CHAPTER - 07

POND ASH-RED MUD GEOPOLYMER

7.1 General

The development of geopolymer technology led to minimising the use of cement and led to low emission of carbon dioxide (CO_2) to protect the earth's environment. This approach requires the search for the best use of non-conventional materials such as Fly ash, Red mud, GGBFS and other industrial waste for infrastructure development. In this chapter, the synthesis of geopolymer with the use of Pond ash and Red mud with the addition of alkali has been discussed in terms of geotechnical properties, unconfined compressive strength, and microstructural analysis. Mixes of Pond ash-Red mud have been planned by replacing the Red mud with pond ash at 10% up to 90%. These mixes were also activated with sodium hydroxide at concentrations of 2, 4, 6, 8 and 10M. Finally, the representative strength due to Si-Al reactions achieved in the pond ash - Red mud mixes is comparable with calcium-based geopolymers as discussed in previous chapters in the case of Pond ash-GGBFS, Red mud-GGBFS mixes.

7.2 Compaction Characteristics of Pond ash-Red mud Mixes

The compaction characteristics of Pond ash-Red mud mixes (Fig.7.1 &7.2) have been calculated according to IS: 2720: Part-7 (1980). As the Pond ash was replaced with Red mud the maximum dry density of the mixes increased and the optimum moisture content of the mixes did not follow any trend but overall decreased. The maximum dry density (MDD) of the mix $P_{100}R_0$ without any Red Mud addition is 1.157 g/cc and the optimum moisture content of the raw Pond ash is 31.2%. When Pond ash was replaced with 10% Red Mud the MDD of the mix $P_{90}R_{10}$ reached 1.181 g/cc and OMC for this mix was recorded at 31.65%. On further increasing the amount of Red mud in the mix the maximum dry density of the mixes has been continuously increased. On 20% replacement of Pond ash with the Red mud the maximum dry density has been increased to 1.229 g/cc and slight decrement in OMC value (31%). The value of 1.43g/cc maximum dry density and 25% optimum moisture content of this mix has been attained with the addition of 50% replacement of Pond Ash with Red mud in the mix $P_{50}R_{50}$. Further improvement has been observed in the value of maximum dry density 1.459 g/cc on 60 % replacement of Pond Ash with Red Mud and further decrement has been observed in the OMC value 23.6% for this mix $P_{40}R_{60}$. Improvement has been continuously observed in the value of maximum dry density up to 90% replacement of Pond Ash with Red Mud. At 90% replacement of Pond Ash with Red Mud 1.53 g/cc value of MDD has been recorded for mix $P_{10}R_{90}$.

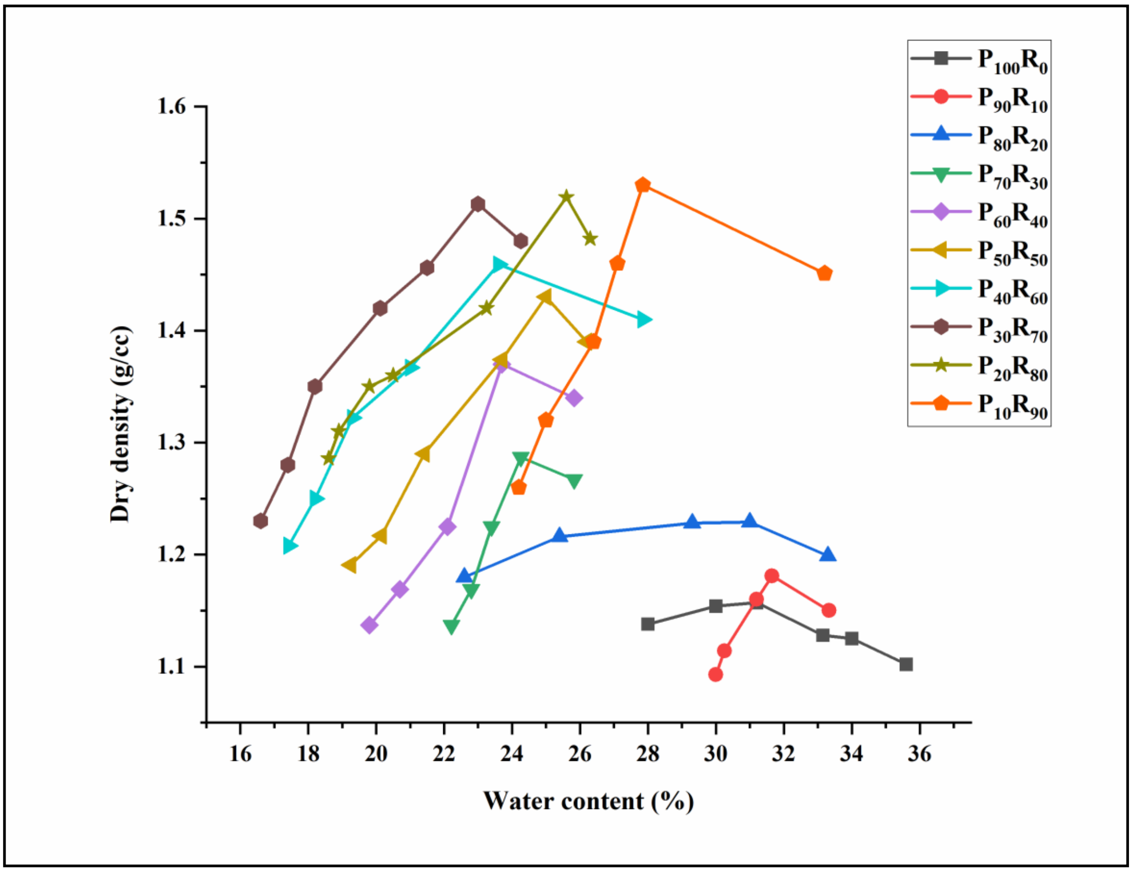

Fig: 7.1 Compaction Characteristics of Pond ash-Red mud Mixes

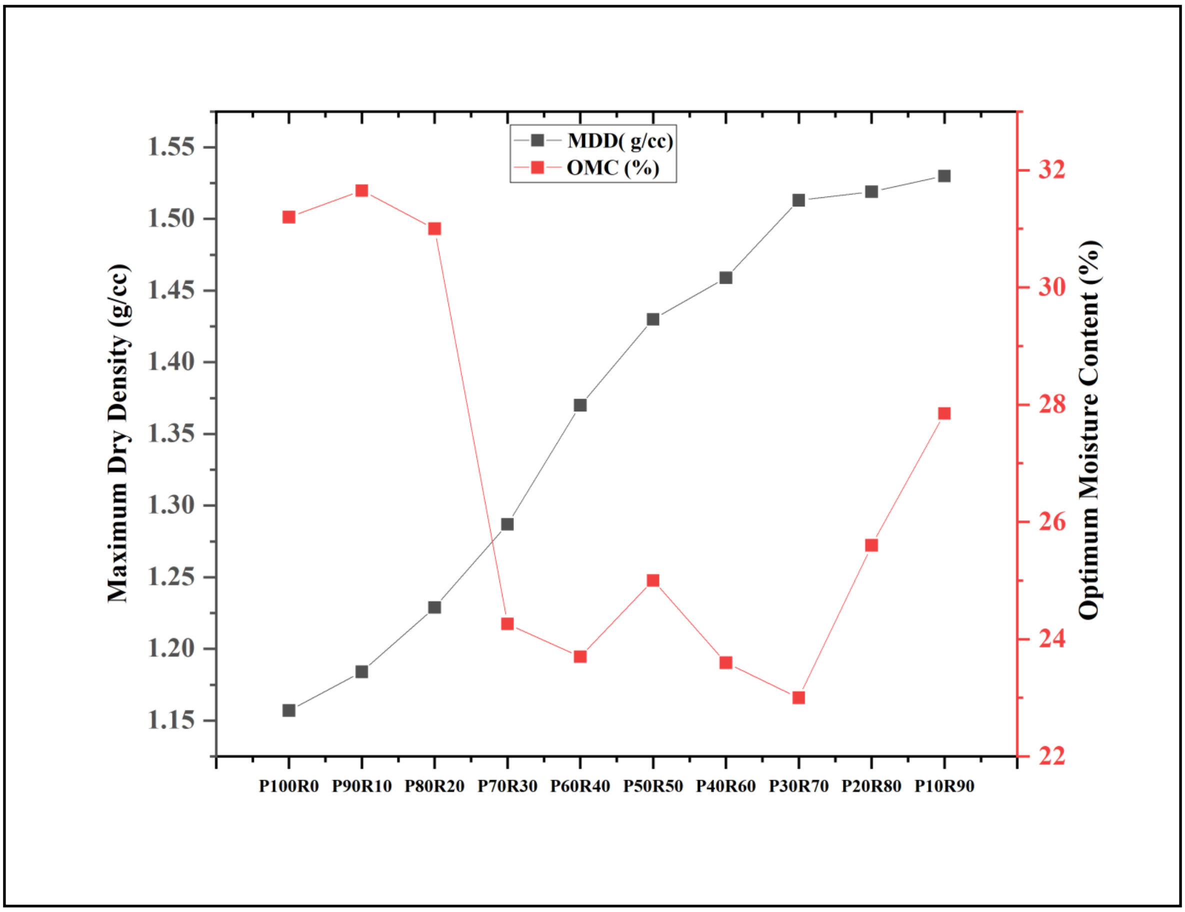

Fig: 7.2 MDD and OMC parameter of Pond ash-Red mud Mixes

7.3 UCS Analysis of Pond ash-Red mud Mixes

In this study the pattern of UCS of Pond ash-Red mud (Fig. 7.3-7.5) did not follow any trend. The UCS has been observed on replacing the Pond Ash with Red Mud with alkali activation of various concentrations of NaOH. With the amount of replacement of Pond Ash with Red Mud increases, the value of overall UCS increases up to 8M NaOH concentration. The 10 M mixes show the decreasing value of UCS on increasing the replacement amount of Pond ash with Red Mud. Up to 40% replacement of Pond Ash with Red Mud, the UCS has been increased as the concentration of sodium hydroxide increases to the 10M. The UCS of the Mix $P_{100}R_0$ is 0.072 MPa activated with 2M NaOH at 7 days of curing period. As the concentration of sodium hydroxide increased to 4M, the UCS has been reached to the value 0.114 MPa. Further on increasing the concentration of NaOH to the 6M, UCS has been recorded 0.54 MPa. 8M and 10 M NaOH activated mix $P_{100}R_0$ possesses 1.21 MPa and 4.6 MPa respectively. On 10% replacement of Pond Ash with Red Mud the UCS of mix $P_{90}R_{10}$ has been recorded 0.121 with 2M NaOH activation. On increasing the concentration of NaOH to 4M, the UCS of mix $P_{90}R_{10}$ improved to 0.1895 MPa and this value reached to 0.747 MPa on further increased concentration 6M NaOH. Finally, this mix $P_{90}R_{10}$ attained 2.35 MPa at 10 M NaOH activation. Beyond 40% replacement of Pond Ash with Red Mud mixes $P_{50}R_{50}$, $P_{40}R_{60}$, $P_{30}R_{70}$, $P_{20}R_{80}$ and $P_{10}R_{90}$ did not follow the above trend. In the case of these mixes, UCS decreases by increasing the alkali concentration.

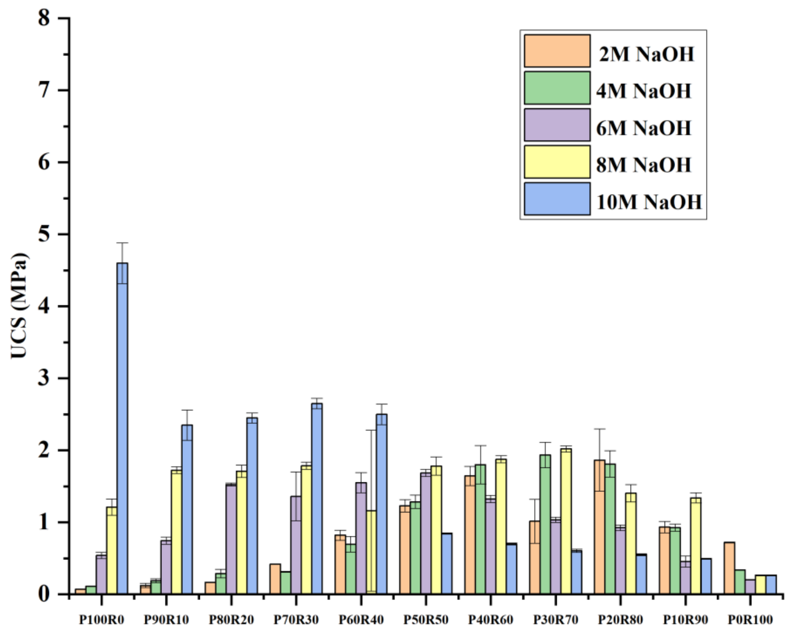

Fig: 7.3 UCS of Pond ash-Red mud Mixes Activated with NaOH at 7 Days

On increasing the curing period to 28 and 56 days the UCS follows the same trend. Up to 50% replacement of Pond Ash with Red Mud the UCS of the mixes $P_{100}R_0$, $P_{90}R_{10}$, $P_{80}R_{20}$, $P_{70}R_{30}$, $P_{60}R_{40}$ and $P_{50}R_{50}$ has increased with increment in the concentration of sodium hydroxide. The effect of increasing the curing period to 28 days has been observed in the UCS of the mixtures. The mix $P_{100}R_0$ possesses 0.12 MPa activated with 2M NaOH at 28 days of curing period. Further on increasing the concentration (4M) of sodium hydroxide, this value of UCS reached 0.182 MPa. With 10M NaOH activation, this value of UCS became 7.0 MPa at 28 days of curing period. The UCS value has been improved to 0.216 MPa on 10% replacement of Pond Ash with Red Mud at 2M NaOH activation of mix $P_{90}R_{10}$. On replacing more Pond Ash with Red Mud, the value of UCS has improved at 2M, 4M, and 6M NaOH activation. While with 8M and 10M NaOH activation, strength decreases on adding the Red Mud to the mixtures.

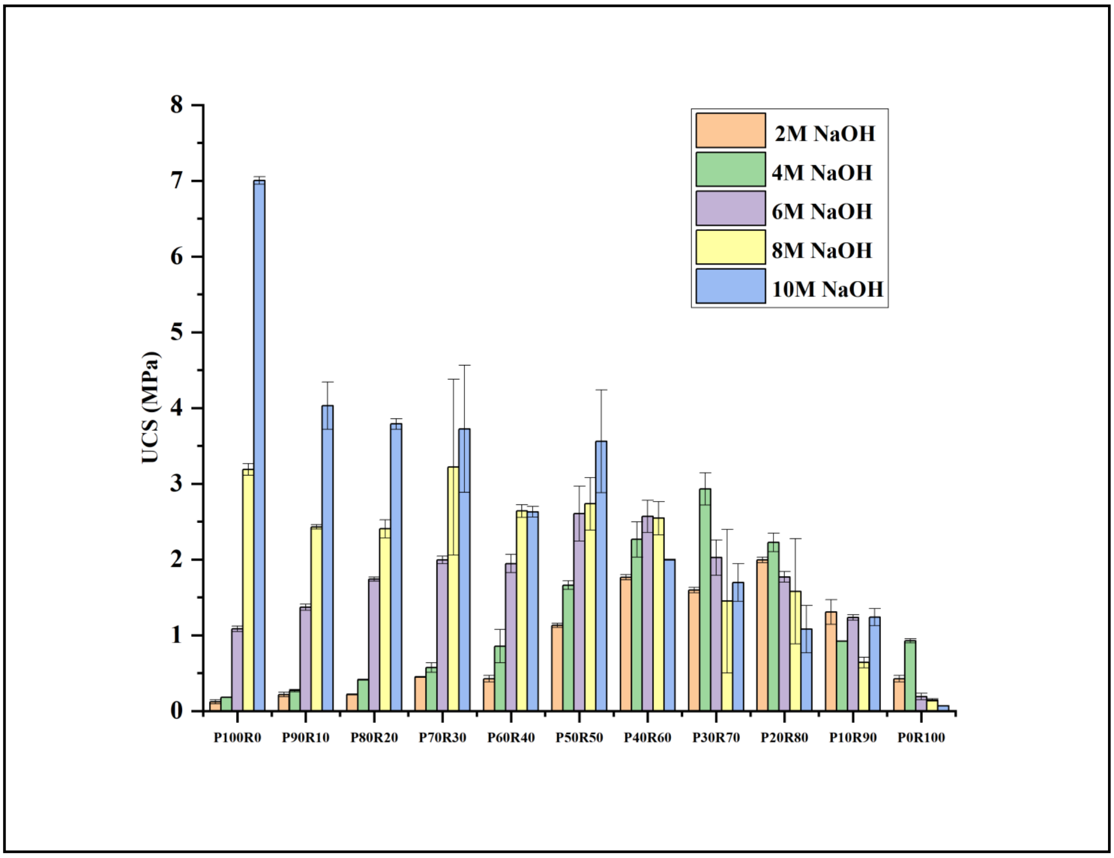

Fig: 7.4 UCS of Pond ash-Red mud Mixes Activated with NaOH at 28 Days

On increasing the curing period to 56 days there is no significant improvement in the UCS value of the pond ash-red mud mixes. At increased curing period these mixtures did not follow the same trend shown above. Also, at 56 days of curing period strength increases with increasing sodium hydroxide concentration up to 10% replacement of Pond Ash with Red Mud. Mix $P_{100}R_0$ provides 0.179 MPa with the activation of 2M NaOH at 56 days of curing period. On increasing the concentration of sodium hydroxide to 4M, this value of UCS reached 1.605 MPa and ultimately this value improved to 6.345 MPa with the 10M NaOH activation. Similarly for mixture $P_{90}R_{10}$, strength increases with an increment in the concentration of sodium hydroxide. But beyond the 10% replacement of Pond Ash with Red Mud UCS did not follow the same trend. For mix $P_{80}R_{20}$ UCS increased to the value 4.5 MPa with the 8M NaOH activation. With alkali concentration of 10M this value slightly decreased to 3.77 MPa. From 20% to 40% replacement of Pond Ash with Red Mud, strength increases with the increasing concentration up to 8M NaOH activation. With 10M NaOH activation the mixes $P_{80}R_{20}$, $P_{70}R_{30}$ and $P_{60}R_{40}$ are shown a slight decrease in strength. With 50% and 60% replacement of Pond Ash with Red Mud, the strength of the mixes $P_{50}R_{50}$ and $P_{40}R_{60}$ increases up to 6M NaOH. Beyond this alkali concentration, the strength diminishes for these two mixes. Overall, the replacement of Pond Ash with Red Mud did not record any improvement with increasing concentration of sodium hydroxide. The mix P_0R_{100} with 100% replacement poses the decrement in the UCS at increasing concentration. As the percentage of Red Mud increased in the mixes, UCS started decreasing at increasing concentration.

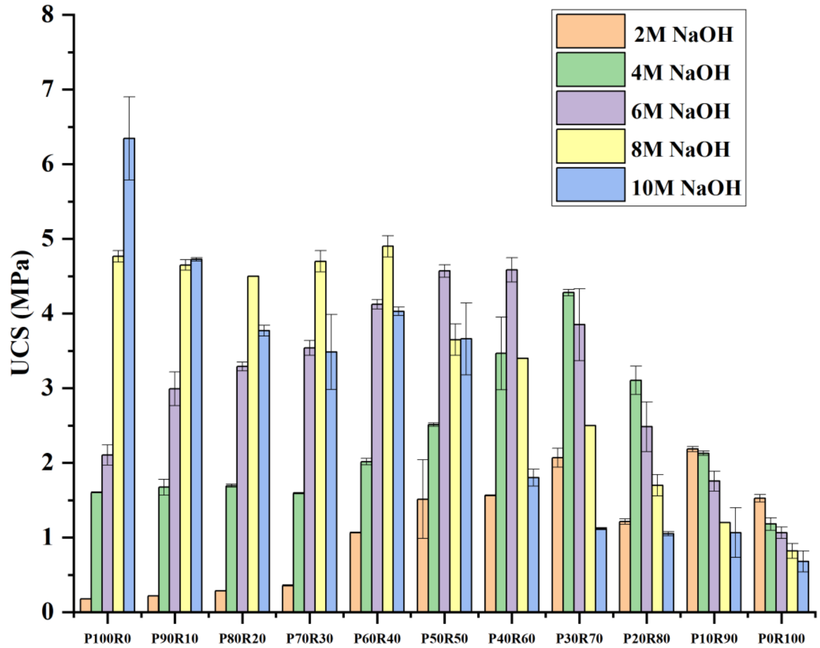

Fig: 7.5 UCS of Pond ash-Red mud Mixes Activated with NaOH at 56 Days

7.4 Tri-axial Results of Pond ash-Red mud Mixes

The Pond ash-Red mud mixes with alkali activation observed low values of UCS as compared to Pond ash-GGBFS and Red mud-GGBFS mixes. Due to this reason low alkali-activated Pond ash-Red mud mixes with 2 M NaOH have been considered for tri-axial shear tests and compared with shear parameters of mixes without alkali activation for samples cured for 7 days and 28 days. According to IS: 2720: Part XI (1993) shear parameters of all Pond ash-Red mud mixes have been reported and shown in Fig. 7.6-7.9 of the curing period. Fig.7.6 shows the angle of internal friction of mix $P_{100}R_0$ was 25.087^0 and the value of cohesion was 0.704 kg/cm^2 after 7 days of curing. On replacing Pond ash with Red mud overall the angle of internal friction and cohesion has been increased. When 10% Pond ash replaced by Red mud the value of internal friction has been reached 26.12^0 and the value of cohesion slightly decreased to 0.53 kg/cm^2. When 50% Pond ash was replaced by Red mud, the value of internal friction was improved to 34.035^0 and the value of cohesion was 0.524 kg/cm^2. The 70% Pond ash replacement with Red mud caused the increment in the angle of internal friction (40.617^0) and in the value of cohesion (1.023 kg/cm^2).

With the increase in the curing period to 28 days, the value of the angle of internal friction and cohesion has also increased. The value of the angle of internal friction of mix $P_{100}R_0$ has been improved to 31.560^0 and the value of cohesion slightly decreased to 0.457 kg/cm^2. On 50% replacement of Pond ash with Red mud, 38.638^0 the angle of internal friction has been observed at 28 days of curing.

With 2M NaOH activation, the value of internal friction increased to 41.613^0 and the value of cohesion has been decreased to the value 0.43kg/cm^2 for the mix $P_{100}R_0$. On 10% addition of Red mud in the mixes led to the increment in the value of angle of internal friction (42.734^0) and value of cohesion (0.585 kg/cm^2). The value of internal friction has become highest (54.557^0) at the 80% addition of Red mud in the mix $P_{20}R_{80}$ and the value of cohesion has become highest (5.028 kg/cm^2) at the 50% addition of Red mud in the mix $P_{50}R_{50}$. On further replacement of Pond ash with Red mud the value of cohesion has been reduced. At 100% replacement of Pond ash with Red Mud in the mix P_0R_{100} the value of cohesion become minimum (0.11 kg/cm^2) and the value of angle of internal friction reported to 49.384^0. On increasing the curing period to the 28 days, there is no significant improvement in the value of angle of internal friction and the value of cohesion. Mix $P_{100}R_0$ represented the angle of internal friction 31.661^0 and the value of cohesion 0.483 kg/cm^2. At 40% addition of Red mud in the mix $P_{60}R_{40}$, the value of angle of internal friction reported to 13.609^0 and the value of cohesion recorded to 6.32 kg/cm^2. On further addition of 50% Red mud in the mix $P_{50}R_{50}$ the value of angle of internal friction displayed the value 42.851^0 and the cohesion has been become 3.82 kg/cm^2. The value of angle of internal friction has been recorded highest

(54.676^0) at the 90% addition of Red mud in the mix $P_{10}R_{90}$ and the value of cohesion in this mix reported to 0.765 kg/cm^2.

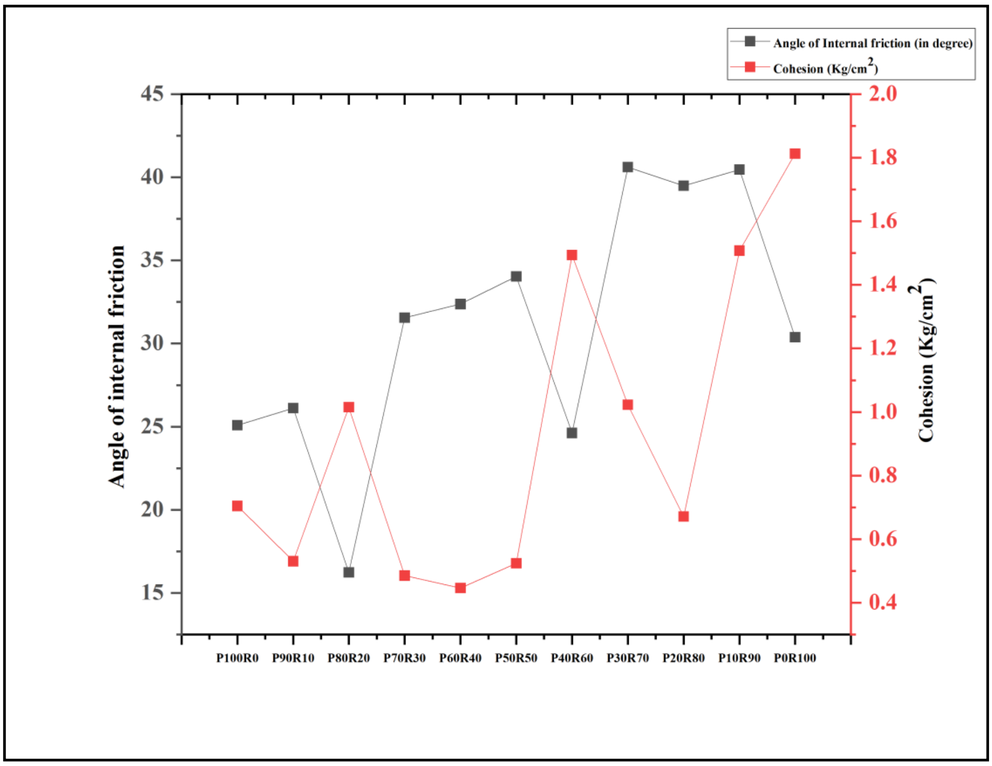

Fig: 7.6 Shear parameters of Pond ash-Red mud mixes without NaOH at 7 days curing period

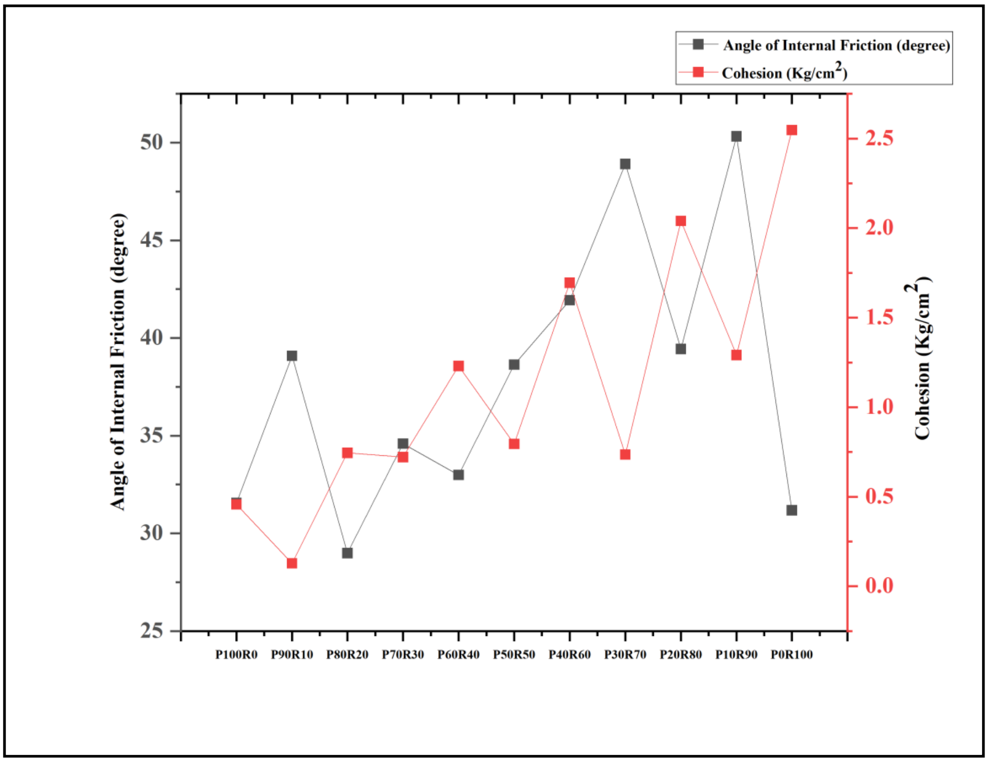

Fig: 7.7 Shear parameters of Pond ash-Red mud mixes without NaOH at 28 days curing period

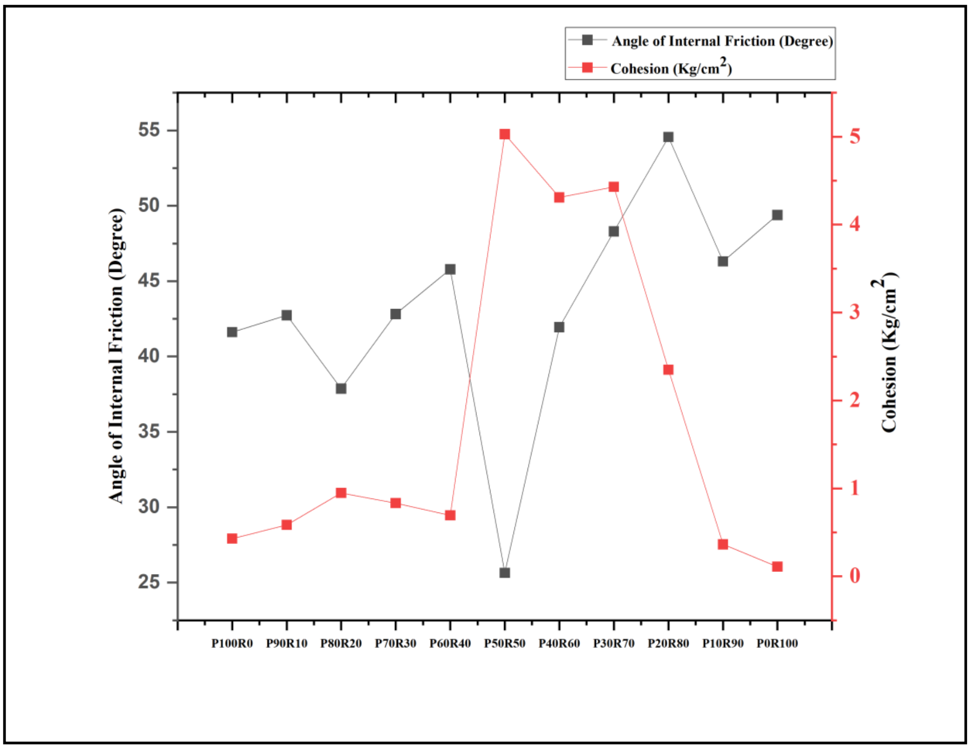

Fig: 7.8 shear parameters of Pond ash-Red mud mixtures activated with 2M NaOH at 7 days curing

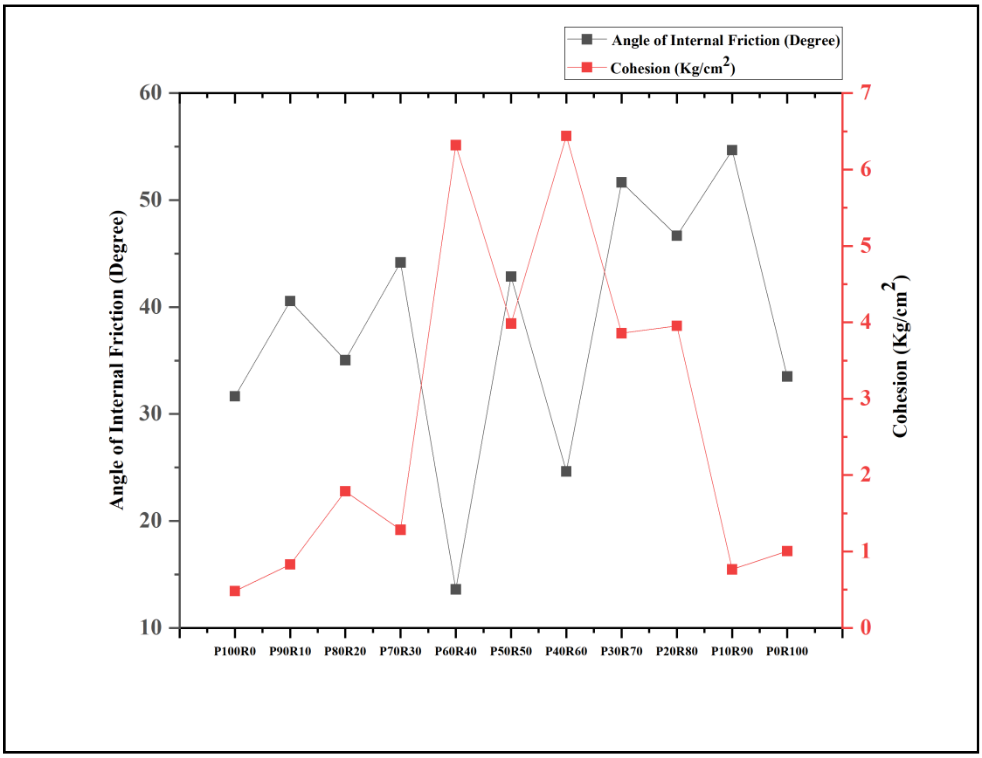

Fig: 7.9 shear parameters of Pond ash-Red mud mixes activated with 2M NaOH at 28 days curing

7.5 XRD Study of Pond ash- Red mud mixes

X-ray diffraction analysis technique was used to determine the mineralogical composition of geopolymers of pond ash-red mud mixes. In this study, strength decreases with the addition of Red mud percentages in the mixes which is confirmed by XRD graphs (Fig.7.10). As seen in the XRD graphs, the crystalline phases are mainly quartz (silica) and mullite (alumina) in the Pond ash. Red mud is highly crystalline and presents the peaks of hematite, quartz and alumina whose presence is also confirmed by the XRF analysis. The probability of solubility of Red mud in an alkaline solution is low due to the higher crystalline nature and higher concentration of hematite (Fe_2O_3). The presence of Red mud only acts as inactive filler and partially contributes high alkalinity required for the geopolymer synthesis. Strength increases as the percentage of Red mud increases in the mixtures for low concentration. But on a higher percentage of Red mud and with activation of a high concentration of sodium hydroxide, strength slightly diminishes. Due to the low solubility of Red mud in an alkaline solution, the strength did not meet the high expectations.

(a) **(b)**

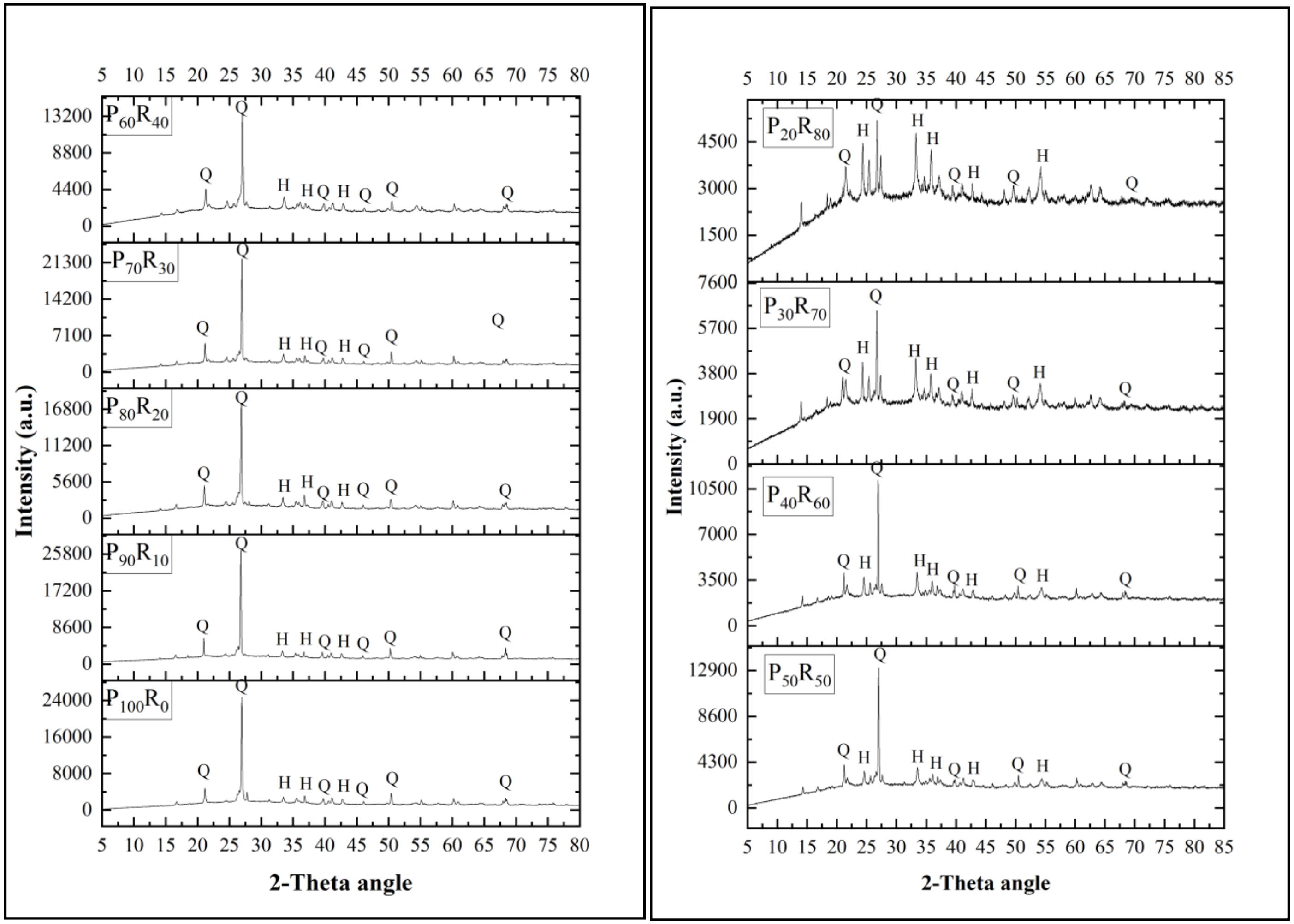

Fig: 7.10 XRD of All Pond ash-Red mud mixes: (a) $P_{100}R_0$ to $P_{60}R_{40}$, (b) $P_{50}R_{50}$ to $P_{20}R_{80}$

7.6 FTIR Study of Pond ash-Red mud Mixes

Fig. 7.11 shows the FTIR spectra of geopolymer samples. When Pond ash-Red mud mixes are activated with NaOH, the intensity of the absorption band has been increased compared to raw material. The strong intensive peak detected at the range 3429-3445 cm^{-1} verified the stretching mode H-OH groups and the wavenumber observed at 1647 cm^{-1} was due to the bending vibration of O-H groups. The change in intensity of these peaks can be attributed to the presence of structural water in the raw materials. The spectra observed at 1396-1404 cm^{-1} characteristics of the asymmetric stretching mode of the O-C-O bonds carbonate component. The fourth strong peak recognized at 1016 cm^{-1} was caused by the asymmetric vibration Si-O-Si and Si-O-Al (Si-O-T where T: Tetrahedral Si or Al) in $P_{100}R_0$. Adding Red mud in the mixtures this band shifted towards the lower wavenumber (991 cm^{-1}) which is the key indicator of geopolymerization. Shifting of this peak towards the lower wave number indicated the development of the geopolymeric gels (NASH) which is responsible for the gaining the compressive strength of the Pond ash-Red mud mixes. The other fifth peak identified at 789 cm^{-1} was attributed to the Si-OH stretching indicating the presence of quartz (Zhang et al., 2012; Ismail et al., 2014; Wan et al., 2017). The peak observed at 457 cm^{-1} was due to the bending vibration of Fe-O bonds (Kumar and Kumar, 2013).

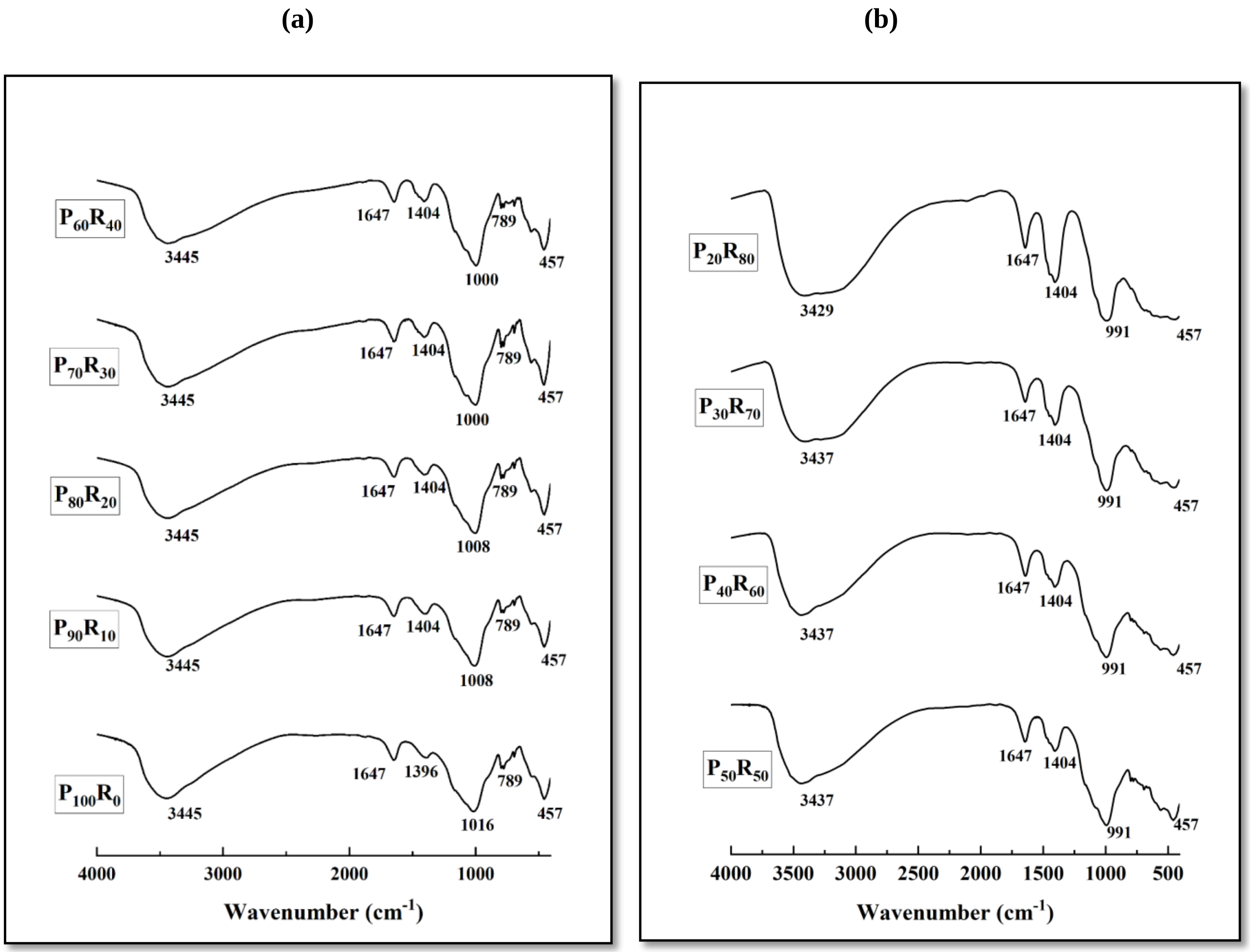

Fig: 7.11 FTIR Analysis of All Pond ash-Red mud mixes: (a) $P_{100}R_0$ to $P_{60}R_{40}$, (b) $P_{50}R_{50}$ to $P_{20}R_{80}$

7.7 Summary

This present chapter discusses the performance of mixes of Pond ash-Red mud geopolymers without the addition of GGBFS. This study has shown that strength increases with the addition of the alkali with the replacement of pond ash has been increased with the red mud but not followed the specific trends. Over all the strength of geopolymers of Pond ash-Red mud mixes are lower than mixes of Pond ash, Red mud with GGBFS mixes.