EFFECT OF ALCCOFINE 1203 ON SETTING TIMES AND STRENGTH OF TERNARY BLENDED GEOPOLYMER MIXES WITH MSAND CURED AT AMBIENT TEMPERATURE

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Using the geopolymer concrete/mortar in the construction industry can reduce CO_2 emissions by consuming low embodied energy and fewer natural resources than the Ordinary Portland Cement (OPC). Most of the previous works on geopolymer concrete/mortar were cured in elevated temperature to attain the strength. This is considered to be a limitation in using the geopolymer technology in the construction industry. The present study investigated the effect of alccofine 1203 in the ternary blended geopolymer mortar and concrete with msand as fine aggregate and geopolymer specimens cured at ambient temperature. The results showed that with increasing the percentage of alccofine 1203 content in the ternary blended binder has significantly influenced the consistency, setting times and the compressive strength than the mix without alccofine 1203. Using fly ash, GGBFS and alccofine 1203 with msand can replace the use of OPC completely. The study also includes the effect of setting times and the SiO_2 to Al_2O_3 ratio on the compressive strength of geopolymer specimens.

Keywords: *fly ash, GGBFS, alccofine 1203, alkaline solution, and compressive strength*

1. Introduction

Cement is used as a binder material in the construction industries for the centuries, because of its easy in operation and availability. The demand for the cement increases rapidly with the increase in population and urbanization. According to the statistics, the requirement of cement would reach 550 million tons with a shortage of 230 million tons by the year 2030 in India. The major disadvantage of cement production, such as consumption of 5% natural resources and it is estimated that annually 1.35 billion tons or 5-7% of the total greenhouse gas emissions are from Ordinary Portland Cement (OPC) [1-3]. With the rapid increase in infrastructure, cement usage is unavoidable. In order to build a sustainable environment and to meet the future demand of concrete, it is extremely important for the construction industries to find the alternate source of binding material in concrete with less impact on the environment. Several researchers focused on alternate binding material in partial replacement of OPC with supplementary cementitious materials with fewer carbon emissions. On the other hand, the industrial growth rate in the 20th century has increased to meet the basic needs of the country. The byproducts of thermal power plants, iron industries, steel industries, rice industries, and mining industries create a threat to the environment if disposed of without proper treatment. These industrial byproducts such as fly ash, GGBFS, rice husk ash, alccofine1203, silica fume, and metakaolin require a vast area of land for their safe disposal. The safe disposals of industrial byproducts are a non-viable factor for the industries. The industrial byproducts can be used as the replacement of cement or as an additive in cement to build green concrete [4]. Every year tons of industrial byproducts are generated and cause environment and water pollution by land fillings to the surrounding fields [5]. Increase in the awareness of environmental consequences on human health due to solid waste generation and disposal, made researchers to use industrial byproducts as a construction material [5]. In the year 1979 Davidovits a French scientist to reduce the usage of cement, introduced geopolymer concrete by utilizing the industrial byproducts (i.e. fly ash) and alkaline solution [6]. This geopolymer concrete can reduce Co_2 emissions, which are a major contributor of global warming. Geopolymer technology can transform alumina-silicate industrial byproduct materials into value-added, which in turn protects the environment from pollution [7]. The industrial byproducts such as fly ash, GGBFS, alccofine 1203, rice husk ash, metakaolin, and silica fume are rich in alumina and silica are used as a primary precursor to form amorphous geopolymer binder in the presence of alkaline solution [8,9]. Due to the formation of tetrahedral bonds between the elements Si-O-Al, geopolymers are considered as inorganic polymers [10]. The efficiency of geopolymer concrete mainly depends on alkali activators and alumino-silicate source materials [11]. Using 100% fly ash as a binder in geopolymer

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concrete, cured at ambient temperature develops slow compressive strength [12]. Hardjito et al. [13] suggested that for fly ash based geopolymer concrete, temperature curing can significantly improve the compressive strength. Temperature curing restricts the usage of geopolymer concrete at site conditions; to remove this limitation Pradip Nath et al. replaced fly ash with GGBFS to increase the calcium content in the source materials, to accelerate the geopolymerization reactions at ambient temperature [14]. Incorporating Alccofine 1203 as a ternary blender in geopolymer concrete improved the pore filling and increases the workability at low water content. Replacing the river sand with msand can protect the natural streams and reduces the scarcity of the sand in the construction industry.

The aim of the study is to widen the applications of geopolymer technology in the construction sector. Consistency, setting times for the geopolymer paste mixes and compressive strength are studied for both the geopolymer concrete and mortar mixes by varying the percentages of alccofine 1203 in the ternary blended geopolymer mixes cured at ambient temperature with msand as fine aggregate.

2. Materials

Geopolymer concrete is prepared by utilizing the locally available industrial byproducts low calcium class F fly ash as per ASTM C 618 [15] (CaO<10%). Fly ash is obtained from the Kakatiya Thermal Power Plant Telangana. The particle shape of fly ash is spherical in nature shown in Fig. 1, with specific gravity 1.9 and fineness 224 m^2/kg. The commercially available Ground Granulated Blast Furnace Slag (GGBFS) is a byproduct of iron ore industry and obtained in a processed form supplied by Astraa Chemical Chennai with chemical moduli (BS:6699) [16] $CaO+MgO+SiO_2$=76.03%, $CaO+MgO/SiO_2$=1.03 and CaO/SiO_2=1.07. The specific gravity of GGBFS is 2.5 g/cc and fineness is greater than 390m^2/kg. Alccofine 1203 (Ultra-fine Slag) is low calcium silicate material improves the workability and compressive strength due to controlled granulation and high glass content. Alccofine 1203 is commercially available, processed by Counto Micro fine products Pvt. Ltd. confirming to the ASTM C989-99 [17] with fineness 1200m^2/kg and specific gravity 2.86. The particle shape of GGBFS and alccofine 1203 is angular in shape, mentioned in Fig. 1. The chemical properties of fly ash, GGBFS, and alccofine 1203 are mentioned in Table 1. The alkaline solution binds the alumina silicate based industrial byproducts, fine aggregate and coarse aggregate to form hard rock like geopolymer structure. Alkaline solution is prepared a day prior to usage. Alkaline solution is the combination of (12M) Sodium hydroxide (NaOH) and Sodium silicate (Na_2SiO_3). Sodium hydroxide used is industrial grade with 98% pure and allowed to dissolve in distilled water of required molarity. Sodium silicate solution is prepared with (SiO_2=32.62%, Na_2O=14.30%, and H_2O=53.08%) mass ratio of SiO_2 to Na_2O is 2.28.The ratio of sodium silicate to sodium hydroxide used for the entire work is 2.5. The fine aggregates used is msand confirming to zone II and fineness modulus is 3.2 and coarse aggregate passing through 20mm and retained on 12.5 mm with fineness modulus 6.89 (IS 393) [18] is used in this work. Aggregates are in surface saturated dry condition at the time of usage. Properties of aggregates are mentioned in Table 2. Super plasticizer and additional water is used in the mixes to improve the workability.

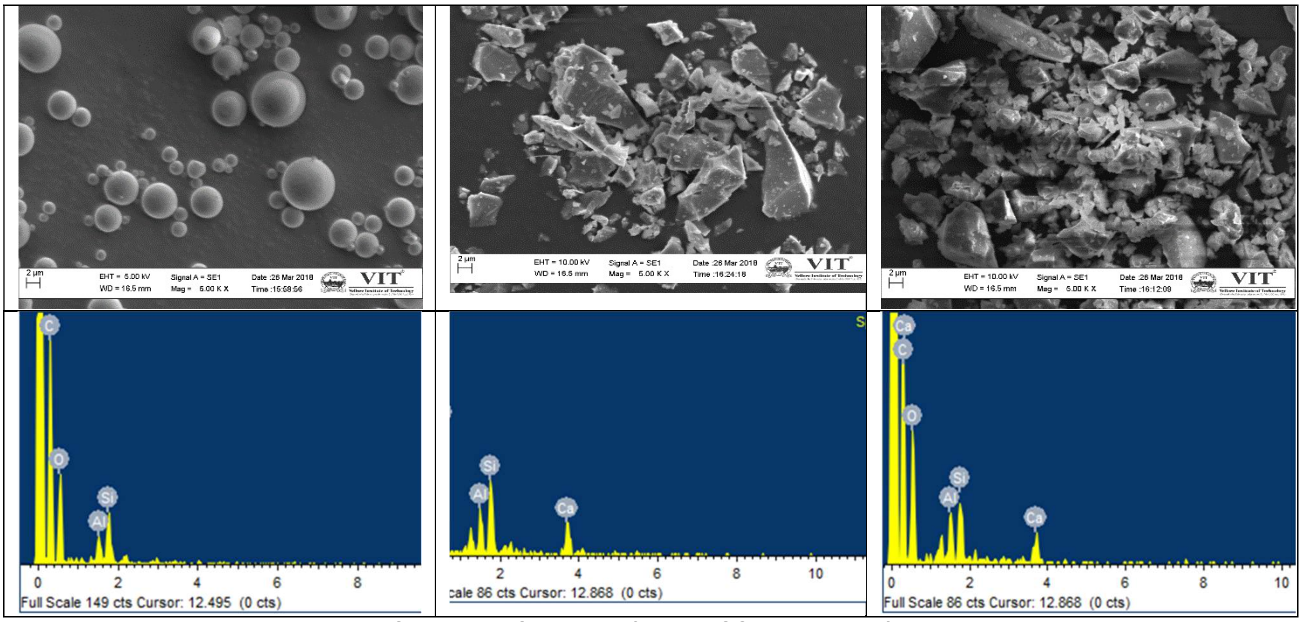

Fig.1 - SEM and EDS analysis of Flyash, GGBF, and Alccofine 1203.

Table 1

Chemical composition (%) of Binder Material

Binder	SiO_2	Al_2O_3	Fe_2O_3	CaO	K_2O	TiO_2	MgO	Na_2O	SO_3	Others
Flyash	57.3	23.4	6.73	6.21	1.99	1.84	1.14	0.235	.60	0.55
GGBFS	32.99	14.5	0.18	40.91	0.33	0.66	7.73	0.25	1.84	0.61
Alccofine 1203	36.5	21.5	1.18	32.2	-	-	6.1	-	1.2	1.32

Table 2

Properties of aggregates

Property	Fine Aggregate	Coarse aggregate	IS codes
Specific gravity	2.45	2.77	383-1970
Apparent specific gravity	2.58	-	383-1970
Water absorption	2.14%	1.67	383-1970
Bulking of sand	5.6%	-	2386-part-3
Silt content	5.2%	-	383-1970

Table 3

Mix proportions of geopolymer concrete and mortar

	Concrete Quantity (Kg/m³)							Mortar Quantity (Grams)						
Mix	C1	C2	C3	C4	C5	C6	C7	M1	M2	M3	M4	M5	M6	M7
Flyash	175.1	157.6	140.6	122.6	175.1	175.1	175.1	200	180	160	140	200	200	200
GGBFS	175.1	175.1	175.1	175.1	157.6	140.6	122.6	200	200	200	200	180	160	140
Alccofine	0	17.5	35	52.5	17.5	35	52.5	0	20	40	60	20	40	60
CA	1204	1204	1204	1204	1204	1204	1204	0	0	0	0	0	0	0
FA	769.8	769.8	769.8	769.8	769.8	769.8	769.8	400	400	400	400	400	400	400
SS	112	112	112	112	112	112	112	128.5	128.5	128.5	128.5	128.5	128.5	128.5
SH	45	45	45	45	45	45	45	51.4	51.4	51.4	51.4	51.4	51.4	51.4
SP	7	7	7	7	7	7	7	0	0	0	0	0	0	0
water	35.2	35.2	35.2	35.2	35.2	35.2	35.2	40	40	40	40	40	40	40

Note:- CA-Coarse Aggregates, FA- Fine Aggregates, SS- Sodium Silicate, SH- Sodium Hydroxide, SP- Super Plasticizer

3. Mix proportions

Total 7 concrete and 7 mortar mixes were prepared with different binder proportions to study the effect of replacing fly ash and GGBFS with alccofine 1203. Mix proportions are shown in Table 3. The mix design of geopolymer concrete was done according to the previous researches Lloyd and Rangan [19]. The mix proportions of geopolymer concrete are indicated with C series and the mortar mixes are indicated with M series. Mixes C1 and M1 are control mix of concrete and mortar having 50% fly ash and 50 % GGBFS. In the mixes 2, 3 and 4 fly ash is replaced with alccofine1203 at 5%, 10%, and 15% and in the mixes 5,6, and 7 GGBFS is replaced with alccofine 1203 at 5%, 10%, and 15% respectively. All the mixes are having a constant alkaline to binder ratio of 0.45 and sodium silicate to sodium hydroxide ratio 2.5. The alkaline solution is prepared 24 hours before for effective geopolymerization [20]. Consistency and settings times of the geopolymer paste are done to understand the reactivity of fly ash, GGBFS and alccofine 1203 with the alkaline solution in the corresponding geopolymer paste mixes.

4. Experimental work

4.1. Consistency of ternary blended geopolymer mixes

The procedure for determining the consistency of geopolymer paste is similar to the consistency of Ordinary Portland Cement (OPC) as per IS 4031 Part 4 [21]. The Vicat apparatus confirming to IS: 5513 [22] is used to determine the consistency. Consistency is the percentage of an alkaline solution required to prepare the geopolymer paste. The test conducted with different proportion of binder and different percentages of alkaline solution until the penetration of needle is 5 mm to 7 mm from the bottom of the mould. The consistency of geopolymer paste is highly influenced by the fineness of binder materials, molarity of the NaOH and Na_2SiO_3/NaOH ratio [23-24].

4.2. Setting time of ternary blended geopolymer mixes

Setting times of geopolymer paste help to understand the time required for transport, placing and compacting the geopolymer concrete and the workable time of the geopolymer mixes. Initial setting time and the final setting time helps to understand the workable time of the geopolymer paste. The initial and final setting time of geopolymer paste is determined similar to the OPC paste as per IS 4031 part 5 [25]. Time is recorded when the alkaline solution is added to the binder materials. Initial setting time is found by allowing the 1mm square needle to penetrate into the paste for every 10 minutes until the reading on the index scale shows 5mm to 6mm from the bottom of the mould. Final setting time is determined by penetrating the annular collar of 5 mm into the paste for every 10 minutes until it fails to make an impression on the surface of the paste. The setting time depends on the factors like amount of the alkaline solution, the molarity of NaOH, particle size, shape, and proportions of binder materials and the ratio of the Na_2SiO_3 to NaOH [24]. Fly ash alone in the geopolymer mortar has a setting time of nearly 25 hours [26] and by replacing fly ash with GGBFS reduces the initial and final setting time of geopolymer paste [23]. The presence large amount of calcium in GGBFS reacts with the alkaline solution and accelerates the setting time.

4.3. Casting, Curing, and Testing of geopolymer specimens

Manufacturing of geopolymer concrete specimens C1 to C7 is similar to that of OPC concrete. Collect all the dry materials in required quantities (Table 3) and mix it for four minutes until it attains the homogeneous mixture. Gradually add the premixed alkaline solution, water, and super plasticizer to the dry materials and continue the mix for the next four minutes until the mixture has attained a uniformity. Place the concrete in cube molds of size 100 mm in three layers by tapping and place the moulds on the vibration table for 20- 40 sec to remove the entrapped air. The cast specimens are demolded after 24 hours and allowed it to cure at room temperature of 28^0C – 30^0C until the age of testing i.e., 7days and 28 days. Mortar specimens M1 to M7 are cast according to the past research done by D.Hardjito et al. and Tenepalli jai Sai et al.) [27,28]. Collect all the desired quantities of dry materials (Table 3) for five minutes until it attains a homogeneous mixture and add the premixed alkaline solution and water gradually to the dry mix and continue the mix for next five minutes until it attains a uniform mortar mixture. The geopolymer mortars is placed in cube mold of size 70.6 mm (IS 10080) [29] in two layers and place the mould on the vibrating table for 20-40 sec to remove the entrapped air. The casted specimens are allowed to dry for a rest period of 24 hours [30] and demold the mortar cube specimens and allow the specimens to cure at room temperature of 28^0C to 30^0C until the test age of 7days and 28days. Testing of geopolymer concrete and mortar specimens are carried out on compression testing machine of capacity 2000kN.

5. Results and Discussion

5.1. Effect of Alccofine 1203 on the consistency of geopolymer paste

Consistency of geopolymer paste depends on the replacement level of fly ash and GGBFS with alccofine 1203. Fig.2. depicts the influence of alccofine1203 on the consistency of geopolymer paste. Control mix with 50% fly ash and 50% GGBFS has the consistency of 33%. With increase in the replacement level of fly ash with alccofine 1203 consistency is increased, due to increase in the alccofine1203 and decrease in fly ash content in the mixes. Mix 4 with 35% fly ash, 50% GGBFS and 15% alccofine has achieved the highest consistency of 37%. In the mixes 5 to 7 GGBFS is replaced with alccofine1203, consistency decreased due to high fly ash content. The spherical shape of the fly ash consumes less alkaline solution than the GGBFS with angular shape. The mix with high fly ash and high alccofine1203 i.e., mix 7 requires less alkaline solution of 30% and the mix 4 with low fly ash and high alccofine 1203 requires more alkaline solution of 37%. Similar kind of results was observed by G.Mallikarjuna Rao et al. [23] for fly ash and GGBS paste.

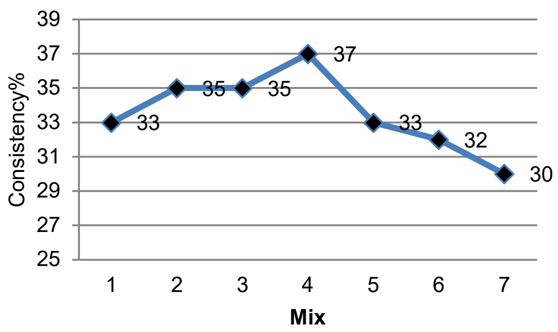

Fig.2 - Consistency of ternary blended geopolymer paste mixes.

5.2. Effect of Alccofine1203 on setting times of ternary blended geopolymer paste

Fig.3. depicts mixes 2-4 fly ash is replaced with alccofine 1203 with an increase in the percentage of alccofine 1203, setting time's increases due to high glass content and low calcium content in the alccofine 1203 makes the paste more workable. The mixes 5-7 GGBFS is replaced with alccofine1203, has given significant higher setting time values than the mixes of fly ash replaced with alccofine1203 because of increase in fly ash content in the mixes. Higher the GGBFS content in the binder lower the setting time of the geopolymer paste due to high calcium content in the mix, similar behavior was reported by (G.F. Hussein *et al*. and M.H Al-Majidi *et al*.) [3,31]. The

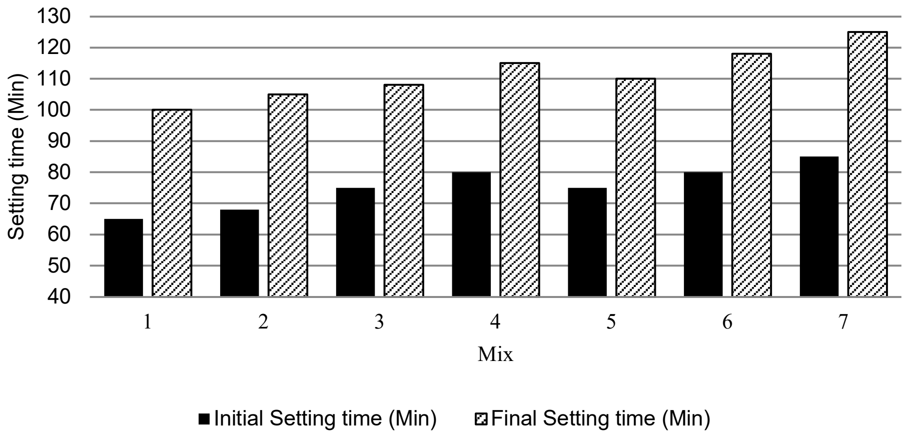

Fig.3 - Initial and final setting times of ternary blended geopolymer pastes.

Table 4

Compressive strength (MPa) of ternary blended geopolymer concrete and mortar specimens

Concrete	7Days	28Days	Mortar	7Days	28Days
C1	52.4	58.5	M1	45.7	49
C2	52.8	62	M2	50.7	51.52
C3	69	69.1	M3	53.11	56.2
C4	71.5	72.5	M4	60.6	63.55
C5	65.6	67.5	M5	48.65	50.74
C6	60.1	61.6	M6	40.28	48.01
C7	48.4	55.4	M7	36.21	46.6

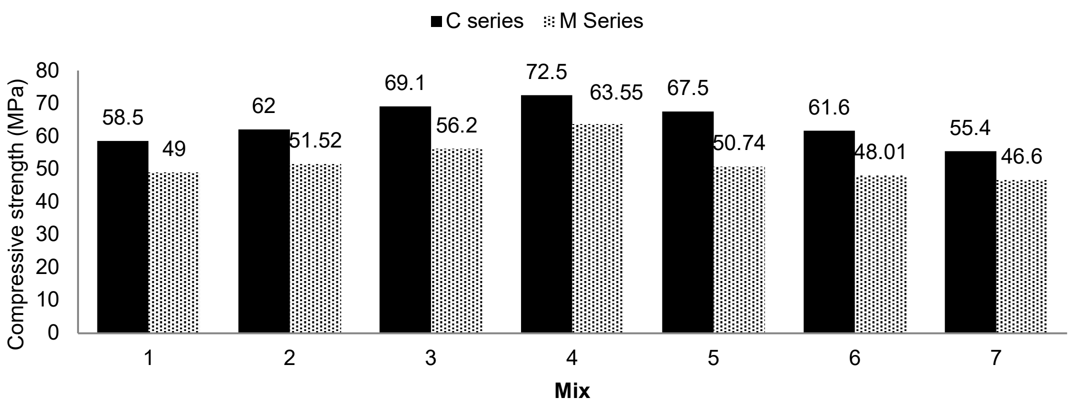

Fig. 4 - Effect of Alccofine 1203 on the compressive strength of concrete and mortar at 28days.

mix 7 with 50% fly ash, 35% GGBFS and 15% alccofine 1203 has the highest initial setting time of 85 minutes and final setting time of 125 minutes. The mix 1 with 50% fly ash and 50% GGBFS has the least initial setting time of 65minutes and final setting times of 100 minutes. Alccofine1203 significantly influenced the setting times of the ternary blended geopolymer pastes.

5.3. Effect of alccofine 1203 on compressive strength of ternary blended geopolymer mixes

Quality of geopolymer concrete and mortar mixes are accessed based on attainment of compressive strength. Compressive strength development of ternary blended geopolymer concrete and mortar specimens are shown in Table 4. The inclusion of alccofine1203 as a ternary binder in geopolymer concrete and mortar significantly influenced the compressive strength at 7days and 28 days. Compressive strength attainment in concrete specimens is relatively higher than the mortar specimens at 5%, 10% and 15% replacement levels of alccofine 1203 with fly ash and GGBFS. 90% of compressive strength in ternary blended geopolymer concrete and mortar specimens have attained in 7 days.

5.3.1. Effect of compressive strength on replacing fly ash with alccofine 1203 in ternary blended geopolymer mixes

From Fig.4 and Table 4, Mix 1 with 50% fly ash and 50% GGGBFS has attained the compressive strength of 58.5 MPa for concrete and 49 MPa for mortar at 28 days. With an increase in the replacement level of fly ash with alccofine 1203 compressive strength increased. Mix 4 with 35% fly ash, 50% GGBFS and 15% alccofine 1203 has attained a compressive strength of 72.5 MPa for concrete and 63.55 MPa for mortar. At 28 days compressive strength of 5%, 10% and 15% replacement levels of fly ash with alccofine 1203 have attained 5.12%, 14.69% and 29.6% higher compressive strength as compared to the control geopolymer mix (no alccofine 1203) for mortar mixes. The concrete mixes at 28 days have achieved 5.9%, 18.11% and 23.93% higher strength than the control mix (no alccofine 1203). The concrete and mortar mixes have a similar percentage increase in compressive strength. The increase in alccofine 1203 content in the mix with replacement to fly ash makes the mix denser and calcium content is increased and makes the mix more workable without an increase in water content. With increasing the replacement of alccofine 1203 with fly ash in the geopolymer concrete and mortar mixes, the compressive strength has increased significantly.

5.3.2. Effect of compressive strength on replacing the GGBFS with alccofine1203 in ternary blended geopolymer mixes.

It is depicted from Fig.4. and Table 4 the mixes 5 to 7 GGBFS is replaced with the alccofine1203 in 5%, 10% and 15% respectively. It is observed that the compressive strength of geopolymer mortar and concrete increases at 5% replacement but at 10% and 15% replacement levels of alccofine 1203 the compressive strength decreases. Low replacement level the compressive strength is increased but at high percentage replacement level strength decreased, this is due to change in the calcium content and the fineness of the alccofine 1203. The similar findings were observed in Ganapathi Naidu *et al*. [32].The percentage decrease in compressive strength from mix 1 to mix 7 is 4.8% for geopolymer mortar and 5.29% for concrete. Fig.4 depicts similarity in the reduction of compressive strength for both the mortar and concrete at 7 days and 28 days.

5.4. Correlating the compressive strength of geopolymer mixes with setting times.

Incorporating the alccofine 1203 with fly ash and GGBFS as a ternary binder in geopolymer mortar and concrete can significantly increase the initial and final setting times of the paste. With the increase in alccofine 1203 content at particular alkaline to binder ratio, setting times and compressive strength of mortar and concrete increased significantly. It is observed in the laboratory, the rheological behavior of geopolymer concrete and paste is different from OPC concrete and paste. With 50% fly ash and 50% GGBFS the setting of geopolymer concrete is low and difficult to handle. Addition of alccofine 1203 as a ternary binder in the geopolymer mixes, the handling time of the fresh mix is improved and due to its ultra-fineness compressive strength increased. From Fig.5. the mix4 with 35% fly ash, 50% GGBFS and 15% alccofine 1203 content has the final setting time of 115 minutes and achieved the compressive strength of 72.5MPa for geopolymer concrete and 63.5MPa for mortar. With an increase in the alccofine 1203 content with replacement of fly ash improved the setting times and increased the compressive strength. Replacing the alccofine 1203 with GGBFS setting times is improved but the compressive strength decreased due to decrease in the calcium content in the mix. The increase in setting time is due 50% fly ash and increase in alccofine1203 content and compressive strength is decreased due to decrease in the calcium content in the mixes. Similar trend of results is observed for the mortar and concrete specimens. The mix with 35% fly ash, 50% GGBFS and 15% alccofine 1203 with Na_2SiO_3 to NaOH ratio 2.5, with 100% msand and alkaline to binder at 0.45 is a recommended geopolymer mix for geopolymer mortar and concrete cured at ambient temperature.

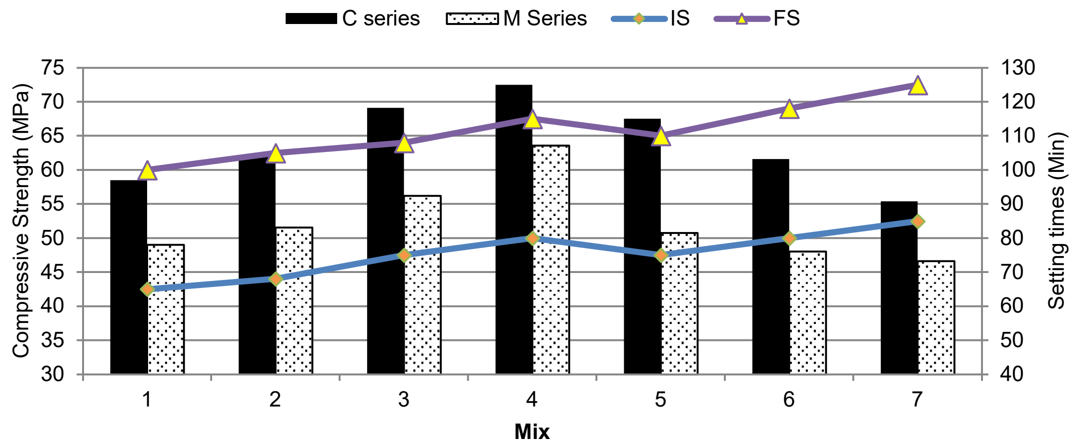

Fig 5 - Correlation compressive strength and setting time of ternary blend geopolymer concrete and mortar specimens.

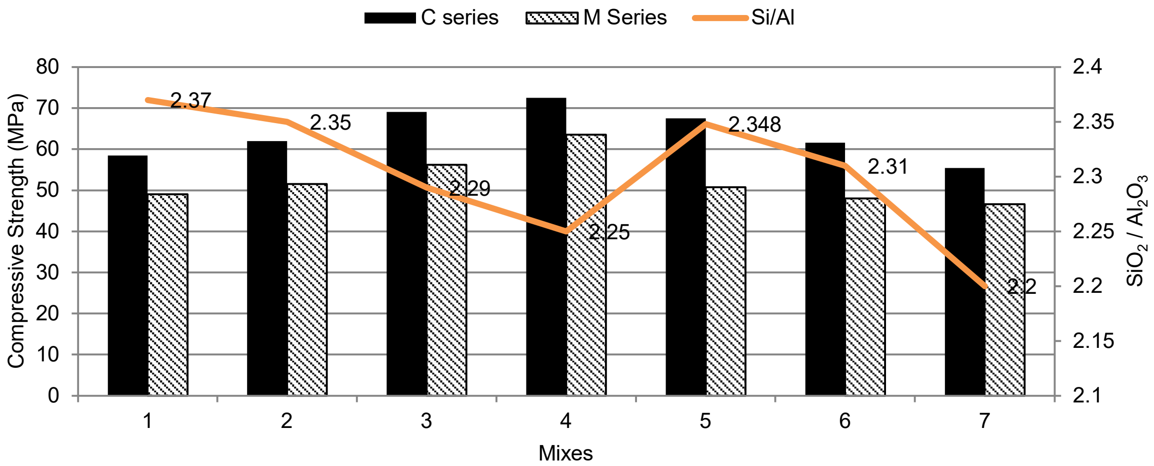

Fig.6. Correlation between compressive strength and Si/Al ratio of geopolymer mixes.

5.5 Effect of SiO_2 to Al_2O_3 ratio on compressive strength of ternary blended geopolymer mixes

The behavior of geopolymer mixes is different from OPC mixes. Fig.6. depicts the variation of SiO_2 / Al_2O_3 ratio in the ternary blended geopolymer mixes with msand as fine aggregates. The microstructure formation of geopolymer mixes depends on the internal kinetic reaction ratios. The presence of SiO_2 and Al_2O_3 is responsible for the formation of SiO_4 and AlO_3 ions in the geopolymer mixes. With the inclusion of alccofine 1203 in replacement of fly ash at 5%, 10%, 15% the SiO_2 / Al_2O_3 ratio decreases, this will result in an increase in the covalent bonds of Si-O-Si and ultimately results in the development of compressive strength. The increase in the replacement of GGBFS with alccofine 1203, SiO_2 to Al_2O_3 ratio decreased and is responsible for the reduction in the compressive strength of the geopolymer mixes. The soluble silica present in the sodium silicate is responsible for the condensation process and introduces more silica in the mix. The mix 4 with SiO_2 to Al_2O_3 ratio 2.25 has attained the highest compressive strength of 72.5 MPa for concrete and 63.55 MPa for geopolymer mortar mixes. Mix 7 with 2.2 has attained the lowest compressive strength of 55.4 MPa and 46.6 MPa for geopolymer concrete and mortar mixes. The similar kind of results was observed by M.Ghanbari *et.al*. [33]. SiO_2 / Al_2O_3 have negative effect on compressive strength. Higher the ratio the system will in saturate with Na^+ ions.

6. Conclusions

Industrial byproducts based geopolymer concrete can effectively replace the OPC concrete or mortar with superior performance. This helps in conservation of natural resources and protects the environment from pollution.

- Replacing fly ash and GGBFS with alccofine 1203 has significantly influenced the consistency values of the geopolymer paste. The mix 4 has the highest consistency of 37% and mix 7 has attained a lowest consistency of 30%.
- Alccofine1203 as a ternary binder in geopolymer paste has significant impact on the setting time, with increase in the replacement levels of fly ash and GGBFS with alccofine 1203 setting times increased. The increase in initial and final setting times from mix 1 to mix 4 is 15 minutes and the increase in the initial and final setting time form mix 1 to mix 7 is 20 minutes and 25 minutes. The improved setting times is an added advantage for working longer duration.
- The percentage increase in compressive strength at 15% replacement level of fly ash with alccofine 1203 is 29.69% for mortar and 23.93% for concrete than the mix with no alccofine1203. At 15% replacement level of GGBFS with alccofine 1203, the compressive strength decreases by 4.89% for mortar and 5.29% for concrete than the mix with no alccofine 1203. Replacing fly ash with alccofine 1203 is effective than replacing with GGBFS. The mix 4 has attained the highest compressive strength and the mix 7 has the lowest compressive strength for both the mortar and concrete. The compressive strength development in the geopolymer mortar and concrete is similar.
- The compressive strength of geopolymer mixes depends on the ratio of SiO_2 / Al_2O_3, mix4 with the ratio 2.25 has achieved the highest compressive strength of 62.55MPa for mortar and 72.5MPa for concrete. Mix 7 with SiO2 / Al_2O_3 ratio 2.2 has attained the lowest compressive strength among all the geopolymer mixes.

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