STABILIZATION OF SOIL USING GEOPOLYMER AND BIOPOLYMER

A Thesis Submitted in Partial Fulfilment of the Requirements for the Degree of Master of Technology (Research)

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DECLARATION

I hereby state that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by any other person nor substance which to a substantial extent has been accepted for the award of any other degree or diploma of the university or other institute of higher learning, except where due acknowledgement has been made in the text.

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This is to certify that the thesis entitled **"Stabilization of Soil Using Geopolymer and Biopolymer''** being submitted by **Kajal Swain** in partial fulfilment of the requirements for the award of **Master of Technology (Research)** degree in **Civil Engineering** with specialization in **Geotechnical Engineering** at National Institute of Technology Rourkela, is an authentic work carried out by her under my guidance and supervision. To the best of my knowledge, the matter embodied in this report has not been submitted to any other university/institute for the award of any degree or diploma.

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ABSTRACT

As stabilization of soil improves its engineering properties, chemical and mechanical stabilization processes are in use. In the present study two difficult soils; expansive soil and dispersive soil are stabilized with geopolymer and biopolymer. Sodium based alkaline activators and fly ash as an additive is used as geopolymer and Xanthan gum and Guar gum are used as biopolymers. The effectiveness of geopolymer is studied in terms of unconfined compressive strength (UCS), differential free swelling (DFS), swelling pressure (SP), durability and dispersion tests. The swelling pressure got reduced by 97.14% finally with addition of 40% fly ash and 15% bentonite. The dispersion test showed bentonite to be an extremely dispersive soil, whose dispersiveness is controlled by addition of alkali activated fly ash. From UCS and durability test it is observed that bentonite added with 40% fly ash and 10% solution gave better results. The effectiveness of biopolymer is studied based on UCS tests on dispersive soil and pond ash at their moisture content. For dispersive soil, durability, dispersion and DFS tests are also done. It is observed that dispersive soil and pond ash mixed with various percentages of Xanthan gum and Guar gum are not dispersive and are more durable than ordinary bottom ash and dispersive soil samples. Guar gum is found to imparts higher confined compressive strength and durability than Xanthan gum.

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CHAPTER 1

Introduction

1.1 Introduction

Soil stabilization in a broad sense includes various methods used for modifying the properties of soil to enhance its engineering performance. By stabilization the major properties of soil, i.e., volume stability, strength, compressibility, permeability, durability and dust control is improved, which makes the soil suitable for use. There are different methods of stabilization, which include physical, chemical and polymer methods of stabilization. Physical methods involve physical processes to improve soil properties. This includes compaction methods and drainage. Drainage is an efficient way to remove excessive water from soil by means of pumps, pipes and canal with an aim to prevent soil from swelling due to saturation with water. Compaction processes lead to increase in water resistance capacity of soil. Drainage is less common due to generally poor connection between method effectiveness and cost. But, compaction is very common method. Although, it makes soil more resistant to water, this resistance will be reducing over time. Chemical soil stabilization uses chemicals and emulsions as compaction aids, water repellents and binders. The most effective chemical soil stabilization is one which results in non-water-soluble and hard soil matrix. Polymer methods of stabilization have a number of significant advantages over physical and chemical methods. These polymers are cheaper and are more effective and significantly less dangerous for the environment as compared to many chemical solutions. In the present study two difficult soils, expansive soil and dispersive soil are considered for effectiveness of geopolymer and biopolymer stabilization.

1.2 Expansive Soil

Expansive soils also known as swelling soils or shrink-swell soils are the terms applied to those soils, which have a tendency to swell and shrink with the variation in moisture content.
Expansive soil and bedrock underlie more than one third of world's land surface. Each year, damage to buildings, roads, pipelines, and other structures by expansive soils is much higher than damage that are caused by floods, hurricanes, tornadoes, and earthquakes combined (Jones and Holtz 1973). The estimated annual cost of damage due to expansive soils is $1000 million in the USA, £150 million in the UK, and many billions of pounds worldwide

(Gourley*et al*. 1993). However, as the hazards due to expansive soils develop gradually and seldom present a threat to life, these have received limited attention, despite their severe effects on the economy. Much of the damage related to expansive soils is not due to a lack of appropriate engineering solutions but to the non-recognition of expansive soils and expected magnitude of expansion early in land use and project planning. The damage to foundations on expansive soil can be avoided or minimized by proper identification, classification, quantification of swell pressure and provision of an appropriate design procedure. These types of soils are generally found in arid and semi-arid regions of the world.Expansive soils are mainly found over the Deccan lava tract (Deccan Trap) including Maharashtra, Madhya Pradesh, Gujarat, Andhra Pradesh and in some parts of Odisha, in the Indian sub-continent.

These are also found in river valley of Tapi, Krishna, Godavari and Narmada. In the north western part of Deccan Plateau and in the upper parts of Krishna and Godavari, the depth of black soil is very large. Basically, these soils are residual soils left at the place of their formation after chemical decomposition of the rocks such as basalt and trap. These soils are rich in lime, iron, magnesia and alumina but, lack in the phosphorus, nitrogen and organic matter. Soils containing the clay minerals montomorillonite generally exhibit these properties. Their colour varies from black to chestnut brown and basically, consists of high percentage of clay sized particles. Bentonite is a highly expansive and also extremely dispersive soil. In case of this soil, free swelling is upto ten to fifteen times to its original volume.

1.3 Dispersive Soil

Soils in which the clay particles will separate instinctively from each other and go into suspension in quiet water are called dispersive soils (Yong and Sethi, 1977; Mitchell, 1993). Dispersivity is a physico-chemical process which is mainly affected by the type of soil minerals and chemical properties of the soil pore fluid (Yong and Warkentin, 1996; Sherad et al., 1976; Penner and Lugaly, 2001). The formation of dispersivity may cause the formation of piping phenomena in earth dams (Fell *et al*., 1992), deterioration and demolition of roads (Nevels, 1993), and the erosion of the compacted soils of landfill clay liners (Tin, 1984; Ouhadi and Goodarzi, 2003). These soils are found to exist in various types of climates in various locations in Australia, Brazil, Iran, New Zealand, the United States, and many other countries (Sherad*et al*., 1976; Ludwig, 1979; Goodarzi, 2003). Based on the importance of the phenomenon of dispersivity, it is necessary to study this problem from a physico-chemical point of view.

1.4 Definition of the problem

In India, almost 20% of the total area is covered by expansive soil. Due to rapid industrialization and huge population growth of our country, there is a scarcity of land to meet the human needs. Further, the cost of rehabilitation and retrofitting of the civil engineering structures established over these soils are increasing day by day. On the other hand, the safe disposal of fly ash from thermal power industries has been a challenging issue demanding urgent solution because of the decline effect of these materials on the environment and the hazardous risk it pose to the human and animals. However, production of cement requires lime-stone and with the rate with which we are utilising cement, the day is not so far when the lime stone mines will get depleted. There is also environment concern that for every 1 kg of cement manufacturing, 1 kg of carbon dioxide is released into theatmosphere, which in turn increases the carbon foot print and also possess serious threat to the global warming. Thus, there is a need to find out alternative binder, which is environmental friendly as well as dependable like cements. The other difficult soil which needs stabilization for e.g. dispersive soil, which in dry state causes dust problem and in saturated condition, piping occurs through this soil causing failure of dams and embankments (Sherad*et al.* 1976). The erosion failure in dam caused due to dispersive soil is presented in Fig. 1.1. Recently few attempts have been made to use alkali activated fly ash also known as geopolymer as an alternative cementitious material. But, the studies are limited to its use in concrete and a single literature (Parhi and Das, 2014) is available in its application for soil.

Modification in soil eco system can be achieved by various microorganism existing in various type of soil present. Role of these living organisms creates a huge difference in the inter soil particles.The major factors that affect the application of microorganisms in the soil ecosystem is its identification and screening for different applications in the geotechnical field. However, from various researches it has been found that microorganisms produce exopolysaccharides that helps in soil aggregation, bioclogging, biocementation and can be helpful in stabilization, mitigation of liquefaction potential, strengthening tailing dams, binding etc. (Ivanov and Chu, 2008). In today's arena use of chemical grouts like suspension of sodium silicate, acrylates, acrylamides, and polyurethanes and microbiological grouting have been augmented to improve the physical properties of soil structure. Similarly, industrially produced water-insoluble gel-forming biopolymers of microbial origin such as xanthan, chitosan, polyglutamic acid, sodium alginate, and polyhydroxybutyrate can also be used as grouts for soil erosion control, enclosing of bioremediation zone, and mitigating soil liquefaction.

Fig.1.1 Typical erosion failure of a bank due to dispersive soil.

1.5 Objective and Scope

The objective of the current research work is to determine the suitability of geopolymer (alkali-activated fly ash) and biopolymer as soil stabilizing agent for expansive soil and dispersive soil.

Scope

- Laboratory investigation for characterization of expansive soil (bentonite) with alkali activated fly ash (geopolymer) as binding material.

- It includes laboratory investigation for characterization of dispersive soil with two commercially available biopolymers i.e., Xanthan gum and Guar gum.

CHAPTER 2

Literature Review

2.1 Introduction

In terms of methods of stabilization of soils, there are physical, chemical and biochemical stabilization methods. Various efforts have been made to stabilize expansive soil and dispersive soil for engineering use. Variety of stabilizers may be divided into three groups (a) conventional stabilizers (lime, cement etc.), (b) by-products stabilizers (fly ash, quarry dust, phosphor-gypsum, slag etc.) and (c) non-traditional stabilizers (sulfonated oils, potassium compounds, polymer, enzymes, ammonium chlorides etc.)(Petry 2002). Disposal of large quantities of industrial by-products as fills on disposal sites adjacent to industries not only requires large space but also create a lot of geo-environment problems. Attempts are being made by various organizations and researchers to use them in bulk at suitable places. Stabilization of expansive soil and dispersive soil is one way of utilization of these by-products. Some of the research work conducted by earlier researchers on the above has been described in this chapter.

2.1.1 Stabilization of Expansive Soil Using Fly ash

Sharma *et al*. (1992) studied stabilization of expansive soil using mixture of fly ash, gypsumand blast furnace slag. They found that mixture of fly ash, gypsum and blast furnace slag in the proportion of 6: 12: 18 decreased the swelling pressure (SP) of the soil from 248 kN/m^2 to 17 kN/m^2 and increased the unconfined compressive strength by 300%.

Srivastava *et al*. (1997) studied the change in micro structure and fabric of expansive soildue to addition of fly ash and lime sludge from SEM photograph and found changes in micro structure and fabric when 16% fly ash and 16% lime sludge were added to expansive soil.

Srivastava *et al*. (1999) have also described the results of experiments carried out to studythe consolidation and swelling behaviour of expansive soil stabilized with lime sludge and fly ash and the best stabilizing effect was obtained with 16% of fly ash and 16% of lime sludge.

Cokca (2001) used upto 25% of Class-C fly ash (18.98 % of CaO) and the treated specimenswere cured for 7 days and 28 days. The swelling pressure was found to reduced by 75% after 7 days curing and 79% after 28 days curing at 20% addition of fly ash.

Pandian*et al*. (2001) had made an effort to stabilize expansive soil with a Class–F Fly ashand found that the fly ash could be an effective additive (about 20%) to improve the CBR of black cotton soil(about 200%)significantly.

Turker and Cokca (2004) used Class C and Class F type fly ash along with sand forstabilization of expansive soil. As expected, Class C fly ash was found to bemoreeffective and the free swell decreased with curing period. The best performance was observed with soil, Class C fly ash and sand as 75%, 15% and 10%, respectively after 28 days of curing.

Satyanarayana*et al.* (2004) studied the combined effect of addition of fly ash and lime onengineering properties of expansive soil and found that the optimum proportions of soil: fly ash: lime should be 70:30:4 for construction of roads and embankments.

Phani Kumar and Sharma (2004) observed that plasticity, hydraulic conductivity andswelling properties of the expansive soil fly ash blends decreased and the dry unit weight and strength increased with increase in fly ash content. The resistance to penetration of the blends increased significantly with an increase in fly ash content fora given water content. They presented a statistical model to predict the undrained shear strength of the treated soil.

Baytar (2005) studied the stabilization of expansive soils using the fly ash and desulpho-gypsum obtained from thermal power plant by 0 to 30 percent. Varied percentage of lime (0 to 8%) was added with the expansive soil-fly ash-desulphogypsum mixture. The treated samples were cured for 7 and 28 days. Swelling percentage was found to reduced and rate of swell was found to increase with increase in stabilizer percentage. Curing resulted in further reduction in swelling percentage. With addition of 25 percent fly ash and 30 percent desulphogypsum, the swelling percentage reduced to levels comparable to lime stabilization.

Amu *et al.* (2005) used cement and fly ash mixture for stabilization of expansive clayey soil.The expansive soil was treated with (i) 12% cement and (ii) 9% cement + 3% fly ash and were tested for maximum dry densities (MDD), optimum moisture contents (OMC), California bearing ratio (CBR), unconfined compressive strength (UCS) and the undrainedtriaxial tests. The results showed that the soil sample stabilized with a mixture of 9% cement + 3% fly ash is better with respect to MDD, OMC, CBR and shearing resistance compared to samples stabilized with 12% cement, indicated the importance of fly ash in improving the stabilizing potential of cement on expansive soil.

Sabat*et al*. (2005) observed that fly ash-marble powder can improve the engineeringproperties of expansive soils and the optimum proportion of soil: fly ash: marble powder was 65:20: 15.

Punthutaecha*et al*. (2006) evaluated class F fly ash, bottom ash, polypropylene fibresandnylonfibres as potential stabilizers in enhancing volume change properties of sulphate rich expansive subgrade soils from two locations in Texas, USA. Ash stabilizers showed improvements in reducing swelling, shrinkage and plasticity characteristics by 20–80%, whereas, fibres treatments resulted in varied improvements. In combined treatments, class F fly ash mixed with nylon fibres was the most effective treatment on both soils. They also discussed the possible mechanisms and recommended type of stabilizers along with their dosages for expansive soil treatments.

Phanikumar and Rajesh (2006) discussed experimental study of expansive clay bedsstabilized with fly ash columns and fly ash-lime columns. Swelling was observed in clay beds of 100 mm thickness reinforced with 30 mm diameter fly ash columns and fly ash-lime addedwith an expansive soil at ranges of 1–10% and 1–20%, respectively. The samples with optimum proportion of fly ash and lime content (15% fly ash and 8% lime) based on compaction, unconfined compression and split tensile strength, were added with 0, 0.5, 1.0, 1.5and 2% plain and crimped polyester fibres by weight. The MDD of soil-fly ash-lime mixes decreased with increase in fly ash and lime content. The polyester fibres (0.5–2.0%) had no significant effect on MDD and OMC of fly ash-soil-lime-fibre mixtures. However, the unconfined compressive strength and split tensile strength increased with addition of fly ash columns. Heave decreased effectively with both fly ash and fly ash-lime columns, with better results for lime stabilized fly ash.

Wagh (2006) used fly ash, rock flour and lime separately and also in combination, indifferent proportion to stabilize black cotton soil from Nagpur Plateau, India. Addition of either rock-flour or fly ash or both together to black cotton soil improved the CBR to some extent and angle of shearing resistance increased with reduced cohesion. However, in addition to rock-flour and fly ash when lime was mixed to black cotton soil, CBR value increased considerably with increase in both cohesion and frictional resistance.

Phani Kumar and Sharma (2007) studied the effect of fly ash on swelling of a highlyplastic expansive clay and compressibility of non-expansive highly plastic clay. The swell potential and swelling pressure, when determined at constant dry unit weight of the sample (mixture), decreased by nearly 50% and compression index and coefficient of secondary consolidation of both the clays decreased by 40% at 20% fly ash content.

Kumar *et al*. (2007) studied the effects of polyester fibre inclusions and lime stabilization onthe geotechnical characteristics of fly ash-expansive soil mixtures. Lime and fly ash were added with an expansive soil at ranges of 1–10% and 1–20%, respectively. The samples with optimum proportion of fly ash and lime content (15% fly ash and 8% lime) based on compaction, unconfined compression and split tensile strength, were added with 0, 0.5, 1.0,1.5 and 2% plain and crimped polyester fibres by weight. The MDD of soil-fly ash-lime mixes decreased with increase in fly ash and lime content. The polyester fibres (0.5–2.0%) had no significant effect on MDD and OMC of fly ash-soil-lime-fibre mixtures. However, the unconfined compressive strength and split tensile strength increased with addition of fibres.

Buhler and Cerato (2007) studied the stabilization of expansive soils using lime and Class C flyash**.** The reduction in linear shrinkage was better with lime stabilization as compared to same percentage of Class C fly ash.

2.1.2 Stabilization using quarry dust

The quarry dust/ crusher dust obtained during crushing of stone to obtain aggregates causes health hazard in the vicinity and many times considered as an aggregate waste.

Gupta *et al*. (2002) made a study on the stabilization of black cotton soil using crusher dust awaste product from Bundelkhand region, India and optimal % of crusher dust (quarry dust) was found to be 40%. There was decrease in liquid limit (54.10% to 24.2%), swelling pressure (103.6 KN/m^2 to 9.4 kN/m^2) and increases in shrinkage limit(12.05% to 18.7%), CBR value (1.91 % to 8.06%), UCS value (28.1 kN/m^{2}to 30.2 kN/m^2) with 40% replacement of expansive soil with crusher dust.

Stalin *et al*. (2004) made an investigation regarding control of swelling potential (SP)ofexpansive clays using quarry dust and marble powder and observed that liquid limit and swelling pressure decreased with increase in quarry dust or marble powder content.

Gulsah (2004) investigated the swelling potential of synthetically prepared expansivesoil (kaolinite and bentonite mixture), using aggregate waste (quarry dust), rock powder and lime. Aggregate waste and rock powder were added with the soil at 0 to 25% by weight with lime varying from 0 to 9% by combined weight. There was reduction in the swelling potential and the reduction was found to increase with increasing percentage of stabilizers and days of curing.

Jain and Jain (2006) studied the effect of addition of stone dust and nylon fibre to Blackcotton soil and found that mixing of stone dust by 20% with 3% randomly distributed nylon fibres decreased the swelling pressure by about 48%. The ultimate bearing capacity increased and settlement decreased by inclusion of fibre to stone dust stabilized expansive soil.

2.1.3 Stabilization using rice husk ash

Rice husks are the shells produced during dehusking operation of paddy, which varies from 20% (Mehta 1986) to 23% (Della *et al*. 2002) by weight of the paddy. The rice husk is considered as a waste material and is being generally disposed of by dumping or burning in the boiler for processing paddy. The burning of rice husk generates about 20% of its weight as ash (Mehta 1986). The silica is the main constituent of rice husk ash (RHA) and the qualities (% of amorphous and unburnt carbon) depend upon the burning process (Nair *et al*. 2006). The RHA is defined as a pozzolanic material (ASTM C 618 ASTM 1997) due to its high amorphous silica content (Mehta 1986).

Rajan and Subramanyam (1982) had studied shear strength and consolidationcharacteristics of expansive soils stabilized with RHA and lime and observed that RHA contributes to the development of strength as a pozzolanic material when used as a secondary additive along with lime and cement. Under soaked conditions, the soil stabilized with rice husk ash had low strength. The RHA, lime combination also decreased the compression index of stabilized soil.

Bhasin*et al*. (1988) made a laboratory study on the stabilization of Black cotton soil as apavement material using RHA, bagasse ash, fly ash, lime sludge and black sulphite liquor with and without lime. The bagasse ash and black sulphite liquor were not found to be effective as a stabilizing agent. The addition of lime sludge alone to black cotton soil improved the CBR values marginally but reduced the UCS values. Lime sludge in combination with lime improved the strength parameters of black cotton soil sufficiently for its use as a sub-basematerial. The rice-husk ash causes greater improvement than that caused by fly ash and bagasse ash due to presence of higher % of reactive silica in rice-husk ash in comparison to maximum reduction in shrinkage observed in lime treated stretch, when additives were used individually. When additives were used in combination, Calcium chloride – sodium silicate treated stretch showed maximum reduction in heave compared to RHA– lime and calcium chloride-RHA stabilized stretches, whereas highest reduction in shrinkage was observed in RHA- lime stabilized stretch.

Ramakrishna and Pradeep Kumar (2006) had studied combined effect of rice husk ash(RHA) and cement on engineering properties of black cotton soil. RHA upto 15% in steps of 5% and cement upto 12% in steps of 4% were added. RHA and cement reduced the plasticity of the expansive soil. The dry density of soil increased marginally with increase in OMC after 4% cement addition. The MDD of soil decreased and OMC increased with the increase in the proportion of RHA- cement mixes. The UCS of Black cotton soil increased linearly with cement content upto 8% and at 12%, strength rate reduced. The soaked CBR of the soil was found to be increased with cement and RHA addition. Similar trends to that of UCS were observed with the increase in CBR rate. At 8% cement content, CBR value of soil was 48.57% and with combination of RHA at 5%, 10% and 15%, the values were 54.68%, 60.56% and 56.62%, respectively.

Sharma *et al*. (2008) had studied the engineering behaviour of remoulded expansive clayblended with lime, calcium chloride and Rice-husk ash. The amount of RHA, lime and calcium chloride were varied from 0 to 16%, 0 to 5% and 0 to 2%, respectively by dry weight of soil. The effect of additives on UCS & CBR was found. The stress–strain behaviour of expansive clay improved upon the addition of upto 5% lime or 1% calcium chloride. A maximum improvement in failure stress of 225 & 328% was observed at 4% lime & 1% calcium chloride. A RHA content of 12% was found to be the optimum with regard to bothUCS& CBR in the presence of either lime or calcium chloride. An optimum content of 4% in the case of lime and 1% in the case of calcium chloride was observed even in clay – RHA mixes.

2.1.4 Stabilization using Copper Slag (CS)

Copper slag is produced as a by-product of metallurgical operations in reverberator furnaces. It is totally inert material and its physical properties are similar to natural sand.

Al-Rawas*et al*. (2002) made an investigation regarding the effectiveness of using cement by-pass dust, copper slag, granulated blast furnace slag and slag-cement in reducing the swelling potential and plasticity of expansive soils from Al-Khod (a town located in Northern Oman). The soil was mixed with the stabilizers at 3, 6 and 9 % of the dry weight of the soil. The treated samples were subjected to liquid limit, plastic limit, swell percent and swell pressure tests. The study showed that copper slag caused a significant increase in the swelling potential of the treated samples. The study further indicated that cation exchange capacity and the amount of sodium and calcium cations are good indicators of the effectiveness of chemical stabilizers used in soil stabilization.

Saravan*et al*. (2005) stabilized the expansive soil using 0%, 10%, 20%, 30%, 40%, 50%, 60%, 70% and 80% by dry weight of copper slag. The MDD increased, OMC decreased with increase in CS content and free swell index decreased by 60% corresponding to soil with 70% CS. However, the soaked CBR improved only after addition of 2% of cement and the expansive soil found to be suitable as a sub-grade material by utilizing 50% copper slag waste along with 2% cement.

2.1.5 Stabilization using silica fume (SF)

Silica fume, a co-product from the production of silicon or ferrosilicon metal, is an amorphous silicon dioxide - SiO_2 which is generated as a gas in submerged electrical arc furnaces during the reduction of very pure quartz. This gas vapour is condensed in bag housecollectors as very fine powder of spherical particles, i.e., in average 0.1 to 0.3 microns in diameter with a surface area of 17 - 30 m^2/g.

Dayakar*et al*. (2003) conducted laboratory investigation for stabilization of expansive soilusing silica fume and tannery sludge with percentage of solid wastes varying from 0 to 70%. The addition of wastes did not improve the index properties & maximum dry density but there was gain in strength of the expansive soil with both tannery sludge and silica fume upto 15%.

El-Aziz *et al*. (2004) investigated the effect of the engineering properties of clayey soilswhen blended with lime and Silica Fume (SF). Based on a series of laboratory experiments with lime percentages varying as 1%, 3%, 5%, 7%, 9% and 11% and SF at 5%, 10% and 15%, the plasticity index (PI) and swell potential decreased from 40.25% to 0.98% and from 19.0% to insignificant, respectively, at 11% lime and 15% of SF. There was considerable improvement in CBR value (3.0% to 17.0%), angle of internal friction (60 to 250) and cohesion (55.52 $kN/m^2$to 157.54 kN/m^2). The consolidation settlement was lowered from 0.025 to 0.007m.

Khare*et al*. (2005) observed that addition of silica fume and aluminium sludge did notimprove the index properties and maximum dry density of the expansive soil, but UCS values increased upto 10%. As the above wastes/ stabilizing agent have cementitious components, curing further increased its UCS value.

Kalkan and Akbulut (2004) studied the effect of silica fume on the permeability, swellingpressure and compressive strength of natural clay liners. The test results showed that the compacted clay samples with silica fume exhibited quite low permeability, swelling pressure and significantly high compressive strength as compared to raw clay samples.

2.1.6 Stabilization using other industrial wastes

Srinivasulu and Rao (1995) studied the effect of barite powder as a soil stabilizer and addedupto 20% of barite powder to expansive soil. The PI, OMC and cohesion decreased and

MDD, angle of internal friction and CBR values increased with increase in barite powder and hence, can be effectively used for any pavement construction in cohesive soil zones and for rural roads at minimum cost.

Swami (2002) had made the feasibility study for utilization of marble dust in highway sector.The marble dust was added upto 60% by an increment of 15% and the optimum proportion of expansive soil: marble powder was found as 75:25. Plasticity Index decreased from 25.1% to 7% with 35% marble dust, PI value at 15% and 25% marble powder were observed to be 15.37 and 8.3, respectively. The dry density increased from 17.56 kN/m^3 to 18.34 kN/m^3 with 45% marble dust, but CBR value increased (4.59 to 6.81%) upto 25% marble dust and decreased with further increase in marble powder.

Mishra and Mathur (2004) studied the stabilization of expansive soil with phosphogypsum(a waste product from phosphoric acid industry) and observed that soil mixed with different proportions of phosphogypsum reduced its liquid and plastic limit thereby, making the soil more workable. The free swell of the soil reduced considerably and the CBR value of the soil increased from 2% to 9 %, when 40% phosphogypsum was added. When the proportion of phosphogypsum was increased beyond 40%, the mix could not be compacted properly.

Parsons *et al.* (2004) presented a summary on the performance of a wide range of soils (CH,CL, ML, SM and SP) treated with cement kiln dust (CKD), to improve the texture, increase strength and reduce swell characteristics. Treatment with cement kiln dust was found to be an effective; strength and stiffness were improved, plasticity and swell potential were substantially reduced. Durability of CKD treated samples in wet-dry testing was comparable to that of soil samples treated with the other additives, while, performance was not as good in freeze thaw testing. CKD treated samples performed very well in leaching tests and in many cases showed additional reductions in plasticity and some strength was gained after leaching.

Koyuncu*et al*. (2004) used three types of ceramic waste, namely, ceramic mud wastes (CMW), crushed ceramic tile wastes (CCTW) and ceramic tile dust wastes (CTDW) for stabilization of expansive soil with Na-bentonite. Swelling pressure and swelling percent of Na-bentonite clay mixed with 40% CCTW decreased by 86% and 57%, respectively.

Al-Rawas (2004) investigated the physical, engineering, chemical and micro fabriccharacteristics of two soils from Oman treated with incinerator ash produced at Sultan Qaboos University. The soils were mixed with the incinerator ash at 0%, 10%, 15%, 20%, 25% and 30% by dry weight of the soils. The results showed that the incinerator ash used was a non-hazardous waste material treated samples showed a reduction in swell percent and cohesion, an increase in angle of internal friction with the addition of incinerator ash for curing periods was observed, 20% and 30% additive showed reduction of swell percent of the soils.

Amu *et al.* (2005) studied the effect of eggshell powder (ESP) on the stabilizing potential oflime on an expansive soil. Based on different engineering tests the optimal percentage of lime-ESP combination was attained at a 4% ESP + 3% lime. But, MDD, CBR value, UCS and undrainedtriaxial shear strength values indicated that lime stabilization at 7% is better than the combination of 4% ESP + 3% lime.

Mughieda*et al*. (2005) studied the feasibility of using composed olive mills solid by-product(COMSB), a solid by-product which causes environmental problems, in stabilization of expansive soil. With addition of COMSB by 2%-8% by weight, the PI, dry density (DD) and UCS decreased. The swell potential was found to reduce by 56%-65% and the swelling pressure by 56%-72% corresponding to untreated soil. Slow direct shear test indicated that the stabilizing agent decreased the cohesion intercept while the angle of internal friction was increased by 45%-65%.

Nalbantoglu and Tawfiq (2006) studied the stabilizing effect of Olive cake residue onexpansive Soil. Olive cake residue is a by-product after olives have been pressed and olive oil extracted. Olive cake residue was heated upto 550^{O}C about 1 hour and the ash produced as a result of heating was added into the soil with 3, 5 and 7% by dry weight of soil. With olive cake residue upto 3%, there was reduction in plasticity, volume change and an increase in unconfined compressive strength, but, with further increase in olive cake residue UCS decreased and compressibility increased. Red mud is a waste material generated by the Bayer Process widely used to produce alumina from bauxite throughout the world. Approximately, 35% to 40% per ton of bauxite treated using the Bayer Process ends up as red mud waste.

Kalkan (2006) studied utilization of red mud as a stabilization material for the preparation ofclay liners. The test results showed that compacted clay samples containing red mud and cement–red mud additives had a high compressive strength and hydraulic conductivity and swelling percentage was found to reduce as compared to natural clay samples.

Degirmenci*et al*. (2007) investigated phosphogypsum with cement and fly ash for soilstabilization. Atterberg limits, standard proctor compaction and unconfined compressive strength tests were carried out on cement, fly ash and phosphogypsum stabilized soil samples. Treatment with cement, fly ash and phosphogypsum generally reduced the plasticity indexwith increase in MDD with cement and phosphogypsum contents but, decreased as fly ash content increased. The OMC decreased and UCS increased with addition of cement, fly ash and phosphogypsum.

Seda*et al*. (2007) used waste tyre rubber for stabilization of highly expansive clays. Theindex properties and compaction parameters of the rubber, expansive soil and expansive soil-rubber (ESR) mixture were determined. While the ESR mixture was more compressible than the untreated soil, both the swell percent and the swelling pressure were significantly reduced by the addition of rubber to the expansive soil.

Attom*et al*. (2007) investigated the effect of shredded waste tire on the shear strength,swelling and compressibility properties of the clayey soil from northern part of Jordan. The shredded tires passing US sieve number 4 were added with the soil at 2%, 4%, 6%and 8% by dry weight of soil. The test results showed that increasing the amount of shredded waste tires increased the shear strength and decreased the plasticity index, maximum dry density, permeability, swelling pressure, swell potential and the compression index of the clayey soil.

Okagbue (2007) evaluated the potential of wood ash to stabilize clayey soil. Results showedthat the geotechnical parameters of clay soil were improved substantially by the addition of wood ash. Plasticity was reduced by 35%, CBR, UCS increased by 23–50% and 49–67%, respectively, depending on the compactive energy used. The highest CBR and strength values were achieved at 10% wood ash.

Peethamparan and Jan (2008) studied four CKD with different chemical and physicalcharacteristics in stabilizing Na-montmorillonite Clay. CKDs considerably decreased the plasticity index, thereby improving the workability of the clay, while, they also considerably increased the initial pH value of clay, providing a favourable environment for further chemical pozzolanic reaction. The addition of CKDs and subsequent compaction substantially increased the UCS and the stiffness of the clay, thus improving its structuralproperties. The extent of improvement of the clay characteristics was found to be a function of the chemical composition of the particular CKD, specifically its free lime content. It was also found that the length of curing period after compaction had a major role in the stabilization process.

Cokca*et al*. (2008) had utilized granulated blast furnace slag (GBFS) and GBFS – Cement(GBFSC) to overcome or to limit the expansion of an artificially prepared expansive soil sample (Sample A). GBFS and GBFSC were added with Sample A in proportions of 5 to 25 percent by weight. Effect of these stabilizers on grain size distribution, Atterberg's limits, swelling percentage and rate of swell of soil samples were determined. Effect of curing on swelling percentage and rate of swell of soil samples were also determined. Leachate analysis of GBFS, GBFSC and samples stabilized by 25 percent GBFS and GBFSC was performed. Use of stabilizers successfully decreased the amount of swell while increasing the rate of swell. Curing samples for 7 and 28 days resulted in less swell percentages and higher rate of swell. It was concluded that GBFS and GBFSC should not be used to stabilize expansive soils in regions near to the drinking water wells.

From the studies of the available literature, it was observed that various efforts have been made to study the possible utilisation of different industrial wastes for stabilization of expansive soil.

2.1.7 Stabilization of dispersive soil using alum

Ouhadi and Goodarzi (2006) used alum to control dispersivity performance of soil. Set of physic-chemical experiments including Atterberg limits, permeability, consolidation, double hydrometer, ion exchange and pH measurement were performed to investigate the fundamental mechanism of soil-alum interaction. Double hydrometer test conducted showed that use of 1.5% alum caused a noticeable change in dispersivity. Results obtained indicated that the addition of alum caused a decrease in pH and liquid limit and increased the hydraulicconductivity. It was concluded that ion exchange and pH effects were two important phenomena responsible for overcoming soil dispersivity.

2.1.8 Stabilization using biopolymer

Chen *et al.* (2013) performed a preliminary study on using Xanthan gum and Guargum, two biopolymers that are naturally occurring and inexpensive, to stabilize mine tailings (MT). The addition of these two biopolymers increased both liquid limit and the undrained shear strength of the MT. Guar gum was found to be more effective than Xanthan gum in increasing the liquid limit and undrained shear strength of the MT, as the Guar gum solution was more viscous than the Xanthan gum solution at the same concentration. A comprehensive study on the mechanical, chemical and polymer stabilization of soil (expansive soil and dispersive soil) is presented in Tables 2.1, 2.2 and 2.3, respectively.

From critical review of literature, it can be seen that the studies regarding geopolymer are limited to its use in concrete and a single literature (Parhi and Das, 2014) is available in its application for soil. Similarly, a single literature (Chen *et al.*) for the use of biopolymer in stabilization of soil is available. So, in this present study an attempt has been made to use geopolymer as an alternative cementitious material in stabilizing expansive soil and biopolymers (Xanthan gum and Guar gum) are used to stabilize dispersive soil.

Table 2.1 Comprehensive studies on the mechanical stabilization of soil

Sl. No.	Types of waste	Investigation	Findings	Reference
1	RHA and Lime	Consolidation and Shear Strength	RHA slightly increased the coefficient of consolidation (Cv). In combination with lime it further increased Cv. RHA in combination with lime considerably decreases Cc.	Rajan and Subramanyam (1982)
2	RHA, Fly ash, bagasse ash, Black sulphite liquor, Lime sludge with and without lime	UCS and CBR	UCS and CBR increased upto addition of certain % waste and lime and then decreased. However, Black sulphite liquor and bagasse ash did not improved the strength.	Bhasin*et al.* (1988)
3	Fly ash, lime and gypsum	SP and UCS	SP reduced and UCS of the soil increased.	Sharma *et al.* (1992)
4	Barite powder	PI, OMC, Cohesion, MDD, angle of internal friction and CBR	PI, OMC and cohesion decreased and MDD, angle of internal friction and CBR increased with increase in barite powder.	Srinivasulu and Rao (1995)
5	a)Fly ash and Lime sludge	a)Microstructure and fabric	a) Remarkable change in micro structure and fabric	a)Srivastava *et al.* (1997)

Sl. No.	Types of waste	Investigation	Findings	Reference
6	Fly ash and Lime sludge	Consolidation and SP	Improvement in consolidation and reduction in SP.	Srivastava *et al.* (1999)
7	Class-C fly ashes	SP	75% decrease in SP with 7 days curing and 79% decrease in SP with 28 days curing.	Cocka (2001)
8	Class F Fly ash	CBR	20% addition of fly ash increased the CBR by 200%.	Pandian*et al.* (2001)
9	Cement by-pass dust, copper slag, granulated blast furnace slag and slag-cement	PS and PI	Copper slag caused a significant increase in the PS; other stabilizers reduced the PS and plasticity at varying degrees.	Al-Rawas *et al*. (2002)
10	Crusher dust	PI, shrinkage limit (SL), CBR, UCS , SP and free swell index (FSI)	PI, SP and FSI was decreased, SL, CBR and UCS was increased.	Gupta *et al.* (2002)
11	Marble dust	PI, compaction and CBR	PI decreased, MDD and CBR increased	Swami (2002)
12	Silica fume and Tannery sludge (separately)	Index properties, compaction and UCS	Index properties and MDD did not improve. UCS increased upto 10% addition of waste, curing further increased strength.	Dayakar*et al.* (2003)
13	Incinerator ash	LL, PL, PS, direct shear, curing for 1, 7 and 14 days and FE-SEM	Increase in PL, reduction in LL, PS and C_C and an increase in Φ with the addition of incinerator ash for curing periods. The use of 20% and 30% additive showed clearly the development of aggregations that contributed to reduction of swell percent of the soils.	Al-Rawas (2004)
14	Silica Fume and Lime	PI, PS, CBR and shear	PI, PS and Consolidation settlement was decreased. CBR value, Internal friction angle and Cohesion increased.	El-Aziz *et al.* (2004)
15	Silica fume	K, SP, UCS	K, SP was decreased,	Kalkan and

Sl. No.	Types of waste	Investigation	Findings	Reference
		and leachate Test	UCS increased and leachate did not affect.	Akbulut (2004)
16	Cement Kiln dust	Strength, swell, durability and leaching	Improvement in properties were found, but performance was not good in freeze –thaw cycles.	Parsons *et al.* (2004)
17	Quarry dust, lime and rock powder	Swelling potential	Swelling potential reduced and reduction was found to increase with increasing percentage of stabilizers and days of curing.	Gulash (2004)
18	Fly ash	Plasticity, hydrauliv conductivity, swelling properties, strength and dry unit weight	Plasticity, hydrauliv conductivity and swelling properties decreased and strength and dry unit weight increased with increase in fly ash content.	Phani Kumar and Sharma (2004)
19	Fly ash and lime	Engineering properties	Optimum proportions of soil:flyash:lime should be 70:30:4 for construction of roads and embankments.	Satyanarayana *et al.* (2004)
20	Quarry dust and marble powder	LL and SP	LL and SP decreased with increase in quarry dust or marble powder content.	Stalin *et al.* (2004)
21	Class C and Class F fly ash and sand	Free swell	Class C fly ash was found to be more effective and free swell decreased with curing period.	Turker and Cokca (2004)
22	Eggshell powder (ESP) and lime	MDD, UCS, CBR and undrainedtriaxial shear strength	MDD, UCS, CBR and undrainedtriaxial shear strength values indicated that lime stabilization at 7% was better than the combination of 4% ESP + 3% lime.	Amu *et al.* (2005)
23	Silica fume and aluminium sludge	Index properties, MDD and UCS	Index properties and MDD did not improve. UCS increased upto 10% addition of sludge.	Khare (2005)
24	Copper slag and Cement	FSI, CBR	FSI decreased, CBR increased.	Sarvan*et al*. (2005)
25	Fly ash-marble	Engineering	Optimum	Sabat*et al.*

Sl. No.	Types of waste	Investigation	Findings	Reference
	powder	properties	proportion of soil:flyash:marble powder was 65:20:15	(2005)
26	Composted olive mills solid by-product(COMSB)	Atterberg's limits, UCS, direct shear strength, Standard proctor density and S_P	Decrease in PI, MDD and UCS. PS was reduced by upto 56% to 65% and the SP was reduced by up to 55% to 72%, decrease in C_C and Φ was increased byupto 45% to 67%.	Mugheida *et al*. (2005)
27	Olive Cake Residue	PI, UCS and consolidation	An addition of only 3% burned olive waste in the soil causes a reduction in plasticity, volume change and an increase in UCS, a greater amount than 3% caused a decrease in UCS, increase in compressibility.	Nalbantoglu and Tawfiq (2006)
28	Red mud and Cement	PI , K, UCS and PS	The test results showed that compacted clay samples containing red mud and cement–red mud additives had a high compressive strength and decreased the hydraulic conductivity and PS as compared to natural clay samples.	Kalkan(2006)
29	Stone dust and nylon fibre	SP, ultimate bearing capacity and settlement	SP and settlement decreased and ultimate bearing capacity increased.	Jain and Jain (2006)
30	Rice husk ash and cement	OMC, MDD, plasticity, UCS and soaked CBR	OMC, UCS and soaked CBR increased whereas, MDD and plasticity reduced.	Ramkrishna and Pradeep kumar (2006)
31	Fly ash columns and fly ash-lime	MDD, UCS and split tensile	MDD decreased with addition of	Phanikumar and Rajesh (2006)

Sl. No.	Types of waste	Investigation	Findings	Reference
	columns	strength	fly ash-lime columns and UCSand split tensile strength increased with fly ash columns	
32	Class F fly ash, bottom ash, polypropylene fibres and nylon fibres	Swelling, shrinkage and plasticity	Swelling, shrinkage and plasticity reduced.	Punthutaecha (2006)
33	Fly ash, rock flour and lime	CBR, angle of shearing resistance, cohesion	CBR increased with increase in both cohesion and frictional resistance.	Wagh (2006)
34	Waste tire rubber	a) PS and SP b)PI, compaction, PS and consolidation	a) PS and SP both decreased. b) Increasing the amount of shredded waste tires increased the shear strength and PI, MDD, K, PS and Cc was decreased.	Attom*et al.* (2007)
35	Lime and Class C fly ash	Linear shrinkage	Linear shrinkage reduced	Buhler and Cerato (2007)
36	Polyester fibre, fly ash and lime	MDD, OMC, UCS and split tensile strength	MDD decreased with increase in fly ash and lime content but polyester fibres had no significant effect on MDD and OMC. However, UCS and split tensile strength increased with addition of fibres.	Kumar *et al.* (2007)
37	Fly ash	PS, SP, coefficient of secondary consolidation and compression index	PS, SP, coefficient of secondary consolidation and compression index decreased.	Phani Kumar and Sharma (2007)
38	Waste tire rubber	a) PS and SP b)PI, compaction, PS and consolidation	a) PS and SP both decreased. b) Increasing the amount of shredded waste tires will increase the shear strength and PI, MDD, K, PS, SP and Cc was decreased.	Seda*et al.* (2007)

Sl. No.	Types of waste	Investigation	Findings	Reference
39	Wood ash	PI, CBR	PI was reduced, CBR and strength increased by 23–50% and 49–67%, respectively, depending on the compactive energy used. The highest CBR and strength values were achieved at 10% wood ash. Curing improved the strength of the wood ash-treated clay.	Okagbue (2007)
40	Granulated Blast Furnace Slag (GBFS) and GBFS cement	Grain size distribution, atterberg's limit, swelling percentage and rate of swell. Effect of curing on swelling percentage and rate of swell and leachate analysis.	Decreased the amount of swell while increasing the rate of swell. Curing samples for 7 and 28 days resulted in less swell percentage and higher rate of swell.	Cokca*et al.* (2008)
41	Cement kiln dusts	PI, Compaction and UCS	Decreased the PI, increased the UCS and stiffness.	Peethamparan and Jan (2008)

Table 2.2 Comprehensive studies on the chemical stabilization of soil

Sl. No.	Types of waste	Investigation	Findings	Reference
1	$CaCl_2$, lime , Sodium Silicate (Na_2SiO_3) RHA, Lime + RHA, $CaCl_2$+RHA, ($CaCl_2$)+ (Na_2SiO_3)	Field and laboratory investigations like UCS and CBR (lab), In-situ heave test and In-situ strength test	Lime –RHA treatment resulted in maximum improvement in strength and highest reduction in shrinkage.	Chandrasekhar *et al*. (2001)
2	Phosphogypsum	PI, free swell percentage, UCS, soaked CBR and direct shear	The plasticity index of the soil goes decreasing upto 40% addition, The free swell of the soil reduced considerably and the CBR value of the soil increased from a value of 2%, to a value of 9 %,	Mishra and Mathur(2004)

			when 40% phosphogypsum was added.	
3	Fly ash, lime and desulphogypsum	Swelling percentage	Swelling percentage reduced.	Baytar (2005)
4	Alum	pH, LL, ion exchange and hydraulic conductivity	pH and LL decreased. Hydraulic conductivity increased. Ion exchange resulted in decrease in thickness of particles.	Ouhadi and Goodarzi (2006)
5	Phosphogypsum with cement and fly ash	Atterberg's limits, standard proctor compaction and UCS	Reduced the PI, MDD increased as cement and phosphogypsum contents increased, but decreased as fly ash content increased. Generally optimum moisture contents of the stabilized soil	Degirmenci *et al*.(2007)
			samples decreased with addition of cement, fly ash and phosphogypsum. UCS of untreated soils was in cases lower than that for treated soils. The cement content had a significantly higher influence than the fly ash content.	
6	Rice husk ash, $CaCl_2$ and lime	UCS and CBR	Improvement in UCS and CBR values.	Sharma *et al*. (2008)

Table 2.3 Comprehensive studies on the polymer stabilization of soil

Sl. No.	Types of waste	Investigation	Findings	Reference
1	Xanthan gum and Guar Gum	Undrained shear strength and LL	Undrained shear strength and LL increased.	Chen *et al.* (2013**)**

CHAPTER 3

Materials and Methodology

3.1 Introduction

In the present study two difficult soils are considered namely expansive and dispersive soil. Both have been stabilized using geopolymers (alkali activators, sodium silicate: sodium hydroxide in 2:1 ratio) and biopolymers (commercially available Xanthan gum and Guar gum). The alkali solution sodium silicate: sodium hydroxide in 2:1 ratio was used in different concentrations.

3.2 Materials

Details of materials adopted for the present study have been presented below.

3.2.1 Bentonite

The commercial available bentonite is used in the present study, which are from Kutch mining area, Bhuj district, Gujarat, India. A small amount (20 gm) of the sample was sealed in polythene bag for determining its natural moisture content. The soil was air dried and pulverized as required for laboratory test. The particle size distribution of bentonite is presented in Fig. 3.1. It shows bentonite has got the finest of finest particles. The geotechnical properties of bentonite soil are presented in Table 3.1, which showed that it belonged to CH (organic clay with high plasticity) classification. Field Emission Scanning Electron Microscopy (FE-SEM) revealed the morphological feature for bentonite which is illustrated in Fig. 3.2. Energy dispersive X-ray Spectroscopy (EDX), revealed the compositional features of bentonite, which is illustrated in figure Fig. 3.3.Elemental composition of bentonite revealed by EDX is presented in Table 3.2.

3.2.2 Fly ash

Safe disposal and management of fly ash are the two major issues concerned with the production of fly ash. At present, the generation of fly ash is far in excess of its utilization. In the present study, fly ash was collected from the hopper of a thermal power plant from Raigarh, Chhattisgarh, India. Two pond ashes were collected from Rourkela steel plant, Rourkela, Odisha, India at two different times and named as RSP1 and RSP2.

Table 3.1 Geotechnical properties of bentonite soil

SL. NO.	Properties	Value	Confirming to IS Code
1	Specific gravity (G)	2.53	IS 2720 : Part 3 : Sec 1: 1980
2	Maximum dry density (MDD)	12.60 kN/m^3	IS 2720 : Part VII : 1980
3	Optimum moisture content (OMC)	23.01%	IS 2720 : Part VII : 1980
4	Differential free swell	438%	IS 2720 : Part XL : 1977
5	Liquid limit	353%	IS 2720 : Part 5 : 1985
6	Plastic limit	39.21%	IS 2720 : Part 5 : 1985
7	Shrinkage Limit	10.33%	IS 2720 : Part 5 : 1985
8	Swelling pressure	700 KN/m^2	IS 2720 : Part XLI : 1977
9	Classification	CH	IS 1498 (1970)

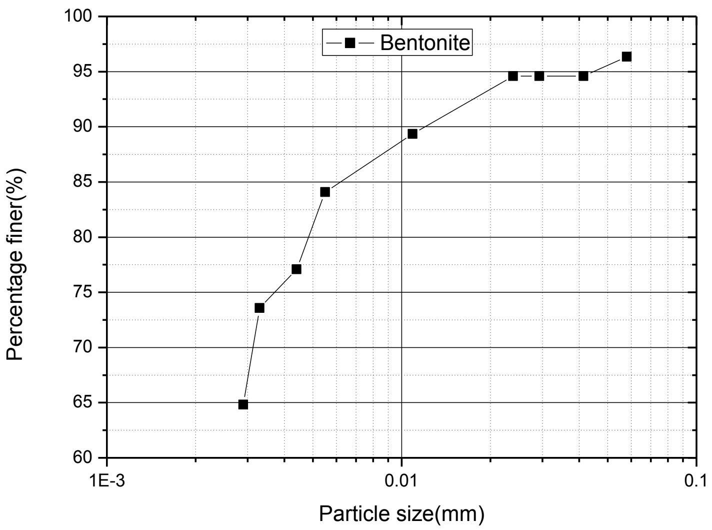

Fig. 3.1 Grain size distribution (Hydrometer analysis) curve of bentonite

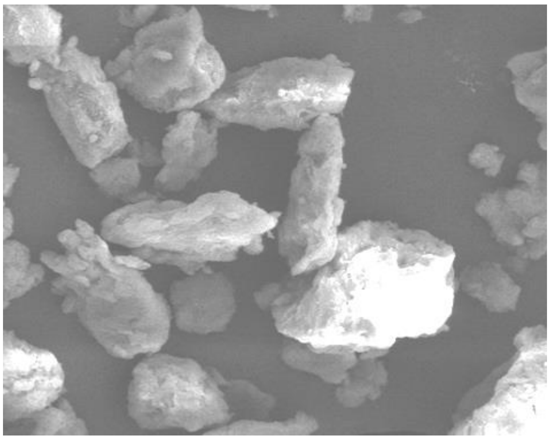

Fig. 3.2 (a)

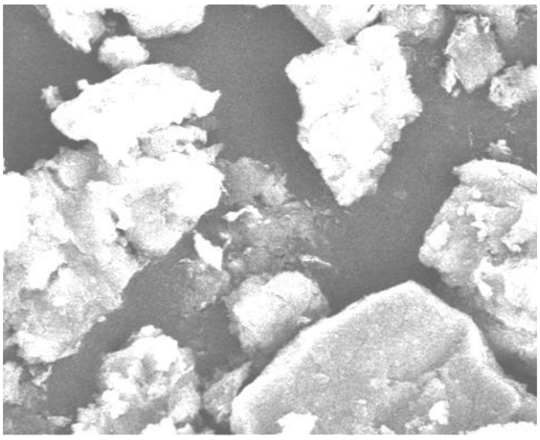

Fig. 3.2 (b)

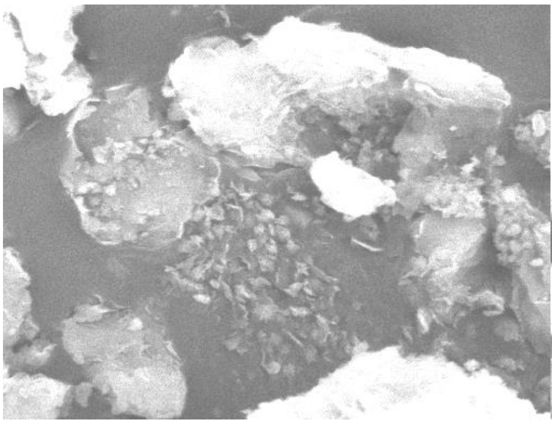

Fig. 3.2 (c)

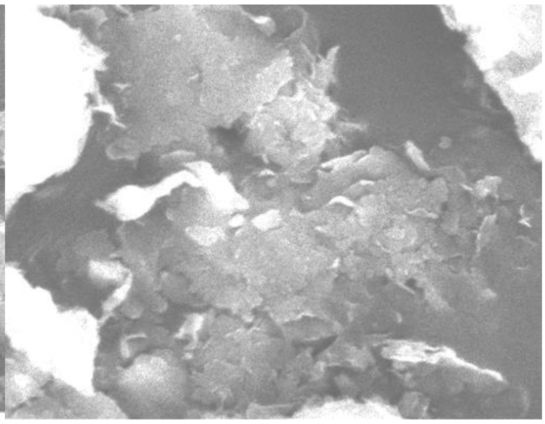

Fig. 3.2 (d)

Fig. 3.2 FE-SEM photograph of bentonite at (a) 4000X (b) 8000X (c) 16000X (d) 30000X magnification

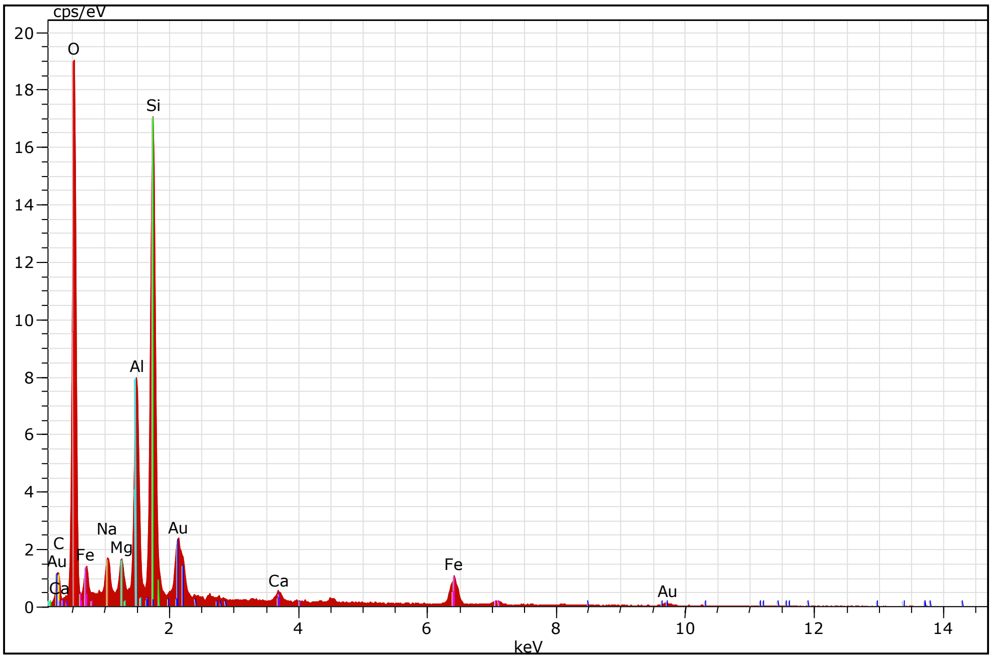

Fig. 3.3 EDX for Bentonite

Table 3.2 Elemental composition of Bentonite

Element	Atomic Number	Normalised percentage in the geomaterial
O	8	60.3
Si	14	16.4
Al	13	7.27
Fe	26	2.98
C	6	8.86
Na	11	2.28
Mg	12	1.45
Ca	20	0.46
Au	79	0

Similarly, another pond ash was collected from Adhunik steel plant, Rourkela, Odisha, India and named as ADN. Here, pond ash is used for comparison with dispersive soil (white soil)as shown in chapter 5.The white soil (WS) is a local residual soil. After obtaining, the fly ashes are screened through 2 mm IS sieve, to separate out the foreign material. To get a clear homogeneity, the samples are mixed thoroughly and heated in an oven maintained at 105-110 ^{o} C for 24 hours and then is stored in an air tight container, for further use. The particle size distribution of fly ash is presented in Fig. 3.4.Fig. 3.5 shows XRD analysis of fly ash, which indicated that the major minerals present in the fly ash are quartz, mullite and hematite. The hump in the XRD plot indicates presence of alumina silicate glass as discussed in Das and Yudhbir (2005). Fig.3.6 shows scanning electron micrographs (FE-SEM) of fly ash. It can be seen that most of the fly ash particles are spherical in nature and are known as cenospheres and plerospheres (Das and Yudhbir 2005). Fig. 3.7 shows EDX for fly ash, which revealed the elemental composition of fly ash presented in Table 3.3.

3.2.3 Alkali Activated Fly ash (geopolymer)

The alkali activation of waste materials has become an important area of research in many laboratories because it is possible to use these materials to synthesize inexpensive and ecologically sound cement like construction materials. Alkali activated fly ash also known as geopolymer, is the cement for the future. The alkali activation of waste materials is a chemical process that allows the user to transform glassy structures (partially or totally amorphous and/or metastable) into very compact well-cemented composites.

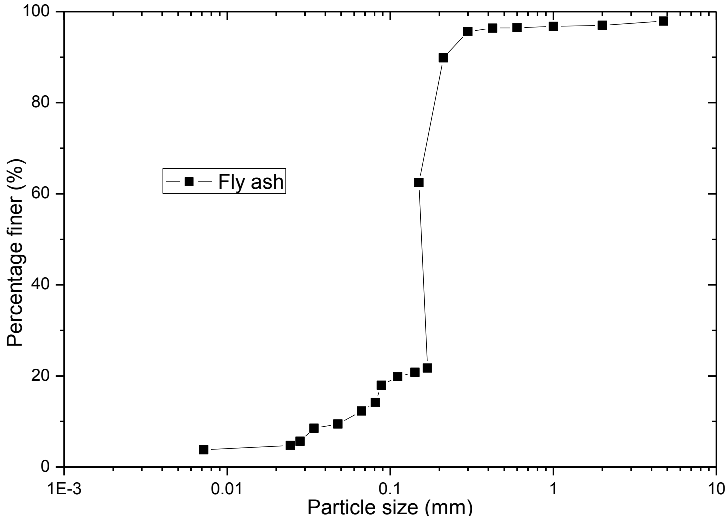

Fig. 3.4 Grain size distribution curve of fly ash

Alkaline activation is a chemical process in which a powdery alumina-silicate such as fly ash is mixed with an alkaline activator to produce a paste capable of setting and hardening within a reasonably short period of time.

The alkaline activation of fly ash is consequently of great interest in the context of new and environmentally friendly binders with properties similar to or that improved on the characteristics of conventional materials.

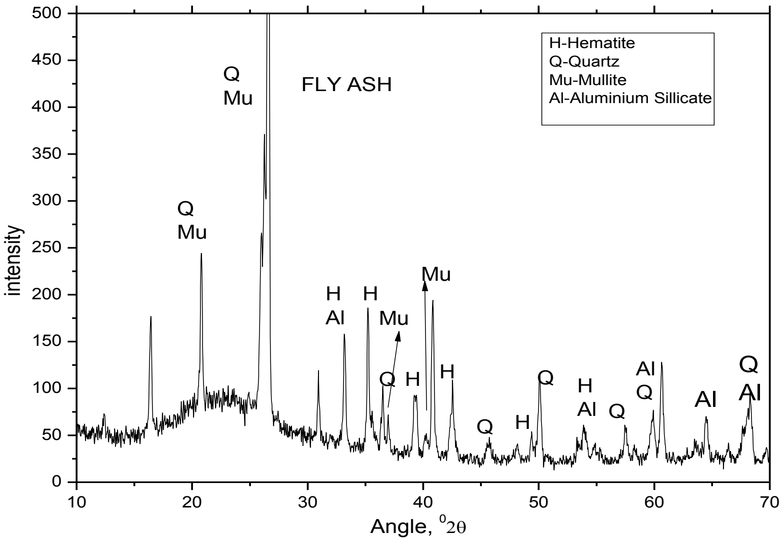

Fig. 3.5 XRD analysis of fly ash

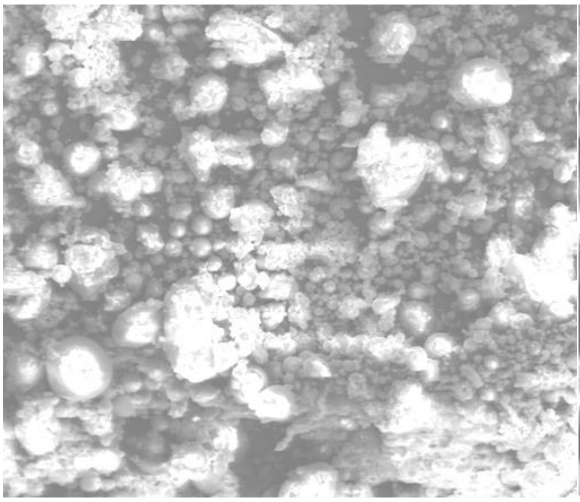

Fig. 3.6 (a)

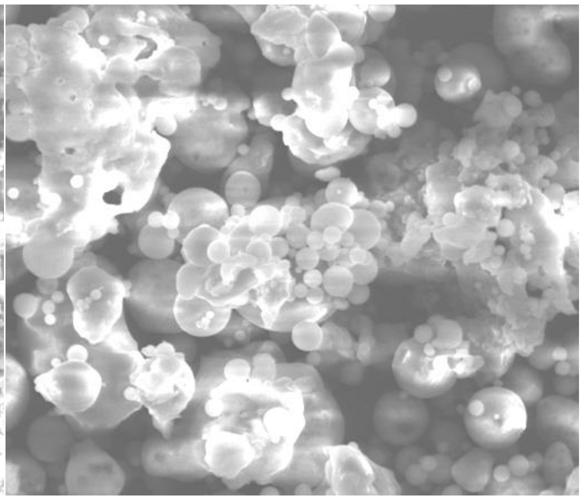

Fig. 3.6 (b)

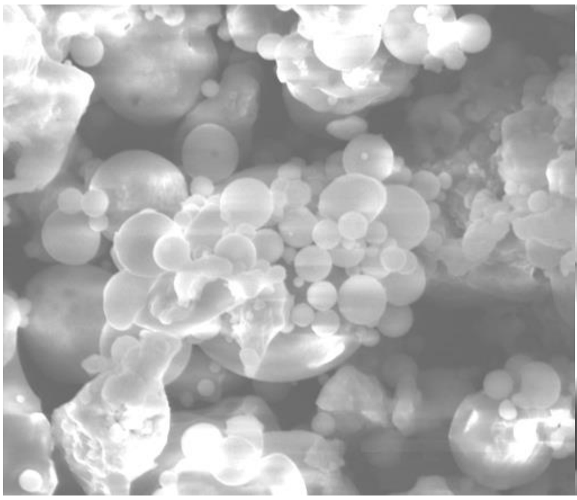

Fig. 3.6 (c)

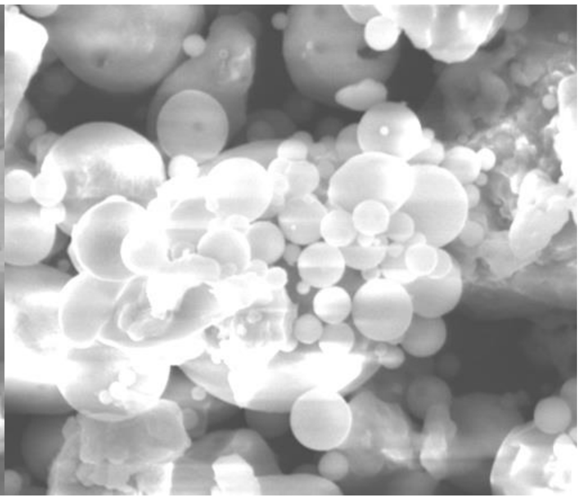

Fig. 3.6 (d)

Fig. 3.6 FE-SEM image of fly ash at (a) 1000X (b) 5000X (c) 8000X (d) 10000X magnification

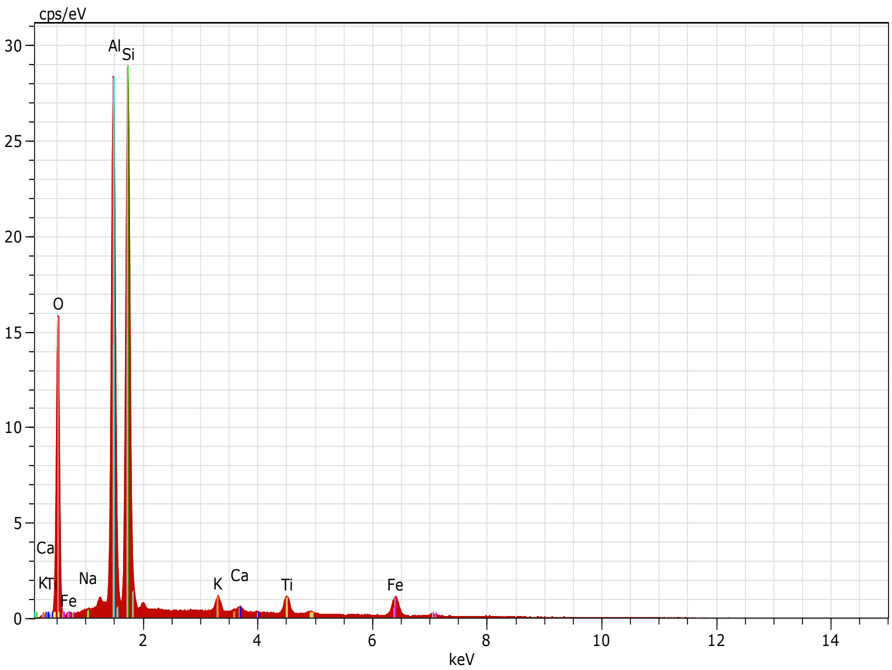

Fig. 3.7 EDX for fly ash

Table 3.3 Elemental composition of fly ash and pond ash

Element	Atomic Number	Fly ash	Pond ash
O	8	50.71	52.15
Si	14	24.12	32.15
Al	13	19.85	17.23
Fe	26	2.72	2.56
Ti	22	1.39	0.04
K	19	0.83	1.26
Ca	20	0.32	0.68
Na	11	0.06	0.00

In general terms, alkaline activation is a reaction between alumina-silicate materials and alkali or alkali earth substances, namely: ROH, $R(OH)_2$), R_2CO_3, R_2S, Na_2SO_4, $CaSO_4.2H_2O$, $R_2.(n)SiO_2$, in which R represents an alkaline ion like sodium (Na) or potassium (K), or an alkaline earth ion like Ca. It can be described as a poly-condensation process, in which the silica (SiO_2) and alumina (AlO_4) tetraedrics interconnect and share the oxygen (O) ions. The process starts when the high hydroxyl (OH) concentration of the alkaline medium favours the breaking of the covalent bonds Si–O–Si, Al–O–Al and Al–O–Si from the vitreous phase of the raw material, transforming the silica and alumina ions in colloids and releasing them into the solution. The extent of dissolution depends upon the quantities and nature of the alumina and silica sources and the pH levels. In general, minerals with a higher extent of dissolution will result in higher compressive strength after the process is complete. At the same time, the alkaline cations Na^+, K^+ or Ca^{2+} act like the building blocks of the structure, compensating the excess negative charges associated with the modification in aluminium coordination during the dissolution phase.

3.2.3.1 Reaction Mechanism

A highly simplified diagram of the reaction mechanism in alkaline activation process is shown in Fig. 3.8 which outlines the key processes occurring in the transformation of a solid aluminosilicate source into a synthetic alkali aluminosilicate (N-A-S-H) gel. When the fly ashes are submitted to the alkaline solution, a dissolution process of the Al and Si occurs. Then the higher molecules condense in a gel (polymerization and nucleation) and the alkali attack opens the spheres exposing small spheres on the inside which will be also dissolved until the spheres, became almost dissolved with the formation of reaction products inside and outside the sphere (Fig. 3.8).

For the sake of simplicity, the figure does not show the grinding or heating of raw materials required to vary the reactivity of aluminium in the system. Though presented linearly, these processes essentially occur concurrently. The dissolution of the solid aluminosilicate source by alkaline hydrolysis (consuming water), yields aluminate and silicate species. The surface dissolution of solid particles and the concomitant release (very likely monomeric) alumina and silica into the solution have always been assumed to be the mechanism responsible for the conversion of the solid particles during alkaline activation. Once dissolved, the species released are taken up into the aqueous phase, which may contain silica, a compound present in the activating solution. A complex mix of silicate, aluminate and aluminosilicate species is thereby formed, whose equilibrium in these solutions has been studied extensively. Amorphous aluminosilicate dissolves rapidly at high pH, quickly generating a supersaturated aluminosilicate solution. In concentrated solutions this leads to the formation of a gel as the oligomers in the aqueous phase condense into large networks. This process releases the water that was nominally consumed during dissolution. Water then plays the role of a reaction medium while nevertheless residing inside gel pores. This type of gel structure is commonly referred to as biphasic, the two phases being the aluminosilicate binder and water.

The time required for the supersaturated alumionosilicate solution to form a continuous gel varies considerably, depending on raw material processing conditions, solution composition and synthesis condition. After the gel forms, rearrangement and reorganisation continue in the system as intra-connectivity increases in the gel network. The end result is the 3-D aluminosilicate network commonly attributed to N-A-S-H gels. This is depicted in Fig. 3.8 in the form of multiple gel stages, consistent with recent experimental observations. And numerical modelling for fly ash based materials. Fig. 3.9 describes the activation reaction as the outcome of two successive, process-controlling stages. The first, nucleation or dissolution of the fly ash and the formation of polymeric series, is highly dependent on the thermodynamic and kinetic parameters. Growth is the stage during which the nuclei reach a critical size and crystals begin to develop. These structural reorganisation processes determine the microstructure and pores distribution of the material, which are critical to determining many physical properties.

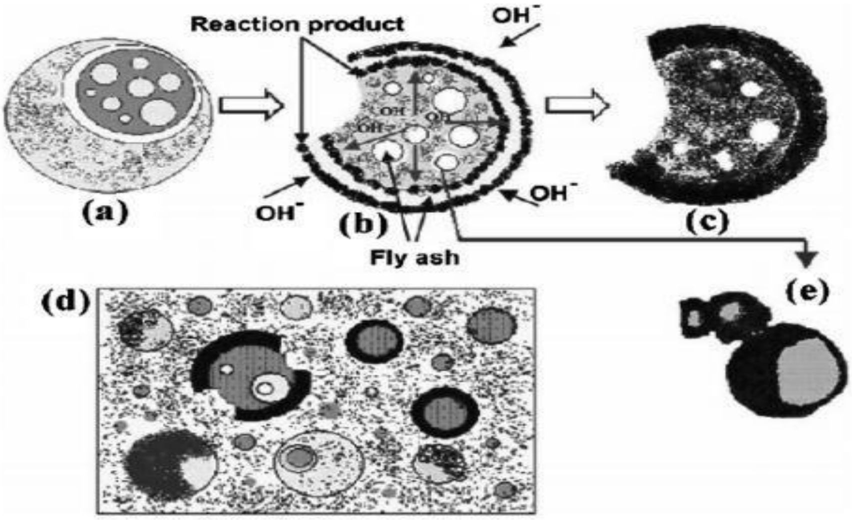

Fig. 3.8 Descriptive model of the alkaline activation processes of fly ash (Palomo and Jimenez 2005)

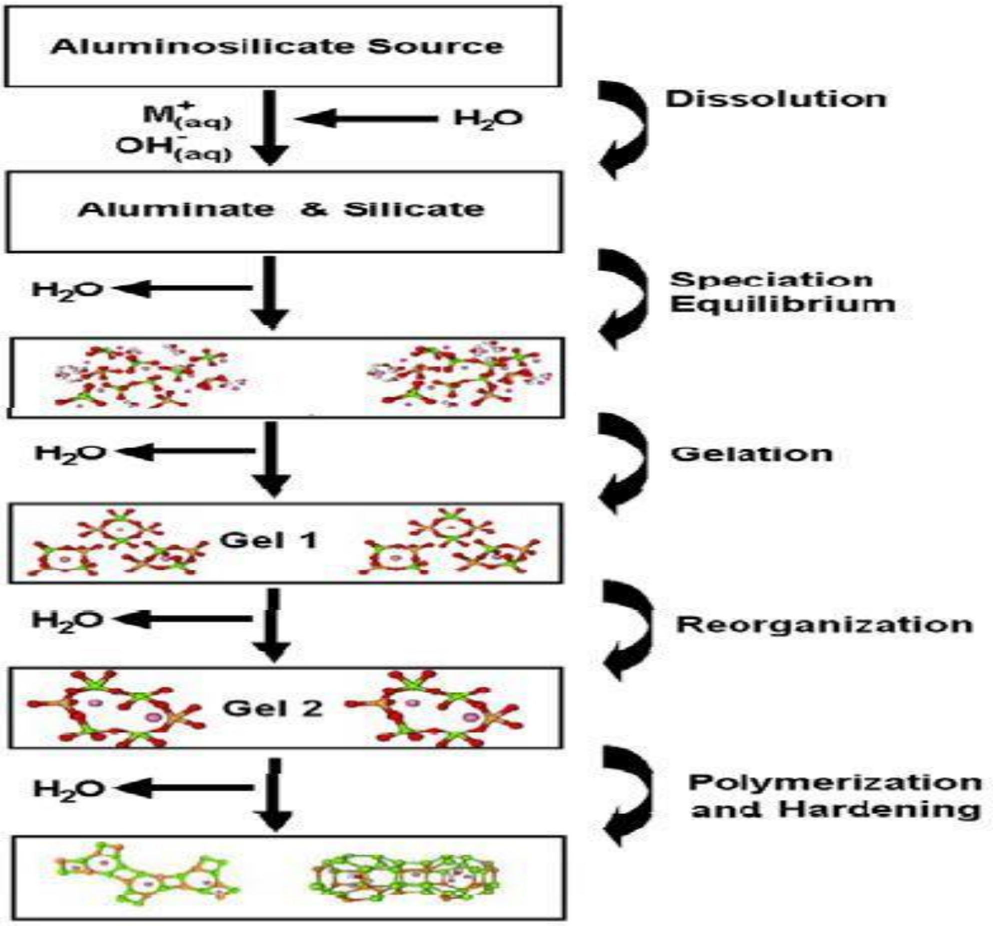

Fig. 3.9 Conceptual model for alkaline activation processes (Palomo and Jimenez 2011)

3.2.3.2 Alkalis

The alkaline alkali used was a combination of sodium silicate and sodium hydroxide. The sodium silicate was originally in powder form and of LobaChemie, Thane, Maharashtra, having molecular weight of 284.20 gm/mole and specific gravity of 1.5. While the sodium hydroxide was originally in pellets form with a molecular weight of 40 gm/mole and specific gravity of 2.13 at 20º C and 95-99% purity. The sodium hydroxide was brought from Merck specialities Pvt. Ltd. Mumbai, Maharashtra, India. The ratio of sodium silicate to sodium hydroxide solution by dry mass was kept as 2. This value was chosen not only because the silicate is considerably cheaper than the hydroxide, but also because of several studies that have analysed the influence of the activator composition of higher ratios resulted in higher strength levels.

3.2.4 Applications of alkali-activated fly ash

The most recent research findings have confirmed the following:

- Concretes made with these materials can be designed to reach compressive strength values of over 40 MPa after short thermal curing times.
- Concrete made with alkali-activated fly ash performs as well as traditional concrete and even better in some respects, exhibiting less shrinkage and a stronger bond between the matrix and the reinforcing steel.
- In addition to its excellent mechanical properties, the activated fly ash is particularly durable and highly resistant to aggressive acids, the aggregate-alkali reaction and fire.
- This family of materials fixes toxic and hazardous substances very effectively.

3.2.5 Dispersive soil

It was collected from hostel area, NIT Campus Rourkela. A small amount (20 gm) of the sample was sealed in polythene bag for determining its natural moisture content. More soil was collected air dried, pulverized and sieved with 425 μm Indian standard as required for laboratory tests. The grain size distribution curve of dispersive soil is presented in Fig. 3.10. The various geotechnical properties are shown in Table 3.4, which showed that it belonged to CL (organic clay with high plasticity) or ML (inorganic silt with low plasticity) category. Fig. 3.11 shows XRD analysis of dispersive soil. The major minerals present in it are quartz, burnt ochre and aluminium silicate. FE–SEM, revealed the morphological feature for dispersive soil which is

illustrated in Fig. 3.12. Fig. 3.13 shows EDX for dispersive soil, which revealed the elemental composition of dispersive soil, is shown in Table 3.5.

Table 3.4 Geotechnical properties of dispersive soil

SL. NO.	Properties	Value	Confirming to IS Code
1	Specific gravity (G)	2.72	IS 2720 : Part 3 : Sec 1 : 1980
2	Maximum dry density (MDD)	17.18 KN/m^3	IS 2720 : Part VII : 1980
3	Optimum moisture content (OMC)	15.19%	IS 2720 : Part VII : 1980
4	Differential free swell	-	IS 2720 : Part XL : 1977
5	Liquid limit	29%	IS 2720 : Part 5 : 1985
6	Plastic limit	22%	IS 2720 : Part 5 : 1985
7	Shrinkage Limit	20.45%	IS 2720 : Part 5 : 1985
8	Swelling pressure	-	IS 2720 : Part XLI : 1977
9	Coefficient of curvature (C_c)	1.46	IS 2720 : Part 4 : 1985
10	Coefficient of uniformity (C_u)	0.58	IS 2720 : Part 4 : 1985
11	Classification	CL-ML	IS 1498 (1970)

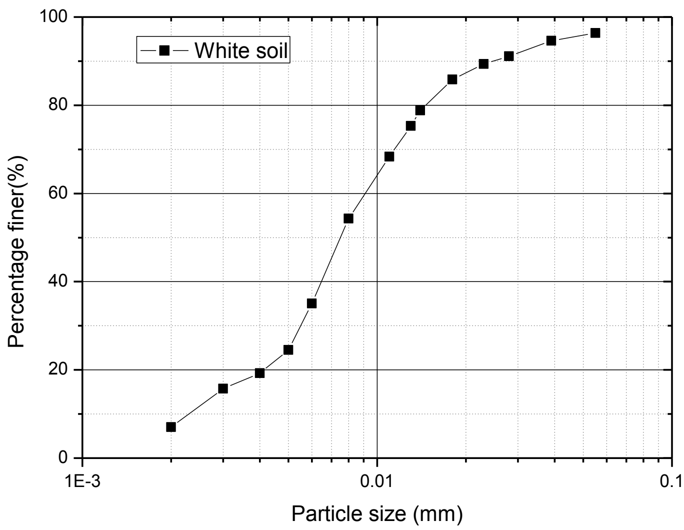

Fig. 3.10 Grain size distribution curve of dispersive soil

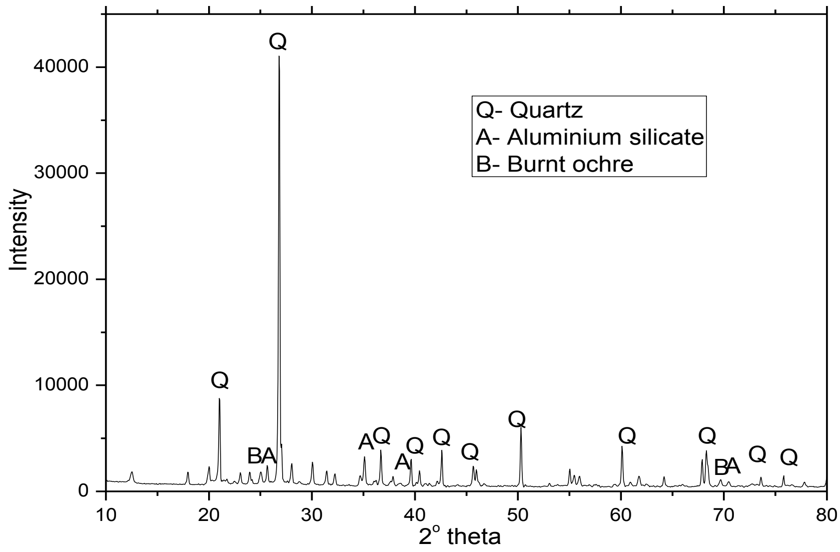

Fig. 3.11 XRD of dispersive soil

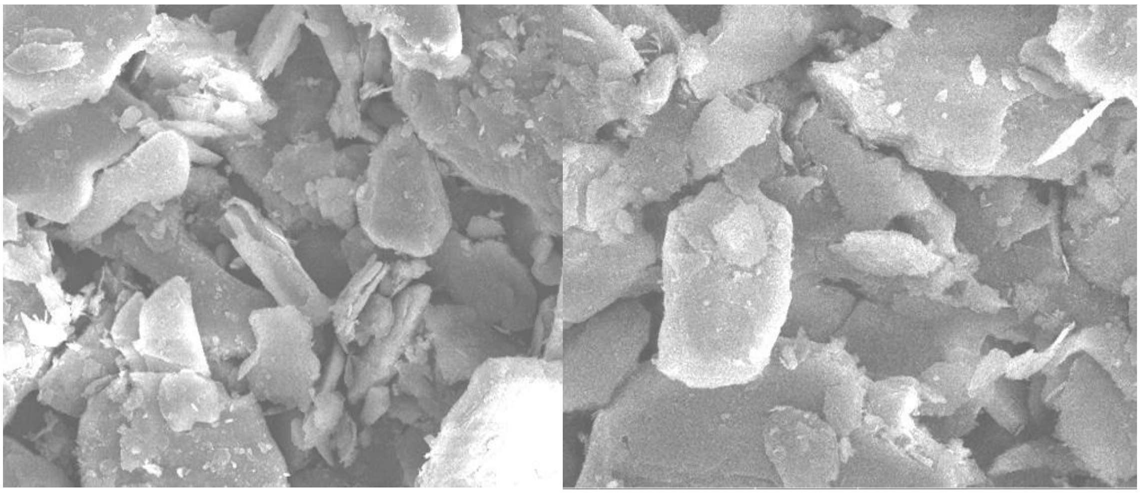

Fig. 3.12 (a) **Fig. 3.12** (b)

Fig. 3.12 FE-SEM of dispersive soil at (a) 5000X (b) 7000X magnification

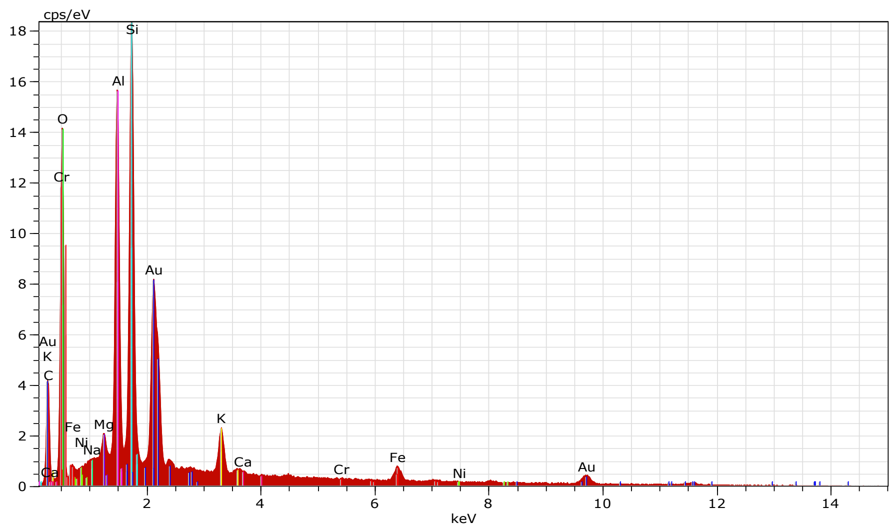

Fig. 3.13 EDX for dispersive soil

Table 3.5 Elemental composition of dispersive soil

Element	Atomic Number	Normalised percentage in the geomaterial
O	8	37.78%
C	6	21.31%
Si	14	17.66%
Al	13	12.98%
Fe	26	4.53%
K	19	3.50%
Mg	12	0.92%
Ni	28	0.70%
Ca	20	0.35%
Na	11	0.20%
Cr	24	0.07%
Au	79	0.00%

3.2.6 Biopolymers

3.2.6.1 Xanthan gum

Xanthan gum is a microbial exopolysaccharide produced by the gram-negative bacterium *Xanthitalics Campestris* by fermenting glucose, sucrose, or other carbohydrate sources. This biopolymer is applied in the food, cosmetic, pharmaceutical and petrochemical industries and in other sectors as a thickening agent, stabilizer, or emulsifier and combined with other gums it can act as a gelling agent (Chen *et al.* 2013).This was added with dispersive soil and pond ash in different percentage (1%, 2% and 3%). XRD analysis of dispersive soil mixed with Xanthan gum is presented in Fig. 3.14, which showed major minerals presented are quartz, burnt ochre and aluminium silicate. FE-SEM showed morphological features of dispersive soil with Xanthan gum, illustrated in Fig. 3.15. Fig. 3.16 showed EDX for dispersive soil with Xanthan gum, which revealed the elemental composition of dispersive soil with Xanthan gum shown in Table 3.6.

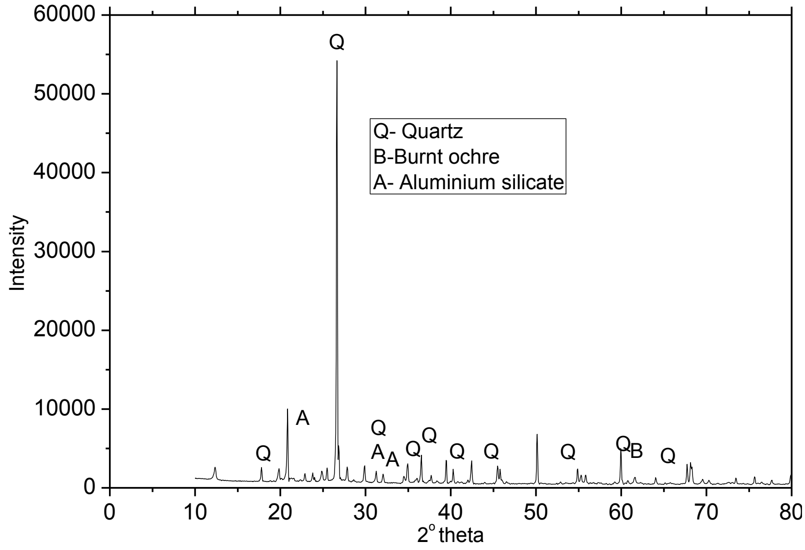

Fig. 3.14 XRD analysis of dispersive soil added with Xanthan gum

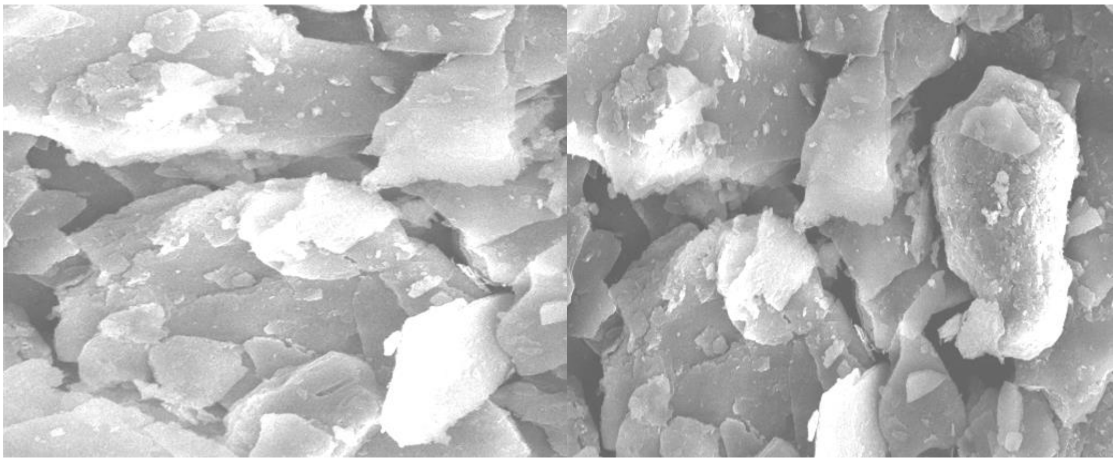

Fig. 3.15 (a) **Fig. 3.15** (b)

Fig. 3.15 FE-SEM of dispersive soil with Xanthan gum at (a) 5000X (b) 7000X magnification

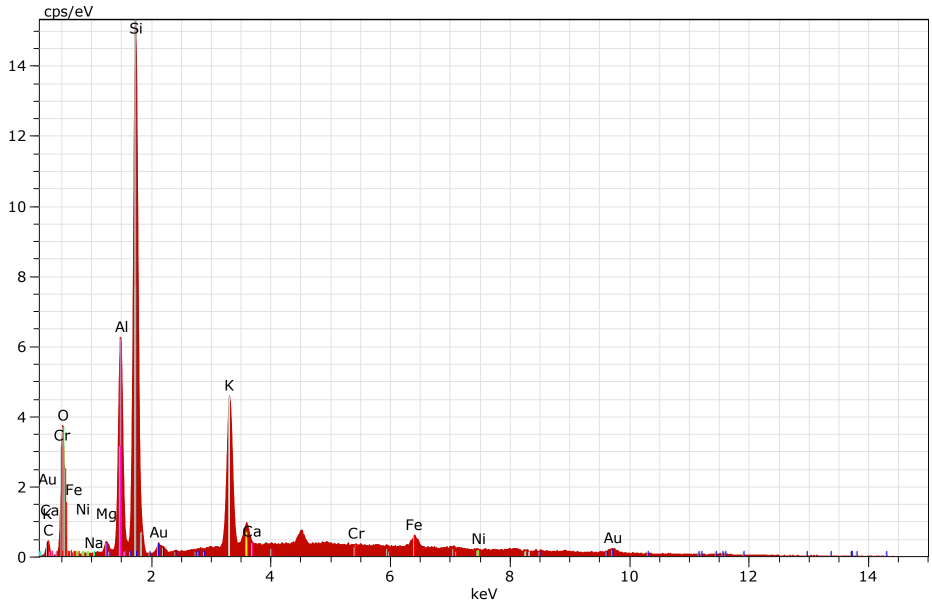

Fig. 3.16 EDX of dispersive soil added with Xanthan gum

3.2.6.2 Guar gum

The Guar or cluster bean (CyamopsisTetragonoloba) is an annual legume and the source of Guar gum. It is also known as Gavar, Guwar or Guvar bean. Few agriculturists in semi-arid regions use guar as a source to replenish the soil with essential fertilizers and nitrogen fixation, before the next crop. Guar as a plant has a multitude of different functions for human and animal nutrition but its gelling agent containing seeds (Guar gum) are today the most important use. This was added with dispersive soil and pond ash in different percentages (0.5%, 1% and 2%). Fig. 3.17 shows XRD of dispersive soil with Guar gum, which showed major elements presented are quartz, aluminium silicate and burnt ochre. FE-SEM showed morphological features of dispersive soil with Guar gum, illustrated in Fig. 3.18. Fig. 3.19 showed EDX for dispersive soil with Guar gum, which revealed the elemental composition of dispersive soil with Guar gum shown in Table 3.7.

The above two commercial available biopolymers, Xanthan gum and Guar gum, of LobaChemie Company was purchased from local market. These two biopolymers were chosen as they have already been found to be effective for stabilization of mine tailings (Chen *et al.* 2013). It is composed of pentasaccharide repeat units, comprising glucose, mannose and glucuronic acid in the molar ratio 2.0:2.0:1.0 (Chen *et al.* 2013).

Table 3.6 Elemental composition of dispersive soil with Xanthan gum

Element	Atomic Number	Normalised percentage in the geomaterial (%)
O	8	35.75
C	6	26.46
Si	14	15.99
Al	13	11.98
Fe	26	5.99
K	19	2.26
Mg	12	0.59
Ni	28	0.49
Ca	20	0.46
Na	11	0.02
Cr	24	0.00
Au	79	0.00

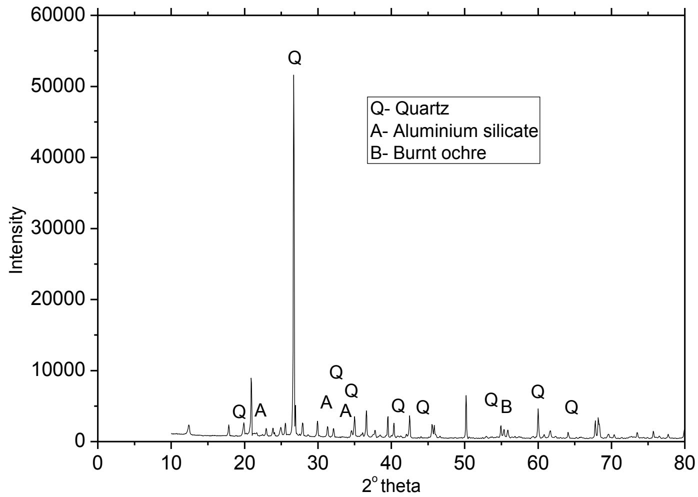

Fig. 3.17 XRD analysis of dispersive soil with Guar gum

3.3 Methodology Adopted

In the present study, methodology of stabilizing soil using geopolymer and biopolymer is explained as follows.

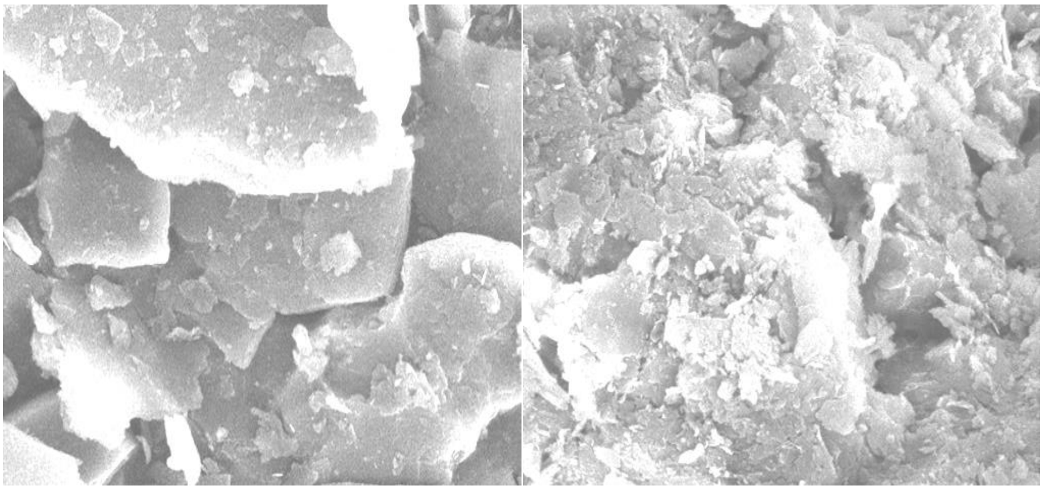

Fig. 3.18 (a) **Fig. 3.18** (b)

Fig. 3.18 FE-SEM of dispersive soil with Guar gum at (a) 5000X (b) 7000X magnification

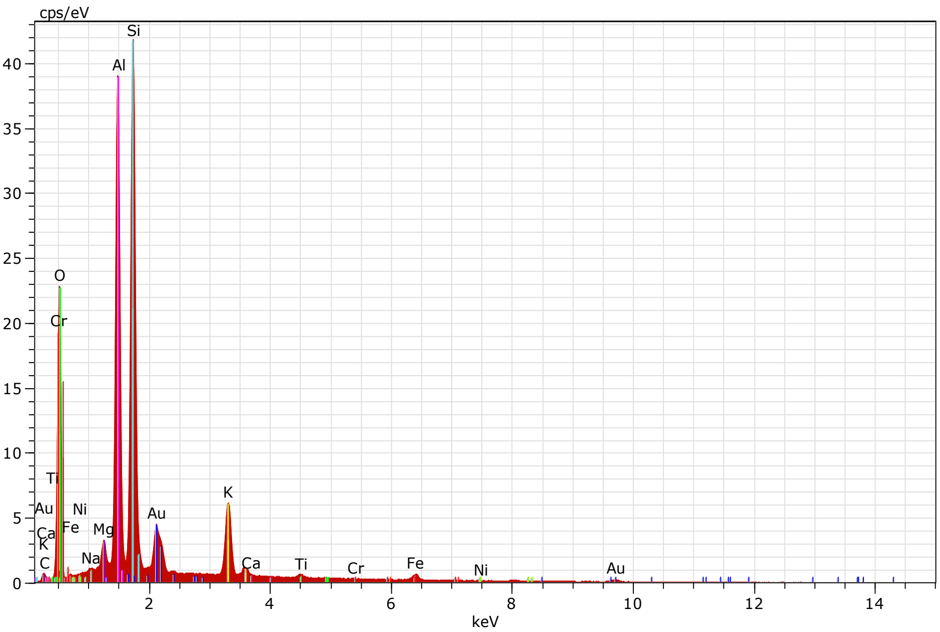

Fig. 3.19 EDX of dispersive soil added with Guar gum

3.3.1 Stabilization using geopolymer

In the present study, the alkali was prepared by taking sodium silicate and sodium hydroxide keeping in view, the ratio of sodium silicate to sodium hydroxide in their dry mass as 2. The prepared alkali (S) was added in varying percentages (5%, 10%and 15%) with fly ash (FA) in different percentages (20%, 30% and 40%) by dry weight of total solids to bentonite. The alkali, taken in 10% with fly ash 40% by dry weight of total solids was also added with dispersive soil. Then, optimum moisture content (OMC), maximum dry density (MDD), unconfined compressive strength (UCS), and durability of different samples were experimentally investigated and compared with only bentonite and dispersive soil samples. Differential free swelling (DFS) with (3, 7 and 14 days) and without curing, swelling pressure and dispersion tests were also done for treated bentonite samples and compared with only bentonite samples.Evaluation of UCS of treated soil samples were done on an interval of 0, 3, 7 and 14 days and compared with only bentonite samples.DFS of treated soil samples were done on an interval of 0, 3, 7 and 14 days. The samples which were tested after 3, 7 and 14 days were wrapped in cling film and left at ambient temperature of 32-35° C and humidity conditions (50–60 % RH). Following Table 3.8 shows the details of the alkali activated fly ash mixed in various percentages with bentonite.

Table 3.7 Elemental composition of dispersive soil added with Guar gum

Element	Atomic Number	Normalised percentage in the geometrical (%)
O	8	37.58%
C	6	27.34%
Si	14	20.56
Al	13	7.56
Fe	26	2.58
K	19	2.15
Mg	12	1.08
Ni	28	0.67
Ca	20	0.25
Na	11	0.24
Cr	24	0.00
Au	79	0.00

3.3.2 Stabilization using biopolymer

The experimental investigations were made on soil and stabilized soil using biopolymer as per Indian standards. It was observed that Guar gum (GG) is more viscous compared to Xanthan gum (XG). Hence, Xanthan gum solutions with percentages of 1, 2 and 3% and Guar gum solutions with percentages of 0.5, 1 and 2% were added with dispersive soil (WS) and pond ash (PA)toinvestigate the effect of biopolymers on compaction characteristics, unconfined compressive strength. Durability and dispersion tests were also done for biopolymer modified dispersive soil and compared to only dispersive soil sample. Table 3.4 and Table 3.5 shows the details of the biopolymer modified dispersive soil and pond ash samples, respectively. Evaluation of UCS of biopolymer modified dispersive soil samples were done on an interval of 0, 3 and 7days and also done for sample kept for sundried (1 day) and compared with only dispersive soil samples. The samples which were tested after 3 and 7 days were wrapped in cling film and left at ambient temperature of 32-35ºC and humidity conditions (50–60 % RH). Table 3.9 and Table 3.10 show details of the dispersive soil specimens and pond ash specimens mixed in different percentages with Xanthan gum (XG) and Guar gum (GG), respectively.

Table 3.8 Details of the alkaline activator mixed soil specimens

S.NO.	Name of the mix	Particulars of the mix
1	Bentonite + FA (20%) + S (5%)	Soil+20%fly ash by weight of total solids+5% alkali by weight of total solids
2	Bentonite + FA (30%) + S (5%)	Soil+30%fly ash by weight of total solids+5% alkali by weight of total solids
3	Bentonite + FA (40%) + S (5%)	Soil+40%fly ash by weight of total solids+5% alkali by weight of total solids
4	Bentonite + FA (20%) + S (10%)	Soil+20%fly ash by weight of total solids+10% alkali by weight of total solids
5	Bentonite + FA (30%) + S (10%)	Soil+30%fly ash by weight of total solids+10%alkali by weight of total solids
6	Bentonite + FA (40%) + S (10%)	Soil+40%fly ash by weight of total solids+10%alkali by weight of total solids
7	Bentonite + FA (20%) + S (15%)	Soil+20%fly ash by weight of total solids+15%alkali by weight of total solids
8	Bentonite + FA (30%) + S (15%)	Soil+30%fly ash by weight of total solids+15%alkali by weight of total solids
9	Bentonite + FA (40%) + S (15%)	Soil+40%fly ash by weight of total solids+15%alkali by weight of total solids
10	WS + FA (40%) + S (10%)	Soil+40%fly ash by weight of total solids+10%alkali by weight of total solids

Table3.9 Details of the biopolymer modified dispersive soil specimens

S.NO.	Name of the mix	Particulars of the mix
1	WS+1% XG	Dispersive soil added with 1% Xanthan gum
2	WS+2% XG	Dispersive soil added with 2% Xanthan gum
3	WS+3% XG	Dispersive soil added with 3% Xanthan gum
4	WS+0.5% GG	Dispersive soil added with 0.5% Guar gum
5	WS+1% GG	Dispersive soil added with 1% Guar gum
6	WS+2% GG	Dispersive soil added with 2% Guar gum

Table3.10 Details of the biopolymer modified pond ash specimens

S.NO.	Name of the mix	Particulars of the mix
1	PA+1% XG	Pond ash added with 1% Xanthan gum
2	PA +2% XG	Pond ash added with 2% Xanthan gum
3	PA +3% XG	Pond as added with 3% Xanthan gum
4	PA +0.5% GG	Pond ash added with 0.5% guar gum
5	PA +1% GG	Pond ash added with 1% guar gum
6	PA +2% GG	Pond ash added with 2% guar gum

CHAPTER 4

Stabilization of bentonite and dispersive soil with alkali activated fly ash

4.1 Introduction

This chapter presents the results of stabilization of bentonite soil with alkali activated fly ash. To determine the optimum moisture content (OMC) and maximum dry density (MDD) of bentonite and treated bentonite samples, light compaction test was done. The increase in strength condition was established by conducting unconfined compression test on samples at 0, 3, 7 and 14 days curing. The samples were of 50 mm diameter (D) and 100 mm height (L), thereby ensuring L/D ratio as 2. These samples comprises of bentonite added with fly ash in different percentages (20%, 30% and 40%) and alkali (sodium silicate to sodium hydroxide ratio taken by dry mass was kept 2) solution varying from 5%, 10% and 15%. The decrease in swelling condition was ascertained by conducting swelling pressure test using consolidometer test on treated soil samples. The decrease in percentage of swelling was also shown by conducting differential free swell (DFS) test on treated soil samples. Resistance to erosion was presented by conducting dispersion test on treated soil sampleswith respect to expansive soil (bentonite).

4.2 Results

This section describes the comparison of experimental results of expansive soil (bentonite) with and without stabilization.

4.2.1 Compaction characteristics

The following graphs show the compaction characteristics of bentonite and alkali activated fly ash added with bentonite, showing optimum moisture content (OMC) and maximum dry density (MDD) of the compacted samples. Fig. 4.1 shows the comparison of OMC and MDD of bentonite and bentonite with fly ash (20%, 30% and 40%) and alkali solution (5%). Fig. 4.2 shows the comparison of OMC and MDD of bentonite and bentonite with fly ash (20%, 30% and 40%) and alkali solution (10%). Similarly results of bentonite with fly ash (20%, 30% and 40%) and 15% alkali solution are presented in Fig. 4.3.

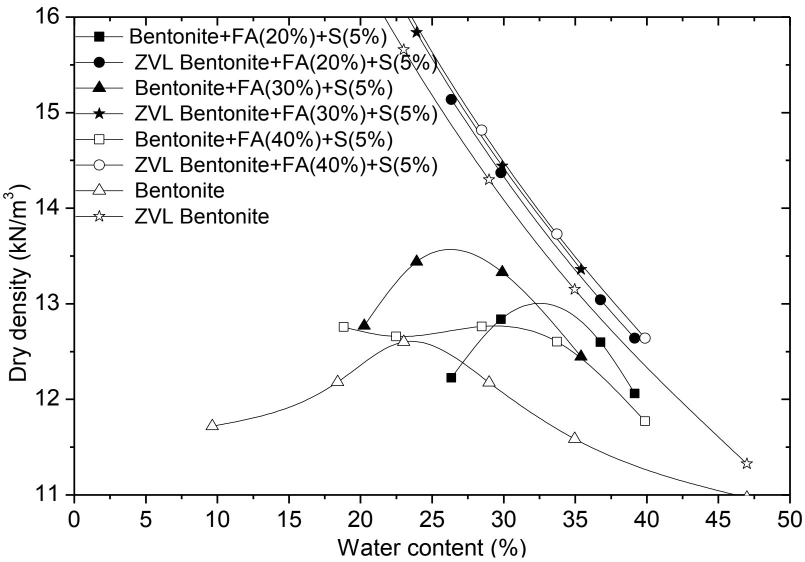

Fig. 4.1 Compaction characteristics for bentonite and bentonite with fly ash (20%, 30% and 40%) and alkalisolution(5%)

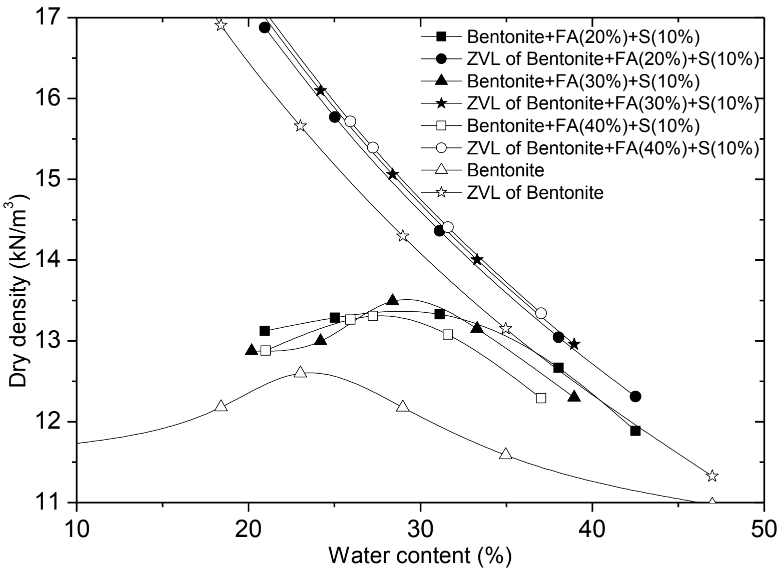

Fig. 4.2 Compaction characteristics for bentonite and bentonite with fly ash (20%, 30% and 40%) and alkalisolution(10%)

The comprehensive results of OMC and MDD for all the above cases are presented in the Table 4.1. It can be seen that the variation in MDD marginal with change in fly ash content and percentage of alkali solution.

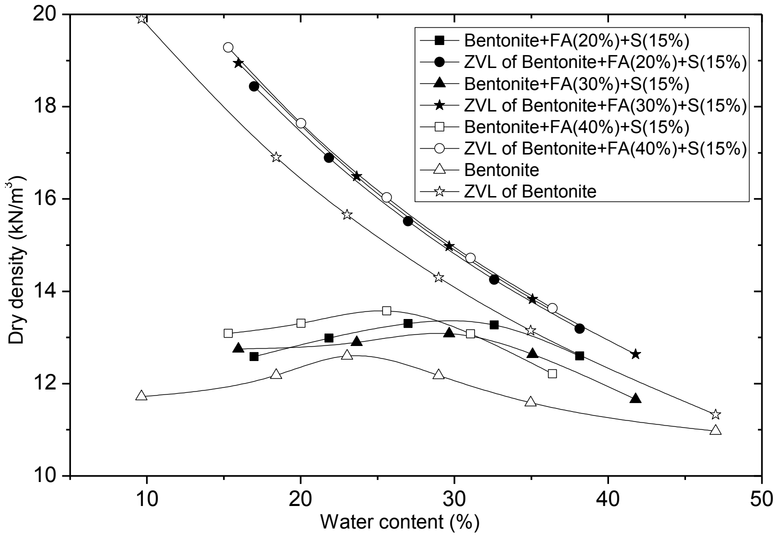

Fig. 4.3 Compaction characteristics for bentonite and bentonite with fly ash (20%, 30% and 40%) and alkali solution (15%)

Table 4.1OMC and MDD of bentoniteandalkali activated fly ash added withbentonite

Sample Name	OMC (%)	MDD (KN/m^3)
Bentonite	23.01	12.60
Bentonite + FA (20%) + S (5%)	29.81	12.84
Bentonite + FA (40%) + S (5%)	28.48	12.76
Ben tonite + FA (20%) + S (10%)	31.12	13.33
Bentonite + FA (30%) + S (10%)	28.38	13.49
Bentonite + FA (40%) + S (10%)	27.23	13.31
Bentonite + FA (20%) + S (15%)	26.99	13.30
Bentonite + FA (30%) + S (15%)	29.66	13.08
Bentonite + FA (40%) + S (15%)	25.60	13.57

4.2.2 Unconfined compressive strength (UCS)

Unconfined compressive strength test was conducted with bentonite and geopolymer treated bentonite at its optimum moisture content. Following graphs show the comparison of the stress-strain curve of bentonite and alkali activated fly ash added with bentonite without curing and with 3 days, 7 days and 14 days of curing. Fig. 4.4 shows comparison of the stress-strain curve of bentonite and bentonite with fly ash (20%, 30% and 40%) and alkali solution (5%) for 0 day (without curing). Fig. 4.5 shows comparison of the stress-strain curve of bentonite and bentonite with fly ash (20%, 30% and 40%) and alkali solution (10%) for 0 day. Fig. 4.6 shows comparison of the stress-strain curve of bentonite and bentonite with fly ash (20%, 30% and 40%) and alkali solution (15%) for 0 day.

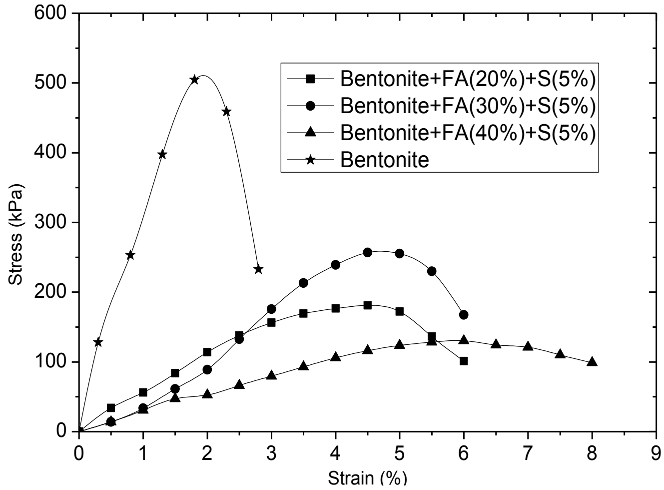

Fig. 4.4 Stress-strain curve for bentonite and bentonite with fly ash (20%, 30% and 40%) and alkali (5%) without curing

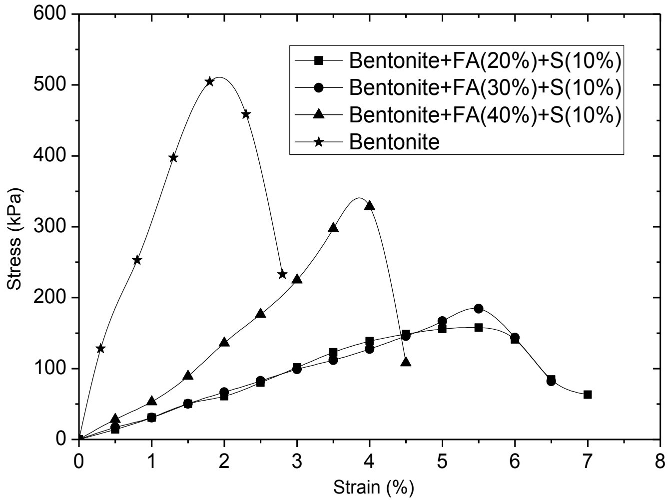

Fig. 4.5 Stress-strain curve for bentonite and bentonite with fly ash (20%, 30% and 40%) and alkali (10%) without curing

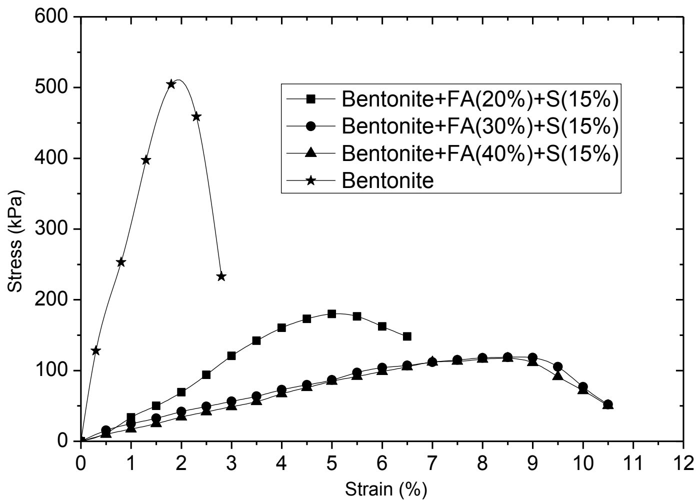

Fig. 4.6 Stress-strain curve for bentonite and bentonite with fly ash (20%, 30% and 40%) and alkali (15%) without curing

Fig. 4.7 shows comparison of the stress-strain curve of bentonite and bentonite with fly ash (20%, 30% and 40%) and alkali solution (5%) for 3 days. Fig. 4.8 shows comparison of the stress-strain curve of bentonite and bentonite with fly ash (20%, 30% and 40%) and alkali solution (10%) for 3 days. Similarly the stress-strain curve of bentonite and bentonite with fly ash (20%, 30% and 40%) and alkali solution (15%) for 3 days is shown in Fig 4.9. It can be seen that with increase in alkali solution to 15%, the stiffness of sample decreases.

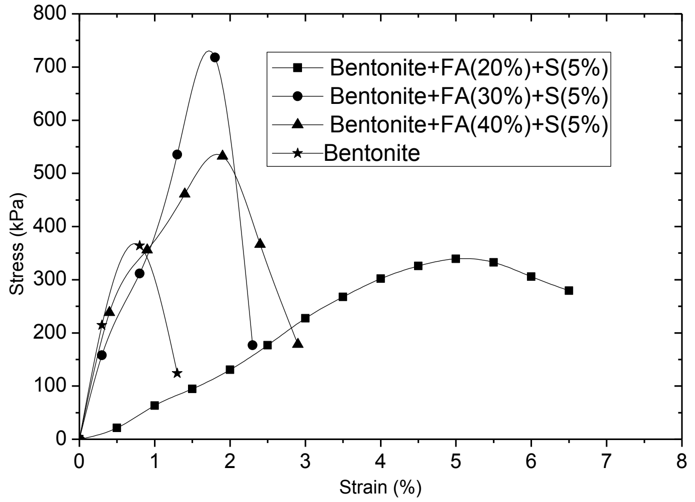

Fig. 4.7 Stress-strain curve for bentonite and bentonite with fly ash (20%, 30% and 40%) and alkali solution (5%) with curing (3 days)

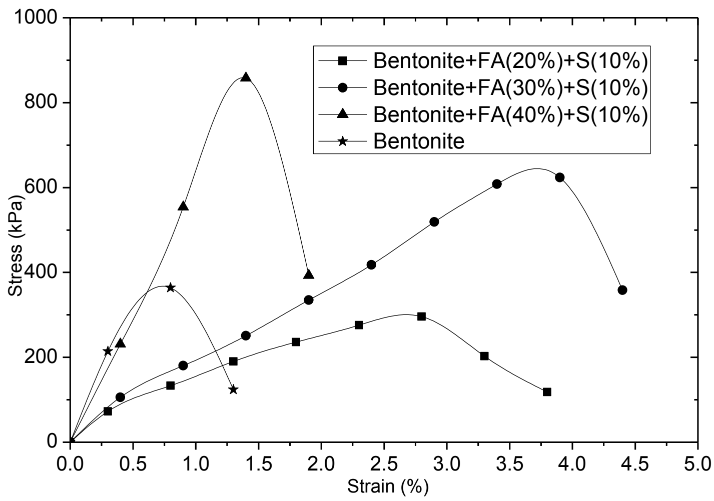

Fig. 4.8 Stress-strain curve for bentonite and bentonite with fly ash (20%, 30% and 40%) and alkali solution (10%) with curing (3 days)

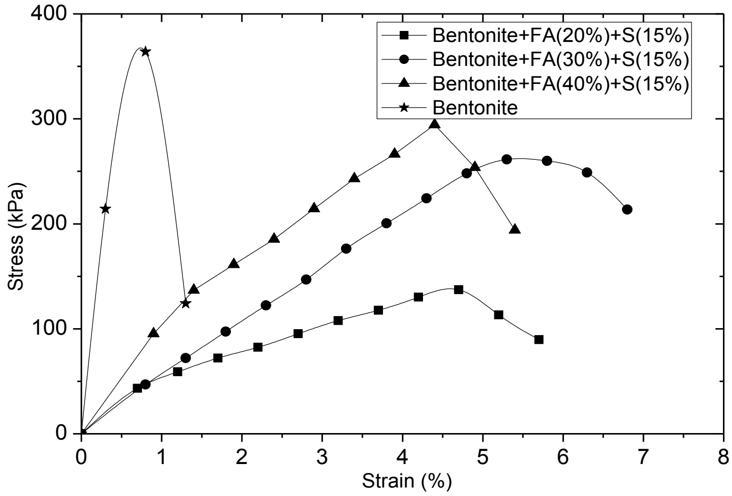

Fig. 4.9 Stress-strain curve for bentonite and bentonite with fly ash (20%, 30% and 40%) and alkali solution (15%) with curing (3 days)

Fig. 4.10 shows comparison of the stress-strain curve of bentonite and bentonite with fly ash (20%, 30% and 40%) and alkali solution (5%) for curing period of 7 days. Fig. 4.11 shows comparison of the stress-strain curve of bentonite and bentonite with fly ash (20%, 30% and 40%) and alkali solution (10%) for curing period of 7 days. Fig. 4.12 shows comparison of the stress-strain curve of bentonite and bentonite with fly ash (20%, 30% and 40%) and alkali solution (15%) for curing period of 7 days. Fig. 4.13 shows comparison of the stress-strain curve of bentonite and bentonite with fly ash (20%, 30% and 40%) and alkali solution (5%) for curing period of 14 days. Fig. 4.14 shows comparison of the stress-strain curve of bentonite and bentonite with fly ash (20%, 30% and 40%) and alkali solution (10%) for curing period of 14 days. Fig. 4.15 shows comparison of the stress-strain curve of bentonite and bentonite with fly ash (20%, 30% and 40%) and alkali solution (15%) for curing period of 14 days.Table 4.2 shows comparison of UCS of bentonite and bentonite added with fly ash (20%, 30% and 40%) and alkali solution (5%) for without (0 day)and with curing period of 3, 7 and 14 days. It can be seen that at 0 day the UCS value of the stabilized bentonite is less than that of only bentonite, which may be due to high apparent cohesion value of only bentonite. With increase in moisture content the apparent cohesion values decreased. There is increase in UCS value with increase in fly ash contents, but, again there is decrease with increase in alkali solution (15%) and the UCS values observed with 40% fly ash and 10% alkali solution is maximum for 3, 7 and 14 days of curing period. This may be due to inappropriate proportion of fly ash and alkali solution.

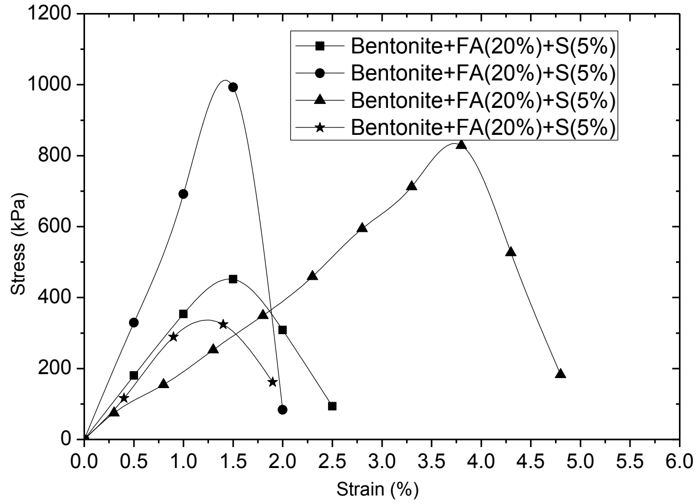

Fig. 4.10 Stress-strain curve for bentonite and bentonite with fly ash (20%, 30% and 40%) and alkali solution (5%) with curing (7 days)

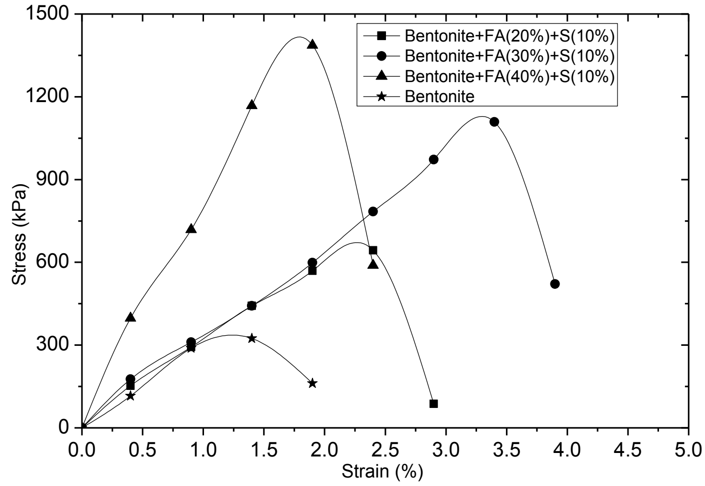

Fig. 4.11 Stress-strain curve for bentonite and bentonite with fly ash (20%, 30% and 40%) and alkali solution (10%) with curing (7 days)

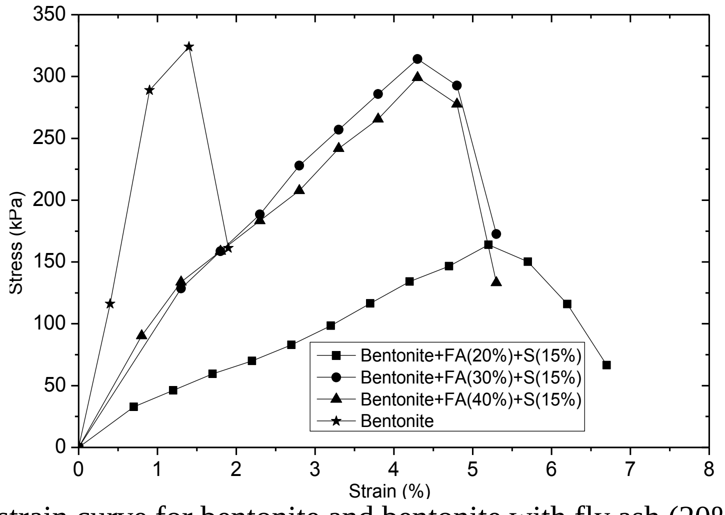

Fig. 4.12 Stress-strain curve for bentonite and bentonite with fly ash (20%, 30% and 40%) and alkali solution (15%) with curing (7 days)

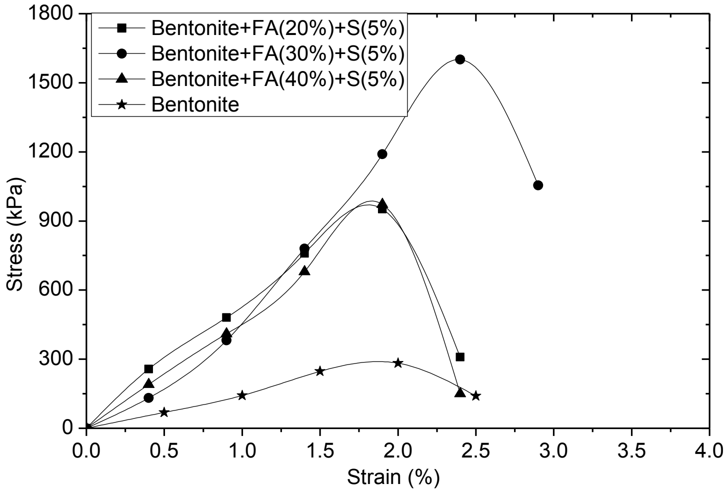

Fig. 4.13 Stress-strain curve for bentonite and bentonite with fly ash (20%, 30% and 40%) and alkali solution (5%) with curing (14 days)

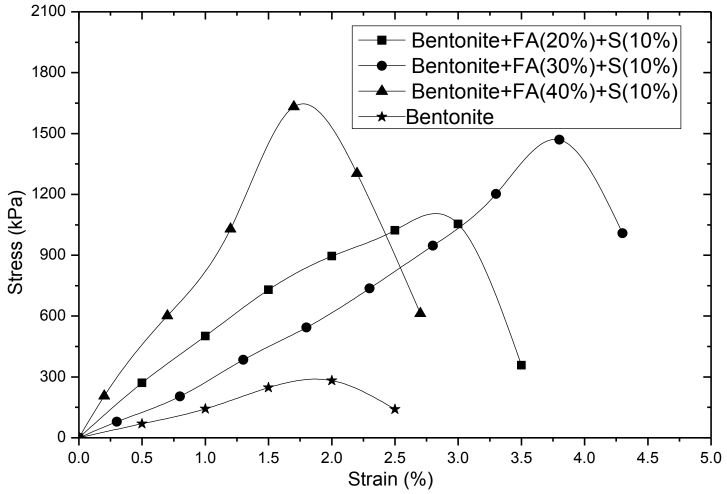

Fig. 4.14 Stress-strain curve for bentonite and bentonite with fly ash (20%, 30% and 40%) and alkali solution (10%) with curing (14 days)

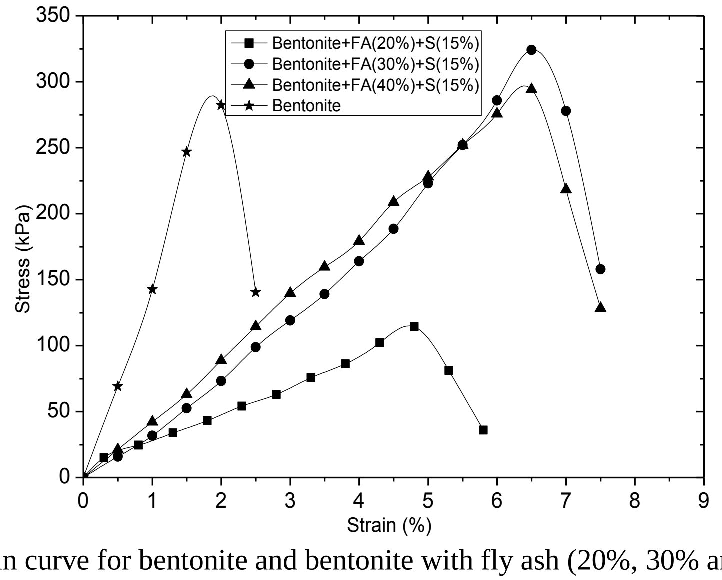

Fig. 4.15 Stress-strain curve for bentonite and bentonite with fly ash (20%, 30% and 40%) and alkali solution (15%) with curing (14 days)

Table 4.2 UCS of bentonite and bentonite with fly ash (20%, 30% and 40%) and alkali solution (5%, 10% and 15%) without curing and with curing (3 days, 7 days and 14 days)

Sample Name	UCS (kPa) 0 day	UCS (kPa) 3 days	UCS (kPa) 7 days	UCS (kPa) 14 days
Bentonite	504.43	363.97	324.02	282.21
Bentonite + FA (20%) + S (5%)	181.06	339.44	451.75	951.80
Bentonite + FA (30%) + S (5%)	255.38	718.10	992.79	1189.76
Bentonite + FA (40%) + S (5%)	130.32	532.43	828.89	972.31
Bentonite + FA (20%) + S (10%)	157.76	296.07	643.27	1053.88
Bentonite + FA (30%) + S (10%)	184.49	623.61	1108.70	1469.20
Bentonite + FA (40%) + S (10%)	328.67	857.92	1386.74	1632.25
Bentonite + FA (20%) + S (15%)	180.09	137.21	163.99	114.30
Bentonite +FA (30%) + S (15%)	118.96	261.44	314.13	324.10
Bentonite +FA (40%) + S (15%)	117.18	294.37	299.17	294.19

4.2.3 Durability Test

The durability tests were conducted on stabilized soil as proposed by Al-Kiki *et.al*(2011). In this case, two sets of stabilized samples were prepared and cured for 2 days at 49^0C, at the end of curing period; the first set of samples was submerged in water for 3 days, called soaked sample and after the end of soaking period the samples were tested to find the unconfined compressive strength. The second set of samples (controlled samples) was subjected to different curing period (at room temperature (25^oC± 3^o) where the curing period is equivalent to the soaking period. The controlled samples were submerged in water for two days before testing. The resistance to loss in strength was determined as the ratio of the unconfined compressive strength of soaked samples to the unconfined compressive strength of controlled samples. Fig. 4.16 shows stress-strain curve of bentonite added with fly ash (20%) and activator (S) (5%) for soaked sample and controlled sample. Fig. 4.17 shows stress-strain curve of bentonite added with fly ash (30%) and activator (S) (5%) for soaked sample and controlled sample. Fig. 4.18 shows stress-strain curve of bentonite with fly ash (40%) and activator (5%) for soaked sample and controlled sample. It can be seen that better stiffness and strength is obtained for soaked sample.

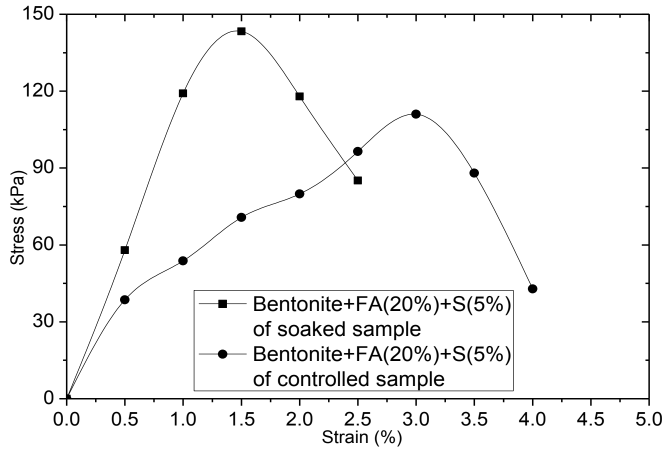

Fig. 4.16 Stress-strain curve of Bentonite + FA (20%)+S(5%) for soaked sample and controlled sample

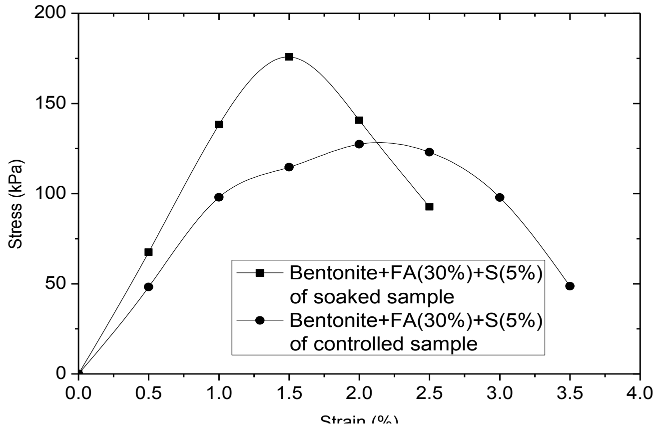

Fig. 4.17 Stress-strain curve of Bentonite + FA (30%)+S(5%) for soaked sample and controlled sample

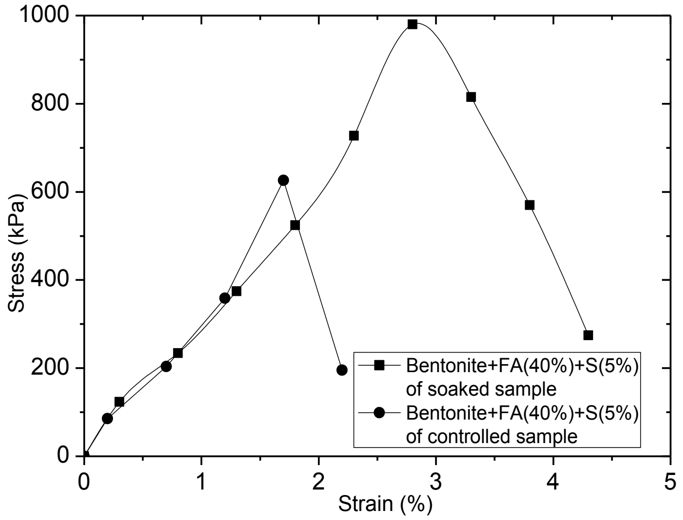

Fig. 4.18 Stress-strain curve of Bentonite + FA (40%)+S(5%) for soaked sample and controlled sample

Fig. 4.19 shows stress-strain curve of bentonite with fly ash (20%) and activator (10%) for soaked sample and controlled sample. Fig. 4.20 shows stress-strain curve of Bentonite with fly ash (30%) and activator (10%) for soaked sample and controlled sample. Fig. 4.21 shows stress-strain curve of bentonite with fly ash (40%) and activator (10%) for soaked sample and controlled sample. Here also similar trend are observed like that for 5% activator solution (S).

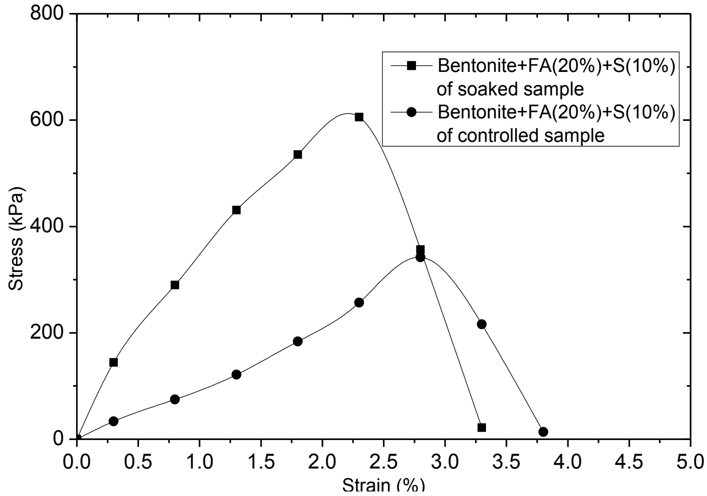

Fig. 4.19 Stress-strain curve of Bentonite + FA (20%)+S(10%) for soaked sample and controlled sample

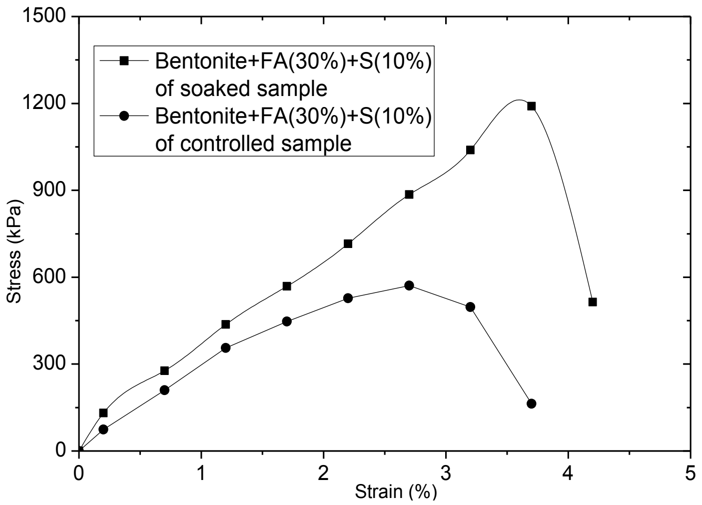

Fig. 4.20 Stress-strain curve of Bentonite + FA (30%)+S(10%) for soaked sample and controlled sample

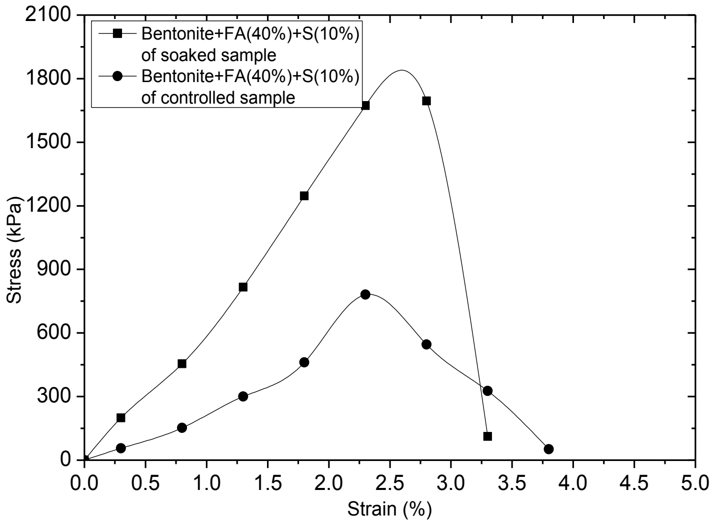

Fig. 4.21 Stress-strain curve of Bentonite + FA (40%)+S(10%) for soaked sample and controlled sample

Fig. 4.22 shows stress-strain curve of bentonite with fly ash (20%) and activator (15%) for soaked sample and controlled sample. Fig. 4.23 shows stress-strain curve of Bentonite added with fly ash (30%) and activator (15%) for soaked sample and controlled sample. Fig. 4.24 shows stress-strain curve of Bentonite added with fly ash (40%) and activator (15%) for soaked sample and controlled sample. It can be seen from above curves that with increase in activator solution content the soaked sample becomes soft. Table 4.3 shows comparison of ratios of UCS of soaked samples to UCS of controlled samples. It can be inferred that bentonite was not durable as when it came in contact with water it swelled and eroded and the resistance to loss in strength (RLS) obtained was maximum for bentonite with fly ash 40% and alkali solution 10% and value decreased with 15% solution. The RLS is defined as the ratio of UCS of soaked sample (UCSS) to that of UCS of control sample (UCSC).

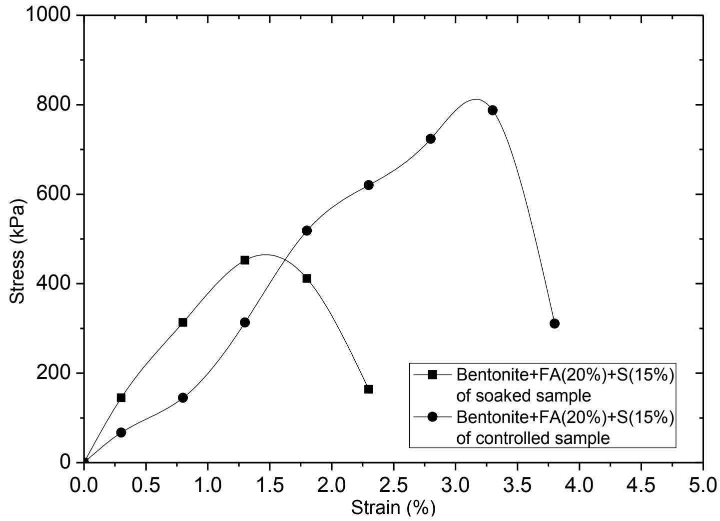

Fig. 4.22 Stress-strain curve of Bentonite + FA (20%)+S(15%) for soaked sample and controlled sample

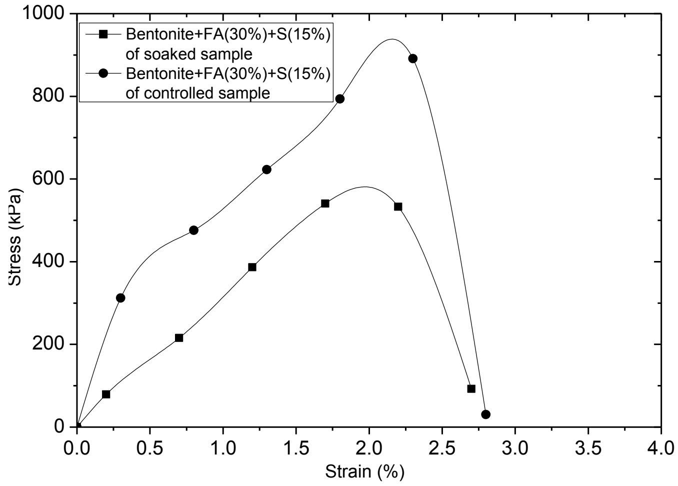

Fig. 4.23 Stress-strain curve of Bentonite + FA (30%)+S(15%) for soaked sample and controlled sample

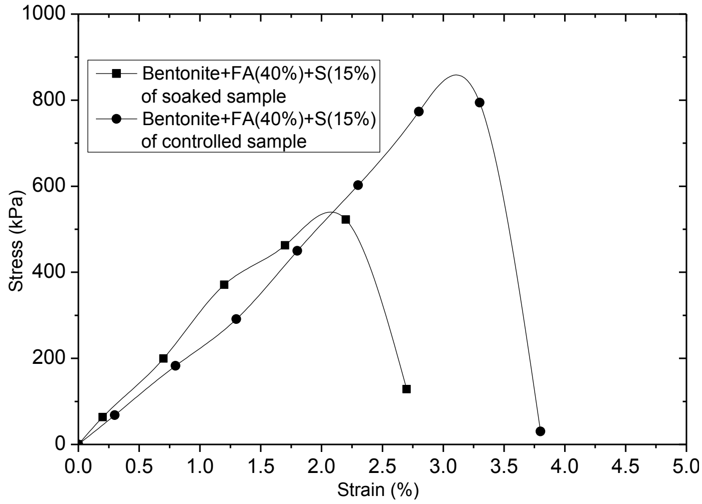

Fig. 4.24 Stress-strain curve of Bentonite + FA (40%)+S(15%) for soaked sample and controlled sample

Table 4.3 Comparison of resistance to loss in strengthforbentonite and alkali solution activated fly ash added withbentonite

Sample Name	UCS of control sample (UCSC) (kPa)	UCS of soaked sample (UCSS) (kPa)	Increase or decrease in strength from control sample (CS) to soaked sample (SS)	Resistance to loss in strength (RLS= UCSS/UCSC)
Bentonite	-	-	-	-
Bentonite + FA (20%) + S (5%)	111.05	143.35	Increase	+1.29
Bentonite + FA (30%) + S (5%)	127.41	175.84	Increase	+1.38
Bentonite + FA (40%) + S (5%)	625.92	980.22	Increase	+1.57
Bentonite + FA (20%) + S (10%)	342.25	605.73	Increase	+1.77
Bentonite + FA (30%) + S (10%)	571.23	1190.56	Increase	+2.08
Bentonite + FA (40%) + S (10%)	780.90	1694.56	Increase	+2.17
Bentonite + FA (20%) + S (15%)	787.72	452.43	Decrease	-0.57
Bentonite + FA (30%) + S (15%)	793.53	540.75	Decrease	-0.60
Bentonite + FA (40%) + S (15%)	794.49	522.46	Decrease	-0.66

4.2.4 Differential Free Swelling (DFS)

The differential free swellingiscalculated as,

$DFS= ((V_d-V_k)/V_k)*100$

V_d – Volume in distilled water

V_k – Volume in kerosene

The samples were tested at 0 days and with curing period of 3, 7 and 14 days. The sample were wrapped in cling film and kept at ambient temperature of 32-35º C and humidity conditions (50–60 % RH) before testing. Table 4.4 shows differential free swell of activated fly ash added with bentonite without curing and with 3 days of curing. It can be seen that DFS decreased with increase in FA and S content.

4.2.4.1 Modified Free Swell Index (MFSI)

This was done as most of the samples after 3, 7 and 14 days showed negative DFS. It is defined as ratio of equilibrium sediment volume of 10 g oven dried soil in distilled water (i.e., V_d) to the dry weight of soil (Sridharan*et al.* 1985).

It is calculated as,

$MFSI = V_d/10$

Table 4.4 DFS of alkali solution activated fly ash added withbentonite

Sample Name	DFS (%) 0 day (without curing)	DFS (%) 3 days
Bentonite+ FA (20%) + S (5%)	72.73	19.05
Bentonite+ FA (30%) + S (5%)	65.22	13.64
Bentonite+ FA (40%) + S (5%)	56.52	9.09
Bentonite+ FA (20%) + S (10%)	65	14.29
Bentonite+ FA (30%) + S (10%)	59.09	9.52
Bentonite+ FA (40%) + S (10%)	52.38	-
Bentonite+ FA (20%) + S (15%)	57.14	-
Bentonite+ FA (30%) + S (15%)	54.55	-
Bentonite+ FA (40%) + S (15%)	47.62	-

Table 4.5 shows MFSI of alkali solution activated fly ash added with bentonite. Table 4.6 shows soil expansivity classification based on MFSI (Sridharan*et al*. 1985). It can be seen that percentage of swelling decreased with increased in percentage of alkali solution activated fly ash. After curing periods of 3 days, bentonite +FA (40%) + S (10%), similarly, after 7 days

and 14 days, bentonite added with fly ash (20%, 30% and 40%) and alkali solution (5%, 10% and 15%), the swelling percentage decreased significantly and the soil became non-swelling type as per Table 4.6. It can be seen that soil becomes non swelling after7 days of curing with FA (20%) and S (10%) and after 14 days of curing with FA (30%) and S (10%).

Table 4.5MFSI of alkali solution activated fly ash added withbentonite

Sample Name	MFSI (cm^3/g) 3 days	MFSI(cm^3/g) 7 days	MFSI(cm^3/g) 14 days
Bentonite + FA (20%) + S (5%)	-	1.48	1.30
Bentonite + FA (30%) + S (5%)	-	1.43	1.25
Bentonite + FA (40%) + S (5%)	-	1.38	1.18
Bentonite + FA (20%) + S (10%)	-	1.33	1.15
Bentonite + FA (30%) + S (10%)	-	1.25	1.05
Bentonite + FA (40%) + S (10%)	1.45	1.18	0.98
Bentonite + FA (20%) + S (15%)	1.35	1.10	0.90
Bentonite + FA (30%) + S (15%)	1.33	1.03	0.83
Bentonite + FA (40%) + S (15%)	1.30	0.98	0.73

Table 4.6 Soil expansivity classification based on MFSI (Sridharan*et al.* 1985)

MFSI (cm^3/g)	Sediment volume in kerosene (cm^3/g)	Clay type	Soil expansivity
<1.5	1.10-3.00	Non-swelling	Negligible
1.5-2.0	>1.1 and < MFSI	Mixture of swelling and non-swelling	Low
1.5-2.0	≤ 1.1	Swelling	Moderate
2.0-4.0	≤ 1.1	Swelling	High
>4.0	≤ 1.1	Swelling	Very high

4.2.5 Swelling Pressure (SP)

The reduction of swelling pressure with addition of fly ash in different percentages (20%, 30% and 40%) and alkali solution in varying percentages (5%, 10% and 15%) by consolidometer method is presented in Table 4.7. It can be seen that alkali activated fly ash added with bentonite decreased the swelling pressure significantly and finally bentonite added with fly ash 40% and alkali activator 15% reduced the swelling by 97.14% after curing period of 3 days.

Table 4.7 Comparison of SP of alkali activated fly ash added withbentonite (after curing period of 3 days)

Sample Name	SP (kN/m^2)
Bentonite + FA (20%) + S (5%)	113
Bentonite + FA (30%) + S (5%)	103
Bentonite + FA (40%) + S (5%)	93
Bentonite + FA (20%) + S (10%)	78
Bentonite + FA (30%) + S (10%)	74
Bentonite + FA (40%) + S (10%)	64
Bentonite + FA (20%) + S (15%)	49
Bentonite + FA (30%) + S (15%)	34
Bentonite + FA (40%) + S (15%)	20

4.2.6 Dispersion test

Here, the double hydrometer test and crumb tests were performed for dispersion test. In the double hydrometer test the dispersion ratio is defined as the ratio of percentage finer than 0.005 mm diameter measured without any dispersing agent to that measured with dispersing agent in a hydrometer test, which is expressed in percentage. The percentage of dispersion is an indicator to evaluate the ability of soils to erode due to their dispersiveness. Here, the dispersion ratio is found to be 84.87%, which is extremely dispersive as per Table 4.11. Fig. 4.25 shows results of crumb test. The cube of bentonite getting dispersed in water after five to seven minutes is shown in Figure 4.25 (a). Figures 4.25 (b), 4.25 (c) and 4.25 (d) show bentonite added with fly ash of 20%, 30% and 40%,respectively and alkali solution (5%). Figures 4.25 (e), 4.25 (f), 4.25 (g) show bentonite added with fly ash 20%, 30% and 40%),respectivelyand alkali solution (10%). Similarly, Figures 4.25 (h), 4.25 (i) and 4.25 (j) show bentonite added with fly ash (20%, 30% and 40%) and alkali solution (15%), where it can be seen that the cubes did not get disperse after five to seven minutes.

Table 4.8 Classification of dispersive soils based on double hydrometer test (Volk 1937).

Dispersion ratio (%)	Classification
<35	Non-dispersive
35-50	Modestly dispersive
50-75	Highly dispersive
>75	Extremely dispersive

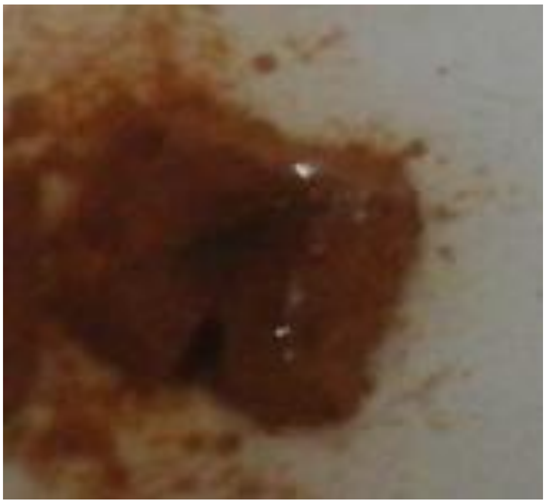


Fig. 4.25 (a) **Fig. 4.25** (b)

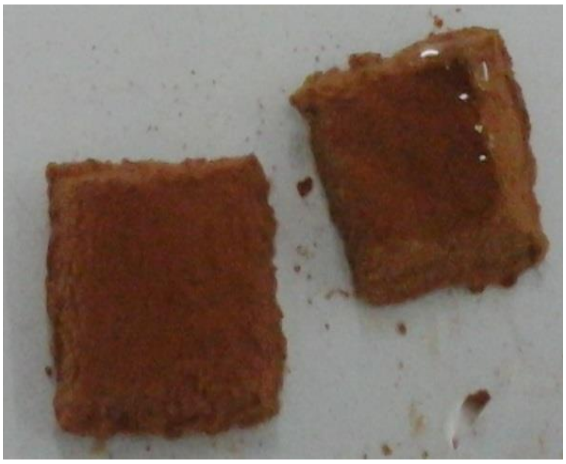


Fig. 4.25 (c) **Fig. 4.25** (d)


Fig. 4.25 (e)**Fig. 4.25** (f)

Fig. 4.25 (g)

Fig. 4.25 (h)

Fig. 4.25 (i)

Fig. 4.25 (j)

Fig. 4.25 (a) Cubes of bentonite in water after five to seven minutes, **Fig. 4.25**(b), (c), (d), (e), (f), (g), (h), (i) and (j) Cubes of Bentonite added with fly ash (20%, 30% and 40%) and alkali activator (5%, 10% and 15%), respectively in water after five to seven minutes.

4.3 Results with respect to white soil (dispersive soil)

In the present section experimental studies of white soil are presented as follows.

4.3.1 Compaction characteristics

The following graphs show the compaction characteristics of dispersive soil and alkali activated fly ash added with dispersive soil, showing optimum moisture content (OMC) and maximum dry density (MDD) of the compacted samples. Fig. 4.26 shows the comparison of OMC and MDD of dispersive soil and dispersive soil with fly ash (40%) and alkali solution (10%).

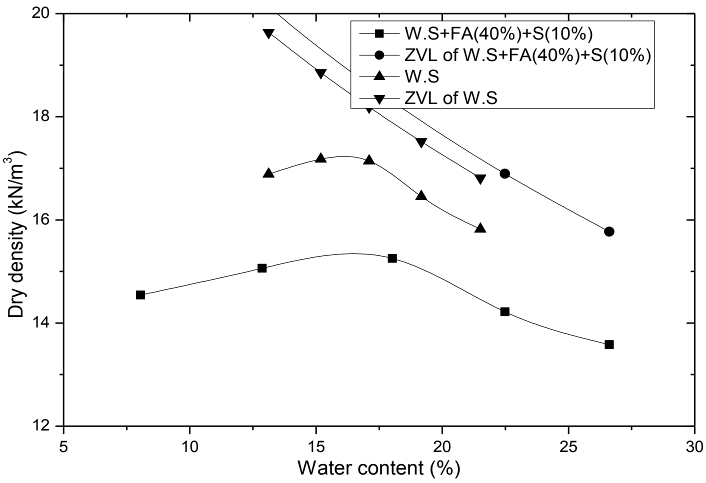

Fig. 4.26 Compaction characteristics for dispersive soil and dispersive soil with fly ash (40%) and alkali solution (10%)

Table 4.9 OMC and MDD of dispersive soil and dispersive soil with fly ash (40%) and alkali solution (10%)

Sample Name	OMC (%)	MDD (kN/m^3)
W.S	15.19	17.18
W.S + FA (40%) + S (10%)	18.03	15.25

From above table, it is observed that OMC of dispersive soil added with fly ash (40%) and alkali solution (10%) is more compared to only dispersive soil and MDD of only dispersive soil is more compared to W.S + FA (40%) + S (10%) sample. As disclosed earlier, the UCS obtained for bentonite stabilized with geopolymer, i.e., with fly ash 40% and alkali solution 10% was maximum. Hence, for a comparison dispersive soil (white soil) was stabilized with same percentage of geopolymers. But, with this percentage the workability was lost and the UCS could not be done as it became very soft.

CHAPTER 5

Stabilizationofdispersivesoil (white soil)with biopolymer

5.1 Introduction

The present chapter presents the experimental investigations made on dispersive soil (white soil), stabilized white soil using biopolymer as per Indian standards for soil. The pond ash which is also dispersive (Sridharan and Prakash, 2007) was also considered to compare the results in this chapter. Durability test of white soil and biopolymer modified white soil is also presented. The micromorphology of the stabilized white soil is also discussed.

Based on experimental studies of stabilized white soil and pond ash with biopolymer,following results are obtained and discussed separately as follows.

5.2 Results of biopolymer stabilized white soil

5.2.1 Compaction characteristics stab

Fig. 5.1 shows the comparison of OMC and MDD of white soil (WS) and white soil with varying percentages of Xanthan gum (1%, 2% and 3%).Similarly Fig. 5.2 shows the comparison of OMC and MDD of white soil and white soil with varying percentages of guar gum (0.5%, 1% and 2%). It can be seen that with addition of XG, OMC increased and MDD decreased. In case of addition of GG there is marginal variation in OMC and MDD value. Table 5.1 shows the comparison of OMC and MDD of white soil and biopolymer modified white soil.

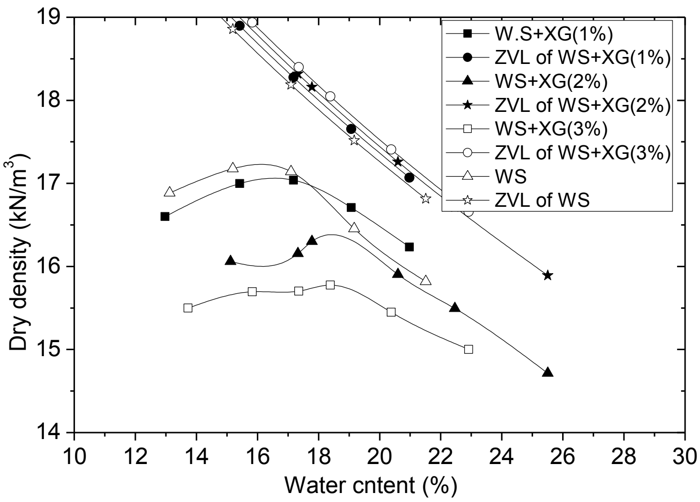

Fig. 5.1 Compaction characteristics for white soil and white soil with Xanthan gum (1%, 2% and 3%)

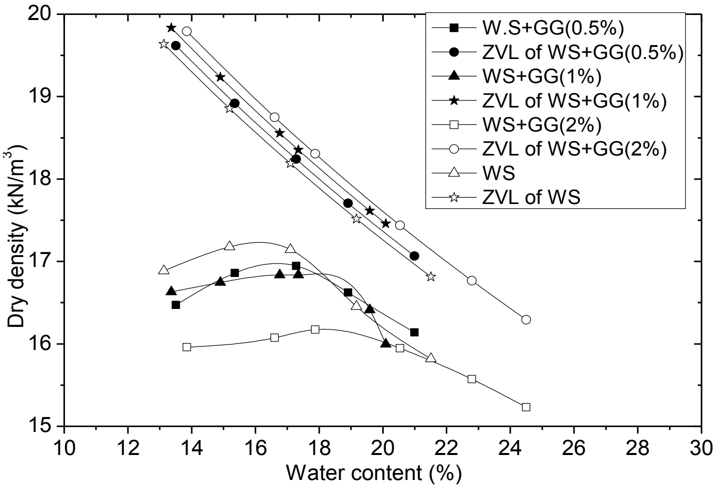

Fig. 5.2 Compaction characteristics for white soil and white soil with Guar gum (0.5%, 1% and 2%)

Table 5.1 OMC and MDD of white soil and biopolymer modified white soil

Sample Name	OMC (%)	MDD (KN/m^3)
WS	15.19	17.18
WS+ XG (1%)	17.18	17.04
WS+ XG (2%)	17.79	16.30
WS+ XG (3%)	18.38	15.78
WS+ GG (0.5%)	17.28	16.95
WS+ GG (1%)	17.35	16.84
WS+ GG (2%)	17.88	16.17

5.2.2Unconfined Compressive Strength (UCS)

Fig. 5.3 shows comparison of stress-strain curve for compacted white soil and white soil stabilized with Xanthan gum (1%, 2% and 3%). Fig. 5.4 shows comparison of stress-strain curve for white soil and guar gum (0.5%, 1% and 2%) added with white soil. It can be seen that the strength of the stabilized WS increased with addition of XG and GG. The ductility of stabilized soil is found to be more than unstabilized soil.

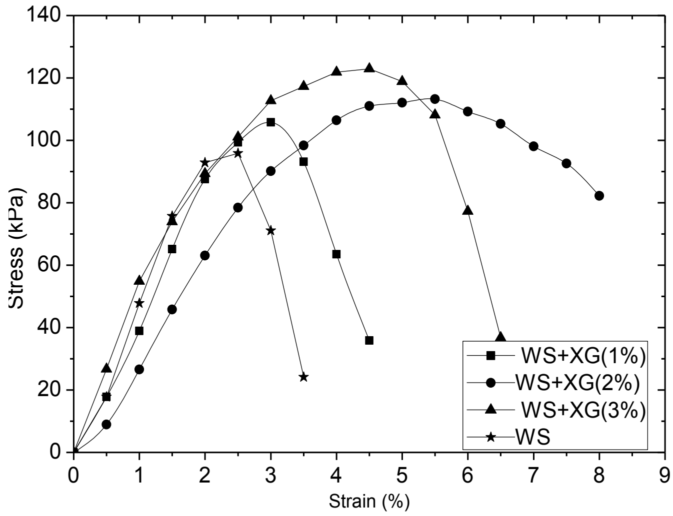

Fig. 5.3 Stress-strain curve for white soil and Xanthan gum (1%, 2% and 3%) added with white soil without curing

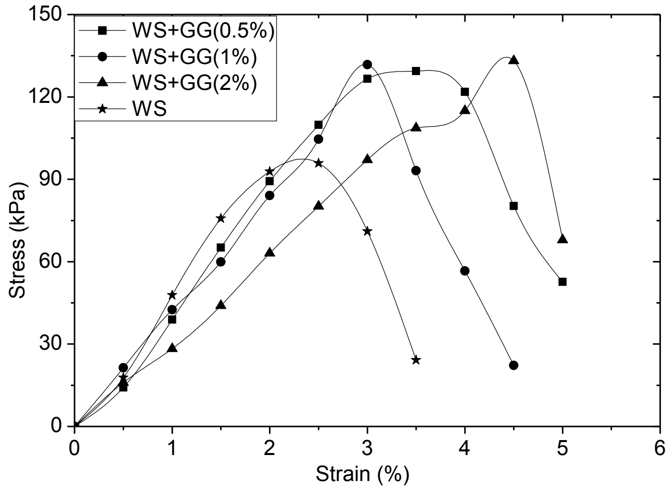

Fig. 5.4 Stress-strain curve for white soil and Guar gum (0.5%, 1% and 2%) added with white soil without curing

The effect of biopolymer on UCS values of the stabilized soil after curing period of 3 and 7 days are also studied. Fig. 5.5 shows comparison of stress-strain curve for white soil and Xanthan gum (1%, 2% and 3%) added with white soil after 3 days. Fig. 5.6 shows comparison of stress-strain curve for WS and guar gum (0.5%, 1% and 2%) added with WS after 3 days.

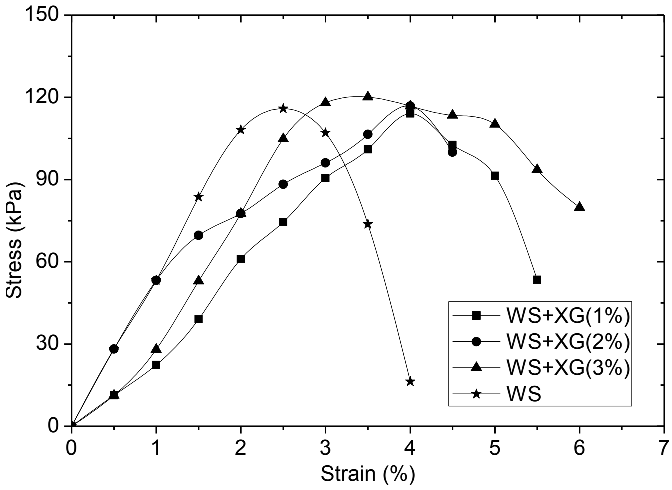

Fig. 5.5 Stress-strain curve for white soil and Xanthan gum (1%, 2% and 3%) added with white soil with curing (3 days)

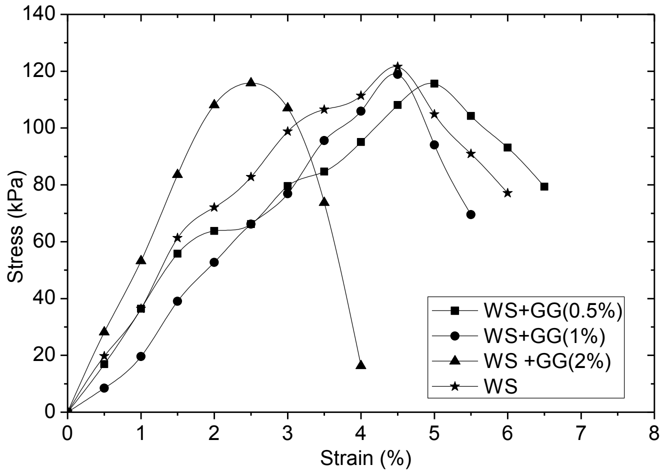

Fig. 5.6 Stress-strain curve for white soil and Guar gum (0.5%, 1% and 2%) added with white soil with curing (3 days)

Similarly Fig. 5.7 shows stress-strain curve for white soil and Xanthan gum (1%, 2% and 3%) added with white soil after curing period of 7 days. Fig. 5.8 shows comparison of stress-strain curve for white soil and guar gum (0.5%, 1% and 2%) added with white soil for curing period of 7 days. The UCS of white soil and biopolymer modified white soil without and with curing period of 3 and 7 days is shown in Table 5.2. It can be seen that UCS value of white soil added with 0.5% GG is increased with age i.e. after 3 days and 7 days and the reduction in UCS value of unstabilized and stabilized white soil may be due to decrease in binding of biopolymer or may be due to condition for curing. Hence, in order to study the mode of curing, the sample was sundried for 3 days.

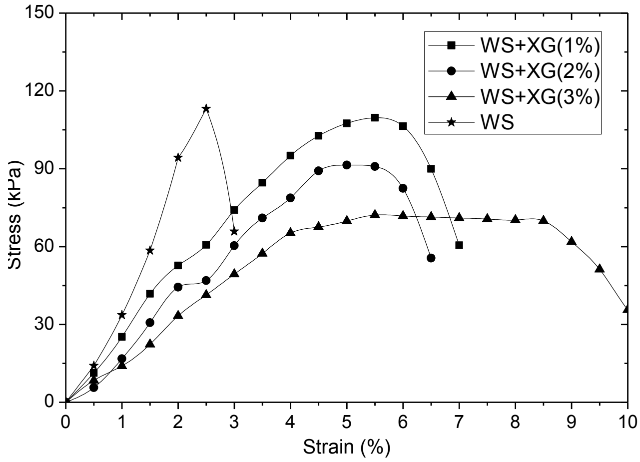

Fig. 5.7 Stress-strain curve for white soil and Xanthan gum (1%, 2% and 3%) added with white soil with curing (7 days)

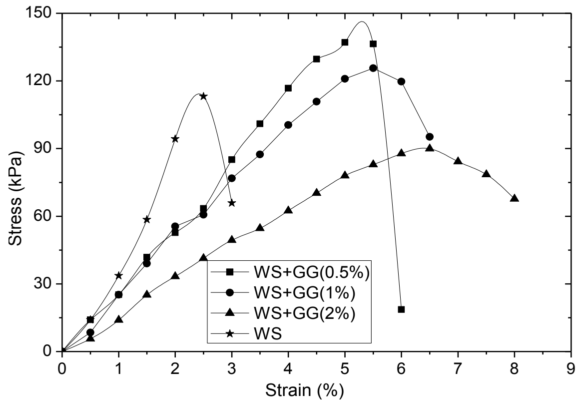

Fig. 5.8 Stress-strain curve for white soil and Guar gum (0.5%, 1% and 2%) added with white soil with curing (7 days)

Table 5.2 UCS of white soil and biopolymer modified white soil without and with curing period of 3 and 7 days

Sample Name	UCS (kPa)0 day (without curing)	UCS (kPa) 3 days	UCS (kPa) 7 days
WS	95.86	115.86	113.10
WS+ XG (1%)	105.77	114.08	109.62
WS+ XG (2%)	113.18	116.79	91.39
WS+ XG (3%)	122.91	120.13	72.19
WS+ GG (0.5%)	129.37	115.58	137.08
WS+ GG (1%)	131.78	118.89	125.66
WS+ GG (2%)	133.16	121.59	89.94

Fig. 5.9 shows comparison of stress-strain curve for white soil and Xanthan gum (1%, 2% and 3%) added with white soil kept for sundried for 3 days. Similarly, Fig. 5.10 shows comparison of stress-strain curve for white soil and guar gum (0.5%, 1% and 2%) added with white soil kept for sundried for 3 days. Table 5.3 shows UCS of white soil and biopolymer modified white soil kept for sundried with curing period of 3 days. It can be seen that with loss in moisture content (sundried) there is increase in UCS of white soil (300 kPa). But there

was multi fold increase in UCS value with XG and GG. The UCS value of white soil with 2 % GG was maximum. This aspect needs further studies for explanation.

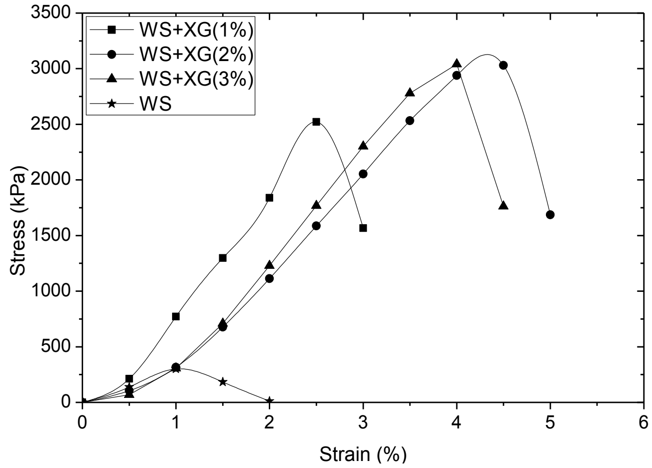

Fig. 5.9 Stress-strain curve for white soil and Xanthan gum (1%, 2% and 3%) added with white soil kept for sundried with curing (3 days)

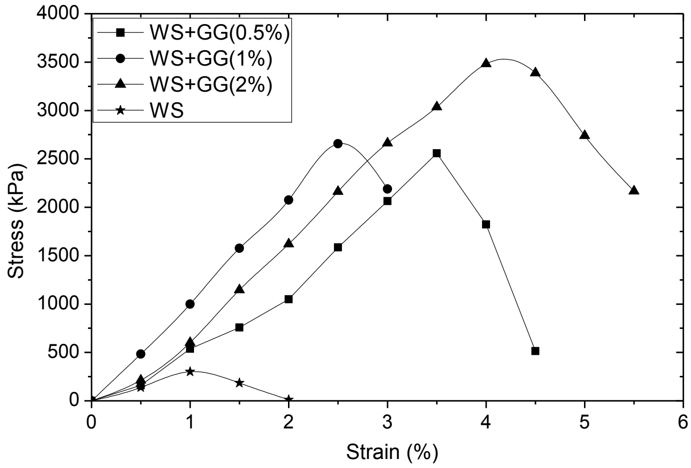

Fig. 5.10 Stress-strain curve for white soil and Guar gum (0.5%, 1% and 2%) added with white soil kept for sundried with curing (3 days)

Table 5.3 UCS of white soil and biopolymer modified white soil kept for sundried with curing (3 days)

Sample Name	UCS (kPa) (sundried 3 days)
WS	300.93
WS+XG (1%)	2521.77
WS+XG (2%)	3030.25
WS+XG (3%)	3041.00
WS+GG (0.5%)	2557.66
WS+GG (1%)	2656.95
WS+GG (2%)	3481.28

5.2.3 Durability Test

In order to know the effect of saturation and submergence on the stabilized white soil durability test was conducted as described for bentonite and alkali activated fly ash in previous chapter.Fig. 5.11 shows stress-strain curve of white soil with Guar gum (0.5%) for soaked sample and controlled sample. The soaked sample found to have better strength. Fig. 5.12 shows stress-strain curve of white soil with 1% XG and GG for soaked sample and controlled sample. It can be seen that strength is more for GG as compared to XG. The stress-strain curve of white soil with XG (2%) and GG (2%) for soaked sample and controlled sampleis shown in Fig. 5.13. Fig. 5.14 shows stress-strain curve of white soil with Xanthan gum (3%) for soaked sample and controlled sample. From graphs, it can be seen that stress of soaked sample was more than controlled sample. Table 5.4 shows comparison of resistance to loss in strength for white soil and white soil with Xanthan gum (1%, 2% and 3%) and Guar gum (0.5%, 1% and 2%). It can be seen that white soil was not durable as when it came in contact with water it got eroded but, biopolymer modified samples showed an increase in stress and the RLS obtained was maximum for Guar gum (1%).

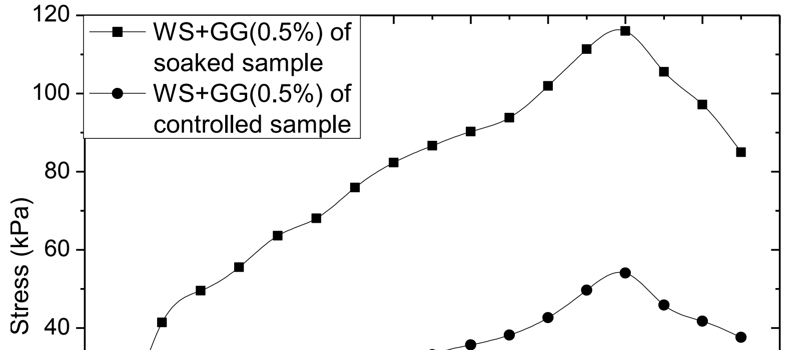

Fig.5.11 Stress-strain curve of WS+GG (0.5%) for soaked sample and controlled sample

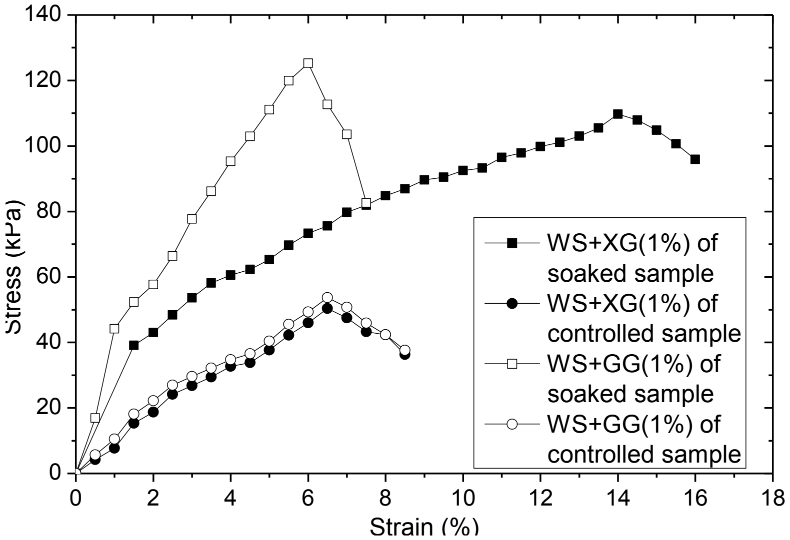

Fig.5.12 Stress-strain curve of WS+XG (1%) and WS+GG (1%) for soaked sample and controlled sample

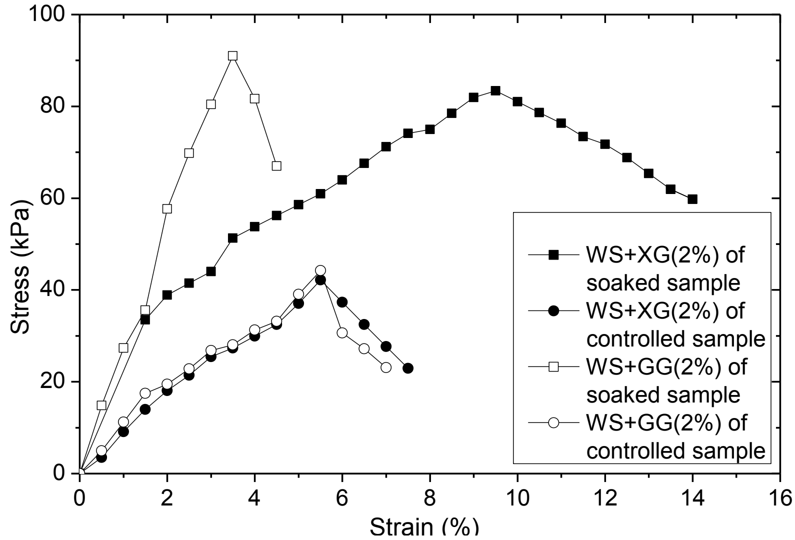

Fig.5.13 Stress-strain curve of WS+XG (2%) and WS+GG (2%) for soaked sample and controlled sample

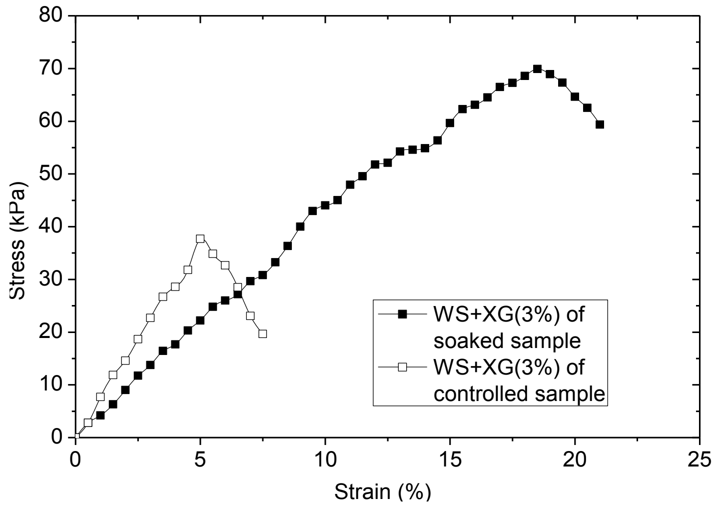

Fig.5.14 Stress-strain curve of WS+XG (3%) for soaked sample and controlled sample

Table 5.4 Comparison of resistance to loss in strength for white soil and biopolymer modified white soil

Sample Name	UCS of controlled sample (UCSC) (kPa)	UCS of soaked sample (UCSS) (kPa)	Increase/ decrease in strength from controlled sample (CS) to soaked sample (SS)	Resistance to loss in strength (RLS= UCSS/UCSC)
WS+XG (1%)	50.37	109.73	Increase	+2.18
WS+XG (2%)	42.20	83.40	Increase	+1.98
WS+XG (3%)	37.71	69.90	Increase	+1.85
WS+GG (0.5%)	54.06	116.02	Increase	+2.15
WS+GG (1%)	53.68	125.27	Increase	+2.33
WS+GG (2%)	44.21	90.98	Increase	+2.06

5.2.4 Dispersion test

The dispersion ratio of white soil as per double hydrometer test was found to be 89.57%, which is extremely dispersive as per Volk (1937) (Table 4.8). Crumb test was also done to assess the dispersiveness of white soils. Fig. 5.15 (a) shows cubes of white soil getting dispersed in water after five to seven minutes. Figures 5.15 (b), 5.15 (c), 5.15 (d), 5.15 (e), 5.15 (f) and 5.15 (g) show cubes of white soil added with Xanthan gum (1%), Xanthan gum (2%),Xanthan gum (3%), Guar gum (0.5%), Guar gum (1%) and Guar gum (2%), respectively, where, it can be seen that white soil added with gums did not get disperse after five to seven minutes. Hence, both XG and GG are effective in stabilizing white soil.


Fig. 5.15 (a) **Fig. 5.15**(b)

Fig. 5.15 (c)

Fig. 5.15 (d)

Fig. 5.15 (e)

Fig. 5.15 (f)

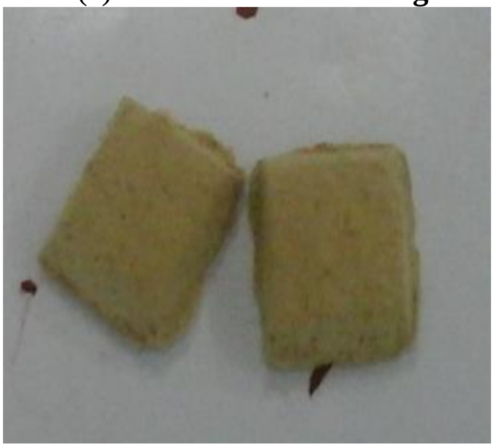

Fig. 5.15 (g)

Fig. 5.15 (a) Cubes of white soil in water after five to seven minutes, **Fig. 5.15** (b), (c), (d), (e), (f) and (g) Cubes of white soil added with Xanthan gum (1%, 2% and 3%), Guar gum (0.5%, 1% and 2%), respectively in water after five to seven minutes.

5.2.5 Modified Free Swell Index (MFSI):

The MFSI test is also conducted to check expansive nature of white soil. The MFSI obtained for white soil is 1.4, which indicated that it is a non-expansive soil as per Table 4.6.

5.3Results of biopolymer stabilized pond ash

5.3.1 Compaction characteristics

The compaction characteristics of different pond ash (PA) and biopolymer modified pond ashes are presented in Figs. 5.16 to 5.20. Fig. 5.16 shows the comparison of OMC and MDD of three pond ash samples. Similarly, Fig. 5.17 and Fig. 5.18 show the comparison of OMC and MDD of pond ash samples being collected from Adhunik steel Plant (ADN) and RSP respectively mixed with XG (2%) and GG (2%). Fig. 5.19 and Fig. 5.20 show the comparison of OMC and MDD of pond ash sample being collected from RSP mixed with various more percentages of gum to know the variation of moisture content when mixed with higher and lower gum percentages. Table 5.5 shows OMC and MDD of various pond ash samples and biopolymer modified pond ash. It can be seen that RSP2 has maximum dry density (11.57 kN/m^3) compared to RSP1 (10.8 kN/m^3) and ADN (11.3kN/m^3). It was also observed that there is reduction in MDD and increase in OMC with addition of biopolymer for the three biopolymer modified pond ashes considered here. This may be due to difficulty in compacting with standard Proctor for the biopolymer stabilized pondash.

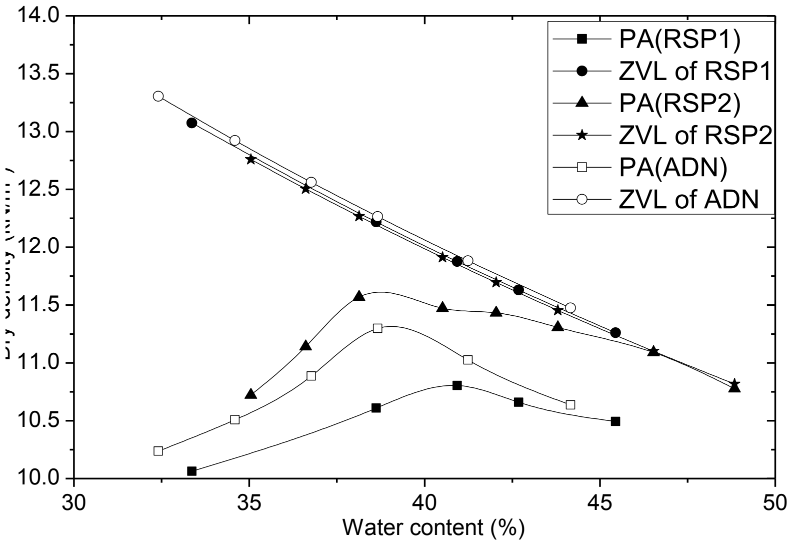

Fig. 5.16 Compaction characteristics for three pond ashes

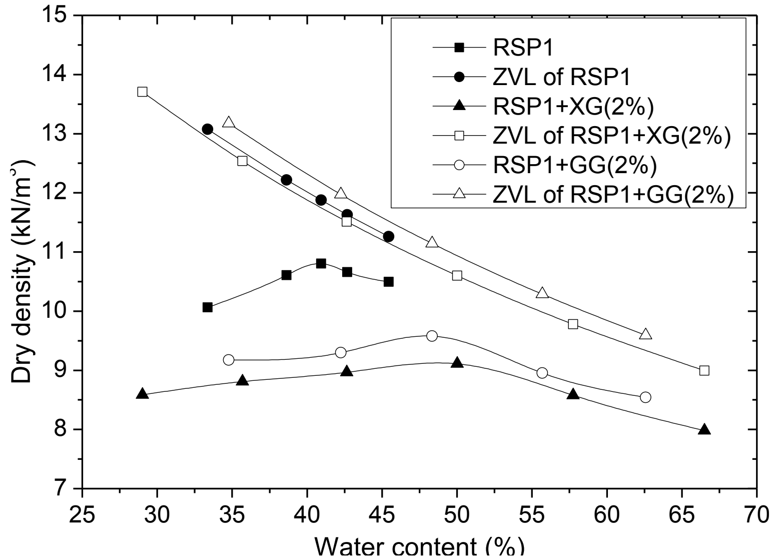

Fig. 5.17 Compaction characteristics for RSP1and with XG (2%) and GG (2%)

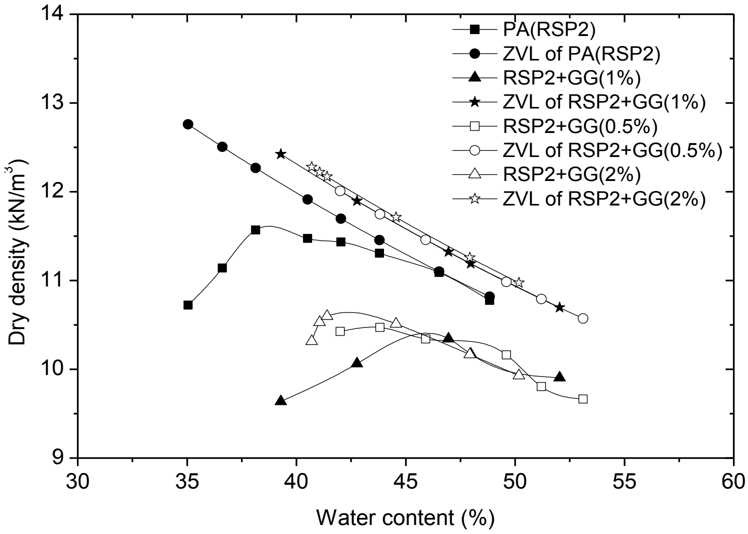

Fig. 5.18 Compaction characteristics for RSP2 and with GG (0.5%, 1% and 2%)

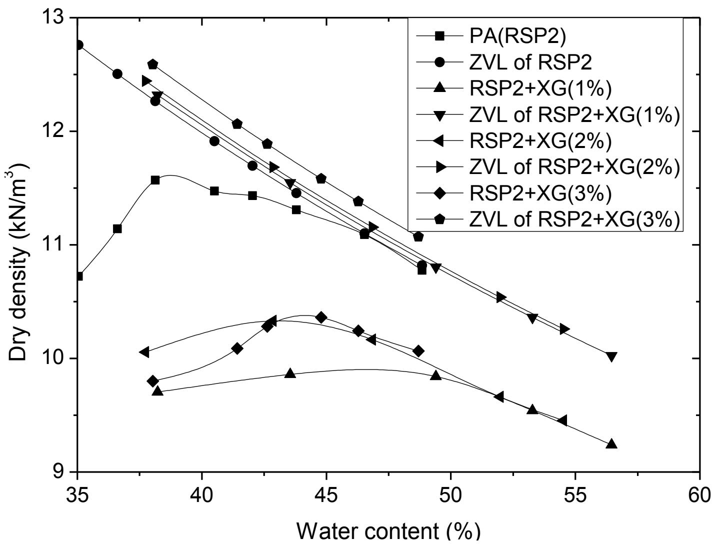

Fig. 5.19 Compaction characteristics for RSP2 and with XG (1%, 2% and 3%)

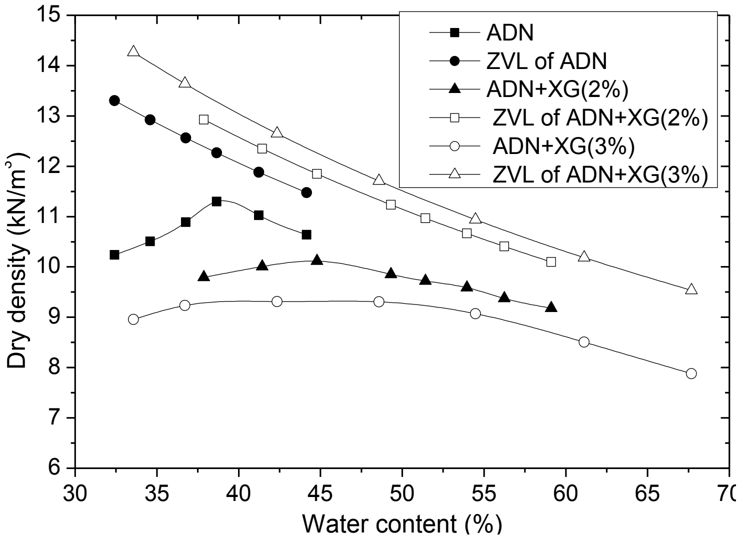

Fig.5.20 Compaction characteristics for ADN and with XG (2%) and GG (2%)

Table 5.5 OMC and MDD of pond ash and biopolymer modified pond ash

Pond ash	Pond ash+ XG/GG (%)	OMC (%)	MDD (kN/m^3)
RSP1	Pond ash	40.93	10.8
	Pond ash+ XG (2%)	55.69	9.11
	Pond ash+ GG (2%)	48.34	9.58
RSP2	Pond ash	38.13	11.57
	Pond ash + XG (1%)	44.79	10.36
	Pond ash + XG (2%)	42.86	10.33
	Pond ash+ XG (3%)	43.55	9.86
	Pond ash + GG (0.5%)	43.83	10.47
	Pond ash + GG (1%)	46.95	10.34
	Pond ash+ GG (2%)	41.4	10.59
AND	Pond ash	38.66	11.3
	Pond ash + XG (2%)	44.79	10.11
	Pond ash+ GG (2%)	42.35	9.31

5.4 Unconfined compressive strength (UCS)

Unconfined strength tests were conducted on different pond ash samples at its optimum moisture content. Fig. 5.21 shows the stress-strain curve of three pond ash samples. It can be seen that RSP2 has higher compressive strength compared to RSP1 and ADN. Similarly, Fig. 5.22 and Fig. 5.23 show the comparison of the stress-strain curve of ADN and RSP1, respectively mixed with 2% of XG and GG, respectively. Fig. 5.24 and Fig. 5.25 show the comparison of the stress-strain curve of RSP2 mixed with various more percentages of gums, which showed that compressive strength increased with increase in gum percentage. Fig. 5.26 and Fig. 5.27showstress-strain curve of 7 days curing of RSP2 mixed with both gums and coated with wax, stored outside. It was observed that the strength at 7 days was less than that of 0 day (without curing). It showed that there was no effect of curing of the gum when kept at same moisture content. Fig. 5.28 and Fig. 5.29 show stress-strain curve of RSP2 mixed with gums, sundried for 1 day. Here, it is observed that in sundried stage, strength increased with increased in gum percentage. The comparison of comprehensive UCS tests conducted with different percentages of gum and under different condition is presented in Table 5.6. It can be seen that the UCS obtained in case of guar gum was more than Xanthan gum. This increase in UCS value of sundried sample may be due to apparent cohesion and needs further investigation in this regard.

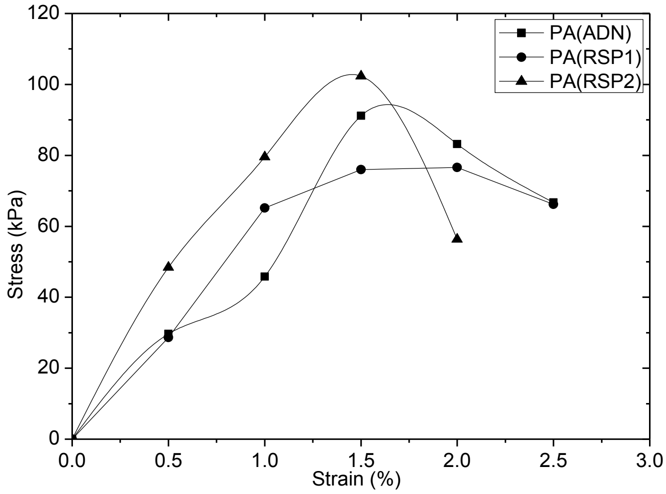

Fig. 5.21 Stress strain curve forRSP1, ADN and RSP2 without curing

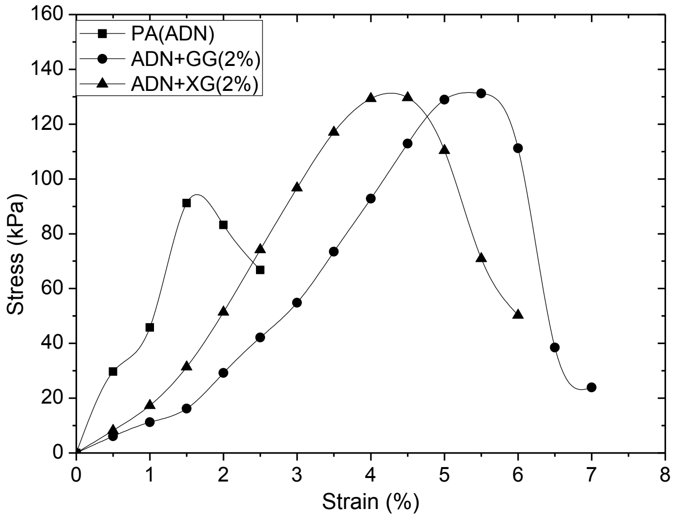

Fig. 5.22 Stress strain curve for ADN and with XG (2%) and GG (2%) without curing

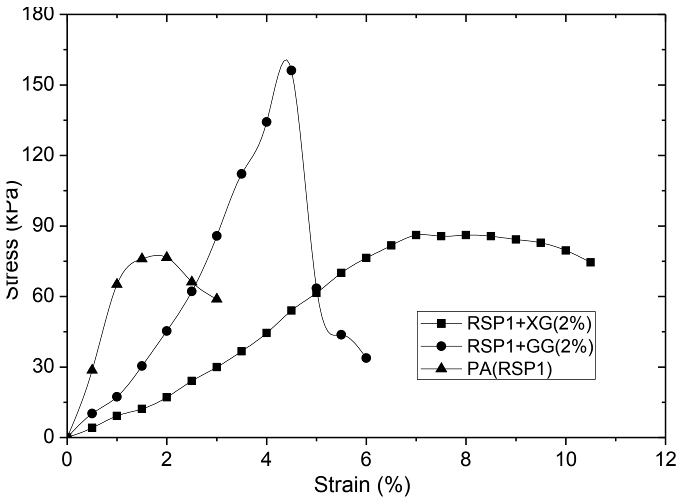

Fig. 5.23 Stress strain curve for RSP1 and with XG (2%) and GG (2%) without curing

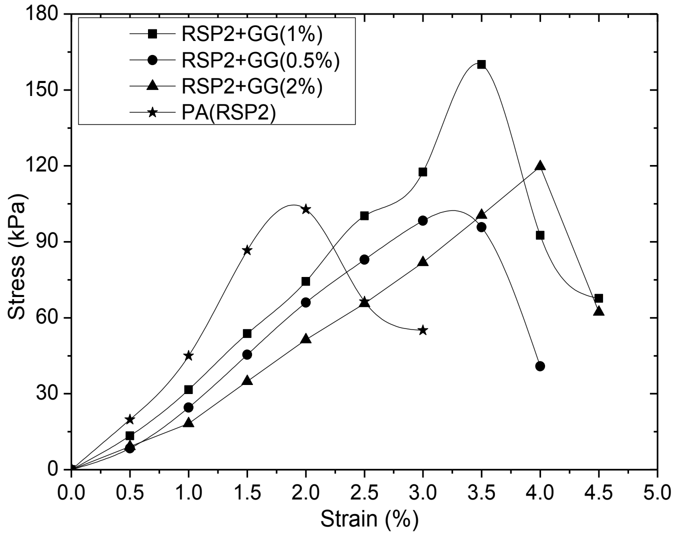

Fig. 5.24 Stress strain curve for RSP2 and with GG (0.5%, 1% and 2%) without curing

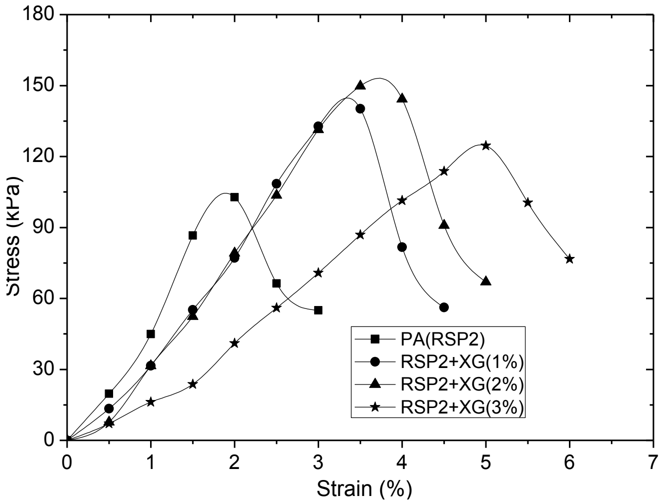

Fig. 5.25 Stress strain curve for RSP2 and with XG (1%, 2% and 3%) without curing

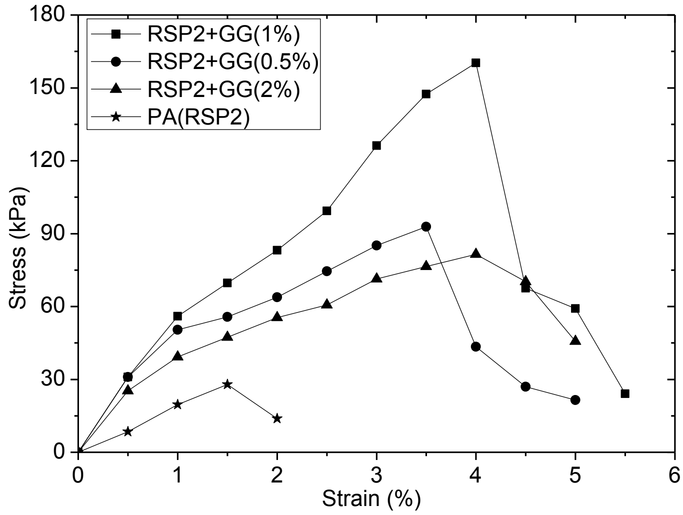

Fig. 5.26 Stress strain curve for RSP2 and with GG (0.5%, 1% and 2%) with curing (7 days)

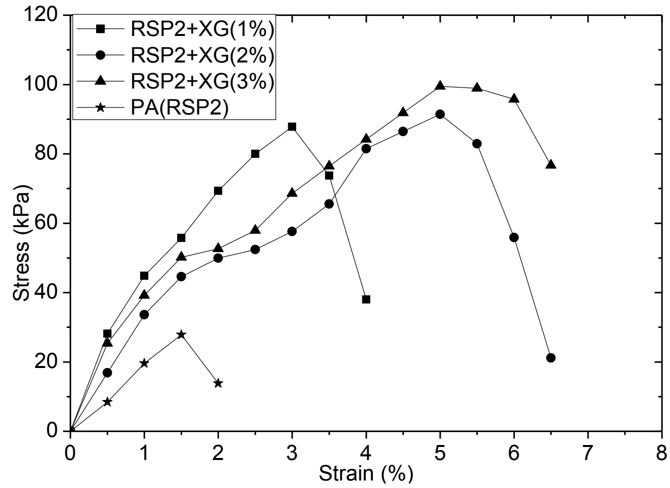

Fig. 5.27 Stress strain curve for RSP2 and with XG (1%, 2% and 3%) with curing (7 days)

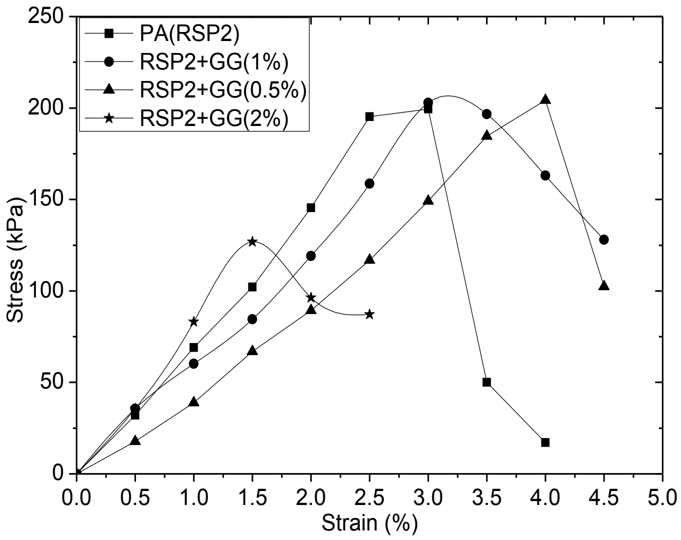

Fig. 5.28 Stress strain curve for RSP2andwithGG (0.5%, 1% and 2%) kept for sundried (1 day)

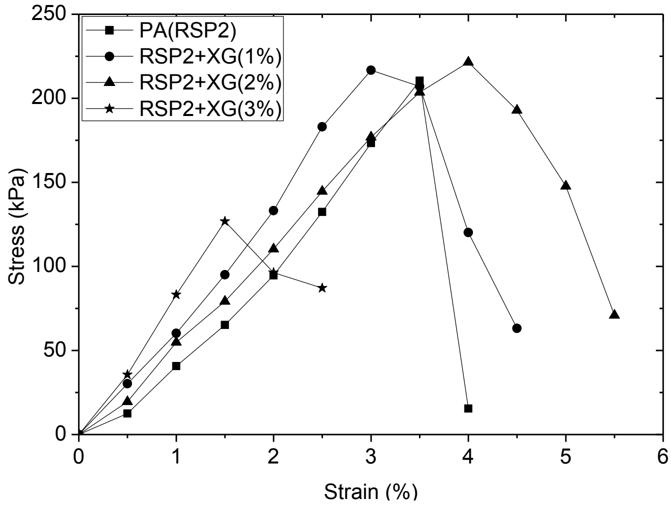

Fig. 5.29 Stress strain curve for RSP2and with GG (1%, 2% and 3%) kept in sundried (1 day)

Table 5.6UCS of pond ash samples and biopolymer modified pond ash

Pond ash	Pond ash + XG/GG (%)	UCS (kPa) 0 day	UCS (kPa) 7 days	UCS (kPa) (sundried 1 day)
RSP1	Pond ash	76.59	-	-
	Pond ash + XG (2%)	86.07		
	Pond ash + GG (2%)	156.14	-	
RSP2	Pond ash	102	28	126
	Pond ash + XG (1%)	140	87	210
	Pond ash + XG (2%)	149	91	216
	Pond ash + XG (3%)	154	99	221
	Pond ash + GG (0.5%)	98	92	199
	Pond ash + GG (1%)	160	147	202
	Pond ash + GG (2%)	169	149	204
ADN	Pond ash	91	-	-
	Pond ash + XG (2%)	129	-	-
	Pond ash + GG (2%)	131	-	-

From experimental study done to compare pond ash and white soil, it is observed that Guar gum is found to be more effective than Xanthan gum for stabilization in both cases. But, Guar gum added to white soil proved to be more effective than it is added to pond ash and Guargum (0.5%) added to white soil gave best result compared to other percentages.

CHAPTER 6

Conclusions and future scope

The stabilization of expansive soil and dispersive soil has been done to avoid its disastrous effect on infrastructural components like road, building, dams, embankments etc. In this work a new idea of stabilizing the expansive soil (bentonite) and dispersive soil (white soil) with geopolymer and biopolymer was discussed.

6.1Conclusions

Based on the obtained results and discussion there of following conclusions can be drawn.

- The maximum optimum moisture content was for bentonite added with geopolymer with fly ash (20%) and alkali solution (10%) and MDD was maximum for bentonite added with fly ash (40%) and alkali solution (15%).
- The UCS value of the geopolymer stabilized bentonite found to vary with percentage of fly ash and alkali solution, and maximum UCS value was obtained with 40% fly ash and 10% alkali solution.
- Based on durability test, the resistance to loss in strength (RLS) was maximum for bentonite with 40% fly ash and 10% alkali solution and it got reduced with addition of 15% solution.
- Based on differential free swell test, it was observed that with increased percentage of alkali activated fly ash, the swelling percentage decreased considerably. After 3 days of curing for bentonite + FA (20%) + S (10%), and bentonite + fly ash (20%, 30% and 40%) + S (15%), the swelling percentage became negligible and the treated soil became non-swelling. Similar observations were made for bentonite + fly ash (20%, 30% and 40%) + S (5%, 10% and 15%) after 7 days and bentonite + fly ash (20%, 30% and 40%) + S (5%, 10% and 15%) after 14 daysof curing.
- Based on crumb test and double hydrometer test it was observed that bentonite was extremely dispersive (84.87%). However, it became non-dispersive with addition of more than 5 % of geopolymer.
- It was observed that with addition of biopolymer, OMC increased and MDD decreased for dispersive soil. However, The UCS value increased with addition of biopolymer.

- With same percentage of gum, it was observed that dispersive soil stabilized with guar gum has better strength compared to that of Xanthan gum.
- Based on durability test the RLS was maximum for Xanthan gum (1%) and guar gum (1%). The RLS decreased with increased percentage of Xanthan gum but, for guar gum RLS obtained was optimum at 1%.
- Based on crumb test and double hydrometer test it was seen that white soil was extremely dispersive (89.57%) and became non-dispersive with addition of biopolymer.
- It was observed that with addition of biopolymer, OMC increased and MDD decreased for pond ash. However, The UCS value increased with addition of biopolymer.
- With same percentage of gum, it was observed that pond ash stabilized with Guar gum had better strength compared to that of Xanthan gum.
- It was observed that sundried sample has better UCS value than sample stored inside coated with film/wax.

The present study showed that biopolymer and geopolymer can be effectively used as stabilizing agents for expansive and dispersive soil. IT was also observed that geopolymer is more effective than biopolymer in terms of stabilization.

6.2 Future scope

Some recommendations made based on the present study for practical applications:

- Efforts to reduce the cost of operation, by searching other natural alkaline materials.
- Field application of this method, by using suitable technology.
- Application of geopolymerin stabilization of other low strength high compressible clays.
- Application of biopolymer in mine reclamation as it is environmental friendly in controlling erosion and dust.

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