RESEARCH ARTICLE OPEN ACCESS

Characterization of Geo Polymer Concrete with Ground Granulated Blast furnaces and Cenosphere as Binder and Glass Powder as Fine Aggregate

Josphine Chelsea L*, Mariraj Mohan S**

*(PG Scholar –Department of Civil Engineering, Government College of Engineering, and Tirunelveli
Email: josphinelawrence99@gmail.com)

** (Associate Professor and Head –Department of Civil Engineering, Government College of Engineering, and Tirunelveli
Email: mari_sundar@yahoo.com)

--************************----------------------------------

Abstract:

Cement serves as a binding and solidifying agent in buildings. The combustion of fossil fuels (5%–8%) during cement manufacture releases significant quantities of CO2, and the high demand for concrete has greatly increased the use of ordinary Portland cement (OPC). Geopolymer, an innovative advancement in the field of concrete, completely replaces cement with pozzolanic elements like fly ash. Extremely alkaline solutions then activate these materials, serving as a binding agent in the concrete mixture. In this era, it is imperative to use supplemental cementitious materials (SCMs) that produce less carbon dioxide as a substitute for cement in order to minimize environmental impact and advance sustainable construction. The study's goal is to find out if waste glass powder (WGP) and cenosphere (CS) can be used instead of fly ash and fine aggregate at a range of 0% to 20%, with a weight increase level of 5% for each. The study will also use a constant 12% GGBS. A number of tests assess the rheological, mechanical, and durability characteristics of CS-WGP-based geopolymer concrete, including workability/fluidity, water absorption, compressive strength, acid attack, flexural strength, and thermal conductivity. Researchers have also proven that the application of CS enhances the mechanical, rheological, and durability qualities. The study determined that substituting 10% of CS and GGBS yielded significant improvements in all specified parameters. We conducted a scanning electron microscopy (SEM) examination on the cenosphere. The results show that adding cenosphere does not strengthen the mix. Hence, incorporating 10% of GGBS as a continual replacement for the mass of fly ash effectively restores the strength diminished by adding the cenosphere. Overall, it was suggested that the decrease in strength caused by adding cenosphere can be mitigated using GGBS, resulting in a reliable level of strength.

Keywords — **Geopolymer, Waste Glass powder, Cenosphere, Ground Granulated Blast Furnace, Mechanical Properties, Thermal Conductivity.**

--************************----------------------------------

I. INTRODUCTION

One potential way to mitigate the environmental consequences of Portland cement binders is to develop low-carbon binders [1]. Aluminosilicate materials don't react quickly with water, but when they're in an alkaline environment, they go through hydrolysis and condensation processes that turn them into inorganic polymers that can handle different loads [2]. Estimates indicate that the production of more than 3.5 billion tons of cement annually produces around 900 kg of CO2 per ton of cement [3].To meet demand, the cement industry faces declining natural resources, rising energy costs, CO2 emission reduction criteria, and a shortage of raw material supply. Geopolymer concrete reduces CO2 emissions, uses natural resources efficiently, uses waste materials, and is cost-effective for long-term infrastructure construction [4, 5]. Expanded perlite (EP) concrete has 30% volume, 1900 kg/m3 density, 70 MPa compressive strength, and 3.3% water absorption [6]. There are two types of geopolymer concrete: bottom ash-based and class F-based. Bottom-ash concrete polymerization is not as flyash-based as gopolymer concrete, but their mechanical properties are similar. We prepared geopolymer concrete by incorporating GGBS as a binder material and combining it with regular particles. The mechanical properties will increase proportionally as the alkaline solution's molarity increases [11]. Raising the molarity of the NaOH solution from 8 M to 14 M resulted in a 33%, 26%, and 42.5% increase in the GPC's compressive strength, splitting tensile strength, and flexural strength, respectively [12]. The specimens lose weight as the temperature rises, with the content of GGBFS in the mix gradually increasing up to 850 °C. However, in oven-cured samples, the weight loss was slightly greater than in ambient-cured samples [13–15]. Glass production has significant environmental impacts due to energy consumption when melting raw materials, as well as gaseous pollution from fuel combustion and chemical reactions [16, 17]. The acoustic properties of lightweight concrete containing cenospheres are comparable to those of lightweight concrete prepared with expanded clay [18]. When utilizing Glass as aggregates, Glass particles of a bigger size exhibit bigger and more active micro cracks, leading to their increased alkali-silica reactivity [19]. The incorporation of waste glass powder into regular cement mortar has the possibility to drastically alter the thermophysical properties of the mortar [20].

II. MATERIAL USED

A. Flyash

Fly ash is a crucial component in the composition of geo-polymer mortar. Although it is abundant, its usage is restricted. To optimize the use of this waste product, it is integrated into building activity as an environmentally beneficial component in geopolymer mortar. There are two distinct categories of fly ash. Fly ash is classified into two types: Class F and Class C. Geopolymer mortar can be produced using only Class F fly ash. However, a substantial quantity of thermal energy is necessary to initiate the polymerization process. Therefore, if only Class F fly ash is employed in the production process of restressed concrete structures. If Class F is utilized alone, it releases a significant quantity of heat energy and undergoes drying before polymerization begins. When ambient curing is being generated, a combination of Class F and Class C fly ash is employed in certain proportions to ensure that it undergoes ambient curing.

TABLE I

Properties of fly ash

SI.NO	Properties	Values
1	Specific gravity of flyash class F	2.33
2	Specific gravity of flyash class c	3

B. Alkaline activator solution

Mixture of Sodium silicate and Sodium hydroxide is used as an alkaline activators sodium hydroxide pellets were dissolved in water to from NaOH solution .The concentration of Sodium hydroxide solution is 12M.Alkaline solutions is prepared 24 hours prior to use. NaOH solution is preferred over KOH because it causes high extent of mineral dissolution.

(a)

(B)

(C)

Figure I (a) NaOH fillets
(b) NaOH Solution, (c) Na_2SiO_3

C. Ground granulated blast furnace slag

GGBS, or Ground Granulated Blast Furnace Slag, is a by-product of the iron industry. It is formed when iron ore, coke, and limestone are heated to a temperature of 1500 C in a furnace, resulting in the production of molten iron. Geopolymer concrete benefits from the inclusion of GGBS, as it accelerates the setting time and enhances the overall strength of the concrete. This makes it particularly suitable for use in ambient temperature conditions. According to research, a GGBS proportion of 40-50% in GPC results in the highest strength. The study utilized GGBS sourced from Astra Chemicals in Chennai.

Parameter	
Grade	Vipra 300
Color	Pale white
Bulk density (gm/cc)	0.35-0.45
Specific gravity(gm/cc)	0.75-0.85g/cc
Moisture	Max 1%
Particle size analysis	05-300 micron
Average particle size	90-120 micron

Describe the physical and chemical properties of GGBS in detail.

Table II

Properties of GGBS

Figure II GGBS

D. *Cenosphere*

The CS samples were acquired from Vipra Cenosphere India, located near Nagpur, India. CS grade 300 has the biggest particles, measuring 300 um in size (Figure 3). The chemical composition of the CS used is displayed in Table 1. The physical and chemical properties of the CS used in this study, including bulk density, moisture content, and pH, may be found in Table and Table 4. The particle size distribution of cenosphere is depicted in Figure 3

Figure III Cenosphere

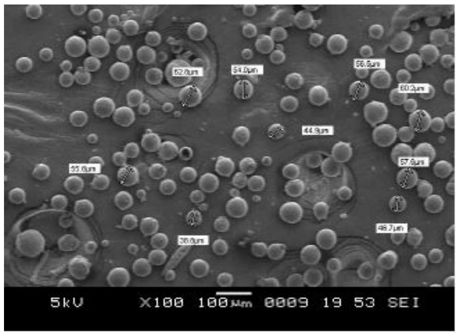


Figure IV Spericity & Diameter

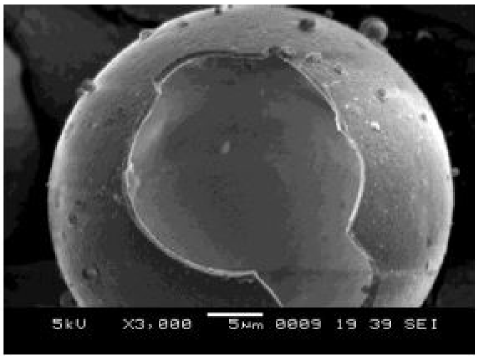


Figure V SEM Analysis of Cenosphere

E. *Water to geopolymer binder ratio*

The ratio of total water (i.e. water present in solution and extra water if required) to material involve in polymerization process (i.e. fly ash and sodium silicate and sodium hydroxide solutions) plays an important role in the activation process.

F. *Fine Aggregate*

Si.no	Chemical composition	CS	WGP
1	SiO2	50-60%	99. 5%
2	Al2O3	25-35%	0. 08%
3	Fe2O3	01-03%	0. 04%
4	CaO	2.08-3.08%	0. 01%
5	MgO	-	0. 01%
6	Loss on Ignition	-	0. 28%

Fine aggregates with most particles passing through a 3/8- inch sieve .Generally the particle above 2.36mm are classified as the fine aggregates. To determine the properties fineness modulus and sieve analysis should be done. Thus the obtained values are given in the Table III and figure 4.

Table III

Properties of Fine aggregates

SI.NO	PROPERTIES	VALUES
1	Type	Waste glass particle
2	Specific gravity of fine aggregates	2.56
4	Fineness modulus of glass particle	2.74
5	Bulk density	1570Kg/m3

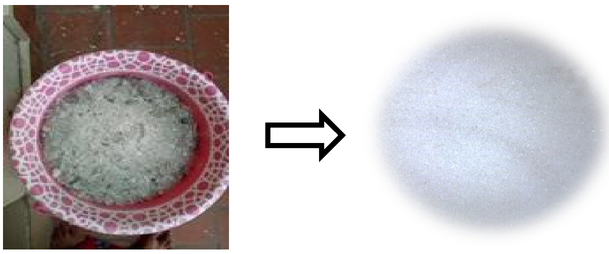


Figure VI Waste Glass Powder

G. COARSE AGGREGATES

Coarse aggregate most of which is retained on 4.75 mm IS sieve. Stones which are hard and durable in nature. For reinforced concrete only crushed rock aggregate of size 20mm are generally considered as satisfactory. For the experimental work 12 mm and 20mm coarse aggregates are used this project. Properties of coarse aggregate are given in the Table

Table IV

Chemical composition of materials

Table V

Properties of Coarse aggregates

SI.NO	Properties	Values
1	Size of aggregates	12mm (25%)
2	Size of aggregates	20mm (75%)
3	Specific gravity of coarse aggregates(12mm)	2.70
4	Specific gravity of coarse aggregates(20mm)	2.71
5	Bulk density of coarse aggregate (12mm)	1713Kg/m3
6	Bulk density of coarse aggregate(20mm)	1767Kg/m3

III. METHODOLOGY

The project commences with the Aim & Objective, followed by a comprehensive Literature Review encompassing Cenospheres, GGBS, and Waste Glass Particles. Following that, the examination of raw materials is carried out, which then leads to the phase of collecting materials. The field of material studies encompasses the investigation of Mechanical Properties, Durability Tests, and Thermal Conductivity. Subsequently, a Mix Design is formulated, which is then followed by the preparation and testing of specimens. The Computation phase include the analysis of SEM data, and the project culminates with the presentation and discussion of the results.

IV. MIX DESIGN

In geopolymer concrete, similar to Portland cement concrete, the combined weight of coarse and fine particles makes up around 75 to 80% of the total mass. The geopolymer concrete mix composition can be designed with readily available Portland cement concrete equipment. A total of 5 high-performance concrete designs were cast in this experiment. The designs consisted of one control mix and four mixes with varying levels of flyash substitution, ranging from 0% to 20% with an interval of 5%, while maintaining a constant 12% GGBS and CS content. The nomenclature of all the mixes is provided in Table VI

Table VI
Mix proportion of Geo-polymer Concrete
Concrete at 12% constant replacement

SI. NO	Alkaline Solution		Extra Water Content	Fly ash	GGBS	CS	FA	CA
	NaOH	Na_2SiO_3						
G0	95.86	239.64	16.5	484	66	0	453.15	898.3
G-5	95.86	239.64	16.5	459.8	66	24.2	453.15	898.3
G-10	95.86	239.64	16.5	435.6	66	48.4	453.15	898.3
G-15	95.86	239.64	16.5	411.4	66	72.6	453.15	898.3
G-20	95.86	239.64	16.5	387.2	66	96.8	453.15	898.3

V. Specimen Preparation

Currently, there is a lack of standardized papers for the design of mixes for Geopolymer concrete mix. The GPC mix for M30 (GPC) concrete grade was successfully achieved using experimental methods in this study. A total of five experimental combinations were produced, each with a binder concentration of 550 kg/m3. The concrete examples were formed by using different proportions of Cenosphere CS (0%, 5%, 10%, 15%, and 20%) and using GGBS at a constant rate of 12% as a partial substitute for fly ash. The ratio of alkaline solution to fly ash binder was maintained at 0.61. Table 4.6 presents the ratios of the different combinations of GPC. The mix proportions were determined in accordance with the specifications outlined in the article. After carefully measuring and combining the raw materials of this mixture, including GGBS, cenosphere, waste glass as fine aggregates, and coarse aggregate, the dry mixture was stirred for two to three minutes. Then, an alkaline solution was added, and the stirring process was continued for a few more minutes. We successfully identified new characteristics, such as density and slump, in various combinations

Figure VI Material of a mix design

Figure VIII casting

VI. Testing Procedure and Details

Various experiments were performed on prepared samples to assess the rheological, mechanical, and durability characteristics of geopolymer concrete mixes with varying degrees of fly ash replacement by (CS and GGBS). The rheological parameters of concrete, including flow ability, were examined to assess its fresh properties. The compressive strength and flexural strength of the mixes were measured to investigate the mechanical properties of geopolymer concrete. The durability properties were evaluated by conducting experiments on sulphuric acid resistance, water absorption, and drying shrinkage. The procedures utilized to carry out all the specified tests are described below.

1. Mechanical Properties of concrete

a) The compressive strength of concrete is an essential component in the quality control of concrete. Typically, 150mm cubes are utilized for testing concrete at 7, 14, and 28 days, in accordance with IS code 456-2000. This code serves as the standard practice for plain and reinforced concrete.

b) Split Strength assesses the concrete's tensile strength. It is employed to assess the capacity of an unreinforced concrete beam to endure failure under bending forces. The calculation is performed using a set of cylinders with a diameter of

15cm and a length of 30cm, in accordance with the specifications outlined in IS code 456-2000 and ASTM C39.

3. The impact of an acid attack was assessed by measuring the decrease in strength and weight of concrete samples by the use of sulfuric acid. The test was performed in accordance with ASTM C1012/C1012M-12 and ASTM C563-07.
4. The thermal conductivity test of concrete is conducted using the ASTM C177 standard test method. This method involves measuring steady-state heat flux and determining the thermal transmission parameters using a guarded hot plate apparatus.

VII. RESULT AND DISCUSSION

The results of this study also demonstrate the potential for using industrial waste materials, such as cenosphere and silica fume, to develop high-performance structures that offer good strength and durability to concrete. The use of these materials can reduce the demand for traditional raw materials, leading to lower production costs and reduced carbon footprint. The lightweight nature of cenosphere concrete can also lead to a reduction in the weight of concrete structures, resulting in easier transportation and reduced construction costs.

1. Mechanical Properties of Geopolymer Concrete

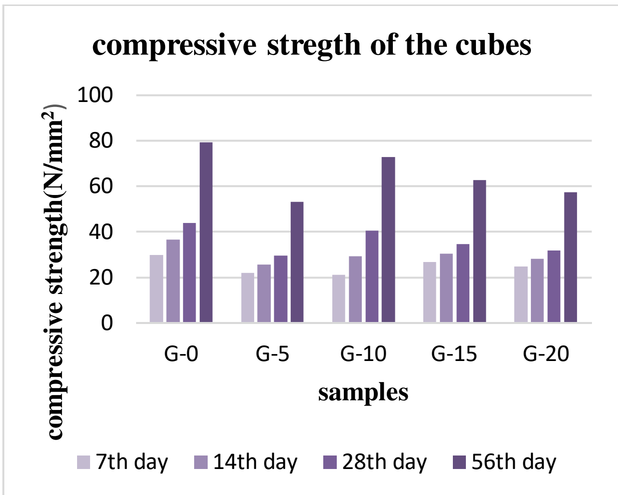
The mechanical parameters of the geopolymer concrete were determined by conducting compression and splitting tests on 150mmX150mmX150mm cubes and φ150mm, 300mm height cylinders using waste glass powder as fine aggregate.

a) Compressive strength

Figure IX testing of compression

Table VII
Compressive strength
of the geopolymer cube

Sample	CS (%)	Area (mm^2)	Compression strength (N/mm^2)			
			7th day	14th day	28th day	56th day
G1	0	3375000	29.8	36.6	43.9	79.02
G2	5	3375000	22.0	25.5	29.5	53.1
G3	10	3375000	20.9	29.2	40.5	72.8
G4	15	3375000	26.5	30.3	34.6	62.64
G5	20	3375000	24.8	28.1	31.8	57.24



Compressive strength –mix rate

The cenosphere has been substituted with flyash as a binder material in varying proportions of 0%, 5%, 10%, 15%, and 20% by weight. The test results are analyzed and presented in table 3 and figure 4. The test results at 7th, 14th, and 28th days demonstrate that the strength of mixtures G-0, G-5, G-10, G-15, and G-20 reduces compared to the nominal mix of G-0. Although the strength diminishes, replacing 10% yields the best strength compared to other alternatives. The results indicate that the presence of cenosphere reduces the compressive strength of concrete.

b) Split tensile strength

The table and chart provided display data regarding the Split tensile strength of the cubes. The standard test method is described in ASTM C496/C496M. The formula to calculate the split tensile strength

$$fst = 2P/\pi LD$$

- f_{st}= split tensile strength (in MPa)
- P = applied load at failure (in N)
- L = length of the cylindrical specimen (m)
- D = diameter of the cylindrical specimen (m)

Table VIII
Split tensile strength
of the geopolymer concrete

Sample	Split tensile strength (N/mm^2)		
	7th day	14th day	28th day
CM	1.8	3	3.5
G-0	3	3.2	3.6
G-5	2.8	3.32	3.71
G-10	3.12	3.61	4.02
G-15	2.52	2.98	3.42
G-20	2.2	2.62	3.02

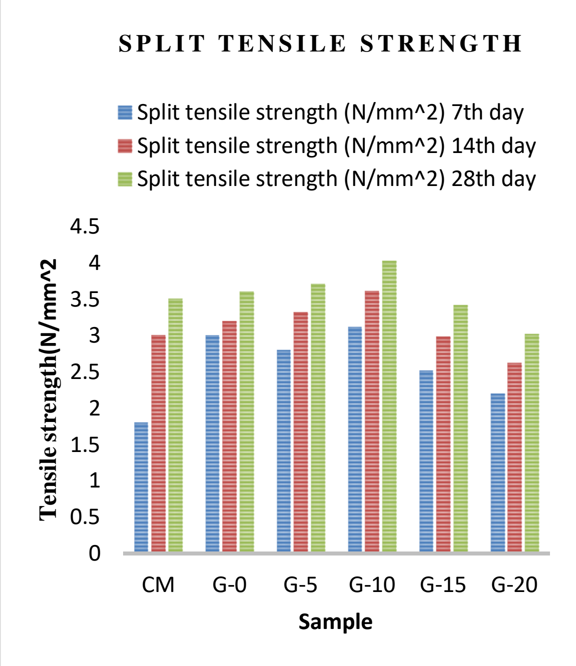


Table 8 shows the Split Tensile Strength data. The test was performed in accordance with IS 516-1959 to determine the concrete's split tensile strength at 7, 14, and 28 days of age. At 28 days, the nominal concrete's split tensile strength is 3.5N/mm2. At 28 days, the maximum split tensile strength of geopolymer concrete is 4.02N/mm2, with 10% of the weight of flyash replaced by the cenosphere. When cenosphere is added at intervals of 5%, the strength of the concrete progressively rises to 10%.The concrete loses strength when the percentage reaches 10%.The maximum split tensile strength of cenopshere substituted with 10% has risen by 12.9% over the nominal mix, as reported in Table 8.

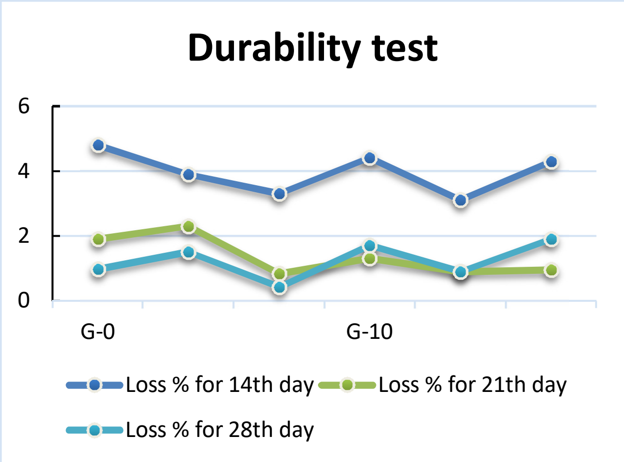
2. Durability of concrete

The resilience of concrete determines its lifespan when subjected to of chemical attacks, such as chloride and sulphuric acid. The results are tabulated below.

Table IX
Durability of geopolymer concrete
Against sulphuric acid attack

Sample	Loss % for 14th day	Loss % for 21th day	Loss % for 28th day
G-0	4.8	1.9	0.98
	3.9	2.3	1.5
	3.3	0.83	0.42

G-10	4.4	1.3	1.7
	3.1	0.89	0.89
	4.3	0.96	1.9



Prolonged exposure of structural concrete to an acidic erosion media results in the detachment of the concrete from the matrix and the exposure of the aggregates. This leads to the loss of concrete mass and consequent structural deterioration. The figure illustrates the rate at which GPC experiences mass loss when it is exposed to a sulfuric acid solution for durations of 14, 21, and 28 days of time. The comparison is done between two types of mixes: nominal mix and a mix with 10% cenosphere replacement. It is found that the mix with 10% cenosphere replacement exhibits the highest compressive strength compared to the other mixes. The figure clearly demonstrates that the mass loss rates of all GPC specimens exhibited a significant and rapid increase after 21 days of immersion time. Within a span of 21 days, the mass of GPC specimens made from fly ash grew by approximately 3%. The mass of cenosphere-based GPC specimens reduced by almost 1.5%, which is more than twice the decrease observed in fly ash-based GPC specimens. Under the specified experimental circumstances, the results demonstrate that the cenosphere-based GPC exhibited much lower acid resistance compared to the fly ash-based GPC.

3. Thermal conductivity test

The thermal conductivity was carried out through guarded plate method and result were tabulated.

Table X
Thermal conductivity

Sample	Thermal Conductivity (w/mk)
CM	1.4
G-0	0.227
G-10	0.109

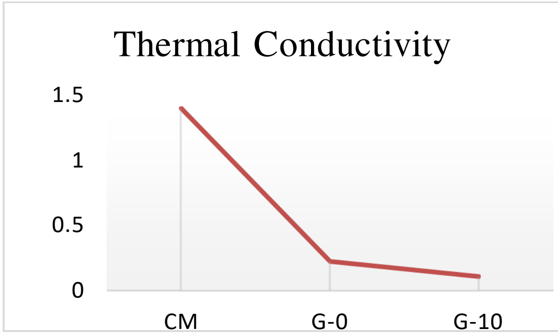


Figure 10 Thermal conductivity chart of geopolymer concrete

The specific thermal conductivity is an essential physical property for accurately estimating the properties of CS composites. The thermal conductivities measured in experiments are 0.109, 0.227, and 0.109 W·m−1·K−1 for CM, G-0, and G-10, respectively. The heat conductivity of concrete is higher than that of geopolymer concrete. The study found that the sample with a 10% substitution of cenosphere in geopolymer concrete exhibited lower conductivity. This can be attributed to the size (200µm) of the cenosphere compared to flyash. .

The data collected on the thermal conductivity of CS enables us to deduce that using these particles as a filler in any matrix can result in a significantly reduced thermal conductivity. The main reason for this is the presence of numerous air-filled spaces within the freely-poured particles, including voids inside the particles and pores in their walls, as well as the air trapped between the particles.

VIII. CONCLUSIONS

This investigation was conducted using concrete that were generated by blending cenosphere and GGBS as a substitute for flyash. An analysis of the material characteristics has been conducted. Cenosphere is a by-product of fly ash that shares similar qualities with fly-ash material. The object possesses a spherical particle is hollow. In general, spherical particles enhance the strength of concrete. This study focused on evaluating the mechanical properties of concrete. The test results lead to the following conclusions.

1. The cenosphere was replaces with flyash. The compressive strength indicates that an increase in the amount of cenosphere results in a decrease in strength when compared to the conventional mix. In order to overcome the strength reduction induced by the cenosphere and enhance the overall strength, it is necessary to consistently replace 12% of GGBS. Despite the decrease in strength, substituting 10% results in the highest strength compared to other mix.
2. Studies suggest that the addition of cenosphere weakens the compressive strength of concrete. The cenosphere and GGBS were substituted with fly ash at a rate of 10% and 12% respectively. Based on a strength analysis, the cenosphere enhances the strength by up to 10% when used as a substitute. Strength decreases beyond a concentration of 10% cenosphere.
3. Typically, concrete has high strength when subjected to compression but is prone to damage when subjected to tension. A gradual reduction in the split tensile strength can be observed as the percentage of cenosphere grows from 0% to 20%.In order to enhance the tensile property, the fiber is incorporated into the mixture to increase the tensile strength.
4. The specific thermal conductivity is crucial for assessing the properties of CS composites. Experimentally measured values for CM, G-0, and G-10 are 0.109, 0.227, and 0.109 $W \cdot m^{-1} \cdot K^{-1}$, respectively.
5. Conventional concrete shows higher thermal conductivity than geopolymer concrete. Notably, incorporating a 10% cenosphere substitution in geopolymer concrete results in lower thermal conductivity, likely due to the larger size (200µm) of cenospheres compared to fly ash.
6. The thermal insulating property of CS is attributed to its ideal spherical shape and chemically stable alumino-silicate composition.
7. The strength of the concrete can improved by using fiber or increasing GGBS content.

Based on the above explanation, it is evident that CS has the potential to be utilized as a partial substitute for fly ash in mortar/concrete up tp 10%. The binder composites' rheological, mechanical, and durability properties were altered. Producing geo-polymer by using glass as fine particles while minimizing mechanical degradation. According to this research, including 10% CS with 12% GGBS in flyash can reduce the heat conductivity of concerete.

ACKNOWLEDGMENT

I want to sincerely thank my supervisor for all of their help, encouragement, and support during this assignment. In order to conduct this research, I would like to express my profound gratitude to the civil department for providing the required resources and facilities.I would like to express my sincere gratitude to my supervisor, [Dr. Mariraji Mohan S, Associate Proferssor and Head of civil Department], for their invaluable guidance, support, and encouragement throughout this project. I am deeply grateful to [Civil Department] for providing the resources and facilities necessary for this research.

REFERENCE

[1]. "Performance evaluation of fly ash and ground granulated blast furnace slag-based geopolymer concrete: A comparative study", Volume23, Issue6 December 2022

[2]. Sourav K. Das, Sandeep Shrivastava," Siliceous fly ash and blast furnace slag based geopolymer concrete under ambient temperature curing condition" Volume22, issues1 January 2021

[3]. Louise Brasileiro Quirino Brito , Pankaj Agrawal, Tomás Jeferson Alves de Mélo, Gustavo de Figueiredo Brito , Crislene Rodrigues da Silva Morais," Recycling of waste glass for the production of hollow blocks using the kiln-casting process" Cleaner Waste systemsvolume 4, April 2023

[4]. Prashant pandey, manisha dhiman, ankur kansal and sarada prasannan subudhi ," Plastic waste management for sustainable environment: techniques and approaches", 06 March 2023 ,Volume 5, pages 205–222

[5]. "The Implementation of a Binary Blend of Waste Glass Powder and Coal Bottom Ash as a Partial Cement Replacement toward More Sustainable Mortar Production" by Stephen Babied olabimtanorcid and Mohammad Ali Mosaberpanah.

[6]. Show moremohd Salahuddin Mohd Basri Faizal Mustapha,Norkhairunnisa Mazlan and Mohd Ridzwan Ishak(2021),"Rice

Husk Ash-Based Geopolymer Binder: compressivestrength,Optimize Composition, FTIR Spectroscopy,Microstructural, and Potential as Fire-Retardant Material",Multidisciplinary Digital Publishing Institute.

[7]. P.ukeshpraven, Dr.J.Guru jawahark, Sai Abhinav C. Sashidhar(2016),"mechanical properties of fly ash and ggbs blended geo polymer concrete using different fine aggregates ",International Research Journal of Engineering and Technology (IRJET)Volume: 03 Issue: 06

[8]. M.srinivasulareddy,P Dinakar andb. Hanumantha Rao,"Mix design development of fly ash and ground granulated blast furnace slag based geopolymer concrete",Journal of Building engineeringvolume 20, November 2018, Pages 712-722.

[9]. Hongguang Wang,ORCID,Hao Wu,Zhiqiang Xing ,Rui Wang andshoushuai Dai(2021),"The Effect of Various Si/Al, Na/Al Molar Ratios and Free Water on micromorphologyandmacro-strengthofmetakaolin-Based Geopolymer",Multidisciplinary Digital Publishing Institute.

[10]. Gautam Kumar and S. S. Mishra (2021),"Effect of GGBFS on Workability and Strength of Alkali-activated Geopolymer Concrete",civil engineering journel Vol7 No6.

[11]. Mohammad Zuaiter,Hilal El-hassanorcid,Tamer El-maaddawyorcid and Bilal El-Ariss(2021),"Properties of Slag-Fly Ash Blended Geopolymer Concrete Reinforced with Hybrid Glass Fibers",Multidisciplinary Digital Publishing Institute.

[12]. Shabarishv.Patil1, Veeresh B. Karikatti and Manojkumar Chitawadagi,"Granulated Blast-Furnace Slag (GGBS) based Geopolymer Concrete - Review ",nt. J. Adv. Sci. Eng. Vol.5 No.1 879-885

[13]. Krishna Prakash Arunachalam,Siva Avudaiappan,Erick I. Saavedra Flores and Pablo Fernando Parra(2023) ,"Experimental Study on the Mechanical Properties and Microstructures of Cenosphere Concrete,"Multidisciplinary Digital Publishing Institute.

[14]. Xipeng Han Li and yuanhu(2023),"Preparation of metakaolin-fly ash cenosphere based geopolymer matrices for passive fire protection",Journal of Materials Research and Technology Volume 23, March–April 2023, Pages 604-610

[15]. Asadhanif,pavithraparthasarathy,hongyanma,tianyuanfanandzongjin Li(2017),"Properties Improvement of Fly Ash Cenosphere Modified Cement Pastes using Nano Silica",civil architectural and engineering faculaty research and creative works.

[16]. Jinyanshi,yuanchunliu,huijiexu,Osman,yimingpeng,qiangyuan,Julong Gao(2022),"The roles of cenosphere in ultra-lightweight foamed geopolymer concrete",Ceramics International.

[17]. Sudeepkpatel,harap.Satpathy,amarn.nayakandchittar.Mohanty(2019),"Utilization of Fly Ash Cenosphere for Production of Sustainable Lightweight Concrete",Journal of The Institution of Engineers Volume 101, pages 179–194, (2020)

[18]. F.Blanco,P.garcõâa,P.Mateos,J.Ayala,"Characteristics and properties of lightweight concrete manufactured with cenospheres",Cement and Concrete Research 30

[19]. Farshadrajabipour,Hamed,maraghechiandgregorfischer(2010),"Investigating the Alkali-Silica Reaction of Recycled Glass Aggregates in Concrete Materials",Journal of Materials in Civil Engineering

[20]. Pawelsikoraa,Elzbietahorszczaruka,Katarzynaskoczylasa,Teresarucinskaa(2017),"Thermal Properties Of Cement Mortars Containing Waste Glass Aggregate And Nanosilica",Procedia Engineering 196.