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Experimental Study on Geopolymer Concrete Using Waste Ceramic Powder: A Review

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Abstract - *Geopolymer is a greener alternative to traditional Portland cement concrete, requiring less energy and emitting less CO2. Because of geopolymer in replacement of Portland cement with industrial waste materials or by-products as binders. Polycondensation using alkali-activating ingredients rich in aluminosilicate is used to make geopolymer concrete. Fly ash, silica fume, metakaolin, and slag were among the components used in the construction of geopolymer concrete. Ceramic waste powder (CWP), which is generated during the final polishing of ceramic tiles and is mostly constituted of silica and alumina, has the potential to be utilized as a geopolymer concrete ingredient in large quantities. Ceramics are mostly composed of silica and alumina, and so have the potential to be used as an aggregate in the production of ceramic geopolymer concrete. Because wastes and/or industrial by-products are used as binders instead of OPC, geopolymer technology uses less energy and has a lower carbon footprint than OPC-based materials.*

Key Words: **Alkali activation solution, CO_2 emission, Conventional Concrete, Ceramic Powder Waste (CPW), Geopolymer concrete, Green Concrete**

1. INTRODUCTION

The most widely used concrete in the world is man-made, making it necessary to use waste material. Even if we use a little bit of other material, we can make a big difference. Carbon dioxide plays a major role in global warming. Carbon dioxide emissions are also very high in the manufacturing of Portland cement. [1]. In our construction sector where cement is the main content, it plays a very big role in the problem of 5 to 8% greenhouse gas emissions every year worldwide.[2]. Several by-products, including fly ash, slag, and silica fume, are efficiently employed as partial cement replacements (i.e., supplemental cementitious materials (SCM)) in the everyday manufacture of concrete to minimize CO_2 emissions[3].

Concrete is currently the most widely utilized material. Concrete is made up of coarse aggregate (CA), fine aggregate (FA), cement, and water in the proportions specified by the water-cement ratio. Because of the continuing exploitation and usage of resources, the amount of waste created by industry has continued to rise. As a result, major issues such as health issues, land contamination, and air pollution have arisen all across the world. Natural resource depletion occurs as a result of these two factors working together. Utilizing the garbage created by industry is one option to improve the situation. Around the world, demolition and construction debris account for 75% of all garbage. Ceramic trash is one of the wastes generated by the building sector. It is believed that roughly 30% of daily ceramic output in the ceramic industry is wasted. According to a recent PWC analysis, India's ceramic tile sector has expanded by almost 20%. Between 2013 and 2014, the market grew by 11% and is predicted to reach Rs. 301 billion by 2016, with a 15 percent compound annual growth rate. India is now ranked third in the world. India produces more than 6% of the world's total output[4].

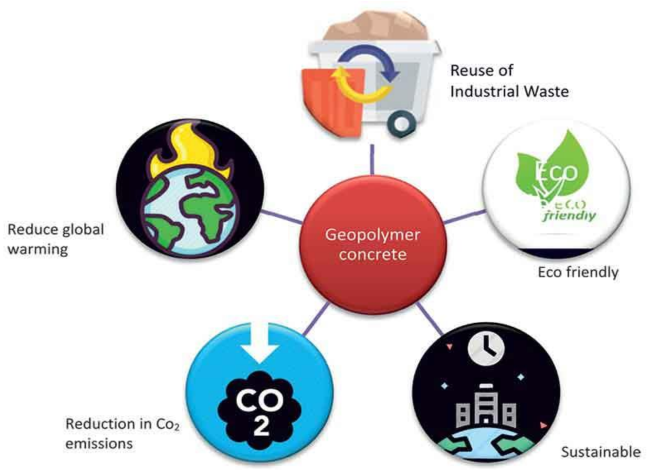

Fig.-1. Geopolymer concrete's advantage in a sustainable building is shown in this diagram.

Inorganic polymeric compounds have a chemical composition comparable to zeolites but an amorphous structure is known as geopolymers. Geopolymers can be compared to artificial rocks. Solid aluminosilicates are combined with a highly concentrated aqueous alkali hydroxide or silicate solution to create them. Davidovits was the first to discuss the chemistry and nomenclature of inorganic polymers in depth. Since Davidovits' initial introduction of the word "geopolymer"[5].

1.1 Objective

The goal of this research is to determine the usefulness and efficacy of waste ceramic powder and alkaline liquids as a geopolymer concrete substitute for standard Portland cement concrete. Before it may be used as a substitute for standard concrete, the qualities of the components must be known. This research focuses on geopolymer concrete, which is made by replacing regular cement with waste ceramic powder.

It would be a watershed moment for the local building industry if geopolymer concrete develops effectively and achieves the same qualities as regular concrete. As a result, the primary goal of this study is to see if pozzolanic materials, such as those used in geopolymer concrete, are feasible. The study's goals are simply outlined here.

- To produce concrete that does not require the use of cement (i.e., Geopolymer concrete).
- The purpose of this research is to see how a percentage substitution of Fly ash with Ceramic Waste Powder affects Geopolymer Concrete.
- To investigate the various strengths of Geo-polymer concrete.
- To analyze the concrete, it was cast in various molds and allowed to cure.

1.2 Need for study

The needs of the following study are listed below:

- To provide the most cost-effective solution for the use of ceramic industry wastes, such as Ceramic Waste Sludge.
- To research recycling and utilizing ceramic waste sludge to help solve an environmental problem while also contributing to the production of sustainable concrete.
- To reduce the cost of construction by lowering the cost of concrete.
- As a result, the research is primarily focused on the effective use of industrial waste as a waste ceramic powder in the production of sustainable or eco-friendly concrete as a partial substitute for Fly ash in geopolymer concrete.

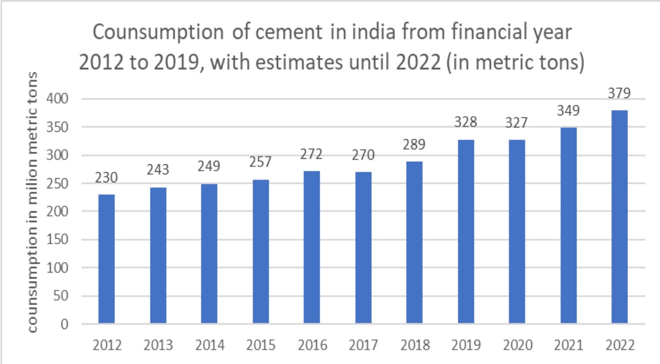

Fig. -2. Consumption of cement in India from the financial year 2012 to 2019, with estimates until 2022 (in metric tons)

2. LITERATURE REVIEW

Multiple experts' analyses and the outcomes of independent study papers are included in the assessment text. The primary findings of the examined Ph.D. thesis, reviews, and books have been published in many national and international publications, and they are discussed and exhibited after this page. This enhances topic knowledge and provides substantial grounding in the proper flow of work.

Fly ash:

K. Vijai et al. (2010) There is little distinction between hot cured and ambient cured concrete. The product of hot cured concrete gives more compressive strength in comparison to ambient cured. Usually, the compressive strength of concrete will increase day by day and maximum strength will achieve during 7 to 28 days. There is no vast difference in the average density of geopolymer made from fly ash and OPC. Geopolymer concrete containing fly ash gives you productive results and effects and in addition to that Geopolymer concrete gives environmental safety[6].

N A Lloyd et al. (2010) Mentioned publication gives brief knowledge about geopolymer concrete made up of fly ash. Geopolymer Concrete has commendable qualities of precast concreting in need of restoration as well as retrofitting. Geopolymer concrete gives economic benefits in addition to environmental benefits. So now the topic of research is the behavior/ of Geopolymer concrete in poor soil conditions and maritime weather[7].

B V Rangan et al. (2010) Fundamental Proportion 75 % of Aggregate of total mass and 0.35 alkaline liquid fly ash is used. Correlative to water cement ratio and increasing temperature curing produce high strength Geopolymer concrete. Ambient geopolymer curing has been tried, and more mixture experiments with ambient curing are being looked into right now. Curing temperature specifications for high and very high strength geopolymer concretes should be correlated to actual specimen temperature; temperature monitoring may be required if strength is critical; and when steam curing, the location of steam vents or hoses, control thermocouples, and specimens is critical the addition of a rest day, which entails 24 hours of ambient curing before steam curing, resulted in compressive strengths that were 20% higher. As with Portland cement concrete, a reduction in added water increased strength while reducing workability and compaction ease. Strength increase is around 80% of the strength obtained after 28 days when cured for 24 hours[8].

A. R. Rafiza et al. (2011) Fly ash-based Geopolymer concrete is a bright future in substitution of OPC in infrastructure projects. It should be noted that due to distinct chemical composition and differenkindsnd of fly ash reactivity may change accordingly. According to recent information influencing factor of Geopolymer concrete is NaOH molarity, fly ash/ alkaline activator ratio, Na2Sio3/NaOH ratio, and curing temperature. In additito Geopolymer concrete gives better performance in terms of durability when exposed to heat than OPC[9].

Benny joseph et al. (2012) When Geopolymer concrete is cured at 100° Celsius it will reflect the best data of compressive strength. After this temperature incre in temperature will start deteriorating concrete. Initially to havean idea about compressive strength it is necessary to have perfect data on curing temperature and duration of curing. Apply 100-degree temperature for 24 hours, he can get 96.4% compressive strength in 28 days, The same strength is obtained in seven days. When comparisons are made between normal concrete and geopolymer concrete, the modulus of elasticity increases by 14.4,% and the poison ratio increases by 19.2%[10].

M.A.M. Ariffin et al. (2013) After 18 months of sulfuric acid exposure, a sample of concrete is packed intact but the surface is a little softer, By considering visual inspection of OPC concrete shows severe damage. After 1monthsth of sulfuric acid exposuto on OPC cement loss of ,bag mass is 20 % whereas in comparison owiththis cement bag it is 8 %. If we compare in terms of Compressive Strength, when we keep them in sulfuric acid exposure for 1monthsth this concrete bag specimen lost 35% of compressive strengdespite of OPC will lose 68 % compressive strength in the same condition[11].

D Hardjito et al. (2015) The invention of geopolymer concrete containing fly ash was discussed herein. Geopolymer concrete containing fly ash has compressive strength and is ideal for structural applications. The effect of several important parameters of features fresh and cured concrete are depicted here. Geopolymer concrete containing fly ash has resistantowardrdsulfatete attack, low creep rate, and minimal drying shrinkage.[12].

P. Nath et al. (2015) To minimize setting time and increase compressive strength slag was added to Geopolymer concrete containing fly ash. After adding 30 % slag in 28 days overall binder resulted in compressive strength of 55Mpa. The amount of slag will rise the setting time will fall. The slump of fresh concrete will go down as slag content will increase in amount. If alkaline activator solution grew from 35 to 45 % of to the tal binder setting time increase and compressive strength will fawn and it also improves the slump of fresh concrete.[13].

Sudipta Naskar et al. (2016) As per the result of the current experiment it is preferable to add micro silica and titanium dioxide to low calcium geopolymer concrete containing fly ash to achieve good compressive strength. The standard curve and predicted compressive strength from the rebound hammer number and bgiveives comparable results. UPV number shows the quality of geopolymer concrete in all instances, as per IS code table which is temporarily created for cement-based concrete. The In the use of alkaline solution as the source material pH of sample is nearly constant in all circumstances.[14].

M. Tuyan et al. (2021) Due to the challenges in the production process compared to the straightforward fabrication of OPC concrete, the usage of alkali-activated/geopolymer mixes in the concrete industry has only recently become common. In the last 15 years, a one-part mixing approach for alkali-activated and geopolymer materials, comparable to OPC systems, has been possible as an alternative to the more difficult two-part mixing technique. Alkali-activated/geopolymer concrete manufacturing might soon become widespread if development is made. There have been significant advancements in the precast manufacture of alkali-activated/geopolymer concrete in recent years. Pre-setting pressure was used in the studies, along with a modest binder dose. For binders activated with alkalis, concretes produced using the hot (high temperature) pressing procedure can achieve improved mechanical performance. Research on different aluminosilicates, types, and concentrations of alkali activators, and combination proportions is needed to further refine such manufacturing procedures[16].

Ground Blast Furnace Slag:

L.Krishnan et al. (2014) Based on the results of the current experiment, it can be inferred that micro silica and titanium dioxide can be added to low calcium fly ash-based geopolymer concrete to achieve enough compressive strength. The standard curve and the predicted compressive strength from the Rebound hammer number both exhibit comparable results. UPV is a good number for assessing the quality of geopolymer concrete in all instances, according to the table in the IS code, which is primarily created for cement-based concrete. The table can be tweaked to make geopolymer concrete work. Due to the use of the alkaline solution as the source material, the pH of the geopolymer sample is nearly constant in all circumstances[17].

Jahangir Mirza et al. (2018) Elevated the quantity of waste ceramic powder in AAMs from 50 to 70% improved their resistance to increased temperatures up to 900°C. When used to replace ground blast furnace slag with wasted ceramic powder, specimens lost strength and weight when subjected to high temperatures. Specimens constructed with 70% waste ceramic powder, 20% ground blast furnace slag, and 10% Fly Ash showed the most resiliency when exposed to higher temperatures. The results of XRD, SEM, FTIR, and TGA were used to explain the thermal stability of AAMs with a high amount of waste ceramic powder (70%) when exposed to heat. The study of surface discoloration in fired-AAMs has practical applications in the preliminary assessment of fire damage, allowing the intensity of fire to be determined[18].

Aly Muhammed Aly et al. (2019) Because of the positive effect of NaOH pre-treatment on crumb rubber particles versus the negative effect of increasing the percentage of crumb rubber on concrete, the compressive strength of slag based geopolymer concrete could be slightly increased with an increase in crumb rubber content up to 10%, potentially leading to structurally environmentally friendly mixtures from by-products and wastes with high compressive strength for use in structural elements. When the percentage of crumb rubber on concrete was greater than 10%, the effect of increasing the percentage of crumb rubber on concrete acting against the behavior of NaOH pre-treatment on crumb rubber particles resulted in a drop in compressive strength[19].

Lavanya B et al. (2020) When compared to other combinations, the geopolymer bricks with fly ash: GGBS ratio of 75:25 (with a constant water-cement ratio of 0.7) exhibited the maximum compressive strength. Traditional clay bricks can absorb up to 20% of their weight in water, whereas geopolymer bricks can absorb up to 6%. Acid resistance was improved by increasing the amount of GGBS in the mix fraction[20].

Waste Ceramic Powder:

Zengqing Sun et al. (2013) This study successfully geopolymerized waste ceramic, yielding a material with high compressive strength and good high-temperature properties. The compressive strength of waste ceramic-based geopolymers is determined by the initial reacting system, and the alkaline activating solution plays an important role in the geopolymerization process. The geopolymer in the optimal mix design has a maximum compressive strength of 71.1 MPa. The waste ceramic-based geopolymer exhibits good thermal stability in terms of compressive strength evolution after thermal exposures. The compressive strength rose after 2 hours of calcination at 1000°C, possibly due to viscous sintering and the completion of a subsequent high-temperature geopolymerization phase. The waste ceramic to geopolymer convention was disclosed by SEM photomicrographs and FTIR spectra. The results of this work may provide a technique for in situ recycling waste ceramic for producing value-added geopolymer composites when the waste ceramic is silica and alumina rich (content greater than 70% is optimal) and easy to grind[21].

Sama aly et al. (2017) The late strength growth in both conventional and self-compacting concrete indicates that the reactivity of ceramic waste powder occurs at later ages, indicating likely pozzolanic reactivity. Durability testing revealed that using ceramic waste powder improved chloride ion permeation resistance and increased resistivity. With 10-30% for conventional concrete and 40% for self-compacting concrete, ceramic waste powder has demonstrated its feasibility in producing concrete with adequate fresh qualities and increased toughened and durability features. The ceramic waste powder is also a potential element in geopolymer concrete, which may be used to create green, long-lasting constructions[22].

Sama T. Aly et al. (2018) Waste ceramic powder showed promise for use in geopolymer concrete. The strength improved as the aggregate content grew. To increase the flowability of the mixture, a 4% superplasticizer is required. The use of 40% by weight slag as a partial substitute for waste ceramic powder enhanced the strength and bulk electrical resistivity considerably. The ideal curing regime for improving the performance of the generated waste ceramic powder and slag geopolymer is to cure for 24 hours at 60 degrees Celsius followed by air curing[23].

Yanguang Wu et al. (2019) Researchers and allied sectors are increasingly paying attention to geopolymer because of its remarkable features and long-term viability. In recent decades, great strides have been achieved in the development and implementation of geopolymer products. The raw ingredients, synthesis reaction kinetics, physical qualities, and diverse applications of geopolymer were all thoroughly examined. The effective design of routes and synthesis techniques opens the door to the development of low-cost, high-purity precursors and geopolymer products with desired features. This review delves into the usage of geopolymer as an ecologically beneficial and long-lasting material that may be utilized for global environmental preservation, energy conservation, wastewater treatment, solid waste management, and geopolymer concrete's extremely high performance[25].

Ghasan Fahim Huseien et al. (2019) The compressive strength development of waste ceramic powder-based alkali-activated mortars with fly ash was impacted. As the percentage of fly ash climbed from 0% to 40%, the strong growth decreased. However, alkali-activated mortars produced with 40% fly ash as a substitute for ground blast furnace slag reached a compressive strength of 45.9 MPa, allowing this product to be employed in a variety of building applications. In high-volume waste ceramic powder-based alkali-activated mortars, replacing ground blast furnace slag with fly ash resulted in high-performance mortars in a demanding environment. The resistance of alkali-activated mortar to acid and sulfate attack improved as the fly ash concentration in alkali-activated mortar rose, as determined by residual strength, mass loss, and XRD patterns. Among all the mixes, alkali-activated mortar with 40% fly ash had the maximum resistivity. The low CaO concentration of fly ash was a major factor in limiting gypsum formation throughout the immersion period[26].

Abdul Rahman Mohd Sam et al. (2019) waste ceramic powder was used with ground blast furnace slag and fly ash to improve the workability of alkali-activated mortars. The time it took for the waste ceramic powder to set grew as the amount of waste ceramic powder was replaced. The addition of more than 60% waste ceramic powder to the mix significantly slowed the setting time. At the age of 28 days, compressive strength (36–70 MPa) of large volume ceramic tile wastes between 50 and 70% was found to be appropriate for building applications (50–70 MPa). Microstructure data such as XRD, SEM, and FTIR demonstrate that increasing the waste ceramic powder content by 70% lowered the calcium oxide content and had a detrimental influence on the formation of C-S-H and C-A-S-H gels. The amount of fly ash that replaced ground blast furnace slag at each level of waste ceramic powder altered the compressive strengths of ternary blended alkali-activated mortars. When compared to mixtures prepared with high waste ceramic powder content and low ground blast furnace slag contents replaced with fly ash, mixtures prepared with 50 percent waste ceramic powder, 40 percent ground blast furnace slag, and 10% fly ash presented the optimum compressive strength of ternary blended at age of 28 days (66 MPa)[27].

S.Kavipriya et al. (2020) In geopolymer concrete, adding ceramic waste powder in an equal amount to fly ash (50:50) results in good workability. The workability of geopolymer concrete improves when the proportion of ceramic waste is reduced. When the amount of ceramic waste in the specimens is reduced, the mass density of the specimens increases. The percentage of geopolymer specimens that absorb water decreases as the quantity of ceramic waste added decreases. The addition of 0.5 percent of fibers takes 75 minutes to achieve its saturated stage of water absorption, whereas the addition of 0.75 percent and 1 percent of fibers takes 90 minutes. Polypropylene fibers boost workability and water absorption percentage by up to 0.75 percent when added to the concrete volume. The fresh and hardened characteristics of geopolymer concrete are unaffected by the use of M-Sand instead of river sand. Because ambient curing produces high strength, precast goods may be cast at room temperature to get satisfactory results. In comparison to 60:40 and 70:30 mix proportions, specimens with a 50:50 proportion of fly ash and ceramic waste had outstanding compressive and flexural strength. In comparison to 1 percent addition of fibers, 0.5 percent and 0.75 percent addition of polypropylene fibers in geopolymer concrete achieve good strength qualities[28].

Madhuchhanda Sarkar et al. (2020) Red ceramic wastes might be used as a filler in metakaolin-based geopolymers. The compressive strength of the solely metakaolin-based geopolymer binder was equivalent to that of the purely metakaolin-based geopolymer binder. Red ceramic waste, unlike metakaolin, only partially interacts with alkali activators to generate a binder. The compressive strength of the geopolymer mortar samples was lower than that of the binder samples. Binders with a Na/Al ratio of 1 have the maximum compressive strength. The combined impact of particle packing and the amount of binder phase may be used to phenomenologically explain the compressive strength of red ceramic waste-incorporated mortar samples[30].

Table -1: Literature Review Paper and Its Comparison

chemical properties (%)	Zengqing Sun (2013)	Arvind Pathak (2014)	Ghasan Fahim Huseien (2019)	Jahangir Mirza (2019)
Silica dioxide (SiO_2)	65.52	65.3	72.6	72.6
Aluminium Oxide (Al_2O_3)	21	13.45	12.6	12.2
Iron Oxide (Fe_2O_3)	6	8.62	0.56	0.56
Calcium Oxide (CaO)	1.11	3.34	0.02	0.02
Magnesium oxide (MgO)	1.95	-	0.99	0.99
Potassium Oxide (K_2O)	3.31	4.07	0.03	0.03
Sodium Oxide (Na_2O)	0.36	3.26	13.5	13.46
Sulphur trioxide (SO_3)	0.17	-	0.01	0.01
Loss on ignition (LOI)	0.14	1.97	0.13	-

3. MAJOR FINDINGS FROM THE LITERATURE REVIEW

1. The Alkaline Activator Solution content is the most important factor in all of the mix designs.
2. The most expensive component is the Alkaline Activator Solution.
3. As the amount of fluid in the system increases, the strength of the system diminishes.
4. Fly ash and powdered granulated blast furnace slag are mixed in equal parts.
5. It has also been demonstrated that high-temperature curing is not necessary for all situations of Geopolymer concrete, since sunshine curing (average temperature of 30 °C) may be utilized for Geopolymer concrete mixtures, at least in tropical areas.
6. Geopolymer concrete's compressive strength improves.
7. Geopolymer concrete's split tensile strength improves.
8. Geopolymer concrete's flexural strength improves.

Table -2: Chemical Properties of Waste Ceramic Powder from Literature Review Paper

Year	Material Used	Optimum % Used	Grade of Concrete
Abbas Mohajerani (2019)	GGBFS and Fly ash	40%	M35
Lenka Scheinherrová (2020)	ceramic waste powder	43%	M30
Adriano Galvão (2020)	ceramic tile powder, GBFS, FA	30%	M15
Ghasan Fahim Huseien (2019)	WCP, GBFS, FA	40%	M35
Yanguang Wua (2019)	Class F fly ash, WCP	30%	M30
Ghasan Fahim Huseien (2019)	class F Fly-Ash, Ceramic waste powder	70%	M55
J. Payá, (2015)	fly ash, ground granulated blast furnace slag	40%	M60

4. CONCLUSIONS

Based on the results of prior research on the mechanical characteristics of Geopolymer concrete. The following is a summary of the findings:

There is a growing demand for innovative materials with low CO2 emissions that may be used for a variety of applications. So, geopolymer concrete might theoretically be used as a substitute for OPC; however, this will only happen if both an effective raw material supply chain and a product supply network are in place. The recent market in this area is positive, but it will take time for geopolymer concrete to establish itself as a globally marketable product. The geopolymer concrete has all of the desirable mechanical and structural qualities, making it an excellent construction material. The strength and durability features of geopolymer concrete have been examined, and it can be stated that geopolymer concrete outperforms OPC concrete in terms of chemical and fire resistance. However, more research is needed on the behavior of geopolymer concrete at high temperatures and deterioration owing to environmental factors.

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