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Behavioural Analysis of Fly Ash Based Prestressed Geopolymer Concrete Electric Poles

[1]S. Muthuramalingam, [2]R. Thenmozhi, [3]T. Senthil Vadivel and [4]V. Padmapriya

[1]Executive Engineer, Tamilnadu Electricity Board, Chennai - 600 002. Tamilnadu, India
[2]Government College of Technology, Coimbatore - 641 013, Tamilnadu, India
[3]R.V.S. Technical Campus - Faculty of Engineering,
Coimbatore - 641 402, Tamilnadu, India
[4]SRM University, Chennai - 603 203, Tamilnadu, India

Abstract: The geopolymer concrete is the promising alternative material for the cement concrete which produces high strength, durability and lowering green house gases also. The recent studies of geopolymer concrete on its properties have also shown its suitability for various construction applications. This made the researchers to think about the utilization of geopolymer concrete in the precast and prestressed concrete members such as electric poles, rail sleepers and fencing posts etc. The current research is an attempt to use geopolymer concrete as a prestressed element in electric poles and analyze its suitability compared with OPC concrete based prestressed electric poles. This study has been carried out with Low Calcium Fly Ash as a source material, sodium hydroxide and sodium silicate as alkaline liquid to enhance the polymerization process and Glenium-B233 as super plasticizer to improve the workability. Two 7.5 m prestressed concrete PSGC poles and two PSC poles were cast to analyze and compare the behvaiour of PSGC poles. The identified transverse strength PSGC poles are high and the deflection was lesser than the PSC poles. The determined mechanical properties of geopolymer concrete were also compatible with the cement concrete.

Key words: Geopolymer Concrete · Low Calcium Fly Ash · Sodium Hydroxide · Sodium Silicate · Glenium-B233 · Prestressed Geopolymer Concrete Poles · Prestressed Concrete Poles

INTRODUCTION

Concrete is the essential man made material used all over the world for construction purpose. Statistics says that more than one tone of concrete has been produced each year for every human being. But the major disadvantage in the concrete was the production of green house gases by its constituent materials especially cement. India is the second largest consumer of cement in the world likely to be improved by 550 million tons in the year 2020. Hence the industry is in need of identifying a new material which replaces cement. In the other hand, increasing quantity of waste materials and industrial by-products, solid waste management is the prime concern in the world. Scarcity of land-filling space and because of its ever increasing cost, recycling and utilization of industrial by-products and waste materials has become an attractive proposition to disposal. One such industrial waste material abundantly available was fly ash which will be increased further about 400 million tons in the year 2020. The geopolymer concrete was the only solution for both the cases which can be effectively reduces the green house gases and gives the sustainable solution for the solid waste disposal.

The geopolymer concrete was developed in the year 1950 but its application has gained attention only in the recent years. Geopolymer concrete results from the reaction of a fly ash with large amount of silica and alumina with an alkaline liquid. Alkaline activators are normally enriching the polymerization process which contains sodium hydroxide and sodium silicates. Hardjito *et al.* [1] were discussed about the influence of sodium hydroxide concentration, $NaOH/Na_2SiO_3$ ratio and curing temperature in the strength characteristics of geopolymer concrete. They have reported that the NaOH concentration and alkaline ratio show positive improvement in the compressive strength of the geopolymer concrete. Further, they have proved that the elevation of curing temperature from 30 to 90°C also produces higher compressive strength. Bondar *et al.* [2]

Corresponiding Author: S. Muthuramalingam, Executive Engineer, Tamilnadu Electricity Board, Chennai - 600 002. Tamilnadu, India.

ascertained that water to fly ash ratio increment show negative impact in the strength characteristics of geopolymer concrete. Many researchers concentrated the abovesaid issues in the geopolymer concrete but the studies have been limited in the area of prestressed concrete. The current study has been established for analyzing the behaviour of Prestressed Geopolymer Concrete (PSGC) Electric Poles and which has been compared with Conventional Prestressed Concrete (PSC) Electric Poles.

Experimental Programme: The experimental programme was carried out to determine the mechanical properties of the designed geopolymer concrete, its transverse strength and deflection when it has been used in the prestressed concrete poles. The research programme includes the casting of cubes, cylinders and prisms of standard sizes and 2 Nos. of 7.50 m Prestressed Geopolymer Concrete Poles and Prestressed Concrete Poles. The materials, mix proportion, casting, curing and testing of specimens were discussed below.

Materials Used: This study was carried with Low Calcium Fly Ash (LCFA) obtained from Mettur Thermal Power Station, Tamilnadu, India. The major constituents in the fly ash are Si and Al with the ratio of 1.63, very low influence of calcium (0.65) and higher iron oxide representation compared than the cement were found. Commercial grade sodium hydroxide pellets with 98% purity and 53 grade sodium silicate were used as alkaline liquids. Natural river sand passing through 4.75mm IS sieve, crushed angular shaped 12 mm and 6 mm aggregates, Glenium-B233 as super plasticizer, High Tension Wires (HTS) as reinforcement and standard potable water have been used for the research [3, 4].

Mixing, Casting & Curing: The trial mix proportion has been arrived by assuming the density of geopolymer concrete as 2400 kg/m^3. The designed mix was 1:1.17:2.88:0.48 (Fly Ash: Sand: CA: Alakline Liquid) and the ratio between alkaline was taken as 1:2.5. Glenium B233 was added by 2% in the weight of fly ash as super plasticizer. Table 1 show the mix proportion of the geopolymer concrete. The fly ash, sand and coarse aggregate were thoroughly mixed using mixer machine and alkaline liquid which were prepared with 16M concentration of NaoH solution a day before and Na_2SiO_3 were added in the mixture with super plasticizer and water. The fresh geopolymer concrete was cast in the moulds such as cube, cylinder, prism and pole in three layers. The moulds were properly compacted using vibrating needle. Then the specimens were properly sealed and placed in the heat curing chamber and cured for 24 hours at 90ºC[5,6].

Analysis of Test Results: The tests have been carried out for both fresh geopolymer concrete and hardened geopolymer concrete using well accepted destructive testing methods. The procedures and results were discussed below.

Workability: The geopolymer concrete in the previous studies exhibited high viscosity and cohesive nature. According to them the increasing the mixing time increases the temperature of the fresh geopolymers and hence reduced the workability. Further they have suggested using admixtures to reduce the viscosity and cohesion which will improve the workability. The current study has taken the above studies into account and added Glenium B233 by 2% in the weight of fly ash as super plasticizer which increased the workability as expected and produced 73 mm slump. Figure 1 show the progression of slump test[7-9].

Fig. 1: Slump Test of Geopolymer Concrete

Table 1: Mix Proportion of Geopolymer Concrete

Ingredients	Fly Ash	River Sand	Jelly 12 mm	Jelly 6 mm	Alkaline / Fly Ash Ratio	Alkaline Liquid	NaOH	Na_2SiO_3	Super Plasticizer	Added Water
Weight (kg/m^3)	485	567	524	591	0.48	233	66.57	166.43	9.70	9.70

Mechanical Properties: The cast specimens were tested for compressive strength, split tensile strength and flexural strength. The results were very much compatible with the conventional concrete. Since the geopolymer concrete has been designed for M40 concrete and the characteristics compressive strength achieved was very closer to the target mean compressive strength. The higher curing temperature results the better mechanical properties in just one day curing which may be very much suited for prestressed concrete to produce electric poles in early days. Figure 2 show the testing of specimen and Figure 3 show the mechanical properties of geopolymer concrete.

Fig. 2: Compressive Strength Test Setup

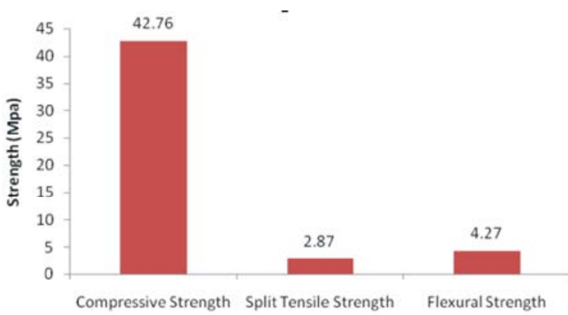

Fig. 3: Mechanical Properties of Geopolymer Concrete

Pole Destruction Test: The electric pole of 7.50 m was having bottom end size 280 mm x100 mm and 100 mm x100 mm at the top end cast with 10 Nos. of 4 mm Ø High Tension Wires as reinforcement and which were pretensioned by one tone each with the pressure of 120 kg/cm^2 using dynamometer. After prestressing, the each wire was anchored by tapping the wedges and cast with geopolymer concrete and hot cured by 90ºC for 24 hours was tested. The same specimen were cast with conventional concrete and tested for comparison. The prestressed geopolymer concrete pole has been tested for its transverse strength in conformity with IS 2905-1966. The pole was placed horizontally on the testing bed which has been marked at an interval of 0.3m to identify crack and one end of the pole (bottom end) up to a length of 1.50 m was fixed and load was applied at 0.60m from the other end (top) of the pole by using chain pull lift along with dynamometer of 1200 kg capacity was used for Pole Destruction test. The working load of the 7.50 m pole was 140 kg with factor of safety 2.5 and load was given up to fatigue load of the pole. The maximum deflection limit of the pole is less than 2 to 5% length for 50% maximum failure load and less than 10 to 15% length for maximum failure load of the pole. Figure 4 show the prestressing procedure and cast pole specimens.

Fig. 4: Prestressing Procedure and Cast Specimens (PSC & PSGPC Poles)

Behaviour of Prestressed Concrete Poles: The hair line cracks were developed in the pole at distances of 190 cm and 245 cm from the bottom end at 380 kg. The failure occurred at 425 kg and fatigue crack occurred between 162cm-179cm from bottom end. The safe working load was 140 kg. The factor of safety was determined by the ratio between failure load and safe working load (i.e.) 425 /140 =3.036 >2.5. The mean compressive strength of the auxiliary specimen was 42.432 N/mm^2. The deflection was 9.6% of length for the maximum failure load of 425 kg and 3.87% of length for the load of 245kg, which were well within the prescribed standard of 15% length and 5% length of the pole. Hence the PSC pole was found safe and suitable for HT/LT line pole erection. Figure 5 show the load -deflection relationship of the PSC poles.

Behaviour of Prestressed Geopolymer Concrete Poles: The hair line cracks were developed in the pole at distances of 120cm, 145cm from the bottom end at 425 kg. The failure occurred at 475 kg and fatigue crack occurred between 152cm-159cm from bottom end. The safe working load was140 kg and factor of safety was 3.39. The mean compressive strength of the auxiliary specimen was 42.134 N/mm^2. At the maximum failure load of 475 kg, the deflection was 6.9333% and at 50% maximum failure load of 245kg, the deflection was 1.467% of length of the pole, which were well within the prescribed standard and hence suitable for HT/LT line pole erection. Figure 5 show the load- deflection relationship of the PSGC poles.

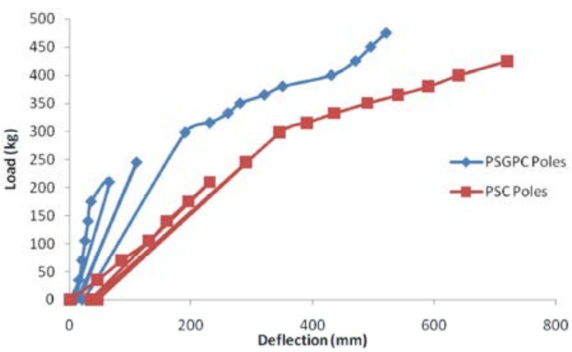

Fig. 5: Loads - Deflection Relationship of PSGPC and PSC Poles

Figure 5 was the indicator that the PSGPC carried higher load than the PSC poles. Further PSGPC show lesser deflection for the given load compared than that of PSC poles. The factor of safety of the PSGPC was also higher than the PSC poles. Hence the geopolymer show good performance in the prestressed concrete compared than the conventional prestressed concrete.

CONCLUSION

With reference to the above discussion, the following conclusions are made:

- The designed geopolymer concrete was workable and show high mechanical properties compared to the conventional concrete mix.
- The Geo polymer concrete has shown higher performance in the mechanical properties within three days of casting. Hence this will be very much suitable for precast concrete products where as in conventional procedure takes 28 days at least.
- The PSGPC electric pole show higher transverse strength and lower deflection compared than the PSC pole specimen. The PSGPC pole test carried out within three days where as PSC poles took 28 days for testing.
- Hence PSGPC could be effectively replaced with PSC since it become less time consuming, economical and safe.

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