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Geopolymer Concrete with Cenosphere as Fine Aggregate: A Material Characterisation

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Abstract

Geopolymer concrete (GPC) is regarded as the successor to traditional concrete as it eliminates the requirement for conventional Portland cement during its manufacturing process, hence decreasing CO2 emissions. This study employed Cenosphere, which are lightweight fine materials, to partially substitute the volume of sand in GPC. Cenosphere was utilized in proportions of 20%, 40%, 60%, and 100%. This experiment examined the fresh and hardened characteristics, durability against freezing and thawing, and ability to withstand impact strength of cenosphere admixed the concrete. The findings demonstrated that the utilization of Cenosphere as a substitute for sand in GPC resulted in marginal enhancement in compressive strength across all time periods and replacement ratios. When comparing the control GPC mix to the use of 60% Cenosphere, there was an increase in compressive strength of up to 4.7% at 28 days. The GPC containing 60% cenosphere exhibited the highest split tensile strength. The slump of GPC is reduced as the proportion of Cenosphere increases. This study found that the application of freezing-thawing cycles (up to 30 cycles) did not have a noticeable impact on the compressive strength of GC. The addition of Cenosphere to GPC resulted in a reduction of up to 25% in impact resistance compared to the control GPC. The study demonstrates that Cenosphere can be incorporated into GPC as a partial replacement for fine aggregate, in order to create a new type of GPC suitable for structural purposes.

Keywords: Geopolymer concrete; cenosphere; freeze and thaw cycle; impact resistance; light weight concrete

INTRODUCTION

Concerns over the use of cement concrete have grown in recent decades. The production of Portland cement results in significant carbon dioxide emissions and a rapid utilization of fossil fuels and limestone, which are both natural resources [1–3]. It is anticipated that Portland cement production will increase to 4.4 billion tons by 2050 [1]. At present, this sector contributes to 5–7% of the world's carbon dioxide emissions [4]. The rapid growth of high-rise concrete structures and their accompanying infrastructure has led to a continuous rise in the demand for concrete. This trend has raised concerns regarding the long-term sustainability of Portland cement concrete. Geopolymer concrete (GPC) serves as an ecologically conscious substitute for conventional concrete. GPC does not utilize cement, but instead relies on silica-alumina rich minerals, which are by-products of the industry. This greatly diminishes the need for cement and the corresponding carbon emissions.

Lightweight concrete is a cost-effective form of concrete that offers advantages to structures by providing a higher strength to weight ratio, reducing foundation costs, and enhancing fire resistance. The production of lightweight GPC has the potential to decrease the structural mass and,

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consequently, the quantity of concrete used, leading to a more sustainable construction process. Currently, there has been a lack of extensive study conducted to examine the efficiency of lightweight GPC. Coppola et al [5]. added an air-entraining additive to geopolymer cement, together with lightweight glass. The test findings indicated that the produced mortar achieved a compressive strength of 8 MPa after 28 days. Aslani et al [1]. incorporated fine rubber at 10% and 20% concentration, as well as expanded polystyrene at concentrations of 25%, 50%, 75%, and 100% to substitute the volume of GPC fine aggregate. The compressive strength of the GPC declined as the polystyrene component increased. Specifically, the strength decreased by 81% when the polystyrene level reached 100%. The strength exhibited a reduction of 37% when rubber was used at a content level of 20%. A decrease in strength by 60% was seen when 20% rubber and 25% polystyrene were combined. Lightweight expanded clay aggregate (LECA) was used in place of 25–100% of the total GC mineral aggregate by Bhogayata et al [6]. They found that replacing mineral aggregates with LECA up to 50% did not have a noticeable impact on compressive strength, tensile strength, or impact resistance. Nanomaterials have demonstrated the ability to improve the performance of gas chromatography [7]. Raza et al [8]. incorporated different quantities of nano titanium dioxide into geopolymer pastes reinforced with micro carbon fibers. The study demonstrated a 23% enhancement in compressive strength and a 40% improvement in flexural strength. In their study, In their study, Alvee et al [9]. examined the impact of incorporating nanosilica and crystalline admixture (CAs) on the mechanical properties of geopolymer pastes. Their findings indicated that the inclusion of nano-silica and CAs at a concentration of 5% resulted in a 33.63% enhancement in compressive strength, as well as a significant rise of 232.69% in both flexural strength and fracture toughness. Alomayri [10]. conducted an experiment to evaluate the mechanical characteristics of geopolymer composites reinforced with micro steel fibers and varying quantities of nano-silica. Their findings demonstrated that the incorporation of 2% nanosilica substantially improved the mechanical characteristics of the composite material.

Research on the utilization of GPC in reinforced slabs for structural applications is currently scarce. Meng et al [11]. conducted experiments on GPC slabs subjected to blast stresses. Steel rebars were used to reinforce all of the slabs, and some of them were further reinforced with steel fibers. The findings indicated that all slabs exhibited an elastic structural reaction, with discernible fractures observed on slabs without steel fibers. Nevertheless, slabs that were further strengthened with steel fibers exhibited significantly fewer apparent fissures and demonstrated excellent structural integrity, with a maximum central deflection of 1 mm. In a further investigation, Meng et al [12]. subjected GPC slabs reinforced with steel wire mesh to blast stresses. The findings demonstrated that the inclusion of wire mesh reinforcement in GPC significantly improved the slab's resistance to blast stresses. Furthermore, GPC slabs exhibited a lower occurrence of cracks compared to the standard concrete slabs they were compared against.

Researchers used cenosphere as fine aggregate in high strength concrete and achieved the compressive strength of upto 70 MPa and density as low as 1500 kg/m^3[13]. Kowsalya et al [14]. replaced M sand with fly ash cenosphere in concrete. From the study, it was reported that the cenosphere reduced the compressive strength, however the replacement upto 35% achieved the target strength upto 31.2 N/mm2 for M25 concrete. Kavinkumar et al [15]. replaced sand with cenosphere upto 30% in lightweight pumice aggregate concrete and obtained the structural concrete. Zhang et al. [16]. found that adding surface-treated cenosphere benefits the mechanical properties of waste mineral admixed concrete with an increase of 7.1%, 3.5% and 6.8% in compressive, split-tensile and flexural strengths, respectively, at 10% dosage.

According to the literature mentioned above, there is a scarcity of knowledge and data about the utilisation of cenoshpere as fine aggregate in GPC. In order to fill this research need and create a more environmentally friendly concrete, six different GPC mixes were created, tested, compared, and assessed, each with a different amount of cenosphere substitution. The research seeks to further examine the efficiency of cenosphere as lightweight fine aggregate in GPC and provide recommendations for GPC mixtures suitable for structural purposes.

MATERIALS AND METHODS

Materials

The binder materials utilized in all mixtures consisted of ground granulated blast furnace slag (GGBFS) and fly ash, with their respective chemical compositions provided in Table 1. The fly ash and GGBFS had specific gravities of 2.83 and 2.57, respectively. The aggregates used in all mixes comprised of 10 mm dolomite stone and river sand, with a maximum aggregate size of 4.75 mm. Cenosphere was utilized as a partial substitute for sand. The cenosphere presented an average specific weight of 0.68 g/cm3, and specific gravity of 2.1. This investigation utilized a high range water reducer, also known as a superplasticizer (SP), and a retarder. The specific gravities of these substances were 1.085 and 1.057, respectively. The GC mixes were activated using a solution containing a blend of sodium silicate (SS) and sodium hydroxide (SH). The alkaline solution had a specific gravity of 1.28.

Table 1. Chemical composition of GGBFS and Fly ash

Parameter	Ca O	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	SO_3 (%)	MgO (%)	Na_2O (%)	K_2O (%)	SrO (%)	TiO_2 (%)	P_2O_5 (%)	Mn_2O_3 (%)	LOI (%)
GGBFS	42.9	33.0	13.3	0.4	2.0	5.4	0.4	0.3	0.8	0.6	<0.1	0.1	0.8
Fly ash	6.1	50.9	17.9	9.8	1.0	7.2	3.8	1.9	0.1	0.8	0.2	<0.1	0.2

Mix Proportion

The GPC mixes were formulated with dolomite content of 611 kg/m^3, activator content of 207 kg/m^3, water content of 177 kg/m^3, fly ash content of 206 kg/m^3, GGBFS content of 206 kg/m^3, superplasticizer content of 9.4 kg/m^3, and retarder content of 2.1 kg/m^3. The fine aggregate in the control mix was 611 kg/m^3 and was partially replaced with cenosphere mixtures in proportion to their volume. The ratio between the fine and coarse aggregates was 1:1.

The variable considered in this study is the cenosphere and the ratio at which sand was replaced such as 20%, 40%, 60%, and 100%. The composition of concrete mixes utilized in this investigation is presented in Table 2. The code "GPC" represents the control geopolymer concrete mixture. The nomenclature for all other mixtures commences with the sand substitution ratio, succeeded by the lightweight substance; C for cenosphere.

Table 2. Mix proportion

Mix	Fly ash	GGBFS	Activator	Water	Dolomite	Sand	Cenosphere	SP	Retarder
GPC	260	260	207	177	611	611	0	9.4	2.07
GPC20C	260	260	207	177	611	489	79	9.4	2.07
GPC40C	260	260	207	177	611	367	159	9.4	2.07
GPC60C	260	260	207	177	611	245	238	9.4	2.07
GPC100C	260	260	207	177	611	0	397	9.4	2.07

Specimen Preparation and Test Procedures

Workability, density, compressive strength at3,7, and 28 days, splitting tensile strength, impact resistance, freezing-thawing effects, and other mechanical and durability parameters were all evaluated in this study. For each mixture, two cylindrical samples measuring 100 x 200 mm were prepared per day of measurement. These samples were used to measure the unit weight as well as the compressive strength at 3, 7, and 28 days. Two additional cylinders with dimensions of 100 x 200 mm were manufactured for the purpose of measuring the indirect tensile strength after 28 days. The prepared concrete sample were compacted using a conventional hammer and rod. The concrete was allowed to remain in the moulds for a duration of 24 hours before the process of removing it from the moulds, labelling, and curing was carried out. The freezing-thawing resistance was assessed by testing the concrete cubes. A disc impact test was performed on specimens with a diameter of 150 mm and a thickness of 50 mm.

RESULTS AND DISCUSSION

This study produced, tested, compared, and assessed five different GPC mixes. In order to determine how well the concrete will hold up over time, its mechanical qualities were examined. This evaluation included an examination of its workability, compressive strength, splitting tensile strength, resistance to freeze and thaw cycles, and impact resistance.

Workability

The workability of the concrete was assessed using the conventional slump test and the flow diameter test as per the IS 1199 (1999). The results of workability are displayed in Figure 1. Compared with the control GPC concrete, the cenosphere replaced GPC slump started to decrease by 9%, 23%, 34%, 42% and 50% at 20%, 40% and 60%, 80% and 100% cenosphere content, respectively. Kowsalya et. al. [14] reported that the cenosphere inclusion in concrete reduced the slump. The fineness cenosphere particles found less than that of river sand. This results in a smaller particle size and a larger surface area of cenosphere compared to sand. As a result, a greater amount of water is needed in the concrete mixture to cover the increased surface area, leading to an increase in slump.

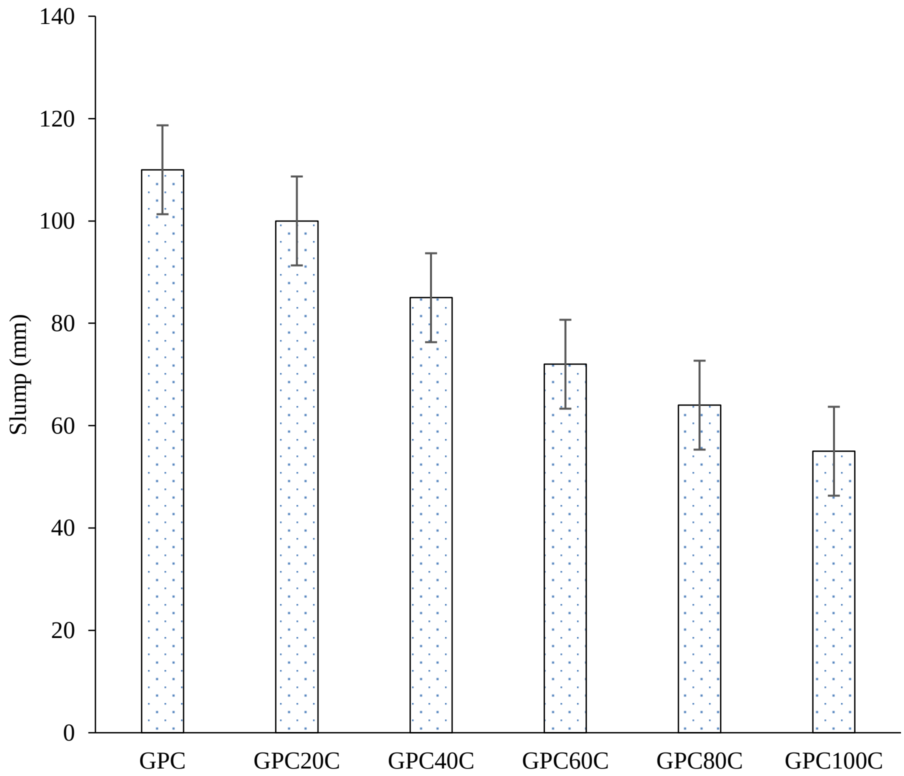

Figure 1. Workability of cenosphere replaced GPC.

Density

Figure 2 displays the recorded mean density for all geopolymer concrete blends.As predicted, the inclusion of a higher proportion of cenosphere in the geopolymer concrete mixture resulted in a reduction in the density of the mixture. Replacing 20, 40, 60 80 and 100% cenoshphere to sand decreased the concrete unit weight by 2.1%, 4.5%, 6.9%, 9.2%. 11.1% respectively. Kowsalya et al [14]. also inferred the similar trend when incorporating cenosphere in reducing the concrete density. The decline in density becomes significant as the fraction of cenosphere increases. Because of its low density and hollow structure, cenoshphere fine aggregate causes concrete's density to fall.

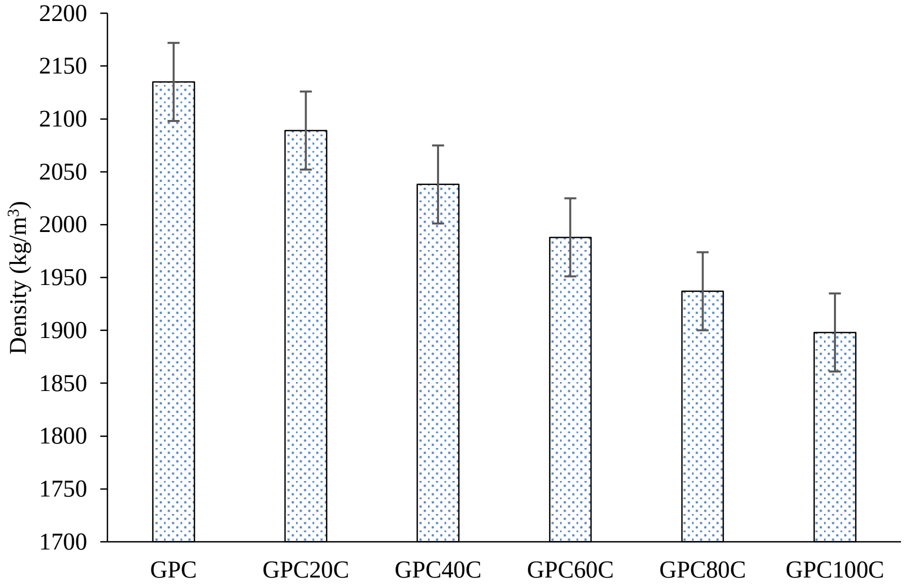

Figure 2. Density of cenosphere replaced GPC.

Compressive Strength

The compressive strength values of the concretes that were substituted with cenosphere at 28 days are shown in Figure 3. Up to 60% cenosphere, the compressive strength of the concretes remained unaffected. In lightweight high strength concrete, researchers[13] discovered a comparable pattern. After 28 days, the compressive strength of the GPC exhibited a slight improvement when the cenosphere was replaced up to 60%. The GPC mix with 60% cenosphere replacement showed 4.7% increase in compressive strength when compared to control concrete. This better performance indicates that the cenosphere has interesting mechanical behavior under high loads, even in spite of its hollowness, indicating that it has potential for the creation of lightweight GPC.

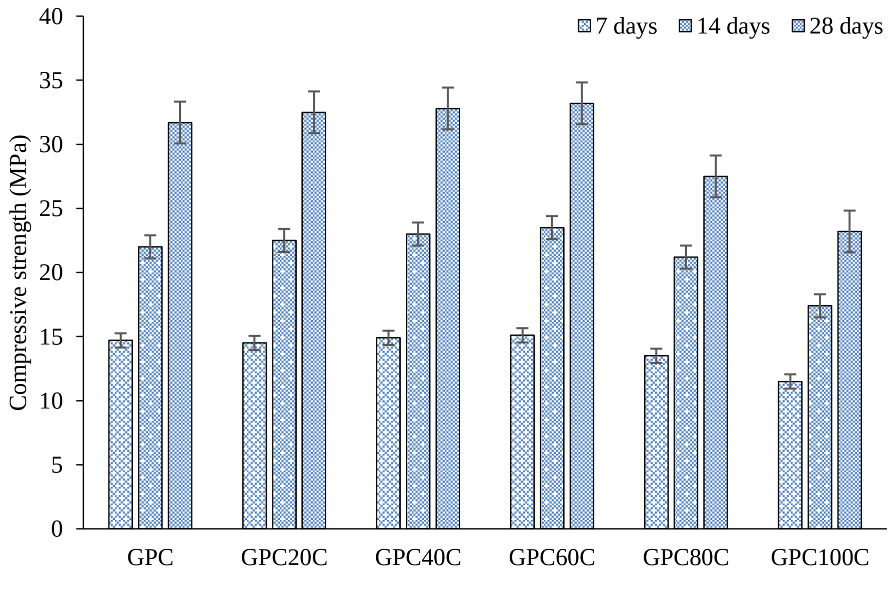

Figure 3. Compressive strength of cenosphere replaced GPC.

Splitting Tensile Strength

Figure 4 shows the calculated and plotted 28-day indirect tensile strength. It is clear that the GPC's splitting tensile strength was unaffected by the cenosphere up to 60%. Researchers[13]. found a similar trend in light weight high strength concrete. The GPC's splitting tensile strength was slightly higher after cenosphere replacement up to 60%. The GPC mix with 60% cenosphere replacement showed 7% increase in split tensile strength at the age of 28 days when compared to control concrete. A decrease in splitting tensile strength was observed in mixture having 80% and 100% cenosphere replaced specimen. The slight increase and subsequent decline in the tensile strength of Cenosphere GPC can be attributed to the same factors that affect its compressive strength, as these two properties are strongly correlated.

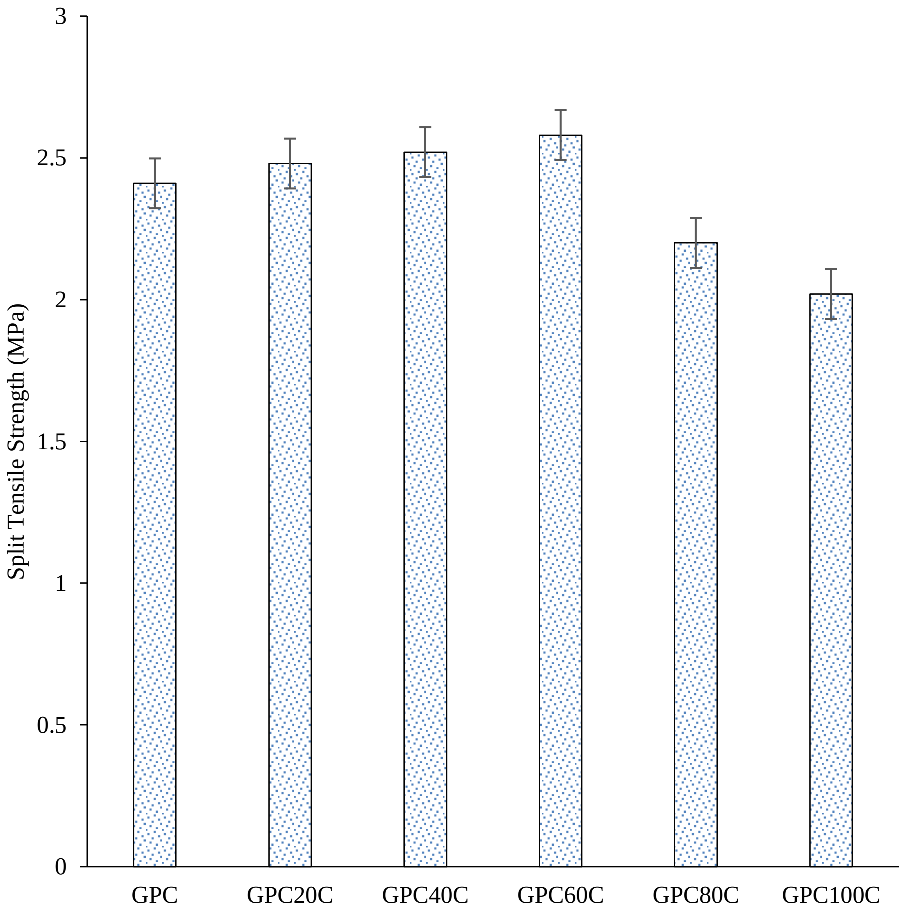

Figure 4. Splitting tensile strength of cenosphere replaced GPC.

Freezing and Thawing Effect

Cycle of freezing and thawing Concrete testing is an essential examination conducted on concrete to assess its durability and ability to withstand damage resulting from repeated cycles of freezing and thawing. Concrete cube of size 100 mm^3 was tested. The experiment was performed using GPC and GPC60C mixtures. The compressive strength of the cubes subjected to freezing-thawing cycles, specifically 10, 20, and 30 cycles, was compared to the compressive strength of the control cubes. Figure 5 shows the compressive strength of cenosphere replaced GPC before and after the freezing and thawing cycles test. Based on the results, it is evident that the compressive strength did not show any notable impact even after subjecting it to the 30 cycles of freezing and thawing. To conduct a more thorough analysis of the effect, it is advisable to test geopolymer concrete using lightweight cenosphere fine aggregate across a more number of cycles.

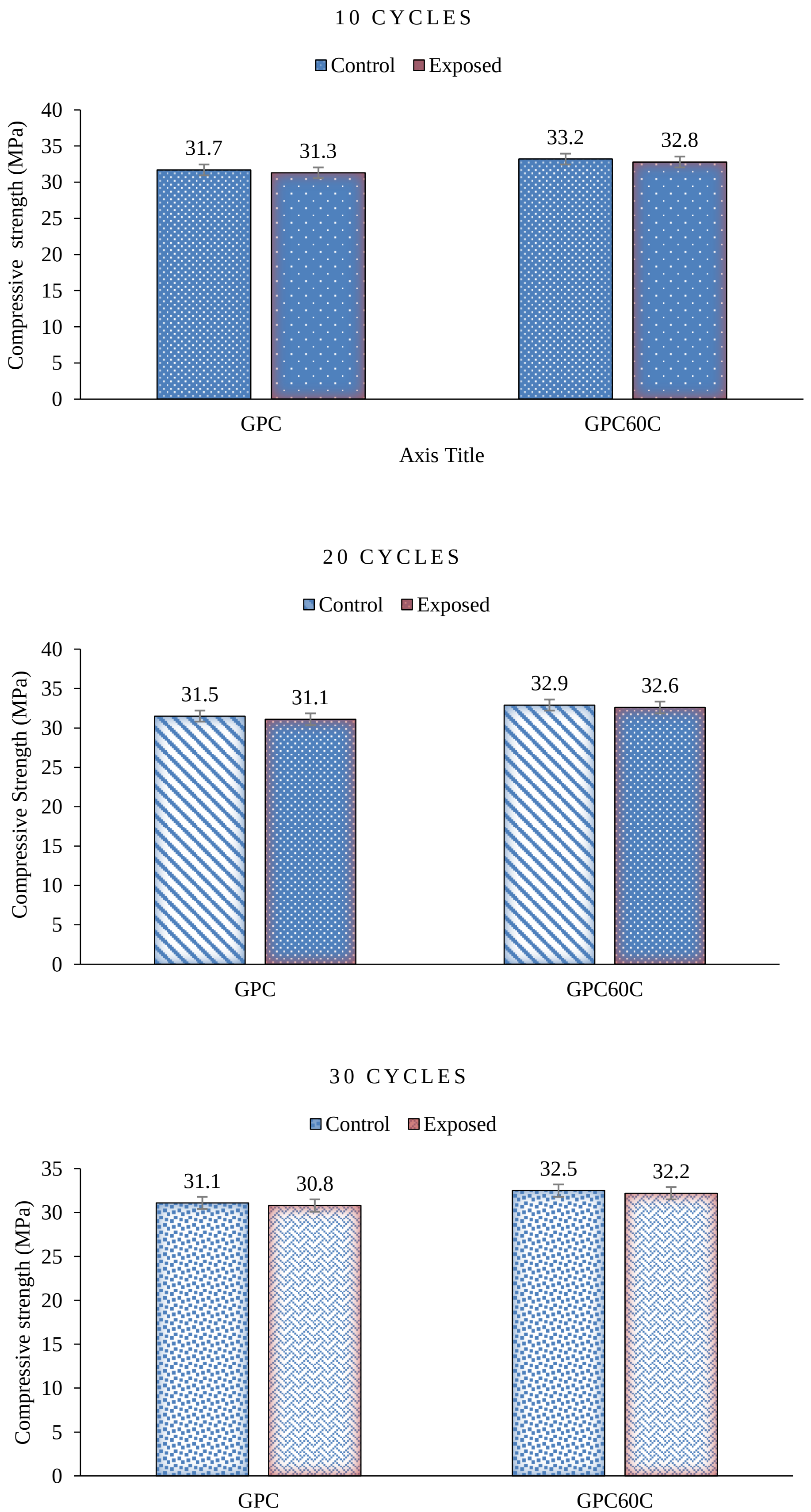

Figure 5. Strength of cenosphere replaced GPC before and after the freezing and thawing cycles.

Impact Resistance

The impact resistance of geopolymer concrete was assessed by conducting a drop weight impact test on 10 discs from each mix, namely GPC and GPC60C. Figure 6 showed the results of the tested specimen. The use of cenosphere, a lightweight material, in geopolymer concrete mixes resulted in a decrease in impact resistance when 60% of the sand volume was replaced. The impact resistance of the sample exhibited a reduction of around 25% compared to the impact resistance of the GPC mixture. However, the compressive strengths of the sample were even greater than those of the control GPC mixture. The lightweight and porous nature of cenesphere could not able to absorb much impact energy and hence the impact resistance is found less.

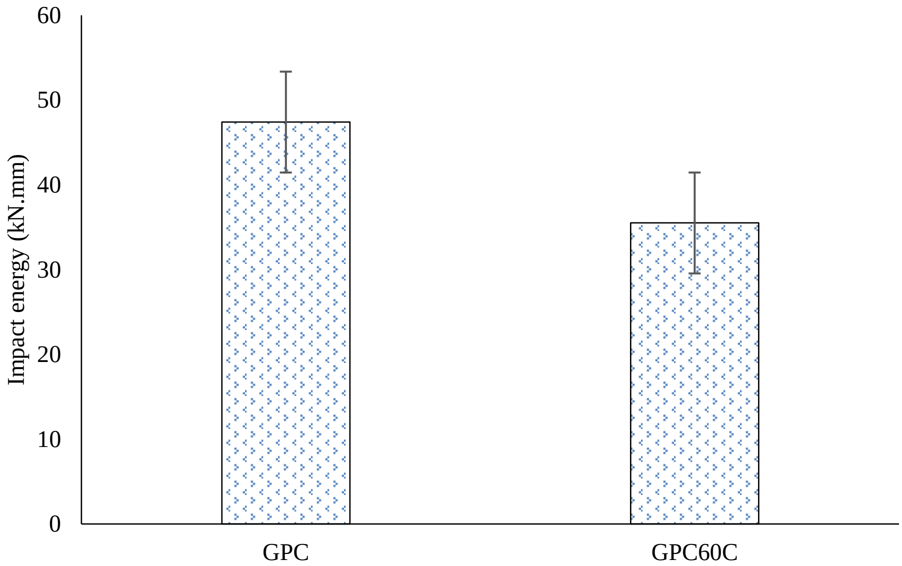

Figure 6. Impact resistance of cenosphere replaced GPC Concrete

CONCLUSIONS AND RECOMMENDATIONS

This research studied the mechanical performance of geopolymer concrete (GPC) including cenosphere lightweight aggregate. A total of five GPC mixes were produced, subjected to testing, compared, and assessed. The variable examined in this study are the lightweight cenosphere fine aggregate and the GPC sand replacement ratios, which are 20%, 40%, 60%, and 100% by volume. The concrete properties that were assessed include workability, density, compressive strength, splitting tensile strength, resistance to freeze and thaw cycles, and impact resistance. The primary findings of this investigation can be summarized as follows:

1. Replacing cenosphere fine aggregate in GPC showed a decrease in slump value. A reduction of 50% slump was found for the 100 % replacement of cenosphere fine aggregate.
2. Cenosphere fine aggregate replacement showed decreased density of GPC. A maximum density reduction of about 11% was observed in specimen having 100% cenosphere.
3. The compressive strength of cenoshphere incorporated mix showed a marginal increase in compressive strength. The mix containing 60% cenosphere showed 4.7% increase in compressive strength.
4. In this work, the use of freezing-thawing cycles up to 30 cycles did not have a noticeable impact on the compressive strength of GPC.
5. The impact resistance of the GPC mixes dropped by approximately 25% by substituting 60% of the sand volume with cenosphere.

When the substitution of fine aggregate with cenosphere reaches up to 60%, the GPC demonstrated superior mechanical performance. These findings demonstrate the practicality of utilizing cenosphere lightweight aggregate in GPC and its suitability for structural applications. It is recommended for future research to evaluate the proposed GPC mixes for their durability by conducting tests on drying shrinkage, water absorption, surface characteristics, abrasion resistance, carbonation, and performing microstructural analyses.

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