An experimental investigation of soil stabilized with almond shells: a tenable solution

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ABSTRACT

Soil stabilization is the alteration of soils to ameliorate their physical properties. It is imperative to acquaint here that recent trends on soil stabilization have evolved innovative and ingenious techniques of utilizing locally available agricultural waste material for the modification and stabilization of deficient soil. Almond shells are available in profusion as a local waste material in most parts of Jammu and Kashmir. It is a woody fibrous material having very good value if used as a fuel and in this study an attempt has been made to use this as a stabilizing agent for geotechnical applications. Since it is a biodegradable material and its strength can be affected by ageing and termite action, hence a diminutive percentage of lime was added to optimize its age and binding capacity with soil. An extensive experimental program on the natural and amended soil after adding different percentages by weight of soil, of the stabilizer was undertaken and its physio-chemical properties were determined in the form of Atterberg limits. To understand its strength behavior, Optimum Moisture Content (OMC), Maximum Dry Density (MDD) and Unconfined Compressive Strength (UCS) tests were performed for all the design mixes at different curing periods. It was found that the OMC and MDD were lowest for a mixture of Soil + 2% powder + 0.5% lime. The maximum value of UCS was found to be 0.076N/mm^2 for this mixture after 28 days of curing. Scanning Electron Microscopy (SEM) and Powdered X – Ray Diffraction (PXRD) was also conducted on these design mixes to understand their quantitative as well as qualitative behaviour. It was found that the experimental results matched well with the microstructural characteristics for all these design mixes.

***Keywords**: Soil Stabilization, Almond Shells, Unconfined Compressive Strength (UCS), Scanning Electron Microscopy (SEM), Powdered X – Ray Diffraction (PXRD)*

I. INTRODUCTION

Stabilization can be used to treat a wide range of sub-grade materials, varying from expansive clays to granular materials. There are many techniques for soil stabilization, including compaction, dewatering and by adding materials to the soil. Soil stabilization has various benefits like cost effective solution, reduced time consumption, environment friendliness, improved weather resistance, etc.

Almond is a species of tree. Almond fruit consists of four portions: kernel or meat, middle shell, outer green shell cover or almond hull and a thin leathery layer known as brown skin of meat or seed coat. The importance of almond fruit is related to its kernel. Other parts of fruit such as shells and hulls were used as livestock feed and burned as fuel. The part of almonds used in this experimental study is the outer hard shell obtained from Kashmir. The total production of almonds in Kashmir is around 10,000 metric tons out of which almost 60% is a waste, i.e., around 40% parts of almond is consumable. [1]

The soil sample, for the study taken up was collected from an agricultural land in Chikbalapur district (13.3908678, 77.8980191) of Karnataka using standard field sampling methods. The soil under study was found to be slightly kaolinitic in nature. Kaolinite occurs in abundance in soils that are formed from the chemical weathering of rocks in hot and moist climates.

In this experimental study, the shells are used in two forms for amending the properties of the soil; Almond Shell Powder /Fibre (ASP) form and Almond Shell Ash (ASA) form. The shells were manually crushed using a rammer into powder/ fibre and the sample passing through 600µ IS sieve was utilized in the study. The ASA used in this study was obtained by igniting partially crushed shells at a temperature of 800^{o} C to 850^{o} C for duration of 4 hours and then allowed to cool down for 24 hours. The ash sample passing through 425µ IS sieve was used for stabilization of soil in various tests.

The project was undertaken to observe the impact and effects of almond shell as an amendment on soil. This has encouraged us to make use of this agricultural waste for the stabilization of weak soils. Almond shells are fibrous materials with high strength characteristics which can prove advantageous in the process of enhancing weak and soft soils. Thus an attempt has been made to study the influence of Almond Shells in powder, fibre and ash form to enumerate various geotechnical properties of soil like Atterberg limits, specific gravity, compaction and UCS. Since lime enhances the binding properties of soil, thus in our experimental analysis we have added lime in small percentages to improve the binding and adhesion between the soil particles and the crushed almond shell particles.

II. LITERATURE REVIEW

2.1 Additives used for stabilization

Following are the various stabilizers and combinations of stabilizers that have been used for accomplishing soil stabilization:

2.1.1 Groundnut Shell

The tests have shown that due to addition of groundnut shell ash as an admixture there has been an effective improvement in the strength, plasticity index and various other geo-technical properties whereas reduction in the hydraulic conductivity without affecting the foundation of the structure. [2]

The Standard Proctor compaction showed an increase MDD with increasing dosage of Groundnut Shell Ash (GSA) up to about 4% of Groundnut Shell Ash. At specific ash contents, the results indicate a decrease in MDD with increasing GSA contents. The UCS at 14 days showed marked differences in values from one another and from that of the 7 days curing period. [3]

2.1.2 Fly Ash

There exists an optimum Dandeli fly ash percentage for mixing with the soil under consideration at which the respective parameter attains its most desirable value from geotechnical point of view. [4]

The plasticity index, swell potential and swelling pressure were reduced by about 50% when the fly ash content was 20%. The resistance to penetration increased significantly with an increase in the fly ash content for particular water content and also the OMC decreases and the maximum dry unit weight increases. Compaction curves shifted upward and toward the left as the OMC decreased. The undrained cohesion of the expansive soil blended with fly ash increases with the fly ash content. Excellent correlation was found between measured and predicted values of undrained cohesion. [5]

Experimental studies determined that addition of fly ash to cohesive soil increased the strength of the resulting mix by virtue of the enhanced frictional strength and pozzolanic reactions. In addition when it is used as a mechanical stabilizer, it reduces the shrink-swell potential of expansive soil, thus providing increased volume stability. [6]

2.1.3 Natural Pozzolana

Natural pozzolana and lime are added to soil within the range of 0% - 20% and 0% - 8% respectively. The plasticity index was found to decrease with increasing natural pozzolana which indicates increase in strength and reduction in swelling and compressibility. The appreciable drop in MDD at 8% lime has been compensated with adding 20% natural pozzolana and also OMC was also reduced in the same case. Microscopic analysis confirmed the addition of lime or lime and natural pozzolana to the investigated clayey soil has caused a marked change in morphology. The SEM and EDX showed presence of C-S-H and C-A-S-H in both lime and natural pozzolana-lime treated clayey soil which indicated improvement in various engineering properties like workability, compaction, strength and shrinkage. [7]

2.1.4 Wood Ash

Results showed that the geotechnical properties have been improved substantially by the addition of wood ash. Plasticity was reduced by 35%, strength was increased by 49% - 67%, depending on the compaction energy used. The highest strength values were obtained by adding 10% wood ash. Also, further increase in strength was observed in cured samples. However, the strength gain was short lived as the strength quickly decreased after 7-14 days of curing. [8]

2.1.5 Saw dust

The OMC shows increase with increase in Saw Dust Ash (SDA) content. UCS increases by 26.35 at 4 % SDA content which is taken as optimum. This investigation has discovered that SDA acceptably acts as a cheap stabilizing material for sub-grade and sub-base purposes in clayey soils. [9]

2.1.6 Bagasse Fibres

Varying proportions of randomly distributed bagasse fibre of 0.5%, 1.0%, and 2.0% were added to expansive soil and hydrated lime-expansive soils mixed with different bagasse fibre proportions were also investigated. The remarkable improvement was more pronounced for the admixtures of hydrated lime-bagasse fibres than merely bagasse fibres treated expansive soils. Also the UCS was found to increase for bagasse reinforced soil which was further increased in case of lime-bagasse fibre reinforcement. The findings of the experimental investigation in this paper demonstrate the combination of hydrated lime-bagasse fibre yielded higher strength and reduced linear shrinkage lower than bagasse fibres alone. [10]

2.1.7 Nylon Fibres

Soil has been reinforced with nylon fibres and the content in this experimental study was varied at 0%, 0.05%, 0.10%, 0.15%, 0.20%, 0.25%, 0.30% by the dry weight of the soil. The length of the fibre was varied at 15mm and 20mm. The secondary compression decreased in the expansive clay specimen reinforced with nylon fibre. [11]

2.1.8 Lignin, Rice Husk Powder (RHP) and Rice Husk Ash (RHA)

3-day UCS increased with increase RHP content from 0 to 15%, further addition of RHP the 3-day UCS slightly decreased. While the 7-day UCS was shown to increases for all percentages of RHP. Curing further improved strength of treated soil. The 3-day UCS soil treated with 10% lignin, 10% RHP and 10% RHA were 156 KPa, 310 KPa and 184 KPa, respectively, compared to 291 KPa, 364 KPa and 400 KPa of 7-day UCS at the same content of lignin, RHP and RHA, respectively. In both cases of 3 and 7 days curing, the addition of 5% lignin had low effect on UCS. The liquid limit (LL) decreased from 148% to 66.4% with increase in Lignin from 0% to 20%.20% Lignin caused a decrease of 55.1% in LL when compared to the LL of the control sample (artificial soil). When the RHA content was increased from 0% to 10%, LL decreases from 148% to 137.2%, respectively. Maximum decrease in swelling potential was obtained for the soil treated with 15% lignin. Swelling percent decreased from 13% to 5.65% when RHA increased from 2.5% to 10%. [12]

2.1.9 Palm Fibres

At a constant palm fibre length, with increase in fibre inclusion, the maximum and residual strengths increased, while the difference between the residual and maximum strengths decreased. A similar trend was observed for constant palm fibre inclusion and increase in palm fibre length. At a constant fibre inclusion rate, an increase in the palm fibre length resulted in the decrease of the degree of homogeneity and isotropy causing irregularity in the failure shear surface. [13]

2.1.10 Fly Ash, lime and Polyester fibre

The stabilizer worked best with lime and the optimum value of lime content and fly ash content in fly ash-soil-lime mixture should be taken as 8% and 15% respectively. The addition of 1.5% of 6 mm plain fibres or 1.0% of 6 mm crimped fibres to fly ash-soil-lime-fibre mixtures (at 8% lime content and 15% fly ash content) increases UCS by about 74% as compared to that of same mixture without fibres. The ratio of split tensile strength and UCS increases with increase in fibre content, which shows that polyester fibres are more efficient when soil was subjected to tension rather than compression. [14]

2.1.11 Fly ash, Polypropylene fibres and Nylon Fibres

The experimental study showed there was reduction in the swelling, shrinkage and plasticity characteristics by 20% to 80%. The improvements reduce expansive soil behavior from problematic characterization levels to non-problematic levels. [15]

2.1.12 Coir waste

The dry density decreases because of reduction of average unit weight of solids in the –coir pith and soil–short fibre mixture. This is because of low specific gravity and unit weight of coir pith and short coir fibre compared with that of soil. [16]

2.1.13 Rice husk ash (RHA) and Calcium Chloride

4% was the optimum content for lime in RHA-blended clays. 12% was the optimum RHA content for clay-lime blends. The high pozzolanic reaction of RHA further increases compressive strength of the blend in presence of lime. [17]

2.2 Lime precipitation

Drastic decrease in the LL and plasticity index of expansive soil has been observed and this reduction is due to the strong short term lime-modification reactions occurring between the precipitated lime and the soil. The UCS increased as the percentage of the percentage of lime precipitation increased. [18]

Results and experience show that lime as a chemical stabilizer yields better results than the others but cement is commonly used because of its cost effectiveness.[19]

III. RESEARCH METHODOLGY

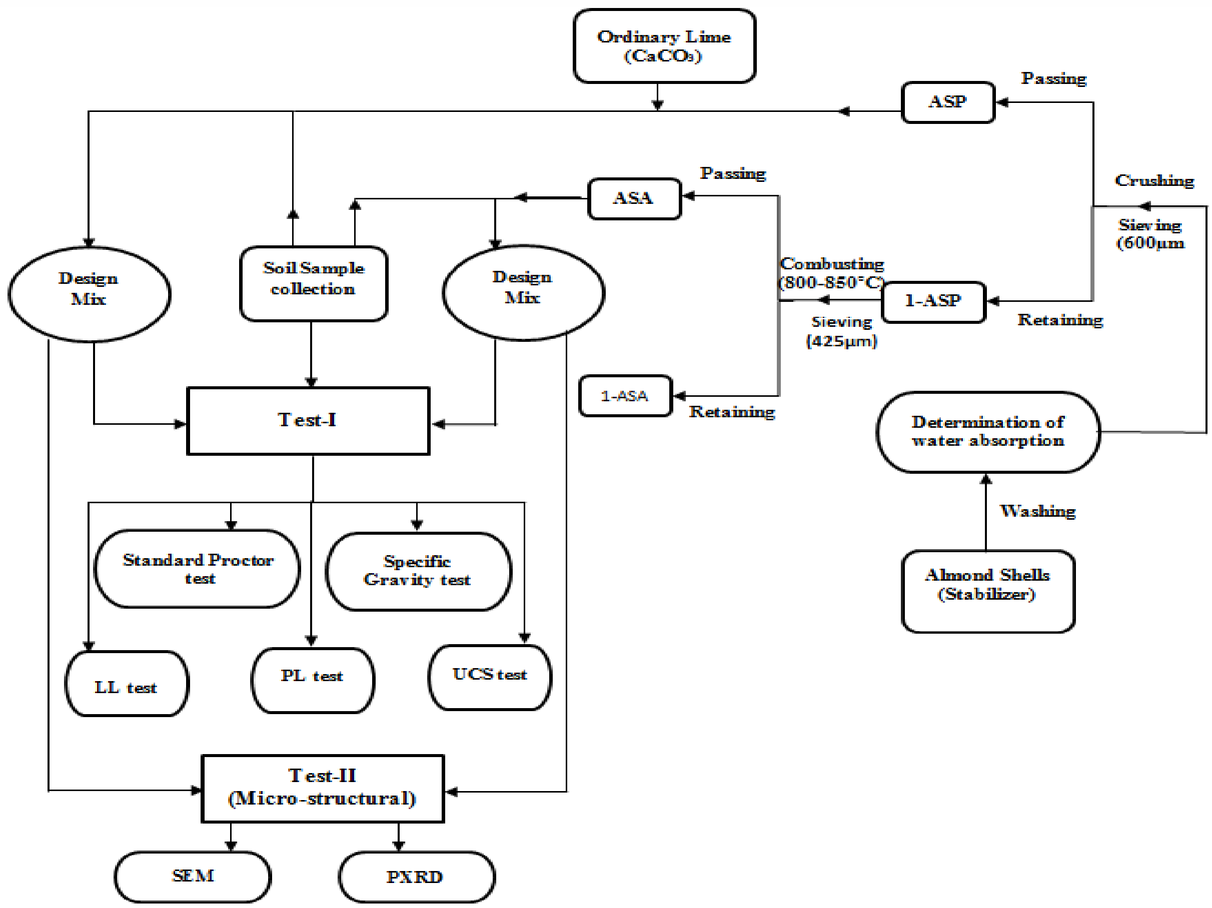

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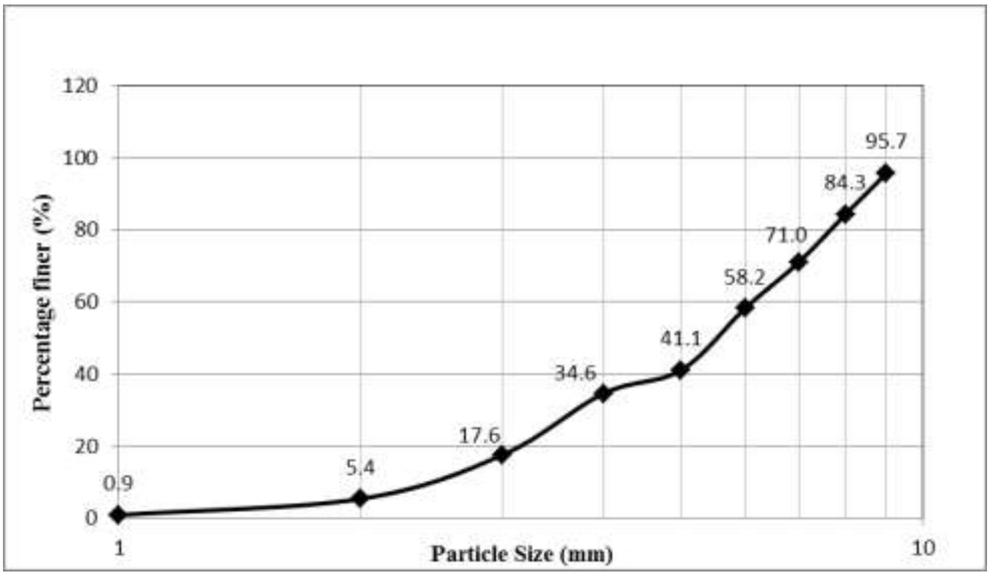
Fig1. Flow chart showing research methodology adopted

IV. RESULTS AND DISCUSSIONS

4.1 Water content

The natural water content was found to be **20.86**%.

4.2 Sieve Analysis



D_{10} = 0.105 mm

D_{30} = 0.250 mm

D_{60} = 0.680 mm

Coefficient of Uniformity, **C_u = 6.47**

Coefficient of Curvature, **C_c = 0.915**

Fig 2. Particle size distribution curve of Kaolinitic Soil

4.3 Specific Gravity

Table 1. Specific Gravity of various natural and amended soil samples

Sample	Specific Gravity
Natural Soil	2.45
Soil + 1% ASP + 0.25% lime	2.41
Soil + 2% ASP + 0.5 % lime	2.15
Soil + 0.5% ASA	2.29
Soil + 1% ASA	2.25

The specific gravity test results show a regular decrease in the values on addition of the stabilizing agent, both in powder and ash form. However, in case of amendment of soil using powder (and fibre) form, the decrease in the value is high and abrupt for 2% addition of ASP as compared to 1% addition of ASP, and in case of addition of ASA, the decrease in the values of specific gravity is found more on adding 0.5% ASA and not much in 1% ASA.

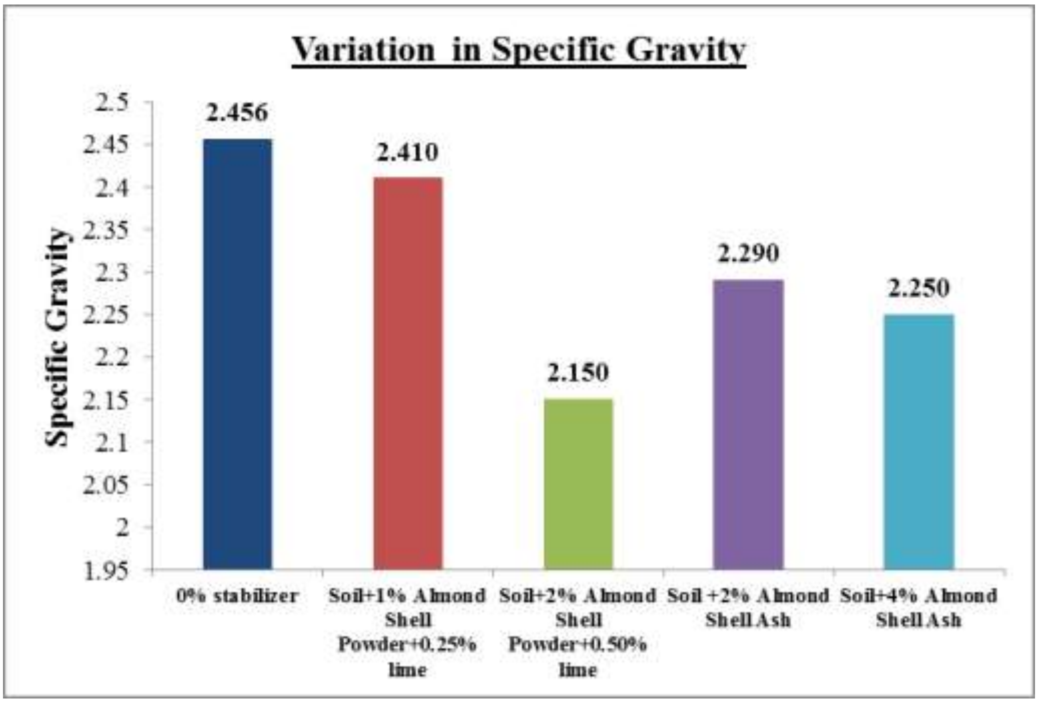


Fig 3.Variation of specific gravity with different amount of stabilizers

From the experimental data, it is evident that specific gravity decreases with the increase in ASP and ASA as a stabilizing agent. This is due the fact that as specific gravity is the ratio of weight of soil sample to the weight of equal volume of water. The weight of almond powder is very less as compared to the volume thereby occupying more space and increasing the weight of water as a result of which specific gravity decreases.

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4.4 Liquid limit (LL)

Table 2. LL of various natural and amended soil samples

Sample	LL
Natural Soil	61.50%
Soil + 1% ASP + 0.25% lime	56.77 %
Soil + 2% ASP + 0.5 % lime	55.50%
Soil + 0.5% ASA	55.50%
Soil + 1% ASA	49.570 %

The LL test show a continuous decrease in the LL values in amended soils as compared to natural soil. The lowest LL is found for the soil amended with 1% ASA.

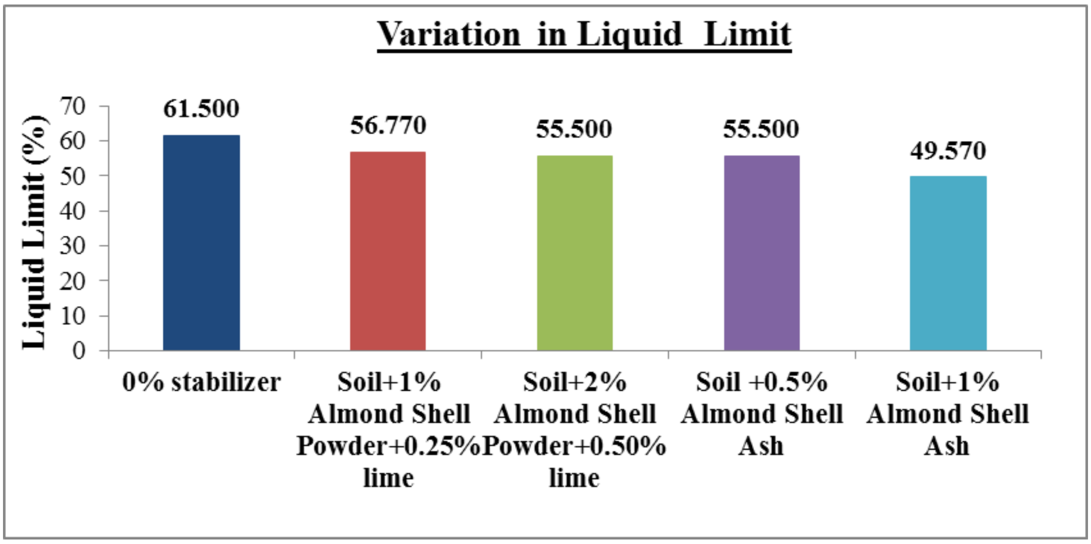


Fig 4.Variation in LL with different amount of stabilizers

There is a decrease in LL with the addition of ASP as well as ASA. As the particles of ASP and ash occupy the inter particular voids of soil, these voids lose their capacity to hold the available water as in case of natural soil and this results in an easier flow at an early stage which causes the decrease in LL of the amended soil.

4.5 Plastic Limit (PL)

Table 3. PL of various natural and amended soil samples

Sample	PL

Natural Soil	30.50%
Soil + 1% ASP + 0.25% lime	32.11%
Soil + 2% ASP + 0.5 % lime	34.08%
Soil + 0.5% ASA	33.33%
Soil + 1% ASA	54.23%

PL increases in amended soils as compared to the natural soil. Thus the plasticity is attained at a later stage in case of amended soils whereas it is attained at an early stage in natural soil. In this experimental study, PL is highest for soil sample amended with 1% ASA. It is observed that the PL increases by addition of almond shells in powder (and fibre) and ash form to the soil. The highest PL being observed for the soil amended with 1% ASA. The reason for the increase in PL is that the water absorption capacity of the stabilizing agent is different from that of the soil, thus having a significant impact on the resistance to flow on addition of water.

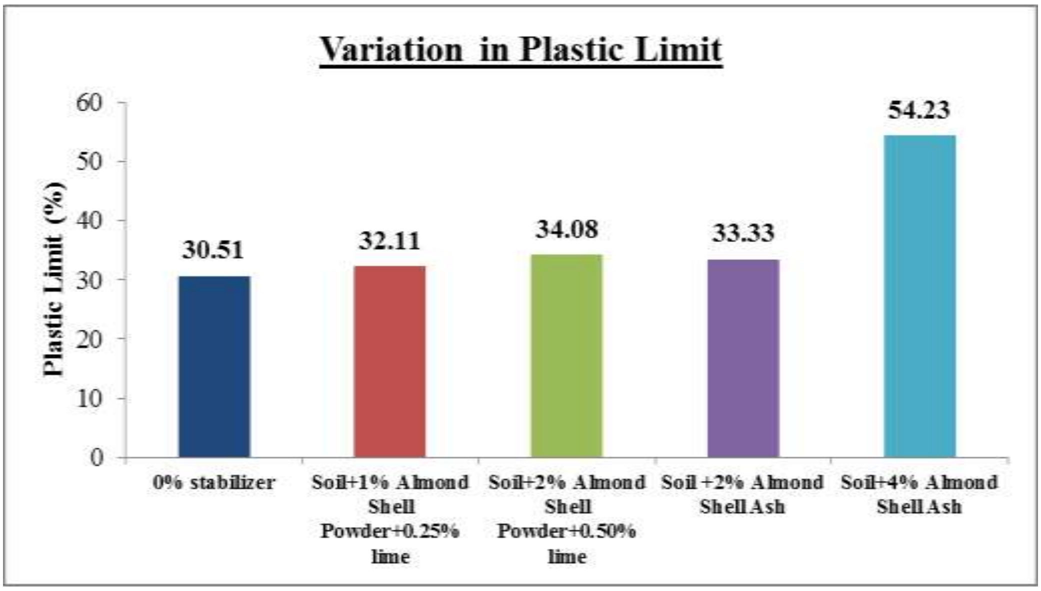
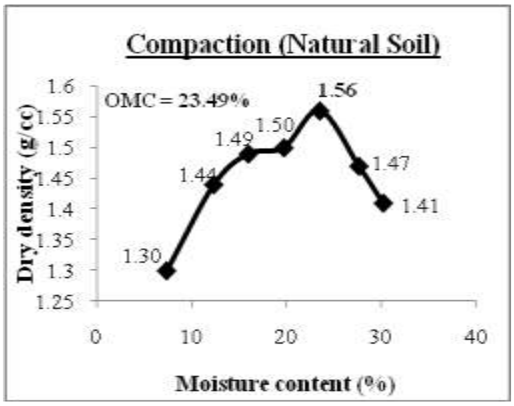


Fig 5. Variation in PL with different amount of stabilizers

4.6 OMC and MDD

Plots of moisture content v/s dry density for various samples of natural and amended soil are illustrated below:



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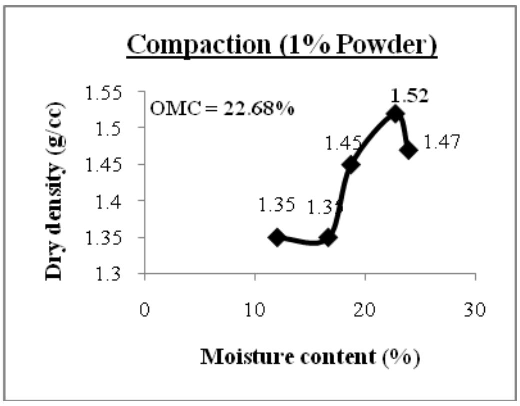

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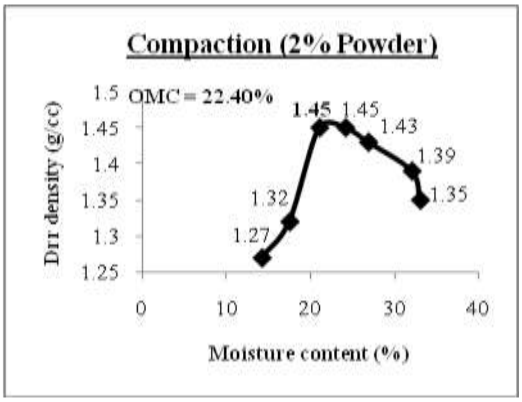

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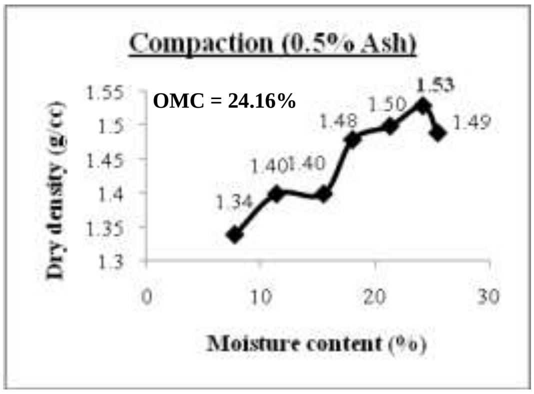

(6d)

The results of standard proctor test on natural and amended soil show that the OMC is lesser for amended soils as compared to the natural soil except for the soil amended with 0.5% ash which has greater OMC than the natural soil. Also the MDD is found low for the amended soils than that of the natural soil.

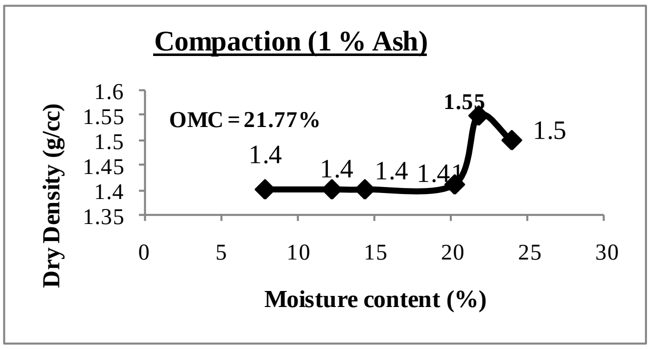

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Fig 6. Moisture content v/s Dry Density graphs of various natural and amended soil samples

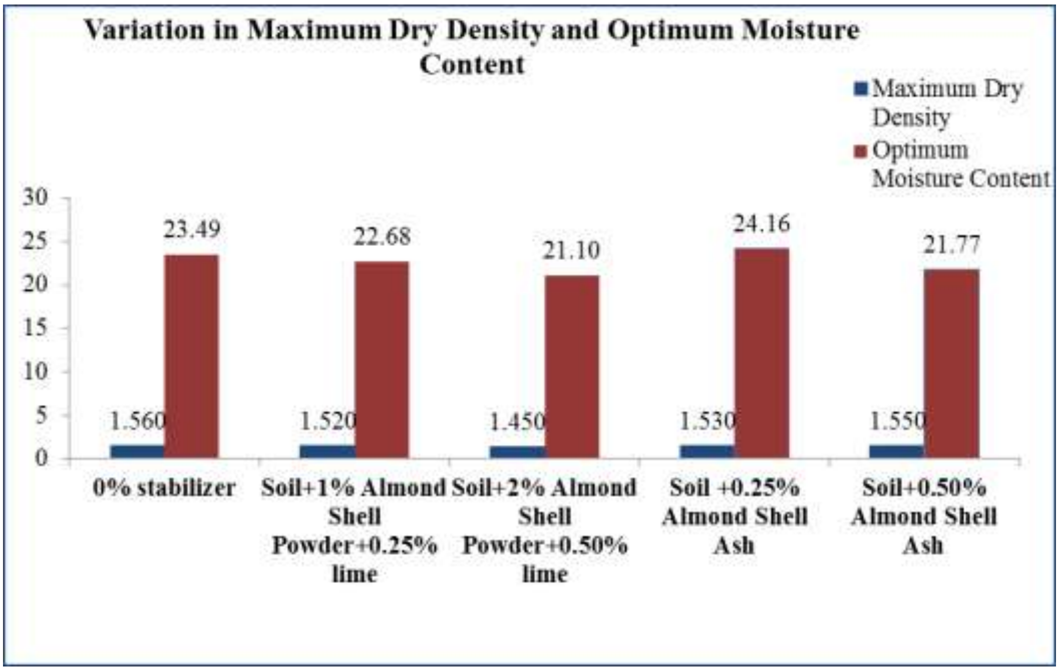

Fig 7. Variation in MDD and OMC with different amount of stabilizers

The overall results of standard proctor test on natural and amended soil show that the OMC has decreased for amended soils. Also the MDD is found low for the amended soils than that of the natural soil. For soils amended with almond shell in powder (and fibre) form, the density is found to decrease to a greater level whereas the MDD of soil amended with almond shell in ash form is close to that of the natural soil. The reason for this behaviour is different compactive strengths for soil and the stabilizing agents.

4.7 UCS

Tabular column representing the observed UCS of the natural and stabilized soil is shown below:

Table 4. UCS of various natural and amended soil samples

Sample	Uncured	21 days curing	28 days curing
Natural soil	0.039 N/mm^2	0.069 N/mm^2	0.049 N/mm^2
Soil + 1% ASP+ 0.25% lime	0.064 N/mm^2	0.065 N/mm^2	0.057 N/mm^2
Soil + 2% ASP + 0.5% lime	0.058 N/mm^2	0.054 N/mm^2	**0.076 N/mm^2**
Soil + 0.5% ASA	0.035 N/mm^2	0.069 N/mm^2	0.070 N/mm^2
Soil + 1 % ASA	0.038 N/mm^2	0.057 N/mm^2	0.046 N/mm^2

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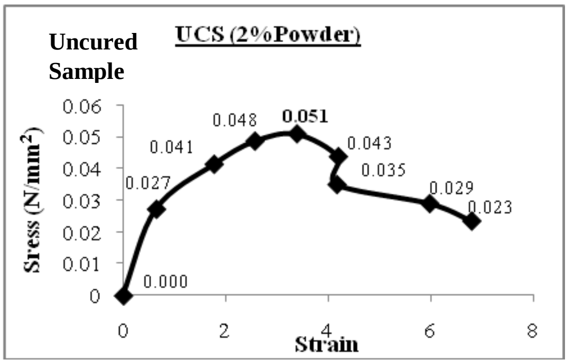

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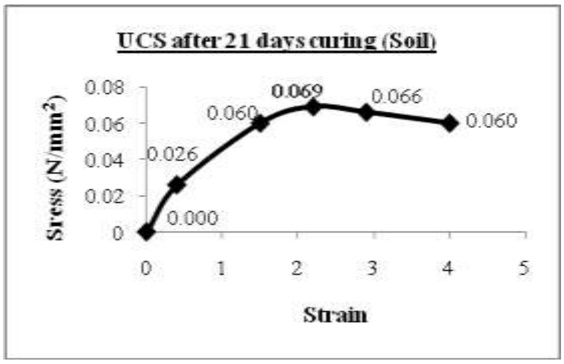

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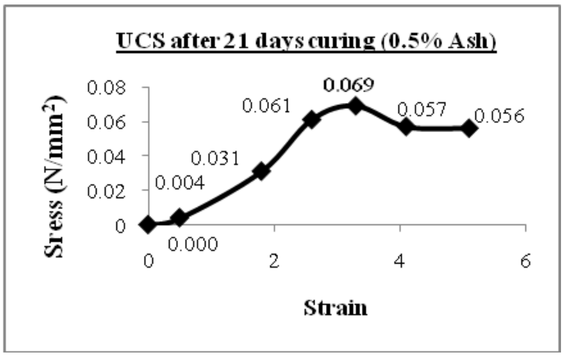

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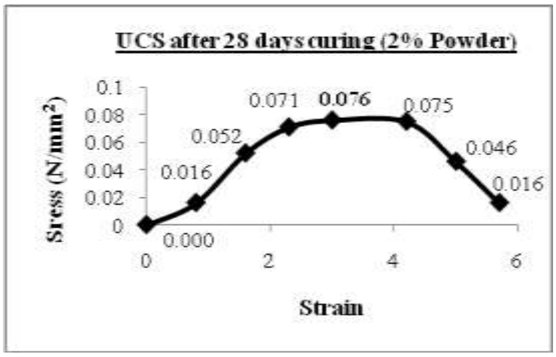

(8d)

Fig 8. Stress v/s strain graph for natural and amended soil samples

The test results of the UCS show that there is a considerable increase in the strength of amended soils.

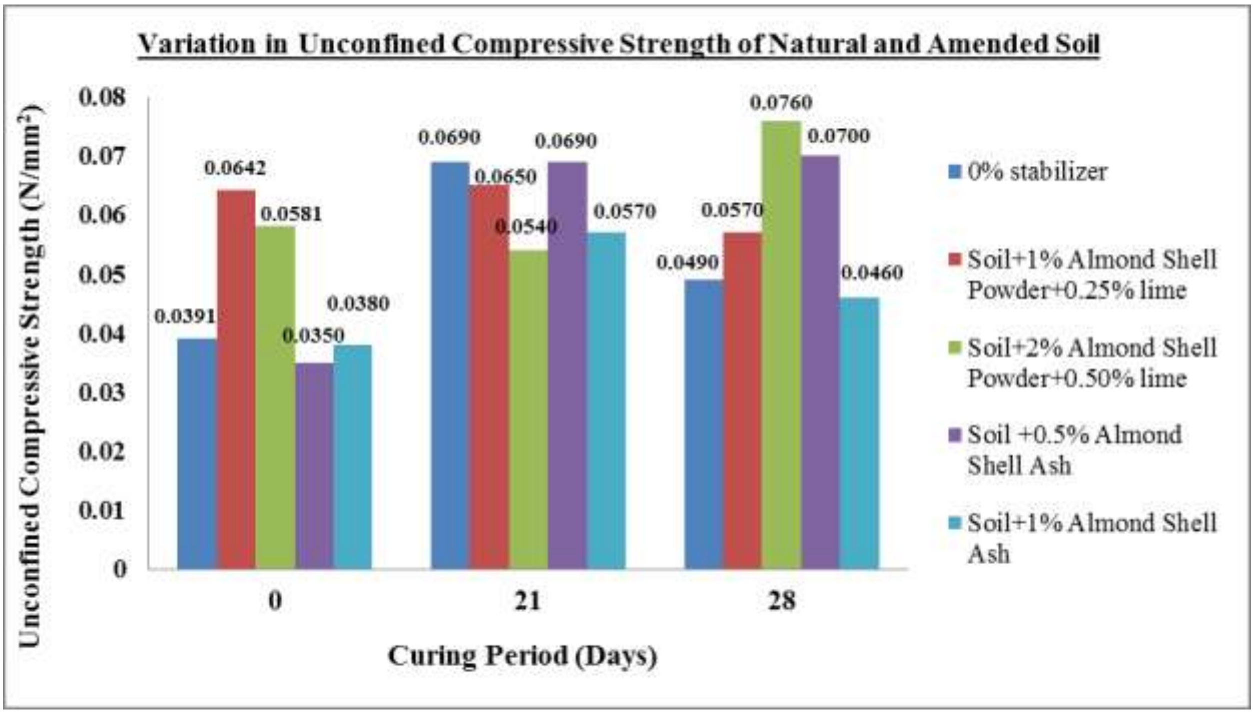

Fig 9. Variation in UCS of Natural and amended soil

Based on the experimental data, on the whole, UCS is found to be maximum on addition of 2% powder and 0.5% lime after a curing period of 28 days at 0.076 N/mm^2. It can be inferred that the presence of lime acted as a good binding agent between almond powder and soil which enhanced its strength.

It is observed that the strength first increases up to 0.5% of ASA, but decreases on further addition of ASA. This may be attributed due to the fact that the strength increases only to a certain content and then due to saturation, further increase in the percentage of the stabilizer results in the decrease of the UCS. The addition of ash up to saturation point fills the voids and any further addition interferes with the bonding of particles.

4.8 Micro-Structural analysis

4.8.1 SEM Analysis

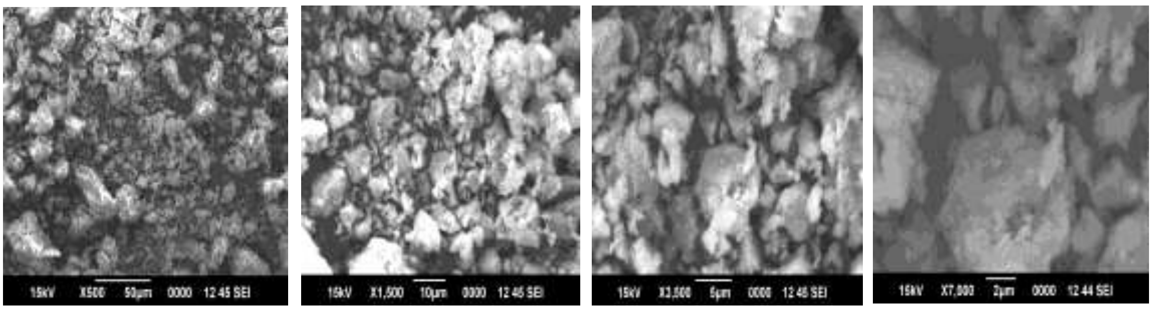

Fig 10. SEM images of soil amended with 1% ASP and Fibre + 0.25% lime

The above figures represent the SEM images taken on soil-almond shell mixture at a resolution of 50 to 2 micrometer In this there is a distinct characterization of almond shell fibres and silica crystals, it looks like the almond fibres are acting as reinforcements to soil, thus complementing its strength by increasing its density and reducing the pore spaces which in turn would enhance its load taking capacity.

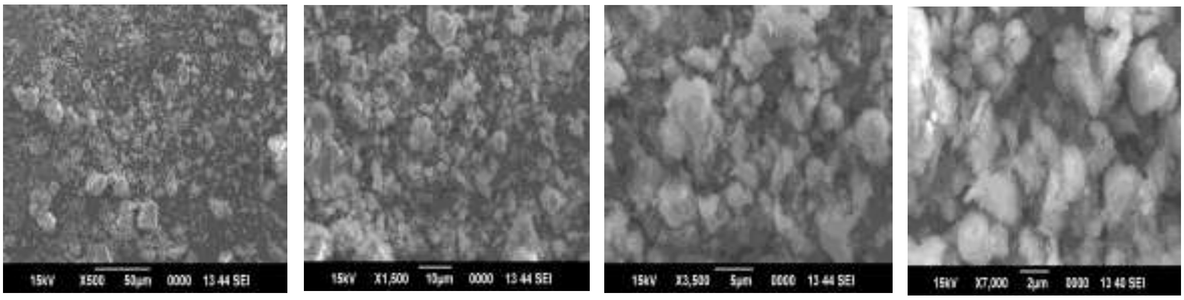

Fig 11. SEM images of soil amended with 1% ASA

The above Figs represent SEM images taken on soil-ASA mixture at a resolution of 50 to 2 micrometer. It can be seen that soil is uniformly distributed with the almond ash, and forms a homogeneous mass. Quartz and silica crystals can be clearly seen. Figs distinctly show the pozzolanic ash and silica of soil have agglomerated and reduced its pores.

4.8.2 PXRD Analysis

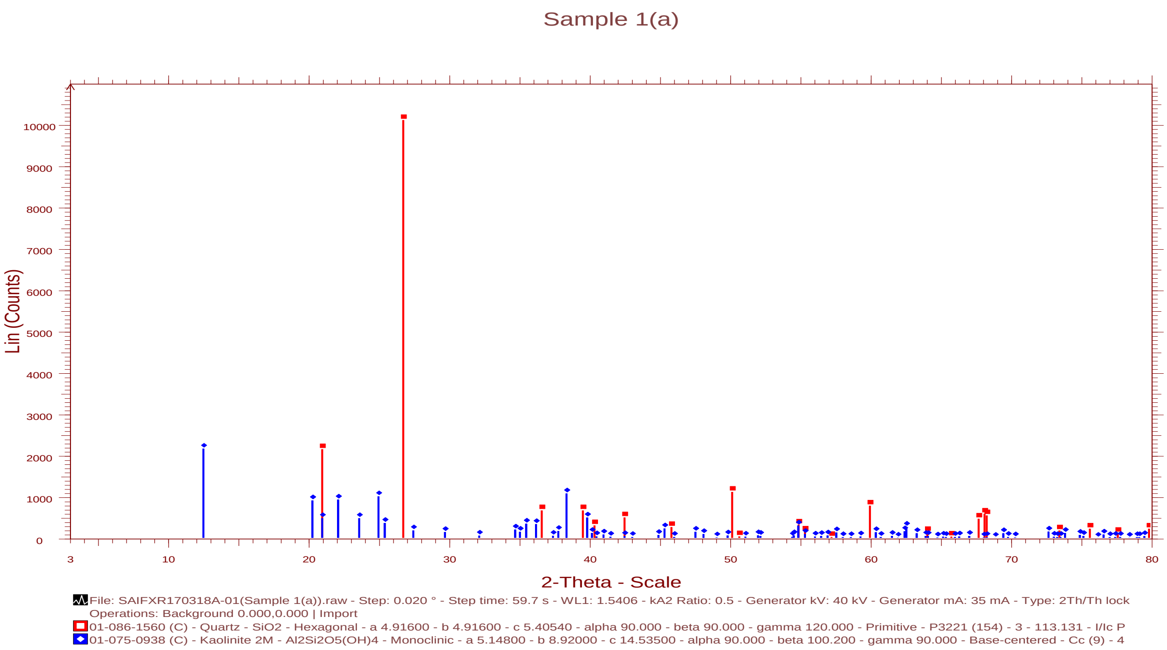

Fig 12. X-Ray Diffraction Analysis of soil amended with 1% ASP and 0.25% Lime

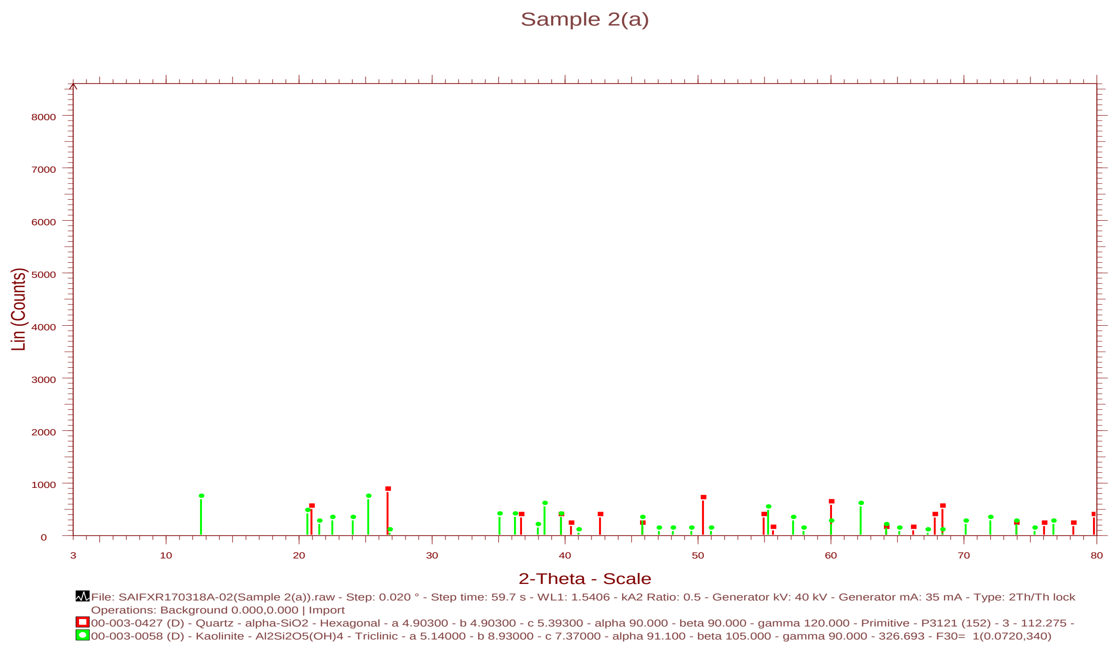

Fig 13. X-Ray Diffraction Analysis of soil amended with 1% ASA

The PXRD data classified the different soil minerals present. It was found that the soil was slightly kaolinitic in nature having quartz and silica as a major component. Since almond powder is a carbon based organic, it could not be seen in the PXRD data.

V. CONCLUSION

After analyzing all the experimental results and considering various economic and environmental factors, it can be summed up that the combination of ASP and fibre along with lime is a more preferable stabilizer as compared to the almond shell in ash form due to its easy availability, cost effectiveness, environment friendliness and better compressive strength. Therefore it can be concluded from extensive experimental and qualitative studies that Soil + 2% almond powder + 0.5% lime is a prospective material for soil stabilization.

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