# Mitigating Problematic Expansive Soil by Using POFA, Lime and DRWPI

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**Abstract.** The Black cotton soil is problematic in nature because it exhibits significant swelling and shrinkage behavior depending upon the moisture content present in the interstices of soil particles. Several researchers have tried different methods to improve the properties of these soils. In the present paper, an experimental study is conducted to observe the properties of the stabilized expansive clay with palm oil fuel ash (POFA), lime and discrete reinforcing waste plastic inclusions (DRWPI). It was observed that the stabilized expansive soil properties are improved to a certain extent and its properties are improved further by the addition of lime and discrete reinforcing waste plastic inclusions (DRWPI).

**Keywords:** Expansive Clay, Palm Oil Fuel Ash, Lime, Discrete Reinforced Waste Plastic Inclusion.

## 1 Introduction

Expansive soil has the tendency to shrink and swell with variation in moisture content. As a result of this variation, significant distress occurs in the soil, subsequently followed by damage to the overlying structures. During periods of greater moisture, like a monsoon, these soils imbibe water and swell. Subsequently, they become soft and their water holding capacity diminishes. As opposed to this in drier seasons like summer, these soils lose moisture held in them due to evaporation become harder.

Roads running through expansive soil regions are subjected to severe distress caused by heaving and settlement of these treacherous soils. This result in severe unevenness with or without cracking, longitudinal cracking parallel to the pavement centre line, rutting of pavement surface and localized failure of the pavement associated with the disintegration of the surface [1-3]. The losses due to extensive damage to highways running over expansive sub grades are estimated to be in billions of dollars all over the world.

A large amount of soil is needed for the construction of highways and embankments. The natural soil can be preserved, if the industrial waste byproducts can be used effectively. In the present scenario, cement stabilization is not preferable because of the increasing cost of cement and environmental concerns related to its production. Utilization of waste materials in the improvement of problematic soils is a cost efficient and environmental friendly. It helps in reducing disposal problems caused by the various industrial wastes. However, it is essential to understand the performance of these waste products prior to use. The present paper evaluated the potential use of palm oil fuel ash (POFA) to stabilize the expansive soil.

### 1.1 Usage of Waste Materials

With the rapid development of industries, various waste by-products accumulated cause environmental problem and it is the foremost task to think regarding the disposal of these waste materials. Handling and disposal of the solid wastes are now a grave concern in the country. Utilization of these waste materials in bulk is the major concern to the researchers.

### 1.2 Need for the Study

New methods and new materials of construction have been continuously explored to fulfil the above problem. The present experimental study has been taken up by partially replacing the expansive clay with Palm Oil Fuel Ash (POFA), a relative new agro waste and further adding it with Lime & Discrete Reinforcing Waste Plastic Inclusions (DRWPI) to improve the performance of the expansive clay.

## 2 Review of Literature

Chemical additives, such as lime, cement, fly ash, and other chemical compounds have been used in expansive soil stabilization for many years with various degrees of success [4]. All the chemical additives used to stabilize expansive soils have cementitious property. Cementitious materials stabilize soils and modify their properties through cation exchange, flocculation and agglomeration and pozzolanic reactions. Additionally, cement provides hydration products, which increase the strength of the base materials as well as enhance the performance of the treatment [5]. Research carried out by Rao et al [6] has proven the efficacy of stabilized fly ash cushions in arresting heave of expansive soil beds. Dayakar & Ramu [7] tried the alternative techniques for improving cohesion in fly ash cushion, the authors tried Discrete Fiber Reinforced Fly Ash Cushion (DFRFAC) as an effective alternative technique in arresting heave of expansive soil beds and it has yielded promising results. Muhammad Sofian Abdulla et al [8] studied the performance of silty soil stabilized with the palm oil fuel ash (POFA) and lime. The effect of the additives and the optimum amount of additives to be used are dependent mainly on the mineralogical composition of the soils. Chemical modification by adding lime and lime – pozzolanic mixes has been practiced for the last two decades. The present work consists of an experimental study to evaluate the impact of the palm oil fuel ash (POFA) as a replacement material to stabilize the expansive soil. The improvement in the properties of the stabilized expansive soil is not as expected and hence lime is used as additive in expansive soil. Its performance is studied further by reinforcing it with discrete reinforcing waste plastic inclusions (DRWPI) through laboratory experimentation.

## 3 Methodology

The composition of stabilised soil samples were prepared by partially replacing the expansive soil by varying the percentage of POFA, Lime and DRWPI. The following percentages taken in this study are presented in the table 1.

**Table 1.**Variables and Percentages Considered.

| Name of the Stabilizer | Percentages Varied |
|---|---|
| Palm oil fuel ash as replacement to the expansive soil | 0, 10, 20, 30 |
| Lime | 0, 2, 4, 6 |
| Discrete Reinforcing Waste Plastic Inclusions | 0, 1, 2, 4 |

### 3.1 Materials Used

**Expansive Soil.** The soil was collected from Appaniramuni Lanka, Near Dindi Village, Sakhinetipalli Mandal of East Godavari District of Andhra Pradesh. The soil has a free swell index of 103 which shows that the soil is of a high degree of expansiveness. The physical properties of the soil were presented in table 2.

**Table** 2.Physical properties of the Expansive soil.

| Property | Value |
|---|---|
| Specific Gravity | 2.64 |
| Differential Free Swell (%) | 103 |
| Sand (%) | 11 |
| Silt (%) | 38 |
| Clay (%) | 51 |
| Liquid Limit (%) | 71.6 |
| Plastic Limit (%) | 31.7 |
| Plasticity Index (%) | 39.9 |
| IS Soil Classification | CH |
| Maximum Dry Density (g/cc) | 1.39 |
| Optimum moisture Content (%) | 27.9 |
| Un-soaked CBR (%) | 2.9 |
| Soaked CBR (%) | 1.4 |

**Palm Oil Fuel Ash (POFA).** Palm Oil Fuel Ash (POFA) is a solid waste by-product of palm oil industry obtained in the form of ash from the burning of the palm oil husk and palm kernel shell used as fuel in palm oil mill steam boiler. The POFA used throughout this study was collected from a local company, M/s Ruchi Oil Company, Samalkot, in East Godavari District of Andhra Pradesh. The collected ash was dried for 24 hours before sieving and then immersed in the water for separation of incomplete burned material. The floated object is considered as organic material and removed from the POFA. The cleaned POFA obtained was dried in an oven at 105 °C ±5°C for 24 hours to remove the moisture content. The dried POFA was then sieved through a 4.75 mm sieve size in order to remove the bigger size particles. The index properties of the POFA are presented in table 3.

**Table 3.**Physical Properties of POFA.

| Property | value |
|---|---|
| Specific Gravity | 1.91 |
| Sand sized particles (%) | 73 |
| Silt and Clay size particles (%) | 27 |
| Maximum Dry Density (g/cc) | 1.28 |
| Optimum moisture Content (%) | 14.3 |

**Lime.** Lime used in this investigation is a commercial lime, manufactured by Birla Lime and available in the local market.

**Discrete Reinforcing Waste Plastic Inclusions (DRWPI).** More than a 100 million tones of plastic is produced worldwide each year. Disposal of plastic through recycling, burning, or land filling is a myth because it does not undergo bacterial decomposition. Once plastic is produced, the harm is done once and for all. Plastic wastes clog the drain and thus hit especially urban sewage systems. So recycling of waste plastics was directly involved to protect the environment. The waste plastic water bottles were used by cutting them into discrete strips.

### 3.2 Sample Preparation and Laboratory Testing

The soil was initially air dried, pulverized and then was sieved through a 4.75 mm sieve, prior to the testing. The samples are prepared by mixing the pulverized soil with the needed amount of Palm Oil Fuel Ash with a certain amount of lime and Discrete Reinforcing Waste Plastic inclusions (DRWPI). The required amount of water is now added to this dry mix to make a consistent mix by through mixing. The tests were conducted in the laboratory on the stabilized expansive soil as per IS codes of practice.

# 4 Discussion of Results

With a view to determine the optimum combination of Palm Oil Fuel Ash (POFA) as a replacement in expansive soil, plasticity, shear strength and CBR tests were conducted on POFA expansive soil mix.

## 4.1 Effect of Palm Oil Fuel Ash (POFA) as Replacement in Expansive Clay

From the figure 1, we can observe the reduction in free swell index with the increase in POFA replaced in the expansive soil. With the increase in percentage of POFA replaced in expansive soil the DFS is decreased from 103 to 70. Figures 2 show the variation of liquid limit and plastic limit of the stabilized soil mix with the percentage of replacement of POFA in expansive soil. With the increase in percentage of replacing POFA in the stabilized soil mix, the liquid limit decreased from 72 to 61 and the plastic limit increased from 31 to 35. This phenomenon may be due to the replacement of plastic soil with a non-plastic waste material.

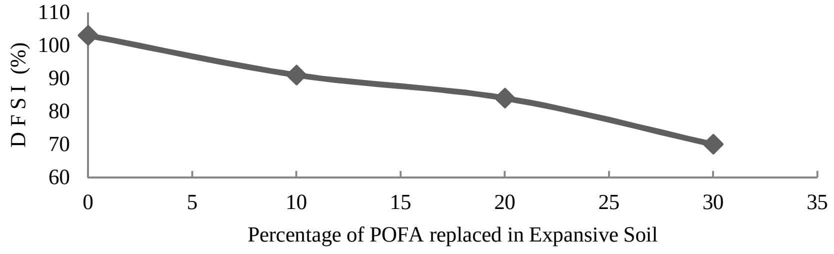


**Fig. 1.** Variation of Differential Free Swell with the percentage of POFA Replaced in Expansive Soil.

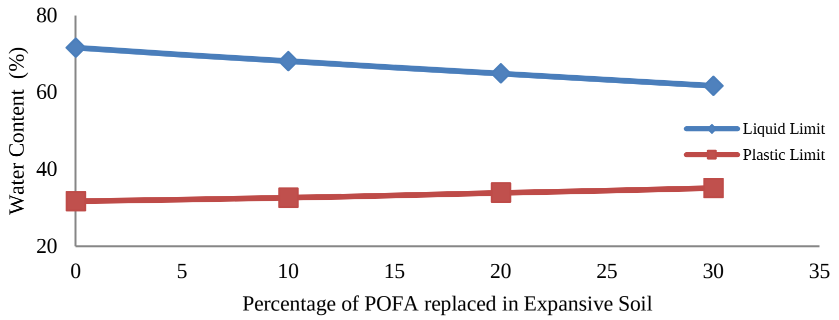


**Fig. 2.** Variation of Liquid Limit and Plastic Limit with the percentage of POFA Replaced in Expansive Soil.

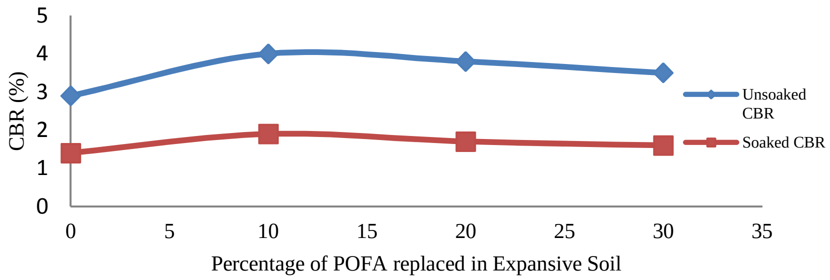


**Fig. 3.** Variation of Unsoaked and Soaked CBR values with the percentage of POFA Replaced in Expansive Soil

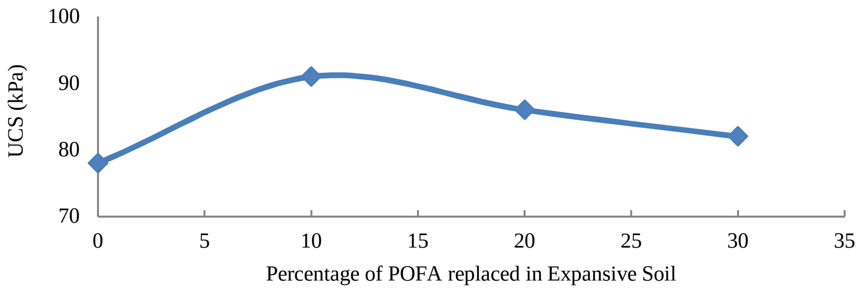


**Fig. 4.** Variation of Unconfined Compressive Strength with the percentage of POFA Replaced in Expansive Soil

Variation of CBR value with the percentage of replacement of POFA in the expansive soil is presented in the figure 3. It can be observed that the maximum unsoaked and soaked CBR values are obtained with the 10% of POFA as replaced in the expansive soil. Figure 4 shows the variation of unconfined strength with the percentage of replacement of POFA in the expansive soil. The maximum unconfined strength is obtained in 10% of POFA as a replacement in the expansive soil.

The results show that there is an improvement of about 46.5 % and 46 % in CBR UnSoaked and Soaked values, respectively up to 10% POFA as replacement and on further replacement there is a decrease in the values. A similar trend is seen in the strength values with an improvement of 26 % for 10 % POFA. This may be due to the possible initial binding of particles with the presence of little amounts of calcium oxide in POFA and also as it is a pozzalonic material. Hence, from the above findings, the optimum percentage of palm Oil Fuel Ash (POFA) as a replacement in expansive clay is 10 %.

### 4.2 Effect of Lime on the Palm Oil Fuel Ash (POFA) Modified Expansive Clay

Figures 5 to 8 shows the variation of various properties of 10 % POFA as a replacement in the expansive clay and mixed with different percentages of lime. The percentage of lime varied from 0 to 6 % with an increment 2 %. It can be observed that the reduction in free swell index with the increase in percentage of lime in the POFA expansive soil mix as shown in figure 5. The DFS value decreased from 91 to 52 with the addition of lime by 6%. From the graphs, it can be observed that the addition of lime by 6 % had reduced the DFS by about 43% and plasticity index by about 42 %. This clearly gives an idea of the improvement of the weak expansive clay when part replaced with a non-plastic agro waste material, POFA and further blending it with binder, lime. The results show a clear improvement in the penetration characteristics and the strength characteristics with the increment in percentage of lime in the POFA expansive soil mix. The CBR values both UnSoaked and Soaked had increased by about 75 % and 116 % respectively with 6 % lime. The unconfined compressive strength (UCS) had improved by about 37 % when 10 % POFA replaced in the expansive soil with the 6 % lime.

Hence, from the above discussions, it is evident that there is improvement in the characteristics of expansive clay when replaced with 10 % POFA and further mixed with 6 % lime. From the trends exhibited in the graphs, further addition of lime might still improve the values, but based on the economic aspects and a motive to utilize the discrete waste plastic inclusions as a sustainability initiative, the percentage of lime was restricted to 6 % and it was considered for the next mode of stabilization step with Discrete Reinforcing Waste Plastic Inclusions (DRWPI).

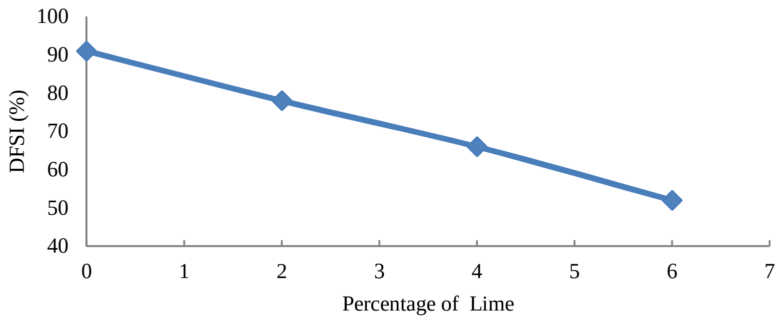


**Fig. 5.** Variation of Differential Free Swell with the Percentage of Lime added to the 10 % POFA Replaced in the Expansive Soil.

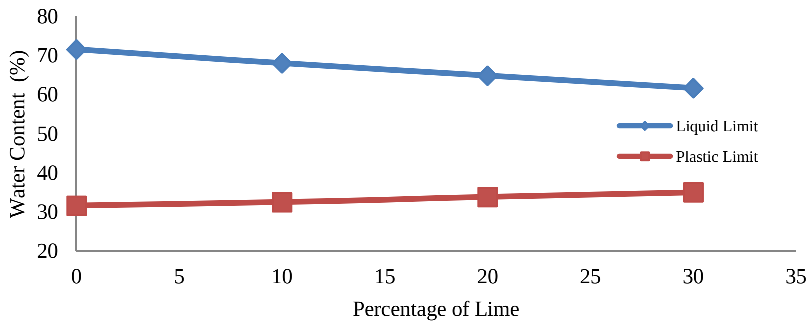


**Fig. 6.** Variation of Liquid Limit and Plastic Limit with the percentage of Lime added to the 10 % POFA Replaced in the Expansive Soil.

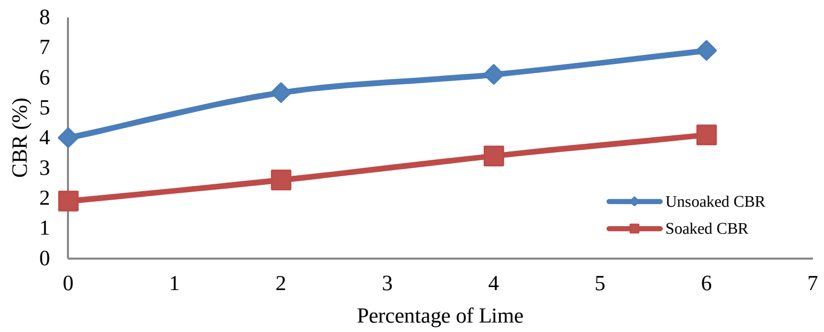


**Fig. 7.** Variation of Unsoaked and Soaked CBR values with the Percentage of Lime added to the 10 % POFA Replaced in the Expansive Soil.

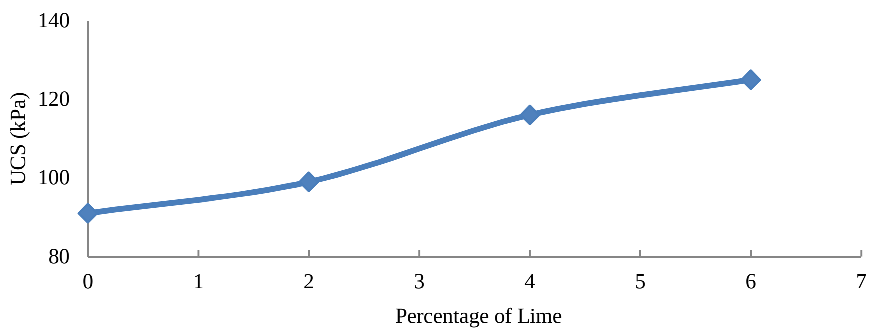


**Fig. 8.** Variation of Unconfined Compressive Strength with the Percentage of Lime added to the 10 % POFA Replaced in the Expansive Soil.

### 4.3 Effect of Percentage of DRWPI as Discrete Reinforcement on the Properties of Treated Expansive Clay

The influence of the Discrete Reinforcing Waste Plastic Inclusions (DRWPI), as discrete reinforcement on the behaviour of Palm Oil Fuel Ash (POFA) and lime treated expansive clay is clearly presented in the figures 9 & 10. The percentage of DRWPI was varied from 0% to 4%, i.e., 0, 1, 2 and 4 %. Figure 9 presents a clear improvement in the penetration characteristics both UnSoaked and Soaked up to an addition of 2 % DRWPI by about 10 % and 40.5 % respectively and there on the values reduced with further addition. The same trend was observed (Fig. 10) in the unconfined compressive strength (UCS) with an improvement of 17%. Hence, it is evident that there is an improvement in the penetration and strength characteristics with the addition of 2 % Discrete Reinforcing Waste Plastic Inclusions (DRWPI) and on further addition, had shown a decrease in the values. This is due to the reinforcing action of the discrete elements in the treated soil matrix with a better orientation up to 2 % and on further addition, there was a distraction in the orientation due to more amounts of discrete elements intervening in the frictional mobilization.

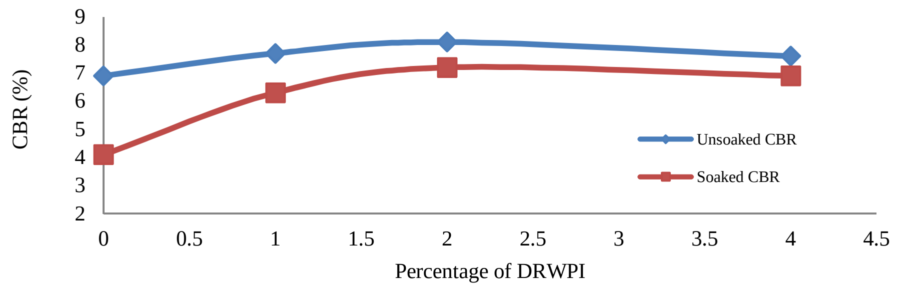


**Fig. 9.** Variation of Unsoaked and Soaked CBR values with the percentage of DRWPI in the POFA and Lime treated Expansive Soil

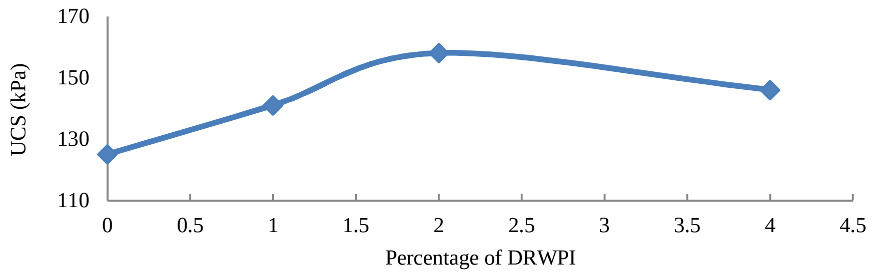


**Fig. 10.** Variation of Unconfined Compressive Strength with the percentage of DRWPI in the POFA and Lime treated Expansive Soil

### 4.4 Curing Studies on POFA and Lime Modified Expansive Clay mixed with Optimum DRWPI

Curing Studies on samples prepared with 2.0% DRWPI + 6% Lime + 10 % POFA as a replacement in expansive soil was presented in the figures 11 & 12. From these results, it was observed that the treatment improved the expansive clay with the time. Figure 11 presents a clear improvement in the penetration characteristics both Un-Soaked and Soaked, upon 28 days curing, by about 27 % and 22 % respectively. The same trend was observed (Fig. 12) in the unconfined compressive strength (UCS) with an improvement of 34 %. The penetration and the strength characteristics of POFA modified expansive clay, further mixed with an optimum percentage of lime and optimum dosage of discrete waste fiber inclusions had shown pronounced improvement as the curing period increased. This is due to the development of strength due to the enhanced binding capacity of the C-S-H gel.

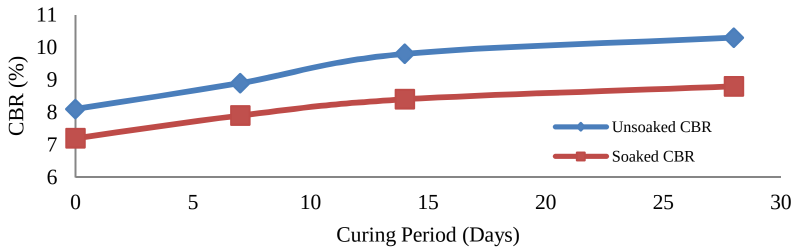


**Fig. 11.** Variation of Unsoaked and Soaked CBR values of samples prepared with 2.0% DRWPI + 6% Lime + 10 % POFA as a replacement in expansive soil with Curing Period.

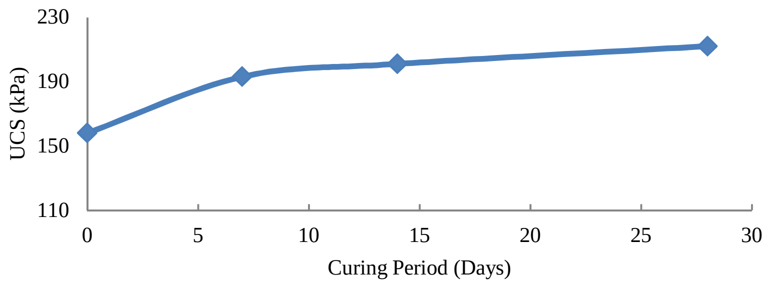


**Fig. 12.** Variation of Unconfined Compressive Strength of samples prepared with 2.0% DRWPI + 6% Lime + 10 % POFA as a replacement in expansive soil with Curing Period

Finally, the above discussions reveal that there is an improvement in all the properties of weak expansive clay with the increase in percentage POFA as replacement and for further mixing with 6 % lime, there was considerable improvement in the values. Based on the economic aspects and a motive to utilize the discrete waste plastic inclusions as a sustainable initiative, different percentages of Discrete Reinforcing

Waste Plastic Inclusions (DRWPI) were mixed to the 6% Lime + 10 % POFA part replaced expansive clay.

This is due to the development of strength due to the enhanced binding capacity of the C-S-H gel. Hence, it can be summarized that the results of the experimental study, ascertain the objective of improving the weak expansive clay by using an agro waste, Palm Oil Fuel Ash (POFA) and Discrete Reinforcing Waste Plastic Inclusions (DRWPI) with a binder lime, thereby giving a two-fold advantage of improving weak expansive clay with a sustainable solution by reusing the waste materials effectively.

## 5 Conclusions

The following conclusions may be drawn based on the experimental results.

a) The differential free swell is reduced by 12% with the 10 % Palm Oil Fuel Ash (POFA) as a replacement in the expansive Clay. It can be further reduced by 43% with the addition of 6% of lime.
b) The 10 % Palm Oil Fuel Ash (POFA) as a replacement had reduced the virgin Plasticity Index of the expansive clay by about 31 % and on further addition of lime by 6 % it had further reduced by about 42.5 %. This is due to the replacement of plastic soil with a non-plastic waste material and chemical reaction with lime and clay.
c) The CBR values both UnSoaked and Soaked had increased by about 38 % and 36 %, respectively, with 10% POFA as replacement and with further addition of lime by 6 %, the values had further increased by about 72.5 % and 116 % respectively.
d) The unconfined compressive strength is increased by about 17%, with 10 % of POFA replaced in expansive soil. The unconfined compressive strength is increased by about 38% with the addition of 6% lime to this mix. It can be further increased by 17% with addition of DRWPI.
e) The penetration and strength characteristics had increased up to an addition of 2 % DRWPI with respect to POFA + lime treated expansive clay and there on the values reduced with further addition.
f) The present study concluded that problematic expansive clay was improved with a sustainable solution by reusing the waste materials giving a dual advantage.

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