ISSN 2228-9860 eISSN 1906-9642 CODEN: ITJEA8

International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies

http://TuEngr.com

Mechanical and Microstructural Properties of Alccofine Based Geopolymer Concrete

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Paper ID: 12A10J

Volume 12 Issue 10

Received 24 April 2021
Received in revised form 10 July 2021
Accepted 22 July 2021
Available online 02 August 2021

Keywords:
Conventional concrete; Geopolymer concrete; Alccofine; Compressive strength; Workability; Stress-strain; Superplasticizer; Geopolymer concrete (GPC); Sodium silicate; Sodium silicate hydrate.

Abstract

This research work reported the characteristics of fly ash-based geopolymer concrete (GPC) that includes alccofine as a binder material. Sodium hydroxide (NaOH) mixed with sodium silicate (Na2SiO3) was used as an alkali activating agent. In the Indian scenario, the fresh and hardening property of alccofine based geopolymer concrete and conventional concrete, e.g. workability, compressive strength, and stress-strain behaviors have been investigated. X-ray Diffraction method was used to identify the chemical compositions of powdered fly ash and alccofine samples. Its microstructures of concrete have been identified through Scanning Electron Microscope (SEM). The result of GPC with alccofine concludes not only the strength of concrete but also the alternative source for conventional concrete. There was a significant impact observed in the polymerization process of GPC by alccofine 1203, which increases the strength and microstructural features. This study identifies optimum molarity and fly-ash content values to improve the tested specimens' strengths.

Disciplinary: Civil Engineering & Construction Technology (Construction Materials, Structural Engineering).

Cite This Article:

Ponraj, G.B., Kamal, S., Saravanan, J., and Thirugnanasambandam, S. (2021). Mechanical and Microstructural Properties of Alccofine Based Geopolymer Concrete. *International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies, 12*(10), 12A10J, 1-13. http://TUENGR.COM/V12/12A10J.pdf DOI: 10.14456/ITJEMAST.2021.199

Nomenclatures and Symbols

CC- Conventional concrete

GPC- Geopolymer concrete

NaOH - Sodium hydroxide

Na_2SiO_3 - Sodium Silicate

NASH - Sodium silicate hydrate

CASH - Calcium silicate hydrate

SEM - Scanning Electron Microscope

XRD- X-ray diffraction

1 Introduction

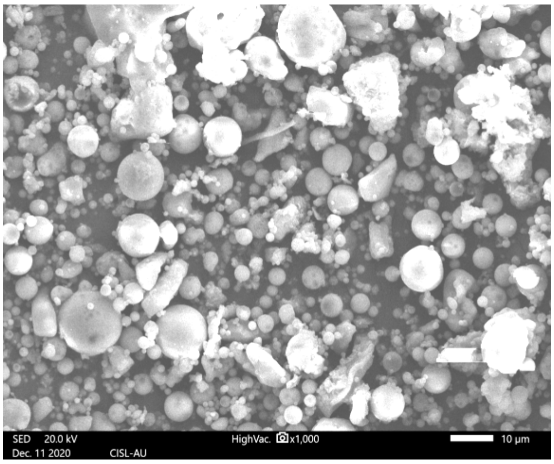
Joseph Davidovits 1987 started the idea of geopolymer, just because geopolymer is inorganic polymeric materials framed by the response between polymeric chain arrangement and an aluminosilicate at relatively low temperature with the ongoing quick increment in the populace, the requirement for framework improvement expanded exponentially. This expanded interest for the new foundation is taking care of the worldwide interest for construction materials, for instance, common Portland concrete (OPC), a basic restricting component in the delivery of concrete. Geopolymer is described by acceptable strength, ecological importance, low vitality consumption and non-utilization of limestone resources. The concrete business is second just to control age in the creation of CO_2 and represents 8-10% of the planet's human-delivered CO_2 discharges (Suhendro, 2014; Assi et al., 2018). Through a constant assessment made in 2020, the CO_2 discharge is predicted to rise by half of the current levels (Davidovits, 1994; Gartner, 2004). These discoveries have squeezed the concrete development industry. Moreover, modern squanders require huge regions of valuable land for removal which thus affects nature and land use. To conquer these difficulties, specialists have to improve a substitute of fastener materials. Geopolymer Concrete (GPC) or Environmental Friendly Concrete (EFC) is one of the foremost materials recommended by specialists, which is nothing but alkali-activated silica and alumina-rich blend (Saxena et al., 2018). The utilization of GPC decreases CO_2, and earth-friendly materials by successfully using industrial wastes, for example, fly-ash slag, rice husk ash. It also discovers that GPC restored at high temperatures can out-perform more than cement concrete based on quality and solidness(Aslani & Nejadi, 2012; Noushini et al., 2016). In this study, the development of alccofine based geopolymer concrete at ambient curing with optimum molarity was identified. The activator solution ($NaOH$+Na_2SiO_3+Water) mixed with low calcium fly ash, alccofine, and filler materials at ambient curing gives the better strength of GPC. Different criteria are considered such as compressive strength, workability, and modulus of elasticity. Further, Scanning Electron Microscopy (SEM) was conducted in which the structures of alccofine and fly ash are present in GPC with appropriate NaOH concentration under ambient temperature. In addition, XRD was conducted for fly ash and alccofine to quantify the chemical composition. This research work focuses on the formation and portrayal of the characteristics of ambient cured alccofine based GPC compared with CC.

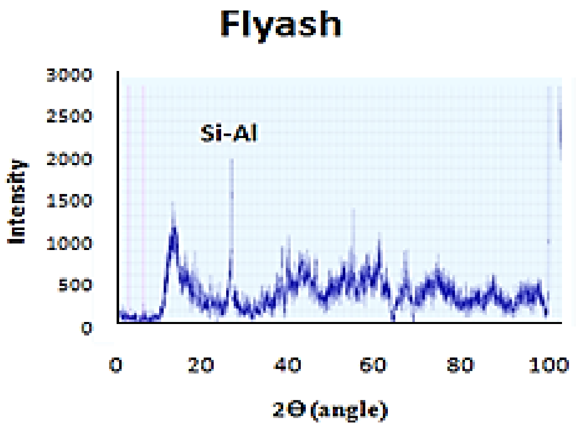
2 Experimental Details: Material Properties

2.1 Fly-ash

In this analysis, locally available low-calcium class-F fly ash was used after procuring it from Mettur thermal power plant, Tamilnadu, India. The specific gravity of fly ash was 2.10. Fly ash chemical compound was calculated through X-ray diffraction (XRD) analysis cited in the code (BIS

3812 (Part 1), 2003) with minimum requirements as shown in Table 1. Figures 1(a) & 1(b) show SEM and XRD analyses for Fly Ash. Fly ash XRD with sharp peaks indicates the presence of silica and alumina. The crystalline form of fly ash with a sharp peak at 2Θ values are 17.52, 23.68, 58.62 (d spacing of 5.24, 2.36, 2.16). A broad diffraction hump in the region of 14-35 degrees denotes that fly ash is in amorphous phases. Silica and Alumina combine to form the amorphous phase(Ponraj et al., 2021).



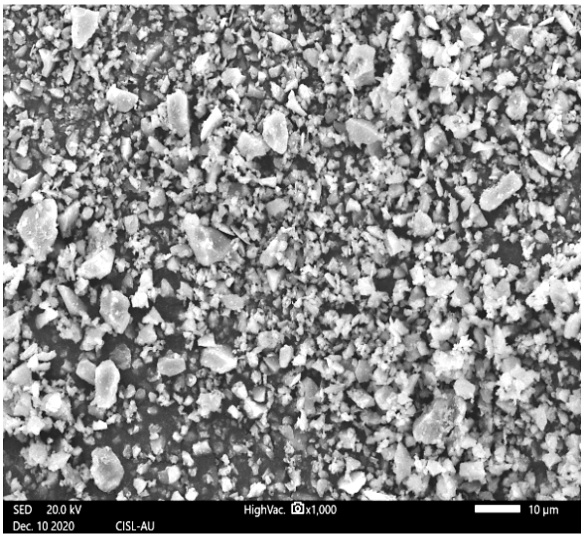


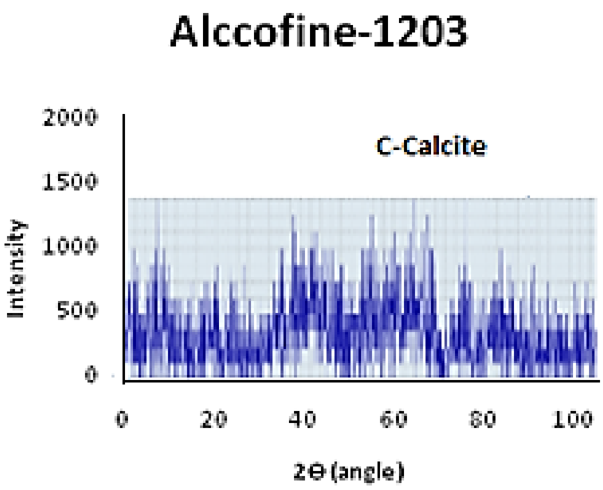
(a) (b)

Figure 1: (a) SEM and (b) XRD image of Fly ash.

2.2 Alccofine 1203

Alccofine 1203 (AF), a unique product, is synthesized by processing high-glass slag. It possesses high reactivity which is produced as a result of the controlled granulation process. Alccofine 1203 (AF) is an established product, owing to its novel chemistry and ultra-thin particle size. It enhances the workability by diminishing the demand for water and increasing the compressive strength (Jindal et al., 2020; Ponraj et al., 2021; Prithiviraj & Saravanan, 2020, 2021).





(a) **(b)**

Figure 2: (a) SEM and (b) XRD image of Alccofine 1203

Alccofine enhances high-performance concrete in hardened states, either as a cement substitute or as an additive. Table 1 shows the chemical composition of alccofine, whereas its physical properties are shown in Table 2. Alccofine was made to undergo SEM and XRD analysis since it generally consists of calcite as described in Figures 2(a) & 2(b). The big hump between 1000-1400 on the XRD pattern of alccofine suggests that it is amorphous. Alccofine has low numbered peaks, indicating that absences of crystalline phase and its particle size is small. The alccofine has a high degree of reactivity (Jindal et al., 2017) and Jindal et al., 2018).

Table 1: Chemical composition

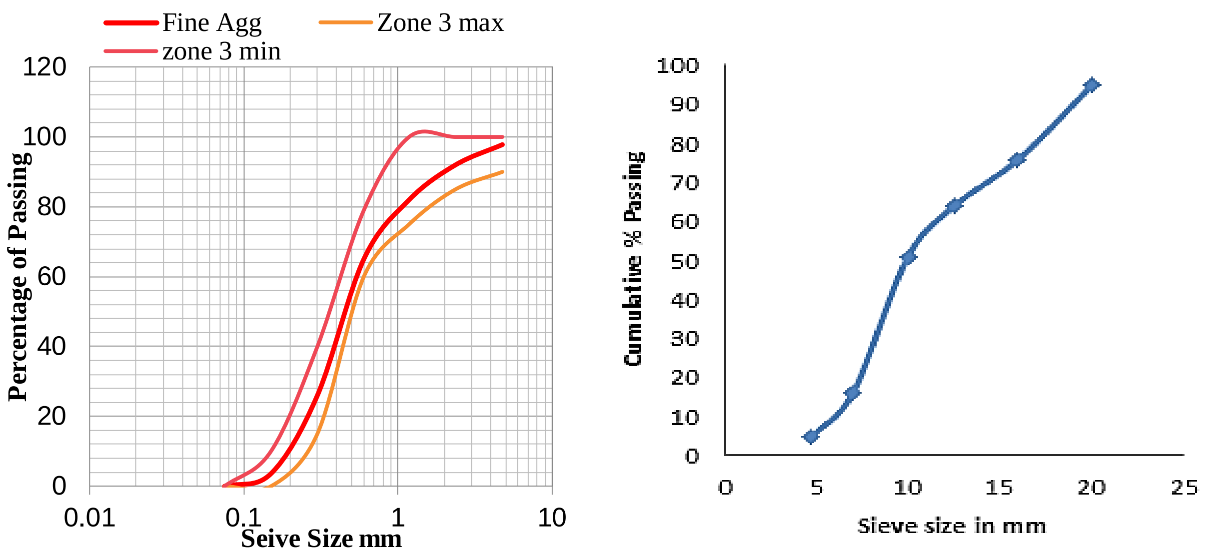
Chemical composition (%)	fly ash	Cement	Alccofine 1203
SiO2 + Al2O3 + Fe2O3	93.82	28.36	57.9
SO3	1.28	2.5	0.13
CaO	1.02	66.67	43.92
MgO	0.38	0.87	5.82
TiO2	2.54	2.5	0.81
Na2O	0.51	0.12	-
LOI	0.52	1.05	-

Table 2: Physical properties.

Description	**fly ash**	**Cement**	**Alccofine 1203**
Specific gravity	2.1	3.13	2.72
Bulk Density [kg/m3]	820	1440	680
Specific surface area m2/kg	321.68	340	1200

2.3 Aggregates

During the preparation of the whole set of test specimens, the authors used high-quality and well-graded aggregates in surface dry conditions. Fine natural sand and coarse aggregates with a maximum size of 20, 12.5,10,7, and 4.75 mm are used. Table 3 shows the characteristics of aggregates whereas Figure 3 shows the grading curves. The authors performed sieve analysis as per the literature (BIS:383 (1970)) to find the distribution of particle size under coarse as well as fine aggregates.



(a) (b)

Figure 3: Gradation curve for a) Fine aggregate and b) Coarse aggregate

2.4 Alkaline Activator

Alkali activator is nothing but a blend of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3). The authors procured 98% pure and pellet-form NaOH along with Na_2SiO_3 with SiO_2/Na_2O ranged between 2 With 65.5% water mass. sodium silicate solution had a chemical composition of Na_2O=8.5% and SiO_2=26%. Table 4 displays the physical properties of Sodium silicate solution had a density of 1.39 g/cm^3 while its relative vapour density was 0.7 at 20°C.

Table 3: Physical properties of Aggregate

Sample	Fine Aggregate	Coarse Aggregate
Specific gravity	2.6	2.8
Finess Modulus	2.75	7.3
Water absorption %	0.72	1.12

Table 4: Physical properties of sodium silicate

Colour	opaque viscous
pH	11.2
Density [g/cm3]	1.39
Total solid content/ Wt%	47.09

2.5 Super Plasticizers

In this study, different superplasticizers were tried to achieve expected workability. Na_2SiO_3 and NaOH solutions possess high viscosity compared to water. So, several trials were conducted to enhance the workability, to make geopolymer concrete more flexible, and increase the strength and setting time of concrete, After a more trial with different superplasticizers Naphthalene sulphonate based superplasticizers with 2% dosage gives good workability as well as strength to the concrete, and the guidelines are taken from BIS 9103 (1999), and ASTM C494 standards.

3 Results

3.1 Mixing Method of Geopolymer Concrete and Curing

As per Parveen & Singhal (2017) and Junaid et al. (2015), the geopolymer concrete design was proposed with different combinations of fly ash and alccofine. Coarse as well as fine aggregates were considered by the entire mixture's mass like the traditional concrete. Based on the molarity, the concentration of NaOH was different. A significant amount of heat is released by mixing sodium hydroxide with water. To compare the target strength of CC M30 (1:1.92:3.85) & M60 (1:1.02:2.34), with various GPC molarities with the optimum percentage of Fly ash and Alccofine was tried (i.e. 10M, 12M, 14M, and 16M). Considering the optimal ratio Na_2SiO_3/NaOH is 2.5(Parveen et al., 2018). To enhance the working capability of freshly-prepared geopolymer mix, a 2% Naphthalene Sulphonate-based superplasticizer was employed to minimize the water requirement and increases the operability of the fresh geopolymer mix (Saloni et al., 2020). The Geopolymer concrete mix was synthesized by blending fly ash, Alccofine, and aggregates along with alkaline activator solution, the dosage of superplasticizer and extra water were mixed in pan mixture for about 5 minutes. Different mix proportions of geopolymer specimens with different fly ash and alccofine content are mentioned in Table 5 with a varying fly ash content of 319.06, 283.61, 248.16, 495.41, 440.36, and 385.32 kg/m³. Twelve GPC mixes with different designations GPC10M1, GPC10M2, GPC10M3, GPC12M1, GPC12M2, GPC12M3, GPC14M1, GPC14M2, GPC14M3, GPC16M1, GPC16M2, GPC16M3 represents molarity and various percentage of alccofine (10%, 20%, and 30%). For all the mixes the water/geopolymer solids ratio was 0.3. Table 5 shows the correct mix proportions for geopolymer concrete mixes. The researcher assessed the impact of different percentages of alccofine upon the workability and compressive strength of GPC. After casting the GPC, curation of the samples was performed under ambient conditions at 27-32°C (room temperature) for 28 days (Manjunatha et al., 2014).

Table 5: Mix proportion

Mix	Fine aggregate (kg/m³)	Coarse aggregate (kg/m³)	Fly ash (kg/m³)	Alccofine (kg/m³)	Cement (kg/m³)	Water (kg/m³)	Molarity NaOH	Alkaline solution (kg/m³)	NaOH (kg/m³)	Na_2SiO_3 (kg/m³)	Extra water (kg/m³)	Super-plasticizer [kg/m³]
CC M30	654.29	1308.58	0	0	340	162.85	0	0	0	0	0	1.7
GPC10M1	654.29	1308.58	319.06	35.45	0	0	10	132.18	18.23	113.95	27	3.55
GPC10M2	654.29	1308.58	283.61	70.9	0	0	10	132.18	18.23	113.95	27	3.55
GPC10M3	654.29	1308.58	248.16	106.35	0	0	10	132.18	18.23	113.95	27	3.55
GPC12M1	654.29	1308.58	319.06	35.45	0	0	12	135.83	21.88	113.95	27	3.55
GPC12M2	654.29	1308.58	283.61	70.9	0	0	12	135.83	21.88	113.95	27	3.55
GPC12M3	654.29	1308.58	248.16	106.35	0	0	12	135.83	21.88	113.95	27	3.55
CC M60	542.46	1241.41	0	159	371	159.01	0	0	0	0	0	5.3
GPC14M1	542.46	1241.41	495.41	55.05	0	0	14	140.6	22.65	117.95	41.28	11.01
GPC14M2	542.46	1241.41	440.36	110.09	0	0	14	140.6	22.65	117.95	41.28	11.01
GPC14M3	542.46	1241.41	385.32	165.14	0	0	14	140.6	22.65	117.95	41.28	11.01
GPC16M1	542.46	1241.41	495.41	55.05	0	0	16	148.15	30.2	117.95	41.28	11.01
GPC16M2	542.46	1241.41	440.36	110.09	0	0	16	148.15	30.2	117.95	41.28	11.01
GPC16M3	542.46	1241.41	385.32	165.14	0	0	16	148.15	30.2	117.95	41.28	11.01

Mix abbreviations:

GPC- Geopolymer concrete,
10M, 12M, 14M, 16M- Different Molarities,
(1-A10, 2-A20, 3-A30) 1, 2, 3 - Various percentage of alccofine in each GPC mix.

3.2 Workability Test

Slump test was conducted as per the standard slump cone apparatus in compliance with (BIS:7320-1974), the workability of freshly mixed geopolymer concrete was tested as per (BIS 1199 : 2004) standards with varying fly ash and alccofine percentage as shown in Figure 4.

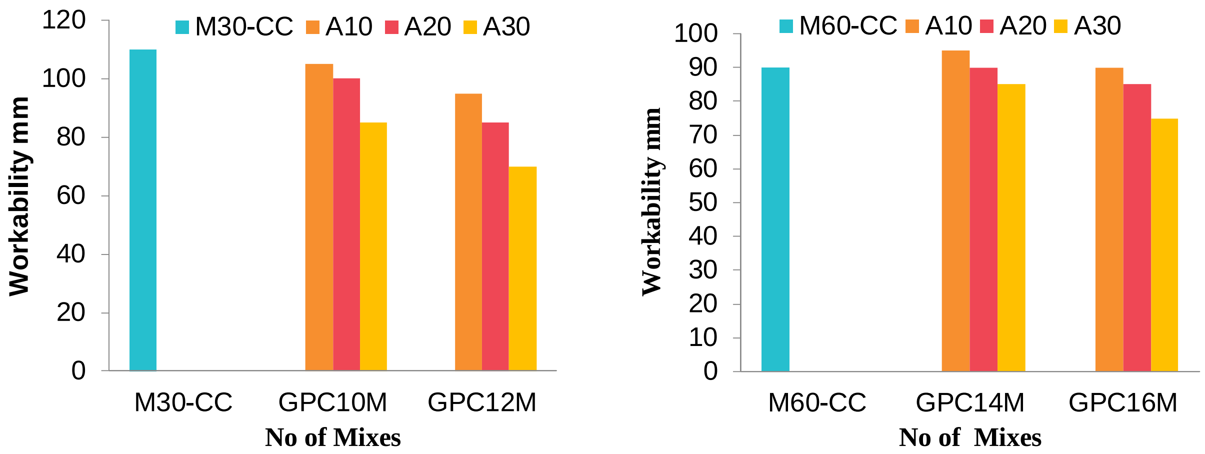


Figure 4: Slump value for CC and GPC mix.

3.3 Compressive Strength

The compressive strength test was conducted on a 150mm cube with an electrically operated compression testing machine with 2000 KN capacity. A gradual load was applied until the specimen becomes fail. The test was carried out on 7th day as well as on 28th day of casting and the average values of three cubes were reported.

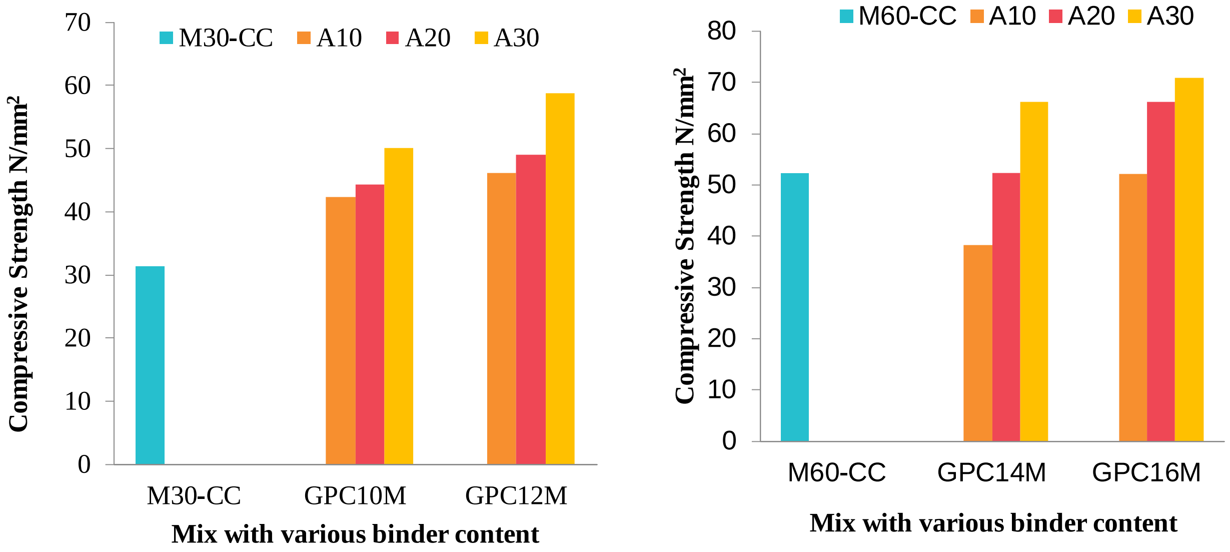


Figure 5: 7 days Compressive strength test on CC Vs GPC

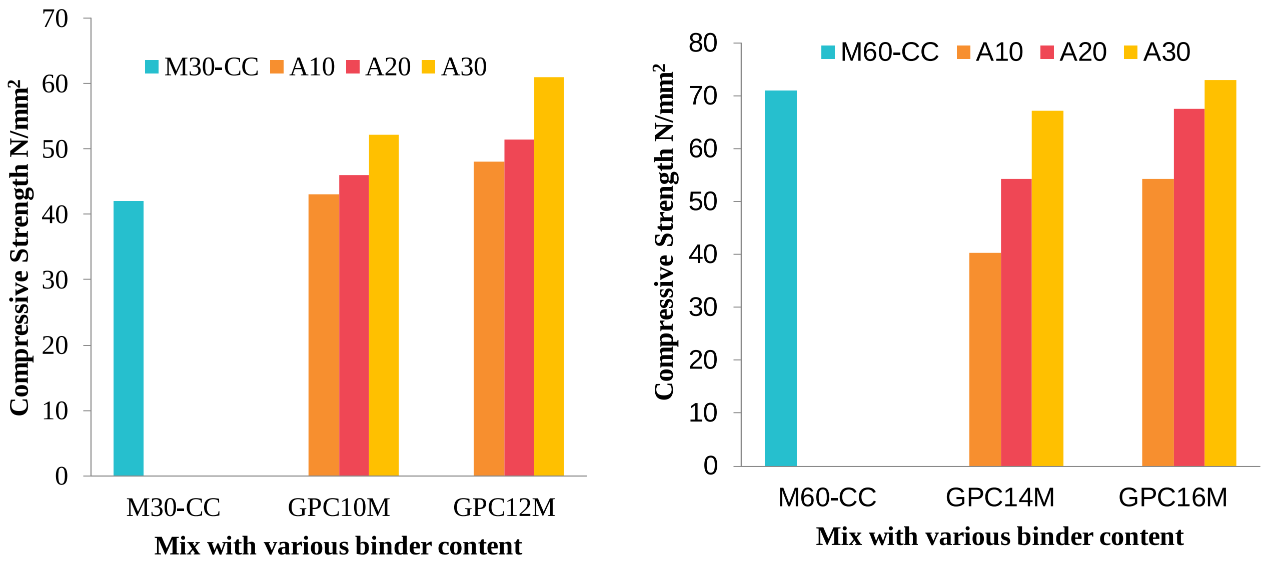
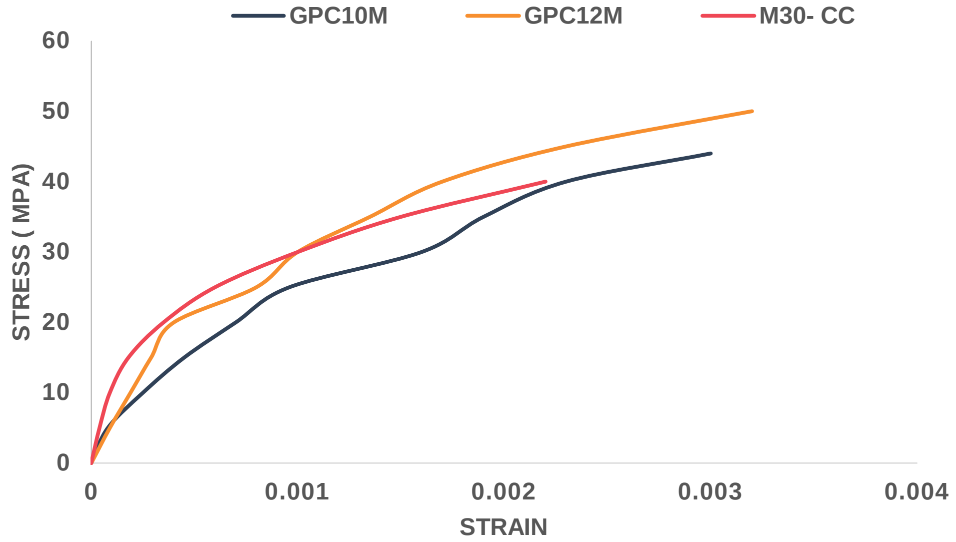


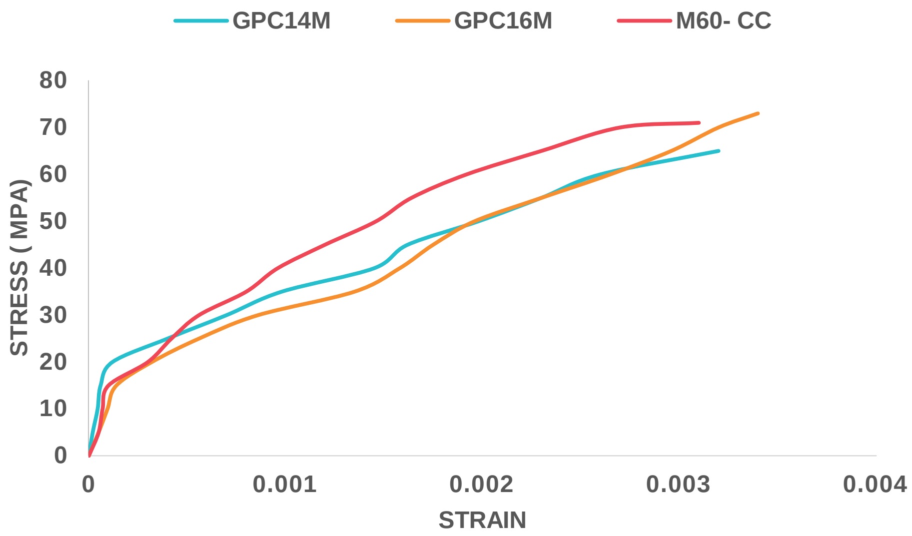
Figure 6: 28 days Compressive strength test on CC Vs GPC

3.4 Modulus of Elasticity

The standard size of cylinder 150mm diameter x 300mm height guidelines taken from (BIS 516: 2004) was cast to examine the elasticity of concrete at 28 days for both conventional (M30&M60) and Geopolymer concrete Molarity10, Molarity12, & Molarity 14, Molarity 16 were tested with the help of a compression testing machine, with 2000 kN capacity. The casted specimen undergoes uniaxial compression and the deformations are measured through a dial gauge attached between the gauge length of 200mm. The researcher applied a gradual load at 10MPa/min and observed the deformation. The true elasticity of the initial tangent modulus with its slope of a tangent to the curve at the origin gives a modulus of elasticity.



(a)



(b)

Figure 7: (a) & (b) Stress-strain curve for CC and GPC concrete specimens on 28th day

4 Discussion

4.1 Workability

One can achieve the fresh property of geopolymer concrete through the slump cone method. The size of the apparatus was 100x200x300mm, the workability was tested as per the guidelines taken from (BIS 1199: 2004). The workability of various fly ash with alccofine content is mentioned in Figure 4. The slump value was noted for M30 CC, M60 CC, and different Fly ash content with increasing alccofine percentage for GPC was noted. A measurable slump value is indicated in Figure 4. It was concluded that the slump value improved by 10% to 15 % when molarity varied from 10-12M and 14-16M. Workability decreased due to the increase of NaOH content in the activator, by adding alccofine gives more flexibility to concrete due to the presence of CaO content. The optimum slump values obtained from all GPC mixes by adding 2% of Naphthalene sulphonate superplasticizer produce good workability to concrete.

4.2 Compressive Strength

The target compressive strength of conventional concrete with its grade M30-CC and M60-CC was compared with Geopolymer concrete (GPC) to its different molarities, Molarity10 and Molarity12 for M30 Mix, Molarity14 and Molarity16 for M60 mix. It has been noted that the geopolymer concrete achieves the target strength of conventional concrete at its 7^{th}day compression test. The test was conducted on the 7^{th} day as well as on 28^{th} day of casting, with the highest compressive strength of GPC concrete 42 Mpa and 71.6 Mpa for the replacement of 90%Flyash with 10%Alccofine and 70%Fly ash with 30%Alccofine on the 7^{th} day of testing mentioned in Figure 5. At the age of the 28th day, the strength was marginally increased from 42 to 43.25Mpa and 71.6 to 73Mpa shown in Figure 6.

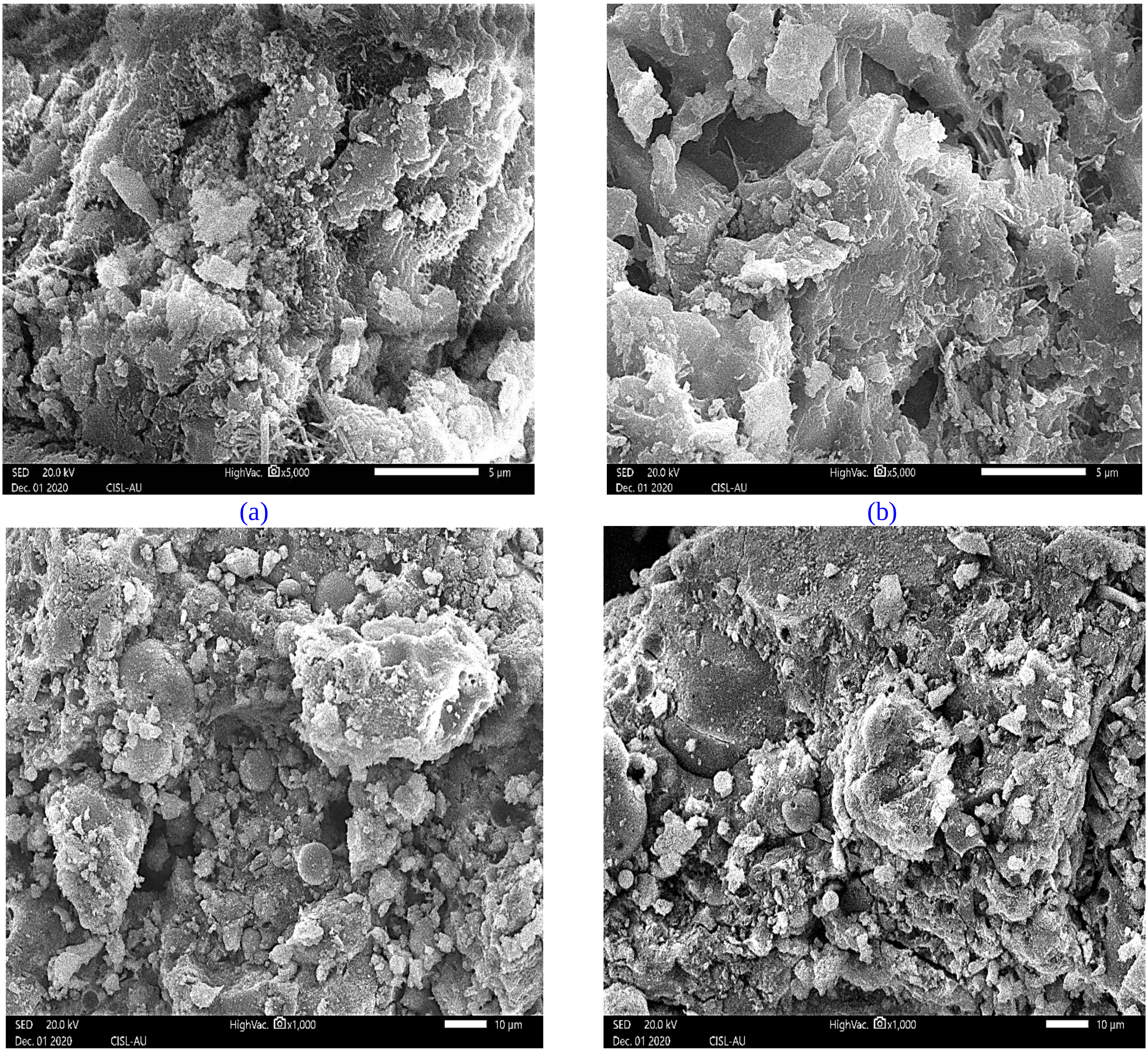
It has been noted that increasing fly ash with the optimum percentage of alccofine increases the compressive strength. It was due to Silica and alumina content in fly ash leads to a good binding effect for further increasing the strength, alccofine was added with fly ash which can densify the concrete. A pozzolanic reaction i.e. C-S-H gel formation occurs due to more CaO content present in Alccofine. In addition to that alkaline activator solution with a binder material, the polymerization process takes place(Amran et al., 2020). Due to the presence of sodium silicate hydrate (NA-S-H)and calcium silicate hydrate(CA-S-H) in the activator which can give maximum strength to the concrete (Yip et al., 2008).

4.3 Modulus of Elasticity

The researcher determined the modulus of elasticity in concrete direct compression with initial tangent modulus from the stress-strain curve of GPC and CC. The stress-strain behavior of GPC and CC is shown in Figure 7. The study obtained the following modulus of elasticity values i.e., 36 GPa for M10, 47GPa for M16, and for CC is 34GPa and 44.5 GPa. Geopolymer concrete had a slightly higher stress-strain behaviour compared to conventional concrete due to the presence of aluminosilicate in fly ash and CaO content in alccofine which gives more bonding capacity.

4.4 Scanning Electron Microscope (SEM)

Under different molarities, the geopolymer concrete's microstructural characteristics were studied with the help of SEM analysis. SEM analyses were performed on prepared specimens CCM30, GPC10M, GPC12M, CCM60, GPC14M, and GPC16M to classify the reactance of fly ash in the internal microstructure and to verify it SEM samples were assessed by using JEOL-JSM-IT 200. The maximum size of the samples was 32mmX10mm. The voltage for this SEM analysis is 0.5kV to 30kV and the image was magnified up to 300000X. The SEM analysis was conducted after achieving the optimum strength and compared with GPC and CC.



(c) (d)

Figure 8: SEM picture for CC and GPC (a) M30-CC (b) M60-CC (C) GPC10M (d) GPC16M

The interlocking between aggregate cement matrix of GPC with conventional concrete has been compared. It has been noted that alccofine added GPC has fewer pores present inside the concrete compared with CC mentioned in Figures 8 (a) & 8(b). GPC with alccofine, which should be tuned with sodium silicate gel, possesses hydration heat. The heat developed due to CaO content in alccofine(Parveen et al., 2018). Figures 8(c) & 8(d) show that the spherical zone indicates calcium aluminosilicate particles in the GPC mix. The voids and cracks present in conventional concrete were more as compared with Geopolymer concrete with optimized alccofine percentage. In addition to that, the higher the addition of NaOH with sodium silicate gives densified concrete with higher strength. Therefore Molarity 10 (GPC10M) and Molarity 16 (GPC16M) gives optimal expected target strength as well as SEM compared with M30 and M60 CC. Hence GPC may achieve earlier strength, higher densification is due to the polymerization process follows sodium silicate hydrate (NA-S-H) and calcium silicate hydrate (CA-S-H) in GPC mix. Figure 8 shows the densification of a concrete matrix using SEM analysis.

5 Conclusion

In this study, alccofine based geopolymer concrete was contrasted with traditional concrete. Geopolymer concrete with the optimum percentage of alccofine compared with Conventional concrete. This study provided advanced results about the mechanical properties and microstructural characteristics of fly ash-based GPC. Compressive strength has been directly proportional to workability. GPC at ambient curing and conventional concrete as water curing was carried out for 28 days. GPC achieves target compressive strength of conventional concrete on 7th day of testing. SEM analysis helps to examine the compactness of alccofine based GPC with internal structure through a dense matrix and little micro-cracks with lesser pores give higher strength. XRD analysis denotes the percentage of chemical components present in fly ash and alccofine. When the molarity of NaOH is enhanced, it increases the mechanical strength but decreases the workability. GPC has a stress-strain behaviour which is 5-10% higher than the conventional concrete.

6 Availability of Data and Material

Data can be made available by contacting the corresponding author.

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