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Compressive Strength and Microstructure Analysis of Geopolymer Paste Using Fly Ash

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ABSTRACT
The present research examines the microstructure and compressive strength of geopolymer paste created with fly ash as a sustainable and green binder. The study investigates the effects of important factors on the mechanical strength and microstructure of the geopolymer paste, including the kind and concentration of activator, curing circumstances, and curing time. The results of the experiments shed light on the microstructural features of the geopolymer materials and provide vital insights into their potential as an alternative to traditional cement-based systems. Avg. compressive strength at 28 days for Mix 1 is 22.45MPa, Mix 2 is 27.14MPa and Mix 3 is 26.9MPa.

I. INTRODUCTION

Traditional Portland cement production has considerable environmental concerns, including the discharge of significant carbon dioxide (CO_2) emissions. Portland cement is a key ingredient in concrete. In this regard, the building industry has paid close attention to the development of sustainable and environmentally friendly substitutes for materials based on cement. Geopolymers, which are inorganic polymers created when aluminosilicate minerals are alkaline activated, have shown promise as alternatives to traditional cementitious binders. By using fly ash as a significant precursor material, this study aims to investigate the compressive strength and microstructure of geopolymer paste, providing the construction industry with a resource- and environmentally-friendly option.

The pressing need to lessen the building sector's carbon footprint is what prompted this study. It is critical to look for environmentally sound substitutes because Portland cement production contributes significantly to world CO_2 emissions. An inventive method of reaching this goal is provided by geopolymer technology, which is based on the activation of fly ash, an industrial waste product. While offering benefits including decreased greenhouse gas emissions, reduced energy consumption, and the use of industrial waste materials, geopolymers have shown the ability to meet or even outperform the performance of conventional cementitious materials.

The goal of the study is to synthesise geopolymer samples using various activator formulations, curing environments, and curing times. By establishing relationships between the compressive strength and microstructural attributes of geopolymer paste, the study hopes to shed light on the material's potential as an environmentally friendly replacement for traditional building materials.

II. REVIEW OF LITERATURE

Concrete is the building material that is most frequently used worldwide. Regular concrete's main components are OPC and natural aggregates. In the Indian context, cement consumption is projected to reach 329 million metric tonnes by 2022 and would likely continue to rise in the years to come by roughly 7-8% [1]. Ordinary Portland Cement (OPC) has a detrimental influence on the environment, which is one of its most important negative impacts. OPC production has a significant carbon footprint, which makes it a major source of greenhouse gas emissions. A large amount of carbon dioxide (CO_2) is released into the environment during the high-temperature heating of limestone and clay used in the production of OPC. In addition to causing climate change, this CO2 release also depletes the earth's finite supply of fossil fuels. Furthermore, habitat damage, biodiversity loss, and landscape modification may come from the exploitation of raw materials for OPC manufacture, such as clay and limestone.

As a result of the exhaustion of natural resources and environmental damage caused by cement manufacture, different building materials having cement-like qualities are now the focus of research. Due to making use of industrial byproducts as cementitious precursors in the production of Fly ash (FA), ground granulated slag (GGBS), and rice husk ash are examples of geopolymer binders (RHA), these binders have demonstrated their potential to become viable eco-friendly alternatives [2].

The cementitious compound known as geopolymer is gaining popularity because it has the potential to replace conventional Portland cement in environmentally favourable ways. Geopolymer is created through a chemical reaction that combines aluminosilicate minerals, such as fly ash, slag, or metakaolin with an alkaline solution, as opposed to Portland cement, which is created by heating limestone and clay at high temperatures. In the concrete industry, geopolymer technology offers a possible replacement for conventional Portland cement as a binder. Its attractiveness stems from its potential to address some of the performance and environmental problems connected to cement manufacture. By chemically fusing aluminosilicate substances like fly ash, slag, or metakaolin with an alkaline solution, geopolymers can be created without the requirement for high-temperature kiln firing, which is a significant source of carbon emissions in the production of cement.

It’s much lower carbon footprint makes it a more sustainable option and is one of its distinguishing qualities. By utilising industrial leftovers, geopolymers can conserve resources and encourage waste utilisation. They frequently have high strength, outstanding durability, and fire resistance, which makes them appropriate for a variety of building applications [3].

The Central Electricity Authority of India (CEAI) [4] states that a substantial volume of fly ash with low calcium. is produced by coal-fired thermal plants. Only 20% of The Indian cement industry now uses the fly ash that is produced each year. [5]. Thus, the market for fly ash-based geopolymer binder is quite promising in India [6]. Indian fly ash has little calcium due to its low calcium content (less than 10%), the corresponding geopolymer binder develops strength more slowly than OPC concrete. Employing calcium-rich additions could strengthen the microstructure of fly ash-based geopolymers with little calcium [7]. Mortar made with geopolymer and concrete's permeability and porosity may be reduced by the enhanced microstructure.

The manufacture of concrete relies heavily on fly ash, a byproduct of coal combustion in power plants, in the building sector. It is an additional cement substance that improves the performance of concrete and is environmentally benign and sustainable. Fly ash boosts durability, reduces heat generation, and promotes workability when used with cement. By lowering the demand for virgin cement, which produces a substantial quantity of carbon dioxide during production, it also lessens the environmental impact. Additionally, fly ash transforms this trash into a useful resource, assisting with the problem of disposing of it. It is a crucial element of contemporary construction techniques because it not only makes concrete stronger but also promotes sustainable building techniques.

By using less natural aggregates, geopolymer concrete can further enhance its position as a sustainable construction material. Previous research has focused on the possibilities for substituting fine and coarse particles in traditional concrete with alternative materials including rubber and recycled aggregates. Tire scraps are mostly used to make rubber aggregates. Every year, India generates more than 6% of the world's waste tyres [8]. Rubber is not biodegradable, making it bad for the environment and public health to dump used tyresin public areas. Rubber aggregates have reportedly been shown to lower the mechanical strength and increase the porosity of concrete [9], [10], despite the fact that using crushed tyres in concrete makes them reusable.

Additionally, adding different kinds of natural and synthetic fibers to cement concrete matrix is advantageous both the fresh phase and the hardened phase [11]. Moreover, fibres are categorized according to their aspect ratio, or l/d, where l and d stand for the fibres' length and diameter, respectively. High aspect ratio glass fibers has a high tensile strength and high elastic modulus. In new concrete, micro-fibers have been found to lessen porosity and prevent the formation of shrinkage cracks [12]. Fibers in hardened concrete increase strength, slow the spread of microcracks during failure, and enhance post-crack behaviour [13]. When GP mortar is heated to cure, there is always a chance that early age shrinkage cracks could form. These fractures could then spread further when a load is applied [14]. Therefore, adding glass fibres to mortar can enhance its creep resistance and post-cracking behaviour while reducing the growth of shrinkage cracks. Glass fibers are a good option for fibre reinforcement in a variety of alkali-activated cements due to their high melting point and resilience in alkaline environments. The research on concrete with microfibers reveals that concrete with low fibers content (less than 0.15%) cannot successfully fill cracks. The overall fibers surface area in the mortar would grow with a higher fibers volume (more than 0.5%), however, and this would decrease the mortar's flow ability [15]. As a result, the glass fibers content used in this investigation is 0.3% by volume.

III. METHODOLOGY

The fly ash sample was collected from Panipat thermal power plant. Then the chemical composition of the sample was tested. The admixture geopolymer samples were prepared with different material with varing quantity (Table-1). Scanning Electron Microscopy (SEM) was done for all the preared mixtures. And their comprehensive strength measured.

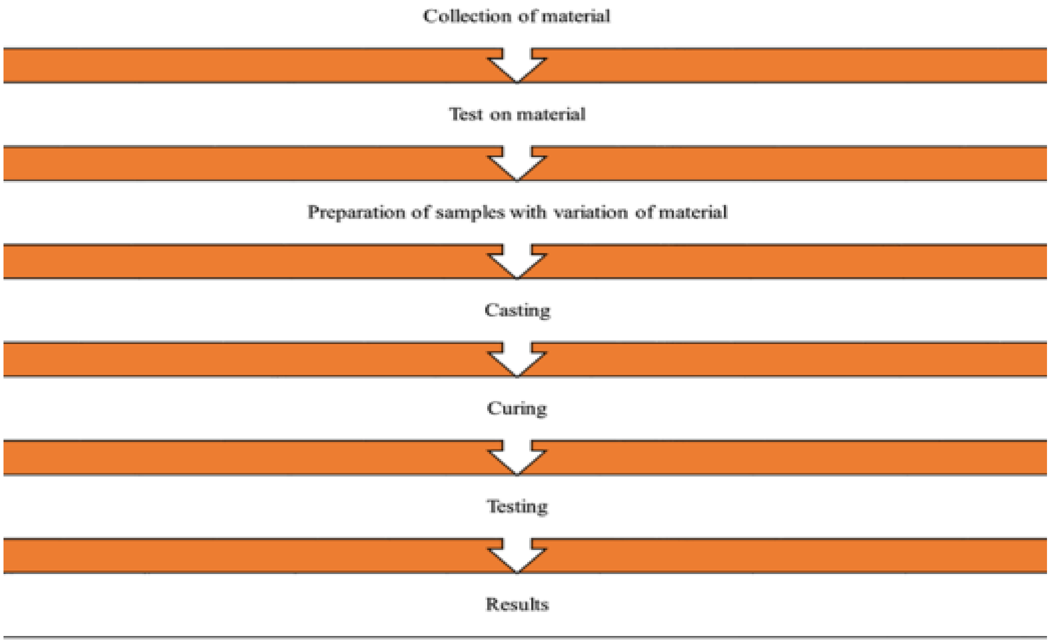

Fig 1- Methodology of the study

Table 1- Mix Proportion

Sample ID	Mix ID	Fly Ash (gm)	OPC-43 (gm)	Sand (gm)	CR (gm)	NaOH(gm)	Na_2SiO_3 (gm)	Glass Fibre (gm)	Extra Water (gm)	Plasticizer (gm)
Mix1	0G0CM1	80	20	150	—	13	32	—	20	2
Mix2	0.3G0CM2	80	20	150	—	13	32	2.6	20	2
Mix3	0.3G5CM3	80	20	150	3.3	13	32	2.6	20	2

IV. RESULT AND DISCUSSION

Table 2- Chemical Composition of Fly Ash

Chemical Composition of Fly Ash

Chemical Composition	Fly Ash (%)
Silica (SiO_2)	61.17
Alumina (Al_2O_3)	28.96
Iron Oxide (Fe_2O_3)	3.92

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Total Sulphur (SO_3)	0.25
Calcium Oxide (CaO)	4.57
Potassium Oxide (K_2O)	-
Sodium Oxide (Na_2O)	0.31
Loss of Ignition (LOI)	0.82
	100

Results of FTIR spectra for various geopolymer mortar samples after 28 days. All of the samples have comparable peak wave numbers and shapes. The bending and stretching vibrations that are asymmetric peaks of the H-O-H and O-H groups in the bound water present in the polymerization and hydration products, respectively, are the characteristic absorption peaks around 3486 cm^{-1} (broad) and 1626 cm^{-1} (weak), which indicate that free water in the system gradually transforms into bound water. The stretching vibration of CO_2 is represented by the peak near 1390 cm^{-1}, which shows that the samples' efflorescence produces some carbonates. Notably, the Si-O-Si (Al) link is being stretched asymmetrically in the absorption band with its centre at roughly 1000 cm^{-1}. The quartz component of the mortar is what causes the weak band about 745 cm^{-1}. Fly ash contains crystalline quartz, which is unreacted during the geopolymer reaction. The Si-O-Si (Al) bonds in plane and bending modes were connected to the bands around 460 cm^{-1}.

Fig 2, fig 3, fig 4 shown the SEM image sof the prepared geopolymer mix 1, 2 and 3 samples.

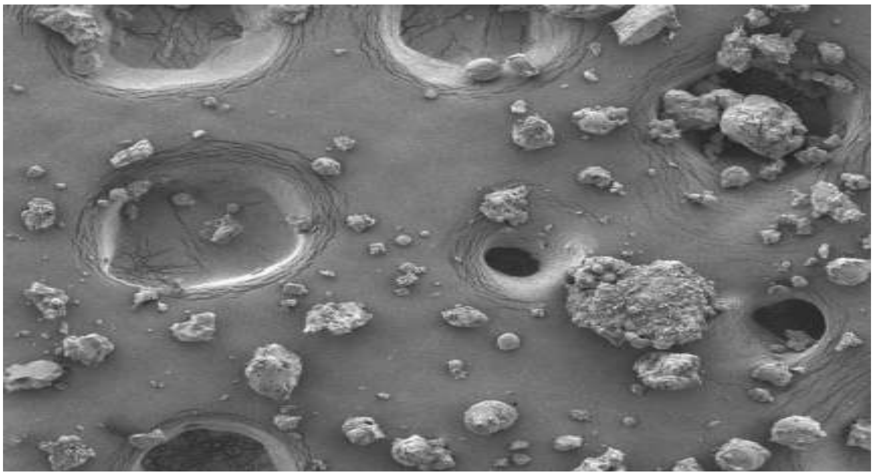

Fig 2- SEM of mix 1 sample

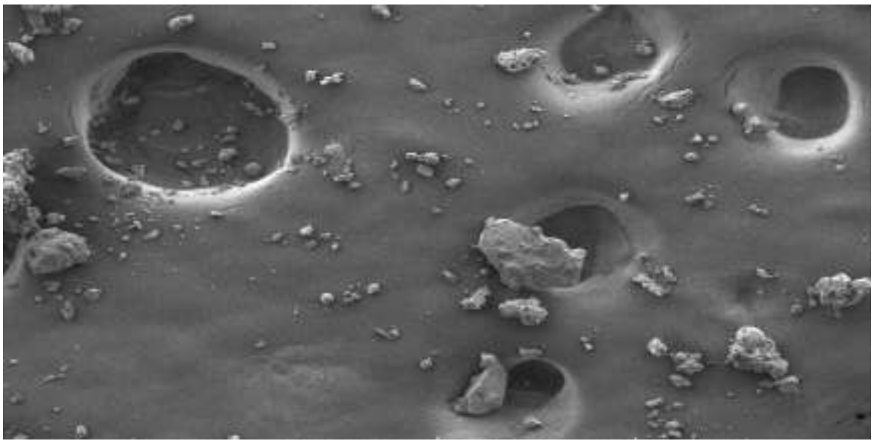

Fig 3- SEM of mix 2 sample

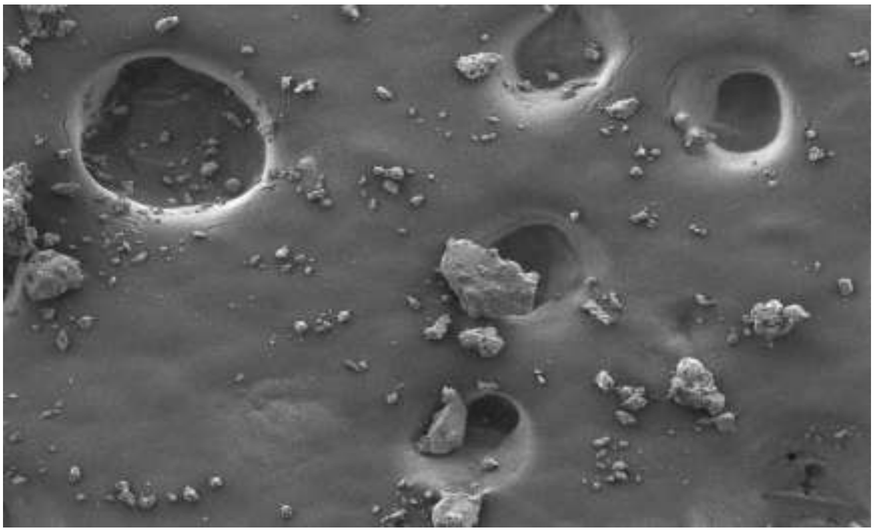
Fig 4- SEM of mix 3 sample

Fig 5- Comprehensive strength of mix 1 sample

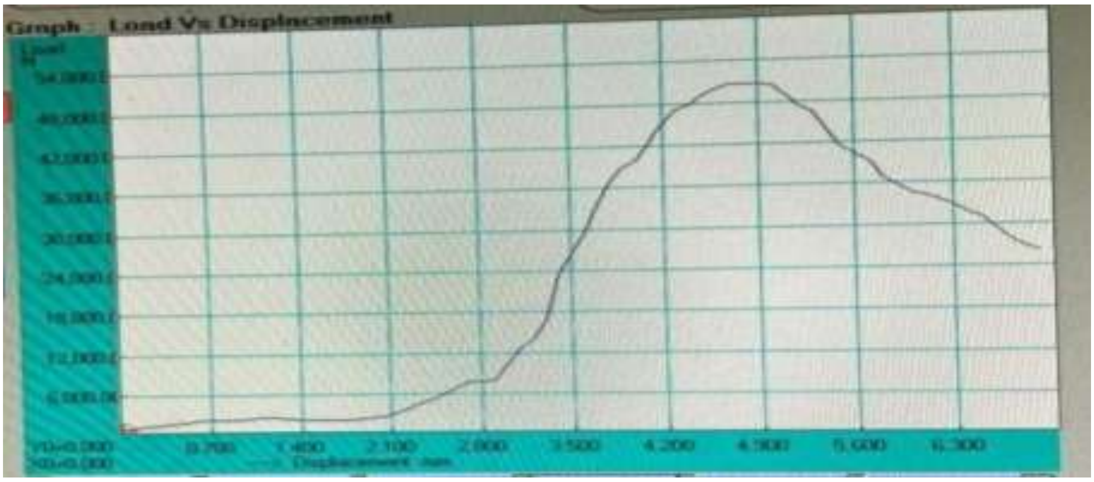

Fig 6- Comprehensive strength of mix 2 sample

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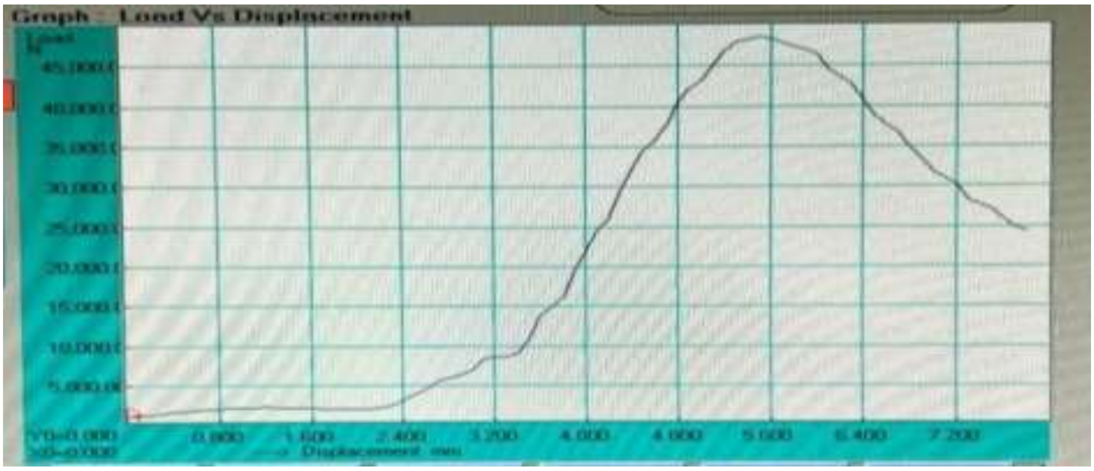
Fig 7- Comprehensive strength of mix 3 sample

Avg. compressive strength at 28 days for Mix 1 = 22.45MPa (Fig – 5)
Avg. compressive strength at 28 days for Mix 2= 27.14MPa(Fig- 6)
Avg. compressive strength at 28 days for Mix 3= 26.9MPa (Fig- 7)

With age, a rise in compressive strength was seen for all of the mixtures. At 28 days old, the control mix 0G0CM1 displayed a compressive strength of 22.45 MPa. According to the test results for Mix 0.3G0CM2, the average compressive strengths of GPM with a volume percentage of glass fibres of 0.3% increased in comparison to the reference GPM mix without fibres, 0G0CM1. The mix 0.3G0CM2 produced the strongest compressive strength across all ages, giving it a 28-day strength of 27.14 MPa. . When compared to a mix without rubber, 0.3G0CM2, specimens with 5% crumb rubber replacement had a 28-day compressive strength of 26.09 MPa, a 3.86% drop.

Future directions for research
Despite the fact that this research offers insightful information, various directions for further study are obvious. Additional research could concentrate on:

1. Studies on durability: Analyzing long-term robustness and resilience to environmental elements including chemical attack and freeze-thaw cycles.
2. Optimization of Activators: Investigating various activators' concentrations to increase compressive strength and speed up cure.
3. Industrial-Scale Production: Expanding geopolymer production techniques for real-world use in the building sector.
4. Life cycle analysis: Conducting a thorough life cycle analysis to determine the environmental advantages of geopolymer materials over conventional cement-based materials.

V. CONCLUSION

In conclusion, this study adds to our understanding of geopolymer materials and their potential to transform the building sector. The results of the microstructure study and the compressive strength tests highlight the potential of geopolymer paste made from fly ash as a high-performance, environmentally friendly replacement for conventional cement-based products. Geopolymer materials are an attractive option as the building industry looks for more environmentally friendly solutions; they have the potential to lower carbon emissions and help create a built environment that is greener and more sustainable. Geopolymer materials will become even more of a cornerstone of sustainable building techniques as a result of forthcoming research and real-world applications.

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