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AN INVESTIGATION OF COMPRESSIVE STRENGTH OF GPC BEAM USING NCA, RCA AND RCA COMBINED WITH SILICA FUME

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ABSTRACT

One of the greatest substitutes for typical Portland cement concrete is Geo Polymer Concrete (GPC), which contains no cement. Cement manufacture results in significant emissions of the greenhouse gas carbon dioxide, yet the pollution and warming of the planet are still consequences. Cement made from portland requires a large amount of energy, making it a pricey product. It also minimizes pollutants and is environmentally beneficial. The old concrete and debris from destroyed buildings pollutes the environment, necessitating the construction of new space to accommodate the disposed of waste. This study examines the strength of fly ash-based GPC employing recycled aggregate. Using natural coarse aggregate, recycled coarse aggregate, and Recycled Coarse Aggregate (RCA) containing silica fume, we examine the strength of fly ash-based GPC. Using natural coarse aggregate, RCA, and RCA with silica fume. With recycled aggregate, there might be a noticeable drop in compressive strength in GPC. By using 10% silica fume, the compressive strength of GPC with recycled aggregate was improved.

KEYWORDS: Geo Polymer Concrete, Cement, Recycled Coarse Aggregate, silica fume and mechanical properties, compressive strength etc.

INTRODUCTION

Davidovits coined the term geopolymer in 1978. Geopolymers are mineral binders that have a polymeric silicon-oxygenaluminum structure. In terms of global warming mitigation, GPC decreases CO_2 emissions from cement plants by around 80%. In geopolymer technology, the source material, which is rich in silicon (Si) and aluminum (Al), is made to react with a highly alkaline solution throughout the geopolymerization process to produce the binding material.A very rapid chemical reaction under very alkaline circumstances results in a dimensional polymer chain with a Si-O-AlO bond pattern and a ring structure. Geopolymers may be synthesized from waste from industries such as fly ash, coal ash, red mud, rice husk ash, and silica fume. Using GPC with fly ash as a base has the extra benefit of being adaptable to a wide range of construction projects.

Geopolymers have an amorphous morphology and are chemically comparable to zeolites. Geo-polymerization converts alumino-silicate minerals into a variety of construction materials. As a result, the new composition gains remarkable chemical and physical qualities such as acid and fire resistance. Geo-polymerization occurs in three distinct stages. Figure 1 shows that polymerization is made up of 15 natural Al-Si minerals.

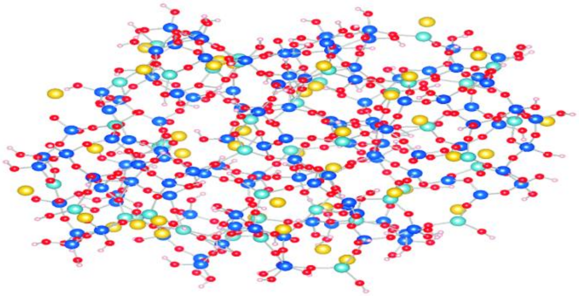
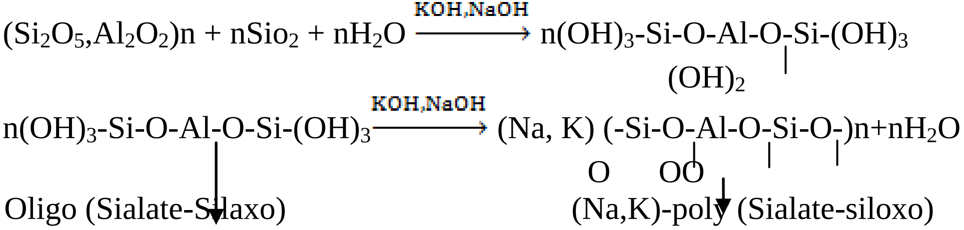


FIGURE 1: GEO-POLYMER CONCRETE STRUCTURE

All of these minerals are soluble in alkaline solution, with NaOH dissolving more than KOH or silicates. Following geopolymerization, minerals that dissolve exhibit increased compressive strength. Mashkin, et al. (2017)

During the first stirring, the silicon and aluminum ions in fly ash, silica fume, and other raw materials dissolve in the alkaline media. The silicon-aluminum hydroxide condensing process creates an oxygen bond here, which connects the water molecules. The oxygen bonding is formed as a result of condensation bonds in the surrounding Si and Al tetrahedra. Figure 2 shows a clear picture of the response.



$$(Si_2O_5,Al_2O_2)n + nSio_2 + nH_2O \xrightarrow{KOH,NaOH} n(OH)_3\text{-Si-O-Al-}\underset{(OH)_2}{\text{O-}}\text{Si-}(OH)_3$$

$$n(OH)_3\text{-Si-O-Al-O-Si-}(OH)_3 \xrightarrow{KOH,NaOH} (Na, K)\ (\text{-}\underset{O}{Si}\text{-O-}\underset{O}{Al}\text{-O-}\underset{O}{Si}\text{-O-})n+nH_2O$$

Oligo (Sialate-Silaxo) (Na,K)-poly (Sialate-siloxo)

FIGURE 2: POLYMERIZATION REACTION

This polymerization process occurs at ambient temperatures and results in strong geopolymers. Geopolymers harden quickly at ambient temperatures, reaching compressive strength of up to 20MPa in a single day. It was reported by the Davidovits and Davidovics.

REVIEW OF LITERATURE

Ganesan et al. (2015) presented the results of an experimental study analyzing the durability qualities of plain and fiber reinforced GPC, as well as a comparison to "Portland cement-based conventional concrete". "Water absorption, scratch and chemical resistance, the impact of consecutive wetting and drying, and endurance against chloride ions" are among the durability characteristics studied.

Rajalakshmi et al. (2016) stated that geopolymerizing GPC for structural applications is becoming increasingly vital for environmental sustainability. This eliminates the need to manufacture OPC and use building rubble as an element in fresh concrete. The development of GPC as a cement-free binder for OPC was a significant achievement in concrete technology throughout the twentieth century, and it was predicted that geopolymer may provide a solution to manufacturing greener concretes for long-term advancement.

Salem et al. (2016) shown that GPC improvement has been a major emphasis in order to expand its use. This study studied the influence of extra water contents, plasticizer contents, NaOH molarity, alkaline solution to fly ash ratio, and NaOH to Na2SiO3 ratio on fly ash reliant GPC. The metrics of fly ash-reliant GPC studied included "workability, compression strength, splitting tension strength, modulus of flexibility digestion, and porosity".

Mashkin et al. (2017) investigated the use of geopolymer technology in recent years. This technology is developed by activating natural or manufactured aluminium silicate source materials in an alkaline environment. Because fire is not used in the process, this approach allows for the creation of construction materials with a minimum of energy. The scientists determined that "fly-ash," which is the primary waste of the coal-based power industry, has enough SiO2 to be used as geopolymerization agents in most scenarios. As a result, employing fly ash as a major component in geopolymer materials reduces the need for extra comminution energy. This means that GPC can be more energy efficient than Portland cement, for example.

Coppola et al. (2017) investigated a novel "phosphonate-based superplasticizer (PNH)" for "ready-mixed concrete". After mixing, concrete samples showed a consistent initial workability of 220 mm slump. The revolutionary the superplasticizer was tested for workability preservation after 0, 30, and 60 minutes.

Awang et al. (2018) examined the benefits of Geopolymer concrete, including the utilization of by-product waste to replace cement and the reduction of greenhouse gas emissions during manufacture. Geopolymer concrete has sparked significant attention among academics and builders. It also offers superior mechanical properties and resilience when compared to standard concretes. According to the findings, geopolymer concrete may replace conventional concrete since it has higher mechanical properties, greater endurance, and desirable structural capabilities when compared to traditional alternatives.

Cao et al. (2018) evaluated the bonding behavior of RAC with steel bars. Researchers discovered that RAC specimens were impacted by many factors in their failure processes. Rather, it revealed the necessity for a thorough examination into the effects of various conditions on the failure mechanisms of RAC samples. The RAC specimen's load-slip curve was affected by the steel bar diameter, the concrete cover to diameter ratio, and the RCA replacement rate. The authors' use of steel bar pictures helps engineers understand the value of RAC's bond strength equations for prediction and bond-slip relationship models.

Hassan et al. (2019) investigated the microstructure of GPC and OPC and examined GPC attributes such as strength and durability. A thorough review of the literature demonstrates that the production of GPC requires significant care and attention, as well as the use of appropriate materials. The high alkalinity of the geopolymer activation step necessitates increased energy use and greenhouse gas emissions. Curing time and temperature have further effects on GPC production. As a result, a user-friendly GPC design method is urgently needed for usage across a wide range of building zones.

Using concrete samples with varied porosity and compressive strengths, Hanbing Wang et al. (2019) evaluated the effects of varying cement-aggregate ratios (C/A, by mass) to determine the ideal C/A for enhancing the compressive strength of the material. Second, the best C/A ratio fly ash was selected to supplement the Portland cement in the mix. A series of environmental experiments, including "suspended solids, ammonia-nitrogen, total phosphorus, and alkali precipitation tests," were then carried out to investigate the concrete specimens' purifying properties. According to the findings of this study, C/A has a significant influence on the properties of earlier concrete. For better strength pervious concrete, a 20% fly ash component and a C/A ratio of 0.20-0.24 were recommended.

Elmrabet (2019) conducted a laboratory experiment at Morocco's cement business Lafarge Holcim- Oujda to investigate the effect of fly ash addition on Ordinary Portland Cement (OPC). In this study, a part of the cement was replaced with various amounts of fly ash. The findings of these testing demonstrated that fly ash cements had the following technical benefits over Portland cements: reduced water demand, less heat of hydration, and less probability of early age cracking, and high late strength increase. Fly ash cements have lower early strength.

Bajpai et al. (2020) investigated the life cycle evaluation by comparing the environmental impacts of GPC mixes to those of typical cement concretes. Alkaline activators and cement were identified as the principal drivers of negative environmental consequences for geopolymer and cement concrete, respectively, in the life cycle analysis. In terms of global warming, geopolymer concretes are more ecologically benign than traditional cement-based concrete. Fly ash-silica fume GPC activated without sodium silicate has little effect on the natural surroundings.

Singh et al. (2020) discuss the physics and chemistry of polymerization, as well as its use in the creation of GPC. This paper describes both the principles for building a GPC and the factors that influence the geopolymerization process in concrete. This study concluded that curing temperature, alkaline liquid ratio, chemical proportion of "silicate and sodium in sodium silicate, Alkaline Liquids / Si-Al source materials size, sodium silicate/hydroxyl ions ratio, existence of calcium, existence of excessive water, and Si/Al proportion in origin sections" all have a significant impact on the advancement and performance of GPC.

A recent research by Sahu (2020) examined fly ash concrete tiles as a replacement for fine aggregates. Design for M 40 grade concrete has been completed. The "fine aggregate" was fed with "fly ash" during a 10-day period, with the amount varied from (0-40)%. Wet transverse tensile strength, water absorption, and wear resistance have all been determined for concrete tiles. The experimental results show that substituting fly ash for the "fine aggregate" significantly increases the strength and durability of the control concrete. This ensures that fly ash-based concrete tiles may be utilized. Fly ash substitutes sand in the manufacturing process, reducing the depletion of natural resources on Earth.

Yang et al. (2020) used fly ash as a fine aggregate to investigate the effects of stress damage and higher temperatures on the practical use of concrete. A rapid "carbonation test" was done to determine the depths of carbonation at different "carbonation times" and to assess the "carbonation resistance" of concretes. Increasing the early stress damage and carbonation time enhances carbonation levels in cement. Furthermore, using fly ash as a fine aggregate in concrete may improve its resistance to carbonation. High temperatures degrade concrete neutralization, and as the temperature rises, concrete strength decreases.

Zakka et al. (2021) investigated the use of commercial and agricultural wastes, such as fly ash and natural pozzolanas, in the building sector. A study found that geopolymer concrete can be created with a high aluminosilicate component. As a result of its superior strength, temperature resistance, dense microstructures, and increased bond strength, GPC has emerged as a viable alternative for OPC concretes. This study resulted in the first comprehensive scientometric evaluation of geopolymer concrete.

Ganesh et al. (2021) investigated the synthesis of high impact strength fiber reinforced geopolymer-based concrete by optimizing a variety of factors that influence its strength and reduce its brittleness. This work introduces a new approach for augmentation of high modulus glass fibers over the intended GPC. This study also conducted thorough experiments to maximize the morality of alkaline solution, use of "Ground Granulated Blast Furnace Slag," and glass fibers in GPC under various curing circumstances. In addition, scanning electron microscopy and the technique of energy dispersive spectroscopy were used to investigate the architecture of the geopolymer matrix.

According to Shobeiri et al. (2021), GPC is much more environmentally friendly than OPC-based concretes. The goal of their analysis was to determine the CO2 equivalent emissions (CO2-eq) associated with the fabrication of a variety of previously manufactured mix designs. Their estimates accounted for not just changes in energy grid and activator solution production, but also the effects of curing, allocation, and transportation. While investigating the effect of transportation, the authors conducted a case study based on the five major Australian capital cities and the critical transport distances at which geopolymer manufacturing became more intensive in emissions than that found in conventional concretes. The relative CO_2 emissions of geopolymer and OPC concretes of the same strength are highly dependent on the system boundaries, allocation scenario, and material transportation durations and modes examined in their findings. Depending on these characteristics, geopolymer concretes may emit less or more CO_2eq than OPC concretes of the same strength. The findings of this study are expected to help identify the best concrete kinds for minimizing CO_2-eq emissions while considering the concrete's intended use.

Shatarat et al. (2021) stated that the impact of fire on Reinforced Concrete (RC) structures is crucial since it endangers human life and property safety. The use of RCA in concrete mixtures is both economical and environmentally beneficial because it conserves natural resources. As a consequence, RCA may be used in high-temperature concrete mixes since the reduction in mechanical properties is negligible in contrast to efforts to limit the harmful effects of RA on the surroundings and human health.

Karimipour et al. (2021) propose a novel formula to estimate the "tensile, compressive, and flexural strengths" of RCA concrete. The authors used as many as 1348 publicly available experimental data for this purpose. They used the "Imperialist Competitive Algorithm (ICA)" to develop equations based on water, cement, RCA, NCA, and natural fine aggregate (NFA).

According to Bhattacharyya et al. (2021), coarse aggregates account for a considerable portion of concrete, and much attention has been dedicated to the mechanical and thermal properties of various types of coarse aggregates at elevated temperatures. Their effort aimed to give a fast critical assessment of the thermal and mechanical properties of various types of concretes and their constituents at severe the temperatures, as well as to suggest key topics for future research.

Elchalakani et al. (2021) tested "Ambient-cured GPC beams" reinforced with BFRP bars for static and impact loads. The damage modes, as well as the static and dynamic responses of these beams, were recorded and studied. The beams broke in a flexural failure mode under static stress and a combined flexure-shear failure mode under impact load, according to the test results. To investigate the residual strength of beams that had been exposed to impact loading, static loading was used.

Sendrayaperumal et al. (2022) present experimental study on the strength of GPC beams reinforced with "Basalt Fibre Reinforced Recycled Polymer (BFRP)/ Glass Fibre Reinforced Polymer (GFRP)" rebars, as well as the effect of adding extra adhesively attached BFRP and GFRP stirrups. M30 grade geopolymer and standard concrete beams with dimensions of 100x160x1700 mm were used to assess the flexural properties of BFRP/GFRP and steel bars. This study used a four-point static bending test to investigate the failure causes, deflection effectiveness, curvature tension capacity, cracking patterns, and dissemination in GPC composed of BFRP/GFRP bars with stirrups. When compared to the findings of normal steel-reinforced concrete beams, the "Basalt and Glass embedded polymer beams" showed preterm and rapid shear failure.

Subramanian et al. (2022) conducted experimental tests on reinforced GPC utilizing synthetic light weight aggregate. GPC mixes with sintering FA aggregate were created. There was a wide range of strength qualities from 23 to 30 MPa. Flexible behavior under two point loads up to failure was studied on four sets of reinforced GPC beams with varied fly ash aggregate and reinforcement mix percentages of 1.33 and 2.17 percent of the balanced section. The deflection, cracking load, failure load, and crack pattern at failure load were all measured and examined in detail. Strain compatibility protocols and IS: 456-2000 standards were utilized to determine the ultimate moment carrying capability of the tested beams.

METHODOLOGY

This section describes a method of experimentation for investigating the mechanical parameters, such as compression strength, split tensile and flexural toughness, durability, and flexibility, of fly ash-based Geopolymer beams made of concrete with recycled aggregate using silica fume. The goal strength of geopolymer cement was set to G30.

COLLECTION OF MATERIALS

In the first stage, all of the materials needed for the investigation were collected, and the component and its qualities were characterized.The suggested study used low calcium (ASTM Class F) fly ash as the base material for the geopolymer concrete. Fly ash from the Tuticorin Thermal Power Plant was collected. Fly ash is typically composed of spherical, glassy particles, however it may contain irregular or angular particles. The particle size ranges between 10 and 100 microns. The particular gravity of fly ash ranges between 2.0 and 2.6. The bulk density of fly ash without strict compaction ranged from 540 to 860 kg/m3, but with compact stage, the range was 1120 to 1500 kg/m3. Flyash has an overall area of 300-500m2/kg. Fly ash has a specific gravity of 2.3.

The main component of concrete is coarse sand, which gives volume and strength to the mixture. The coarse aggregate comes from the rock's center. The physical characteristics of rocks, such as specific gravity, the degree of hardness and texture, differ based on their nature. Aggregates can be described as smooth, rounded, or angular (crushed stone). In the present study, coarse natural aggregate with rough granite broken stone of 20 mm size was used. The recovered coarse aggregate came from the deconstruction of old concrete. While the crushed stone was 20mm in size, the other reused aggregate specifications were derived using IS 383-1970.

Silica fume is created as a byproduct during the manufacturing of silicon metal or the ferrosilicon alloys. One of the most beneficial uses for silica fume is in cement. It is a highly reactive pozzolan because of its chemical and physical properties. Concrete with silica fume can be extremely robust and long-lasting. Electric furnaces emit silica fumes at extremely high temperatures. The fundamental resources are quartz, coal, and woodchips. The smoke created by the furnace is collected as silica fume.Silica fume is used to improve the properties of concrete, namely compressive strength, bond strength, and resistance to abrasion. Local river sand was used as fine aggregate. Fine aggregate aids to the formation of bulk density in concrete while retaining maximum strength. The sand's specific gravity was 2.6, indicating that it belonged to grading zone III after passing through an IS 4.75mm sieve in accordance with IS: 2386-1968 part III. Sand has a density of 1860 kg/m3.

COMPRESSIVE STRENGTH

We evaluate compressive strength by combining cleaned, washed, and dried course gravel with a fly ash-based GPC mix of natural aggregate, recycled aggregate, and RA with silica fume in varied ratios for 8, 10, and 12 molarities. Fine aggregate and fly ash (class F) were blended by weight in a pan mixer under dry circumstances for approximately three minutes.Typically, cubical molds of 150mm X 150mm X 150mm are used for cube testing. The concrete mix contains fly ash, recycled aggregate, and reused gravel with silica fume. It is placed in the mould and carefully tempered to ensure that there are no voids. Following the removal of the molds, the specimens are cured in a heat curing room for 24 hours. The specimens that have just been analyzed are next analysed using compression testing technology. The load should be gradually increased at a rate of 1.37 N/mm2 per minute until the specimens are damaged or destroyed. The compressive strength is calculated by divided the load at failure by the specimen's area.

EXPERIMENTAL INVESTIGATION AND DISCUSSION

The CS is typically obtained by the procedure of hydration and the development of C-S-H solids in the cement paste, whereas FA-based GPC achieves the CS through the polymerization reaction and the generation of amorphous particles as a result of polymerization. In general, concretes are more stronger in compression than in tension. Concrete constructions are constructed with these features in mind to withstand compressive forces that may arise within them.

MIXING, CASTING OF GPC

The fly ash-based GPC mix with "natural overall, recycled aggregate, and used aggregate with silica fume" in various ratios for 8M, 10M, and 12 molarities was created by adding cleaned, washed, and dried course material. Fine gravel and fly ash (class F) were combined on a weight basis and blended in a dry pan mixer for about 3 minutes.

According to the mix design and molarity computations, the alkaline liquid, super plasticizer, and additional water were added to the dry elements, and the stirring process continued for another 4 minutes. The 150mm cubes were cleaned and lubricated, then three equal layers of new GPC of varied molarities and mixes were cast in them. Each layer was tamped with a tamping rod before being placed on the vibrating table for three minutes to ensure good compaction. Concrete cubes were tagged with the mix ID and date for identification tests. Figure 3 depicts the cast geopolymer stone cubes.

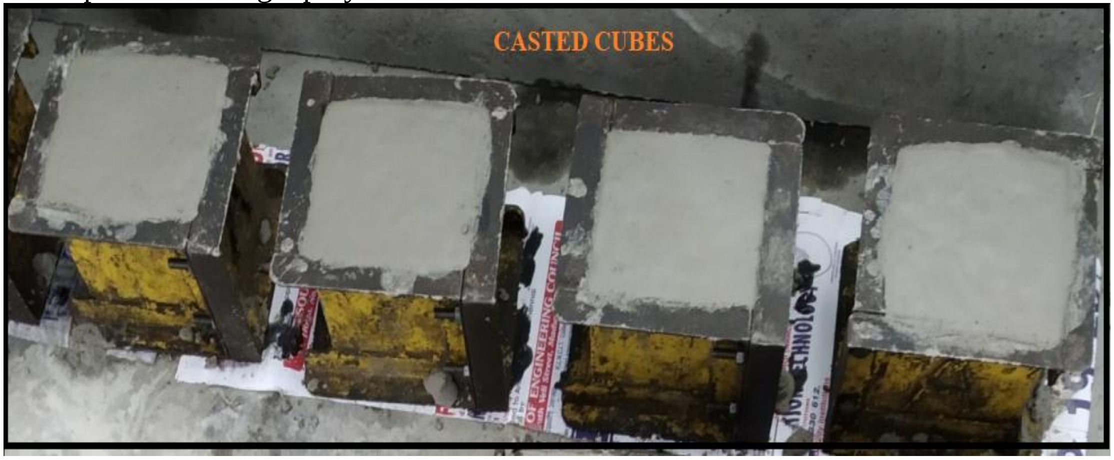


FIGURE 3: CASTED GEOPOLYMER CONCRETE CUBES

After casting, fly ash-based GPC cubes of 8M, 10M, and 12M with "natural the aggregate, which recycled material, and recycled stones with silica fume" in varied proportions of dimension 150mm x150mm x150mm were cured in a heat curing room at 650°C for 24 hours. After curing, the cubes were removed from the heat curing room, demoulded, and stored in the research facility for 7 and 28 days of testing. Figure 4 depicts the technique for curing cubes of concrete in a heat curing chamber.

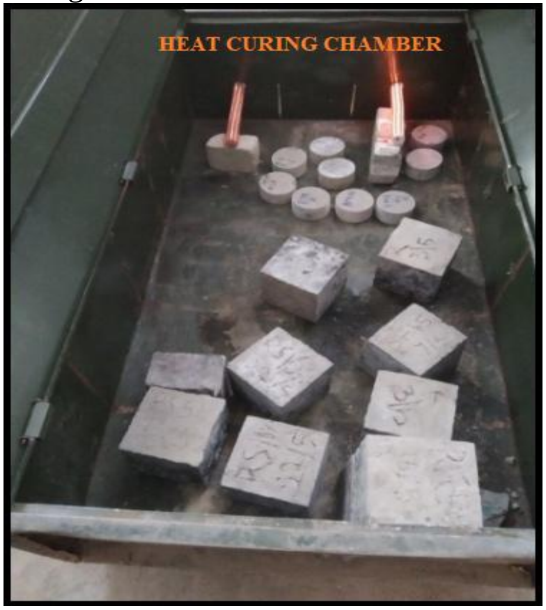


FIGURE 4: CONCRETE CUBES PLACED IN HEAT CURING CHAMBER

FIGURE 5: EXPERIMENTAL SETUP FOR CS TEST

Prior to beginning the experiment, each cube was cleaned and weighed independently.The cube or specimen was put in the center of the plate in a "compression testing machine" with a capacity of 2000kN. Load was applied progressively to the cube until its direction was reversed. The reversed load direction implies sample failure. The load at which the sample failed was documented and designated as the ultimate load. The CS of concrete was then calculated by dividing the ultimate load by the cube's a cross-section region. The tests were carried out according to IS 516:1959. A total of 90 cubes were evaluated for all three molarities (8M, 10M, and 12M) during 7 and 28 days. The test results were tallied and shown as a graph. Figure 5 depicts the experimental setup for a compression test.

DISCUSSION

The strength of NAC was 31.53 N/mm2, but the force of RAC was lowered by 14.65%. Adding 5% silica fume to RAC enhanced strength by 8.67%. In the second testing, adding 10% silica fume enhanced the potency by 21%. In the third testing, adding 15% silica fume raised the concentration by 0.8%.

In 10 Molarity, natural aggregate had a compressive force of 43.46 N/mm2. The addition of 5% silica fume to the RAC mix lowered its strength by 14.55%. The strength under compression rose by 8.17 percent. In the second testing, 10% silica fume was added to the RAC mix, which enhanced compressive strength by 17%. In the third testing, adding 15% silica fume boosted the strength by 14%.

In 12 molarity, "natural aggregate" had a compressive strength of 46.76 N/mm2. The compressive force of RAC reduced by 19.17%. When 5% silica fume was added to RAC, it enhanced compressive strength by 9.15%. In the second testing, 10% silica fume was added to

RAC, which enhanced its compressive strength by 22%. In the third testing, 15% silica fume was added, and the strength rose by 17%.

According to the findings of this study, as molarities or concentrations grow, so does compressive strength. In this study, the combination ID RAC + 10% silica fume (recycled aggregate with 10% silica fume) produced a high compressive strength. This is owing to stronger aggregate-paste bonds and a microstructure that is denser.

Zakka, et al. (2017) And silica fume is incredibly fine, 100 times finer than cement, and because of its fineness and the impact of the filler, it has a high compressive strength. More over 10% silica fume becomes sticky, yet the concrete has the potential to be extremely strong and brittle. As a result, 10% silica fume is the optimal proportion. Table 1 shows the strength under compression for 8M, 10M, and 12M. Figure 6 illustrates a graphical depiction of the compressive strength for 8M, 10M, and 12M.

TABLE 1 COMPRESSIVE STRENGTH IN N/mm^2 FOR 8M, 10M &12,M

MIX ID	8M	10M	12M
Natural Aggregate Concrete (control specimen)	31.53	43.46	46.76
Recycled Aggregate Concrete(RAC)	26.91	37.15	37.77
RAC+5 % Silica Fume	29.46	40.46	41.58
RAC+10 % Silica Fume	34.06	44.75	48.41
RAC+15 % Silica Fume	27.15	43.23	45.96

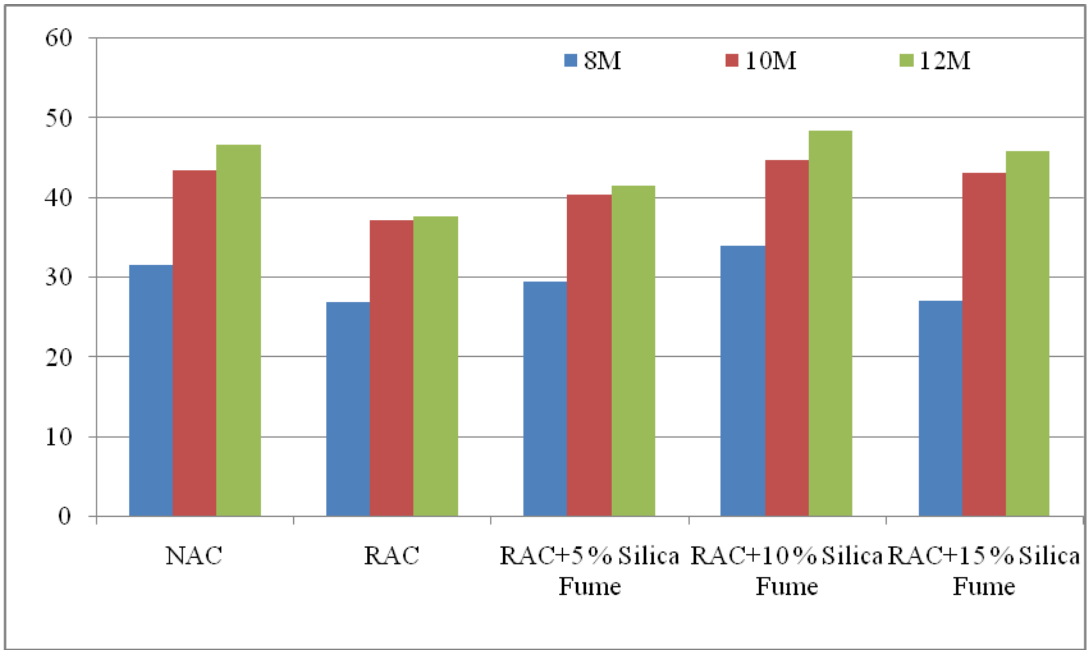


FIGURE 6 COMPRESSIVE STRENGTH OF 8M, 10M, &12M OF GPC

CONCLUSIONS

The study examines the strength of fly ash-based GPC employing recycled aggregate. Using natural coarse aggregate, recycled coarse aggregate, and Recycled Coarse Aggregate (RCA) containing silica fume, we examine the strength of fly ash-based GPC,using natural coarse aggregate, RCA, and RCA with silica fume. The results of the study is shows that the molarity increases, also the compressive strength increases.The mechanical properties namely compressive strength GPC with recycled aggregate got increased by adding 10% of silica fume (RAC+10%SF). The percentage increase in compressive strength was 21%, 17% and 22%for 8M, 10M and 12M respectively.

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