.7
GGBS100%+CR	49.7	54.3
GGBS85%+RHA15%	35.2	37.5
RHA15%+85%GGBS+CR	39.8	44.7
GGBS75%+RHA25%	19.6	22.4
25% RHA+75 %GGBS+CR	21.6	24.7

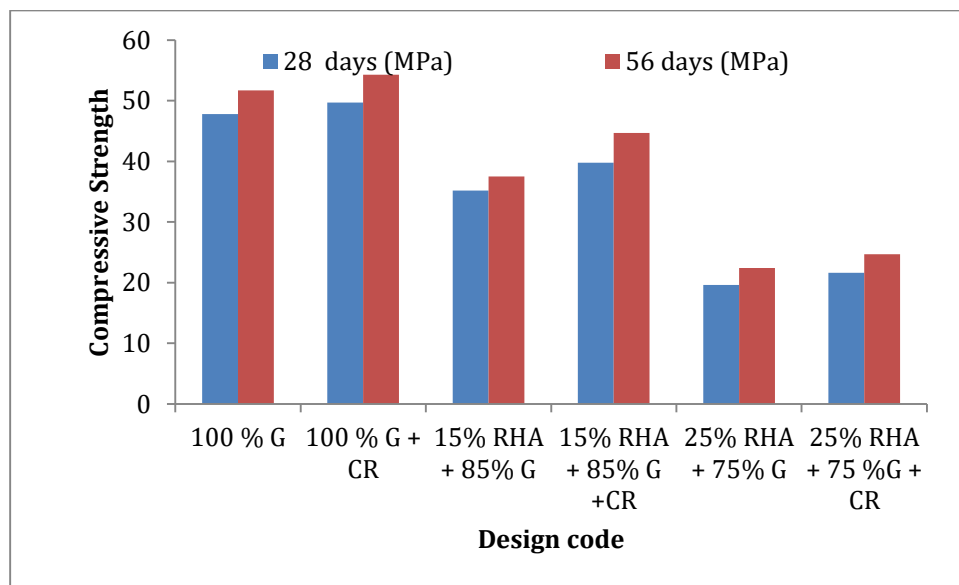


Figure 1: Compressive strength results with 75 microns rice husk ash

Table 2: Compressive strength at 28 and 56 days with RHA particle size of 125 microns

Mix Design Proportions	28 days (MPa)	56 days (MPa)
GGBS100%	47.8	51.5
GGBS100%+CR	49.7	54.3
GGBS85%+RHA15%	29.8	31.7
RHA15%+85%GGBS+CR	32.5	36.4
GGBS75%+RHA25%	13.7	16.1
25% RHA+75 %GGBS+CR	14.8	17.6

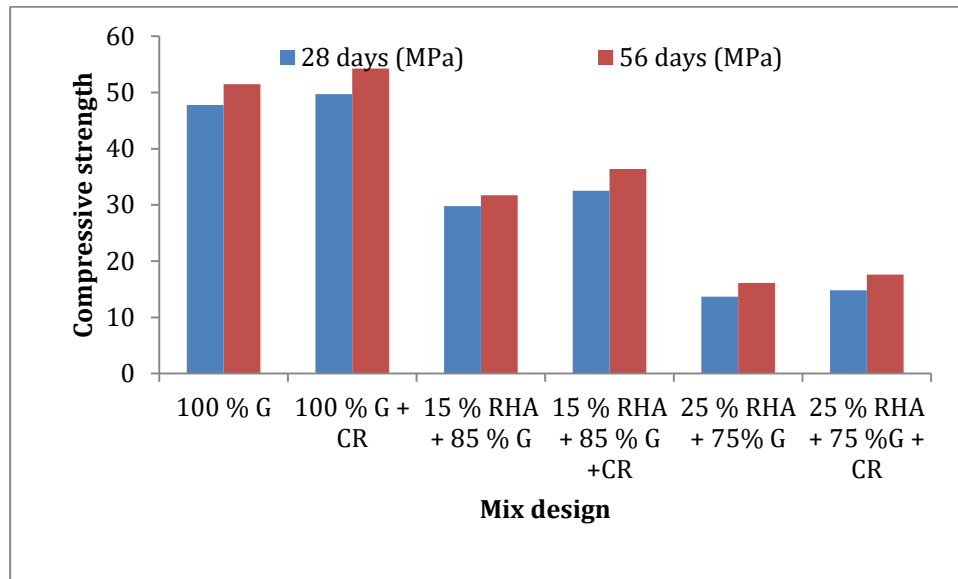


Figure 3: Compressive strength outcomes with 125 μ RHA

Split Tensile Strength The results of tensile strength after 28 days and 56 days are presented in Table 3 for a particle size of 75 microns and in Table 4 for a particle size of 125 microns. The modification of split tensile strength exhibits a trend identical to that of compressive strength, with observations indicating that after 28 and 56 days, GPC containing 100% GGBS demonstrated split tensile strengths of 3.46 MPa and 4.04 MPa, respectively. Despite the addition of 20% RHA, the split tensile strength decreases over 28 days from 3.46 to 2.74, and subsequently over 56 days from 4.04 to 3.21. As illustrated in tables 4.3 and 4.4, strength was further augmented with the addition of crumb rubber in both cases of RHA sizes 75 and 125 microns.

Table 3: Split tensile strength after 28 and 56 days with RHA particle size of 75 microns

Mix Design Proportions	28 days (MPa)	56 days (MPa)
GGBS100%	3.46	4.04
GGBS100%+CR	3.86	4.41
GGBS85%+RHA15%	2.74	3.21
RHA15%+85%GGBS+CR	3.06	3.82
GGBS75%+RHA25%	1.39	1.48
25% RHA+75 %GGBS+CR	1.48	1.57

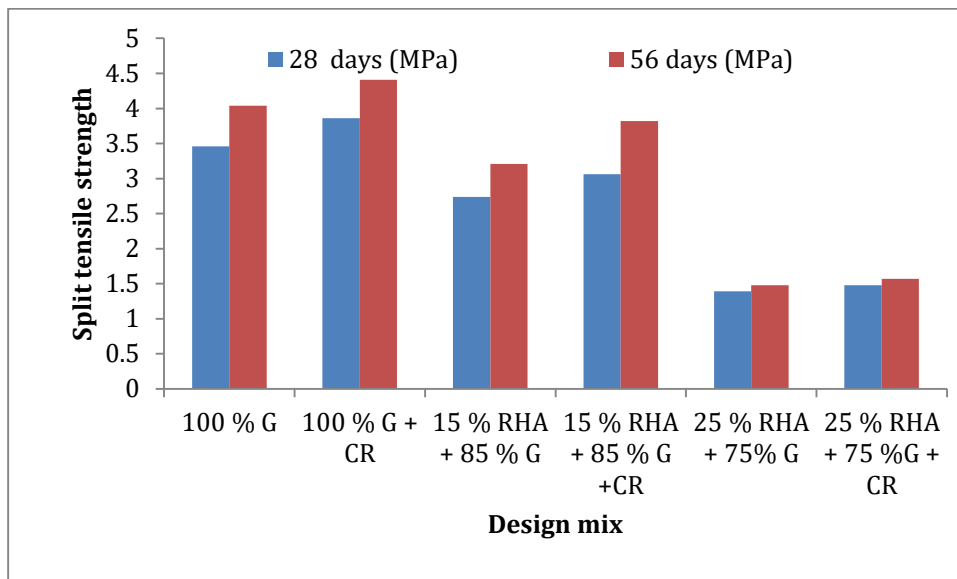


Figure 3: Split tensile strength outcomes with 75 μ RHA

Table 4: Split tensile strength having the RHA particle size 125 micron

Mix Design Proportions	28 days (MPa)	56 days (MPa)
GGBS100%	3.46	4.04
GGBS100%+CR	3.86	4.41
GGBS85%+RHA15%	2.37	2.78
RHA15%+85%GGBS+CR	2.59	3.15
GGBS75%+RHA25%	1.02	1.25
25% RHA+75 %GGBS+CR	1.08	1.29

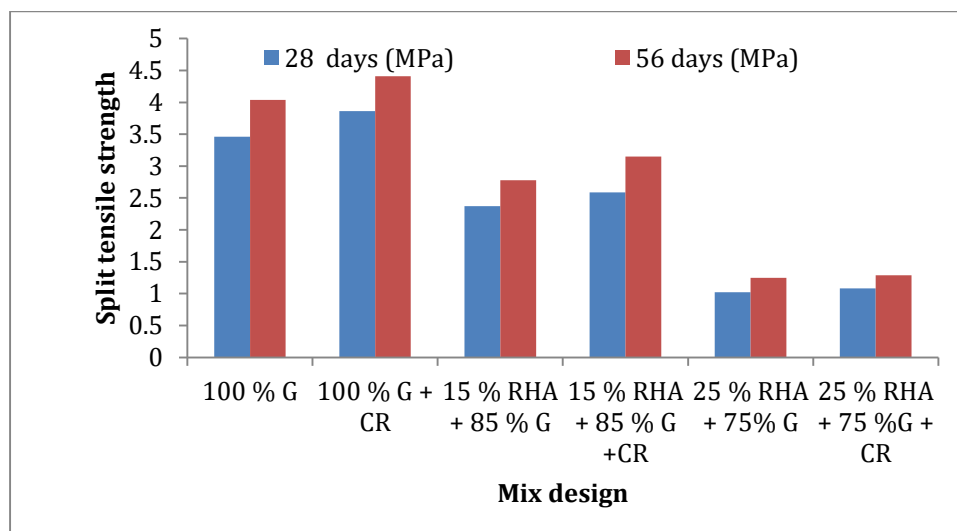


Figure 4: Split tensile strength outcomes with 125 μ RHA

The observed reduction in split tensile strength with the addition of RHA may be attributed to insufficient bonding between the aggregate and RHA. However, increasing the amount of RHA may lead to an increase in porosity within the concrete. The incorporation of crumb rubber increases strength due to its high elasticity, which mitigates concrete cracking and fills the pores created by the addition of rice husk ash (RHA) in the concrete mix.

Sorptivity test result The absorption value illustrated as a function of time over 28 days for a mixture with a particle size of 125 microns is presented in Figure 5. The slope of the absorption curve correlates with sorptiveness to each combination. Sorptivity analysis is shown in table 5.

Table 5: Sorptivity outcomes for 75 μ RHA

Mix Design Proportions	28 days (MPa)	56 days (MPa)
GGBS100%	0.0365	0.0353
GGBS100%+CR	0.0236	0.0181
GGBS85%+RHA15%	0.0387	0.0367
RHA15%+85%GGBS+CR	0.0423	0.0255
GGBS75%+RHA25%	0.049	0.0454
25% RHA+75 %GGBS+CR	0.0447	0.0393

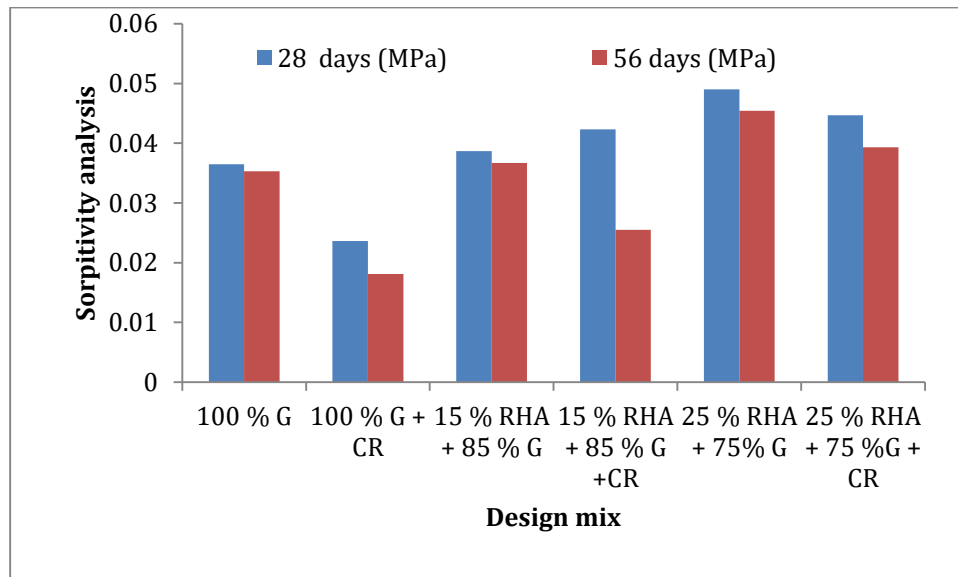


Figure 5: Sorptivity analysis

Figure 5 indicates that the correlation of sorptivity for the various combinations exhibits a particle size of 75 microns after 28 and 56 days, respectively. It is observed that the sorptivity value increases from 0.0365 to

0.0387 when 15% GGBS replaces the 75-micron particle size RHA. This signifies enhancements in sorptivity with an increase in RHA percentage. An increase in sorptivity due to the pores inside GPC predominantly correlates with an elevated percentage of RHA. Moreover, it was observed that the application of 2% CR throughout the mixtures led to a further decline in sorptivity after 28 and 56 days for all mixtures with particle sizes of 75 and 125 microns. This reduction in sorptivity resulted in a decrease in cracks and pores within the GPC, attributed to the incorporation of RHA. Subsequently, the pores created by the CR were filled with CR, and due to the elastic properties of CR, the cracks were further minimized. A mixture of 15 percent RHA (75 microns) and 80 percent GGBS exhibits a sorptivity of 0.0387, similar to that of the identical mixture with a particle size of 125 microns. This indicates that sorptivity mostly depends on the particle size of RHA, which increases with larger particle sizes, and this increase in sorptivity is contingent upon the substantial particle size of RHA. This results in an increased number of pores relative to smaller particle-sized RHA.

Rapid Chloride Permeability Test (RCPT) RCPT test results after 28 and 56 days for 75 micron and 125 micron RHA particle sizes are illustrated in the image below. The measurements for chloride penetration were conducted solely during the initial 30 minutes. The framework for the RCPT examination. It was observed that only the chloride permeability increased after 28 and 56 days during a 30-minute interval following the incorporation of RHA into GGBS-based GPC. Geopolymer concrete without crumb rubber demonstrates increased permeability relative to crumb rubber geopolymer concrete. RHA with a particle size of 125 microns exhibited increased chloride permeability relative to RHA with a particle size of 75 microns. RHA-dependent GPC exhibited reduced permeability to chloride as the curing duration extended from 28 days to 56 days. It was shown that GPC exhibited enhanced permeability with the incorporation of RHA compared to control concrete, regardless of the presence of crumb rubber. An RHA level of 25% demonstrates greater chloride permeability than a RHA content of 15%. The chloride permeability of GPC is contingent upon the percentage of RHA material. The increase in chloride permeability is attributed to the elevated concentration of RHA. Increasing the quantity and dimensions of replacement RHA pores in concrete enhances the current transmitted through the material; however, the incorporation of crumb rubber results in a decrease in current due to the pores being occupied by the crumb rubber.

Conclusions

The subsequent conclusions have been derived from contemporary research: It has been observed that even with 15 percent and 25 percent GGBS substitution by RHA, the compressive strength of GPC diminishes after 28 days and 56 days, particularly when compared to GPC containing 100 percent GGBS. The minimal proportion of crumb rubber in various GPC combinations improves the compressive strength of GPC at all curing ages. The split tensile strength of GPC typically diminishes as the fraction of RHA increases; however, the incorporation of crumb rubber significantly enhances the resistance across all GPC mixes. The strength of the RHA-containing GPC is now observed to vary on the size of the

RHA particles. RHA with a particle size of 75 microns exhibits a compressive strength of 35.2 MPa after 28 days, whereas RHA with a particle size of 125 microns shows a compressive strength of 29.8 MPa after the same duration. The compressive strength of GPC diminishes as the particle size of RHA increases, and vice versa. Testing results demonstrate a reduction in sorptivity of approximately 23.72% at 28 days and 50.42% at 56 days, both with the incorporation of crumb rubber in the mix proportion. Alongside RHA, sorptivity increased by 16.44% and 24.80% for the 15% and 25% replacement levels, respectively, when compared to the control mix after 28 days of curing. The reduction in RHA particle sorptivity often occurs due to an enhancement in the pore diameter of the concrete. The sorptivity of GPC increases with the addition of RHA and decreases with the incorporation of crumb rubber. GPC samples with crumb rubber exhibit a significant resistance to chloride permeability compared to the control mixture and those with 15% and 25% RHA content. GPC with a particle size of 75 microns exhibits superior resistance to chloride penetration compared to GPC with a particle size of 125 microns. The incorporation of RHA above 15% is not advantageous in the GPC. The GPC samples with 25% of the RHAA replacement failed to achieve adequate intensity or demonstrate robustness. GPC demonstrates a favorable performance in strength, sorptivity, and chloride permeability, roughly 15%, indicating its potential as a substitute for OPC-based concrete.

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