INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI
SHORT ABSTRACT OF THESIS

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Thesis Title: Impact of alkaline activator and fly ash on strength, microstructure and durability assessment through corrosion resistance of geopolymer concrete in the presence of chloride ions

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SHORT ABSTRACT

To mitigate the problems related to higher energy consumption, higher CO_2 emission and disposal of industrial wastes, geopolymer binders based on these industrial waste materials are now widely considered as the promising substitute for Portland cement binders. It may be noted that the production of Portland cement accounts for higher energy consumption and higher amount of CO_2 emissions. The geopolymer binder has the potential to produce sustainable concrete. In the present research work, fly ash based geopolymer concrete (GPC) mixes were prepared with different concentrations of NaOH solution i.e., 8 M, 10 M, 12 M, 14 M and 16 M, alkaline solution contents of 190 kg/m^3 and 210 kg/m^3, sodium silicate solution to sodium hydroxide solution (SS/SH) ratios of 1.5 and 1.75, fly ash particles of different sizes i.e., passing through 150 µm sieve, and 300 µm sieve, and fly ash contents of 425 kg/m^3, and 450 kg/m^3. Sodium chloride (NaCl) of different concentrations i.e., 1.5%, 3% and 4.5% by mass of geopolymer solids were admixed in GPC mixes during the time of preparation. For compressive strength test, cube specimens of size 150 mm, and for corrosion measurement, prismatic specimens of size 72 mm × 72 mm × 300 mm with a centrally embedded steel bar were prepared from GPC mixes. Slump test on fresh GPC mixes, and compressive strength test on cube specimens at different ages were carried out. To evaluate the corrosion behaviour of rebar in the presence of chloride ions, half-cell potential measurement, and linear polarization resistance measurement for corrosion current density were carried out on prismatic specimens at different ages. The microstructure of GPC was analyzed by carrying out XRD (X-ray diffraction) analysis, FESEM (Field emission scanning electron microscope) analysis and FTIR (Fourier transform infrared) spectroscopy on geopolymer concrete powder samples obtained from cube specimens and prismatic specimens. In addition, free chloride, total chloride and bound chloride content of GPC mixes were determined from the powder samples obtained from cube and prismatic specimens.

The presence of sodium chloride in GPC mixes improved the consistency when compared with control GPC mix (without admixed NaCl). The compressive strength of GPC increased with increase in molarity of NaOH solution from 8 M to 16 M in control, and 1.5% NaCl admixed GPC mixes whereas in GPC mixes admixed NaCl concentrations of

3% and 4.5%, the compressive strength increased with molarity of NaOH solution from 8 M to 14 M followed by a decrease at NaOH solution of 16 M. Increase in alkaline solution content, and SS/SH ratio resulted an increase in compressive strength of GPC. However, opposite variation in compressive strength was observed with particle size of fly ash between GPC mixes made with lower and higher fly ash contents. The particle size of fly ash greatly influenced the variation in compressive strength of NaCl admixed GPC with change in fly ash content. The GPC admixed with sodium chloride showed lower compressive strength as compared to control mix. Further, the compressive strength decreased with increase in NaCl concentration. The compressive strength of GPC increased with age from 7 to 28 days in control as well as in NaCl admixed GPC mixes, whereas, it mostly decreased with age from 28 to 90 days. The GPC mixes made with larger fly ash particles, and that made with higher fly ash content mostly showed higher free chloride content than that made with smaller fly ash particles, and lower fly ash content. The variation in total chloride content of GPC mixes with mix parameters was similar to that in case of free chloride content. Mostly higher chloride binding was observed at lower molarity of NaOH solution than higher molarity of NaOH solution. The formation of more amount of geopolymer gels in GPC mixes made with larger fly ash particles as indicated by higher compressive strength resulted in higher extent of physical binding of chloride ions with geopolymer gels that led to higher bound chloride content in case of larger fly ash particles than smaller fly ash particles.

From the obtained results of XRD analysis, the peak intensity of albite, anorthoclase, and nepheline in the XRD patterns mostly increased with increase in molarity of NaOH solution from 8 M to 16 M in control as well as 1.5% NaCl admixed GPC mixes at the age of 7, 28 and 90 days thereby showing more formation of geopolymer gels at higher molarity of NaOH solution. In GPC mixes admixed with NaCl concentrations of 3% and 4.5%, the peak intensity of the compounds related to geopolymer gels in the XRD patterns mostly increased with increase in molarity of NaOH solution from 8 M to 14 M followed by a decrease at NaOH solution of 16 M. These variations in the peak intensity of the compounds related to geopolymer gels are corroborated with the variations in the compressive strength of GPC with molarity of NaOH solution. From the XRD patterns, the variations in the peak intensity of albite, anorthoclase, nepheline, sodalite, and muscovite are mostly consistent with the variations in compressive strength of GPC with alkaline solution content, SS/SH ratio, particle size of fly ash, fly ash content, NaCl concentration and age. From the FTIR spectra, the variations in the wavenumber associated with the peak corresponding to asymmetric stretching vibration of Si–O–Si(Al) bond in the FTIR spectra that shows the presence of geopolymer gels in GPC mixes at different ages, and the formation of microstructure in GPC as observed from the FESEM images are in line with the variations in the peak intensity of the compounds related to geopolymer gels in XRD patterns with molarity of NaOH solution, alkaline solution content, SS/SH ratio, particle size of fly ash, fly ash content, admixed NaCl concentration and age.

The extent of chloride induced corrosion increased with increase in alkaline solution content and SS/SH ratio. The obtained results indicated that both particle size of fly ash and fly ash content influenced the corrosion activity of steel reinforcement in the presence of chloride ions in GPC. At the age of 600 days, the GPC made with lower molarity of NaOH solution showed higher free chloride content near rebar level, which resulted in more negative corrosion potential and higher corrosion current density at lower molarity of NaOH solution as compared to higher molarity of NaOH solution. However, higher bound chloride content was observed at lower molarity of NaOH solution as compared to higher molarity of NaOH solution. With SS/SH ratio, there was consistent variation in the effect of chloride ions on extent of corrosion of rebar in GPC at later age for NaOH solution of 10 M whereas there was inconsistent variation at NaOH solution of 14 M. At the age of 600 days, the formation of more amount of geopolymer gels as indicated by higher peak intensity of albite, anorthoclase and nepheline in the XRD patterns of GPC near

rebar level in the prismatic specimens at higher molarity of NaOH solution resulted in denser microstructure that led to lower free chloride content near rebar level thereby resulting in lower corrosion activity in GPC made with higher molarity of NaOH solution than lower molarity of NaOH solution. The formation of more amount of geopolymer gels in GPC mixes at lower alkaline solution content, and lower SS/SH ratio as indicated by higher peak intensity of the compounds related to geopolymer gels in XRD patterns led to comparatively higher extent of physical binding of chloride ions with geopolymer gels than higher alkaline solution content, and higher SS/SH ratio. The formation of more amount of geopolymer gels in GPC as indicated by higher peak intensity of the compounds related to geopolymer gels in XRD patterns in case of larger fly ash particles resulted in lower free chloride content near rebar level at the later age of 600 days when compared with smaller fly ash particles. From the FTIR spectra of GPC near steel reinforcement at the later age, the variation in the wavenumber associated with the peak corresponding to asymmetric stretching vibration of Si–O–Si(Al) bond was not significant with molarity of NaOH solution, alkaline solution content, SS/SH ratio, particle size of fly ash, fly ash content, and admixed NaCl concentration. Further, from FESEM images, the variations in the formation of microstructure with mix parameters are supported by the variations in the peak intensity of the compounds related to geopolymer gels in XRD patterns of GPC near steel reinforcement in prismatic specimens at later age.