RESEARCHERID
THOMSON REUTERS

[I-CONCEPTS-18] ISSN 2348 – 8034
Impact Factor- 5.070

GLOBAL JOURNAL OF ENGINEERING SCIENCE AND RESEARCHES

A STUDY ON OMC AND MDD VARIATIONS IN BLACK COTTON SOIL WITH ADDITIVES

Dr. T.L. Ramadasu[*1], Dr. N. Darga Kumar[2] & Dr. K. Suresh[3]

[*1]Professor, Department of Civil Engineering, CMR Technical Campus, Kandlakoya (V), Medchal (M&D), Hyderabad-501 401, T.S. India

[2]Associate Professor & HOD, Department of Civil Engineering, JNTUH College of Engineering, Manthani, T.S, India.

[3]Professor and Head Department of Civil Engineering CMR College of Engineering & Technology Medchal Road, Hyderabad, 501 401 Telangana INDIA

ABSTRACT

This paper discusses the effect of flyash, stone dust and lime on the compaction properties of black cotton soil. Soil stabilization is the process by which engineering properties of black cotton soils can be improved. It can be done by practicing controlled compaction in-situ, proportioning of admixtures appropriately so as to obtain optimal conditions of soil improvement. Infrastructure projects such as highways, railways, water reservoirs; reclamation sites require earth material in very large quantities. In many situations, where swelling soils or black cotton soils are found, the engineers prefer to start construction after the stabilization of in-situ difficult soil. Most of the instances, to avoid the excess expenses, locally available stone dust, lime and fly ash can be used for soil stabilization. From the results, it is noticed that 4% lime addition to the clay along with fly ash and stone dust has shown improvement in compaction characteristics. There is an increase in maximum dry density and decrease in optimum moisture content which are the desirable properties for stable and durable ground.

Keywords: *Black cotton soil, stabilization, flyash, lime, stone dust.*

I. INTRODUCTION

Infrastructure development has necessitated construction of various projects such as highways, airports seaports and residential buildings. There is a need to identify better soil conditions for proper safety consideration of all these projects. Expansive soils are more problematic for construction and are predominantly available in majority places in Andhra Pradesh, India. These soils undergo swelling and shrinkage as the moisture content changes observed in it. Due to high swelling and shrinkage, these soils pose lot of problems to the structures found on them. Stabilization is the process of improving the properties of soil by changing its gradation. Two or more types of natural soils are mixed to obtain a composite material which is of superior to any of its components. To achieve the desired grading, sometimes the soils with coarser particles are added or the soils with finer particles are removed. The blended soil possesses both internal friction and cohesion. When properly placed and compacted, the blended material becomes stable and also possesses higher load carrying capacity. Seasonal moisture variations bring about volume changes in expansive soils (Hausmann, 1990). Continued efforts are being made all over the world to devise ways and means to solve the problems due to expansive soils. Several measures such as application of adequate surcharge load, pre-wetting, moisture control, CNS layer technique (Katti, 1979). Chemical stabilization (Snethen *et. al*, 1979; Ramana Murthy, 1998) was suggested to alleviate the problems posed by expansive soils. Chemical modification by adding lime has been in practice since two decades (Ramna Sastry *et. al*, 1986). However, these and many other techniques are successful only to a partial extent and hence the attempts to devise better techniques are still going on. In the present work, an attempt is made to understand the effect of Flyash, Stone dust and Lime on the behavior of expansive soil collected from Amalapuram in Andhra Pradesh. The variation of compaction properties of expansive soil are presented and discussed.

ISSN 2348 – 8034
Impact Factor- 5.070

II. EXPERIMENTAL INVESTIGATIONS

2.1. Material Used

2.1.1. Soil

Black cotton soil is collected from Amalapuram in Andhra Pradesh. Black cotton/expansive/swelling soil is collected from the respective locality at a depth of about 1m from the ground level after removing all the vegetation matter. Soil is collected were air dried and pulverized and stored in airtight bags in the laboratory. The basic properties of the soils are presented in Table 1.

Table 1: Properties of Soil

Sl. No.	Property	Soil
1	Liquid Limit (%)	98
2	OMC (%)	26
3	MDD (kN/m^3)	16
4	UCS (kPa)	80
5	DFSI (%)	180
6	Soaked CBR (%)	1.5
7	IS Classification	CH

2.1.2. Flyash:

Maximum dry density, MDD=14 kN/m^3; Optimum moisture content, OMC = 18%; Liquid limit, W_L=30%; and soaked CBR=6%.

2.1.3. Stone dust:

Maximum dry density, MDD = 19 kN/m^3; Optimum moisture content, OMC = 6.8%; and Soaked CBR= 10 %.

2.1.4. Lime:

Commercial lime used in this study.

2.2. Tests Conducted

Heavy compaction test was carried out according to IS: 2720(Part 8)-1983 and the controlled conditions as per the standard procedures given in the respective codes of Indian Standard.

III. GENERAL

Compaction of soil is the mechanical process whereby the soil strength can be achieved in a desired level to suit the requirements of foundation safety. Compaction characteristics such as optimum moisture content (OMC) and maximum dry density (MDD) are the important parameters for a particular clayey soil to be stabilized. In the present study various admixtures of different proportions are admixed to the clayey soil and heavy compaction tests were conducted to understand the behavior of soils when subjected to compaction also the OMC and MDD variations with the varied proportions of admixtures. The admixtures used are FA, Lime, SD and combinations of mixtures FA+lime, FA+SD, SD+lime. The proportions of FA and SD used in the study are 0%, 10%, 15%, 20%, 25%, 30%, 40% and 50%. The proportions of lime used are 0%, 2%, 4%, 6%, 8% and 10%. For the FA+SD combination, the proportions used are 0%FA+0%SD, 5%FA+5%SD, 10%FA+10%SD, 15% FA+15% SD, 20%FA+20%SD and 25%FA+25%SD. The combination of FA+Lime proportions used are 0% FA+0% Lime, 5% FA+4% Lime, 10% FA+4%Lime, 15%FA +4% Lime, 20% FA+4% Lime and 25% FA+ 4%Lime. Similarly for the combination of SD+Lime the proportions used are 0%SD+0% Lime, 5% SD +4% Lime, 10% SD + 4% Lime, 15% SD + 4% Lime, 20% SD+4 %Lime and 25% SD + 4% Lime. The dry density-water content relationships, OMC and MDD variations obtained from the laboratory testing for the above admixtures and combinations are presented in the below sections.

ISSN 2348 – 8034
Impact Factor- 5.070

3.1 Dry Density-Water Content Relationship Curves

The curves explaining relationship between dry density - water content under heavy compaction are presented in Figs.1 to 6 for the admixtures of FA, Lime, SD and combinations of mixtures FA+lime, FA+SD, SD+lime and for the soil. Fig. 1 present the compaction curves for FA treated soil respectively. From the figure, it can be observed that there is a rigid behavior in the FA treated soils compacted at the water contents below the OMC. After the OMC further addition moisture causing the drastic falls in the dry density. As the % FA increases from 0 to 50, the OMC observed in the figure is shifting towards left. Also the dry density of FA treated soils is moving upwards as compared to untreated soil. The range of OMC is varying from 17 to 26% in the figure representing for soil for the FA proportions of 0 to 50%. The MDD values are ranging between 15.5 to 18 kN/m^3 for the soil and the FA proportions of 0 to 50%. Decrease in moisture content and improvement in dry density are the desirable properties of a soil to be chosen for a construction to avoid the adverse effects of the soil.

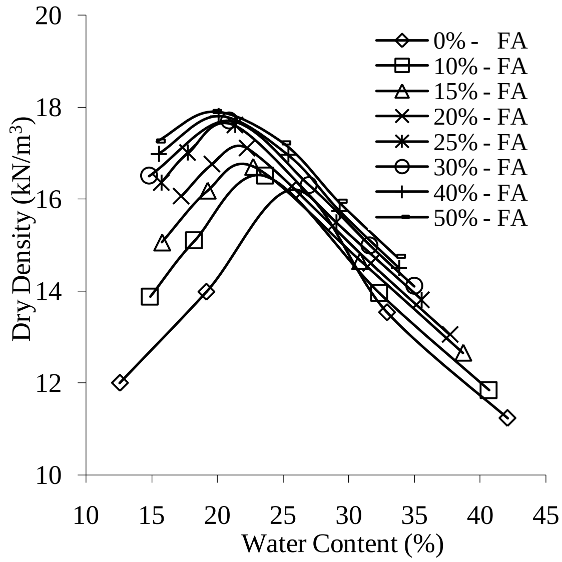

Fig.1 Influence of fly ash (FA) on dry density – water content relation curves of soil

Fig. 2 presents the compaction curves for lime treated soil. From the figure, it can be observed that there is a gradual increase in the dry density as the water content increases up to OMC, thereafter further addition of lime causing reduction in dry density rapidly. It is further noticed that as the % lime increases from 0 to 10%, there is an increase in the OMC. As the % lime increases from 0 to 10, the OMC observed in the three figures is shifting towards right. Also the dry density of lime treated soils is moving upwards as compared to untreated soil. The range of OMC of lime treated soil is varying from 23 to 27% for the lime proportions of 0 to 10%. The MDD values are ranging between 15.5 to 18 kN/m^3 for soil. Increase in moisture content with the addition of lime can be attributed that the formation of water (H_2O) in the chemical reaction. Though there is a marginal increase in the dry density of lime treated soils, the adverse behavior of soil can be very well controlled and the soil – lime mixture after the reaction gives the stable soil matrix.

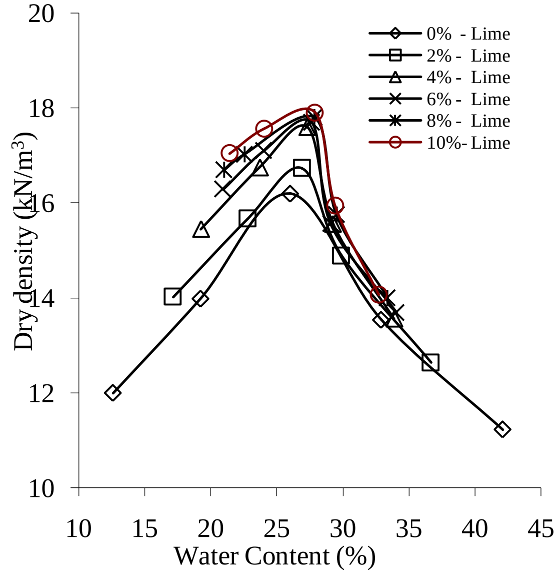

Fig.2 Influence of lime on dry density – water content relation curves of soil

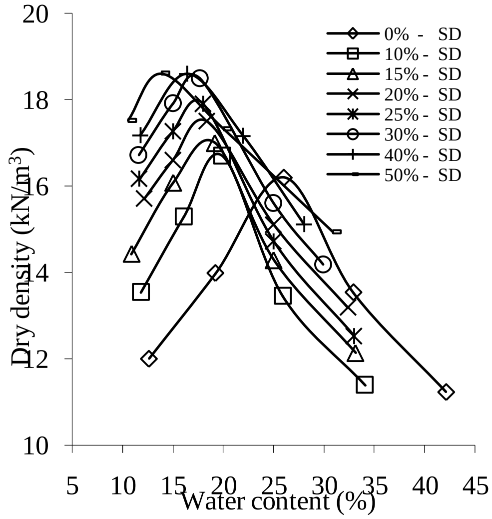

Fig.3 Influence of stone dust (SD) on dry density – water content relation curves of soil-A

Fig. 3 present the compaction curves for SD treated soil. From the figure, it can be observed that there is a gradual increase in the dry density as the water content increases up to OMC, thereafter further addition of SD causing reduction in dry density rapidly. It is further noticed that as the % SD increases from 0 to 50%, there is a decrease in the OMC. As the % SD increases from 0 to 50, the OMC observed in the three figures is shifting towards left. Also the dry density of SD treated soils is moving upwards as compared to untreated soil. The range of OMC of SD treated soil is varying from 11 to 26% for the SD proportions of 0 to 50%. The MDD values are ranging between 15.5 to 19 kN/m^3 for the soil. Decrease in OMC or shifting of OMC towards the left of the axis as the % SD increases can be attributed that the reduction in plasticity of soil. There is a good improvement in the dry density with the % SD addition to the clayey soil

ISSN 2348 – 8034
Impact Factor- 5.070

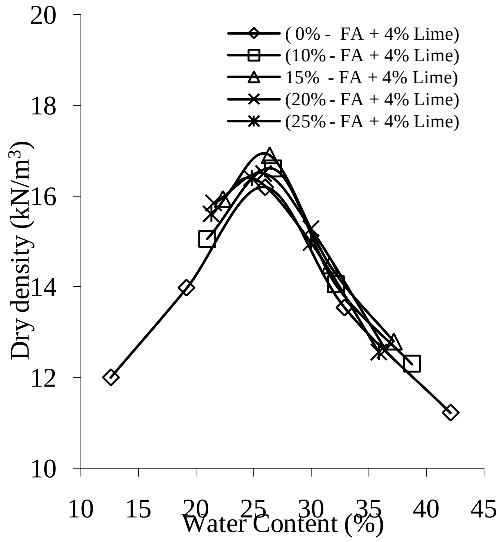

Fig.4 Influence of combination of fly ash (FA) and lime on dry density – water content relation curves of soil

Fig.4 presents the compaction curves for combination of FA and lime treated soil. For the FA proportions of 5%, 10%, 15%, 20% and 25%, the optimum lime of 4% is used as combination admixture. From the compaction results presented in the three figures, it can be observed that there is a marginal increase in the dry density for the water content of below OMC and it is also showing little rigidity in accommodating the soil in the compaction mould. Further it is noticed that beyond the OMC for any small increase in the water content causing drastic reduction in the dry density.

It is further noticed that as the 4% lime added FA proportion increases from 5 to 25%, the change in OMC observed is marginal and it is found to be varying from 24% to 26%. As the 4% lime added FA proportions increases from 5 to 25%, the OMC observed in the figure is not shifting in a wider range, but little shifting towards right of the axis is noticed. The range of OMC of soil treated at 4% lime added FA proportions of 5 to 25% is varying from 24% to 26%. For the same combinations of admixtures and soil the MDD values are ranging between 15.5 to 16.8 kN/m^3. Increase in OMC in the narrow range or shifting of OMC towards the right of the axis as the % combination of admixture increases can be attributed that the development of water molecules due to presence of lime in the chemical reaction. This combination of admixture is not encouraging in terms of the dry density improvement of clayey soils.

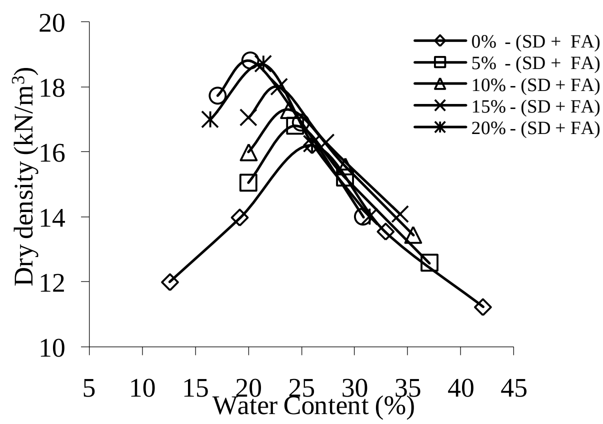

Fig.5 Influence of combination of fly ash (FA) and stone dust (SD) on dry density – water content relation curves of soil

ISSN 2348 – 8034
Impact Factor- 5.070

Fig..5 presents the compaction curves for combination of FA and SD treated soil. For the combination of FA + SD the proportions used in the testing are 0%+0%, 5%+5%, 10%+10%, 15%+15%, 20%+20%, and 25%+25%. From the compaction results presented in the figure, it can be observed that for the water content below the OMC there is a marginal increase in the dry density and it is also showing little rigidity in accommodating the soil in the compaction mould. Further it is noticed that beyond the OMC for any small increase in the water content causing drastic reduction in the dry density.

In all the three figures, it is seen that the OMC values are shifting towards left of the axis and the dry densities are moving upwards from the bottom axis. It is further noticed that as the %FA+%SD proportion increases from 0%+0% to 25%+25%, there is a considerable decrease in the OMC and also considerable increase in the MDD. The variation in OMC for the above admixture combination observed is ranging between 19% to 26% and also the dry density corresponding to OMC is varying from 15.5 to 18.5 kN/m^3 for the clayey soil A. In the figure, particularly it is noticed that the dry densities are almost similar for the FA+SD proportions of 20%+20% and 25%+25%. Decrease in the OMC may be due to the reduction in plasticity behavior of clayey soils. Depending upon the availability of FA and SD locally, the combination of FA and SD up to 25%+25% is suggestible for the construction of civil engineering works. It enhances the dry density of the clayey soils as well as controls the plasticity characteristics.

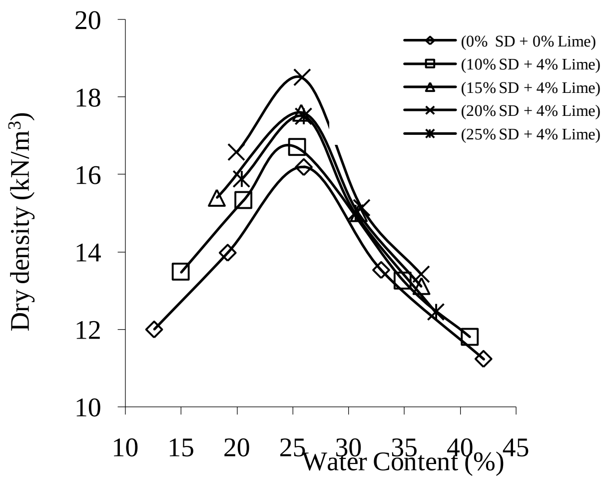

Fig.6 Influence of combination of lime and stone dust (SD) on dry density – water content relation curves of soil

Fig.6 presents the compaction curves for combination of SD and lime treated soil . For the FA proportions of 5%, 10%, 15%, 20% and 25%, the optimum lime of 4% is used as combination admixture, i.e., %SD+%lime proportions of 0%+0%, 5%+4%, 10%+4%, 15%+4%, 20%+4%, and 25%+4%. From the compaction results presented in the figure, it can be seen that there is a marginal increase in the dry density for the water content of below OMC. Further it is noticed that beyond the OMC for any small increase in the water content causing drastic reduction in the dry density. It is further noticed that as the 4% lime added SD proportion increases from 5 to 25%, the change in OMC observed is marginal and it is found to be varying from 24% to 26%. As the 4% lime added SD proportions increases from 5 to 25%, the OMC observed in the three figures is not shifting in a wider range, but little shifting towards right of the axis is noticed. The range of OMC of soil treated at 4% lime added SD proportions of 5 to 25% is varying from 24% to 26%. For the same combinations of admixtures and soil, the MDD values are ranging between 15.5 to 18.5 kN/m^3. Increase in OMC in the narrow range or shifting of OMC towards the right of the axis as the % combination of admixture increases can be attributed that the development of water molecules due to the presence of lime in the chemical reaction. This combination of admixture is encouraging in terms of improvement of MDD of clayey soils. 4% lime and 25% SD can be treated as effective admixture in soil stabilization when field practice needs soil stabilization.

 ISSN 2348 – 8034
Impact Factor- 5.070

3.2 Influence of Admixtures on OMC

The influence of admixtures such as FA, Lime, SD and combinations of admixtures FA+lime, FA+SD, SD+lime on OMC of the soil is brought out in the present study and the results are presented in Figs.7 to 12. Fig.7 presents the OMC variation with the different % of FA. From this figure, it can be seen that as the % FA increases from 0 to 50%, the OMC of the soil is reducing linearly. The order of reduction in OMC at 50% FA addition to the soil is found to be 25%, 24% and 28% respectively as compared to the OMC of the untreated soils. FA consists of silt content and hence upon addition of FA to the clayey soil has resulted in reduction in OMC. Fig.8 presents the OMC variation with the different % of lime. From this figure, it can be seen that as the % of lime increases from 0 to 10%, the OMC of the soil is increasing linearly. The increase in OMC observed for the soil A is marginal even at the lime content of 10%. The order of increase in OMC at 10% lime as compared to the untreated soil is found to be 6%, 8% and 55% respectively.

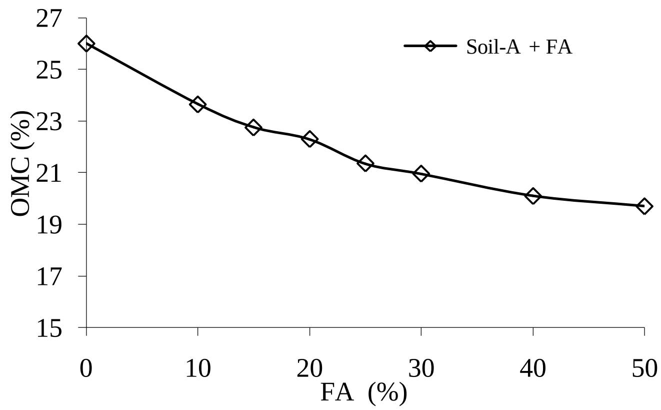

Fig.7 Influence of fly ash (FA) on OMC

This increase in OMC can be attributed that the formation of H_2O in the chemical reaction of soil and lime in presence of moisture.

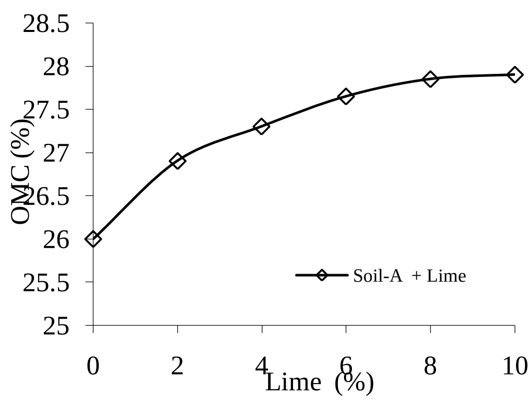

Fig.8 Influence of lime on OMC

Fig.9 presents the OMC variation with the different % of SD. From this figure, it can be seen that as the % SD increases from 0 to 50%, the OMC of the soil A is reducing linearly. The order of reduction in OMC at 50% SD addition to the soil is found to be 44%, 50% and 52% respectively as compared to the OMC of the untreated soils. SD consists of more % of silt content and having no plasticity and hence upon addition of SD to the clayey soil caused the low plastic soil mix. It can be attributed that due to the domination of non plastic SD in the soil mixture, the % reduction in OMC of the clayey soils is drastic.

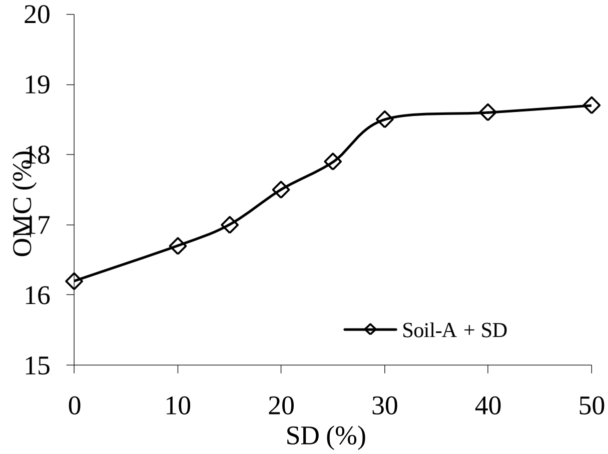

Fig.9 Influence of stone dust (SD) on OMC

Fig.10 presents the OMC variation with the combination of FA and 4% optimum lime content. The FA+lime proportions used are 0%+0%, 5%+4%, 10%+4%, 15%+4%, 20%+4%, and 25%+4%. From this figure, it can be seen that as the % FA+lime content increases in the above proportions, the OMC of the soil is increasing linearly. Up to about 10%FA+4%lime, there is no much change in the OMC of the soil. Overall it is noticed that there is a little increase in the OMC at the admixture proportion of 25%FA+4%lime for soil and this increase is found to be 5% and 8% respectively. Though there is FA content in the soil mixture, due to the presence of lime the changes in OMC levels of soils found to be marginal.

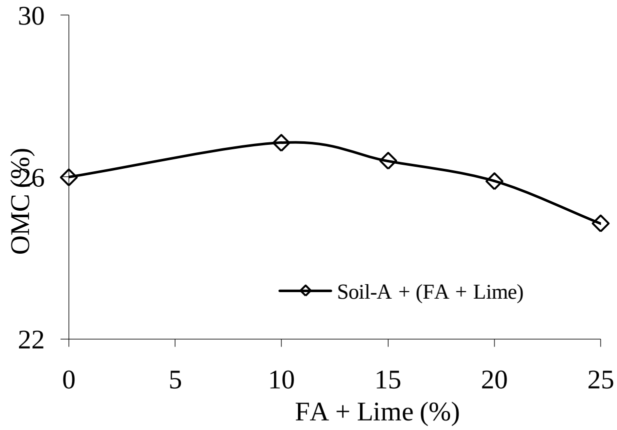

Fig.10 Influence of combination of fly ash (FA) and lime on OMC

Fig.11 presents the OMC variation with the combination of SD and 4% optimum lime content. The SD+lime proportions used are 0%+0%, 5%+4%, 10%+4%, 15%+4%, 20%+4%, and 25%+4%. From this figure, it can be seen that as the % SD+lime content increases in the above proportions, the OMC of the soil is increasing linearly. Up to about 10%SD+4%lime, there is no much change in the OMC of the soil. Overall it is noticed that there is a little increase in the OMC at the admixture proportion of 25%SD+4%lime for soil and this increase is found to be 4% and 1% respectively. Though there is SD content in the soil mixture, due to the presence of lime the changes in OMC levels of soils found to be marginal.

ISSN 2348 – 8034
Impact Factor- 5.070

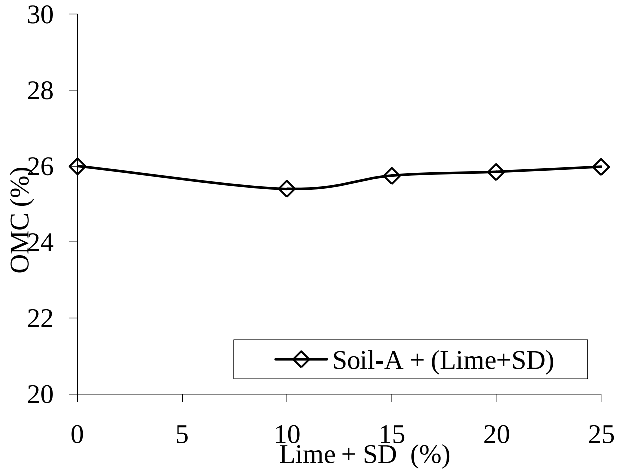

Fig.11 Influence of combination of lime and stone dust (SD) on OMC

Fig.12 presents the OMC variation with the combination of FA+SD. The FA+SD proportions used are 0%+0%, 5%+5%, 10%+10%, 15%+15%, 20%+20%, and 25%+25%. From this figure, it can be seen that as the % FA+%SD content increases in the above proportions, the OMC of the soil is reducing linearly. It is noticed that there is a considerable reduction in the OMC at the admixture proportion of 25%FA +25%SD for the soil and this decrease is found to be 21% as compared to the untreated soils. Due to the domination of non plastic FA and SD combinations in the soils, the OMC has reduced considerably.

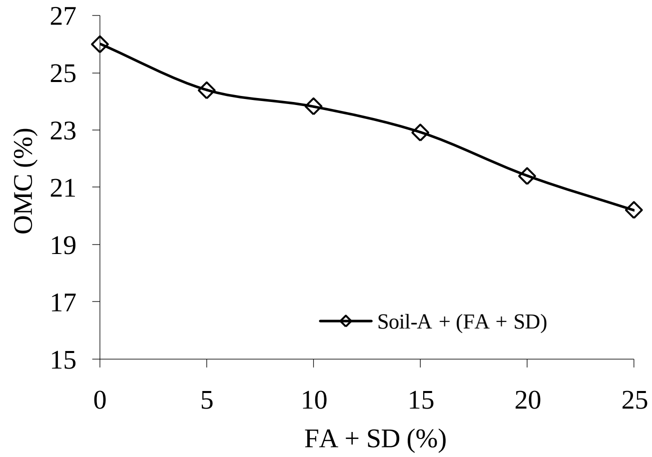

Fig.12 Influence of combination of fly ash (FA) and stone dust (SD) on OMC

3.3 Influence of Admixtures on MDD

The influence of admixtures such as FA, Lime, SD and combinations of admixtures FA+lime, FA+SD, SD+lime on MDD of the three soils A, B and W are brought out in the present study and the results are presented in Figs.13 to 18. Fig.13 presents the MDD variation with the different % of FA. From this figure, it can be seen that as the % FA increases from 0 to 50%, the MDD of the soil is increasing linearly up to about 30% FA and thereafter the increase MDD is found to be marginal. The order of increase in MDD at 50% FA addition to the soil is found to be 11.5% as compared to the MDD of the untreated soils. FA consists of silt content and hence upon addition of FA to the clayey soil has resulted in marginal improvement in the dry density of clayey soil.

ISSN 2348 – 8034
Impact Factor- 5.070

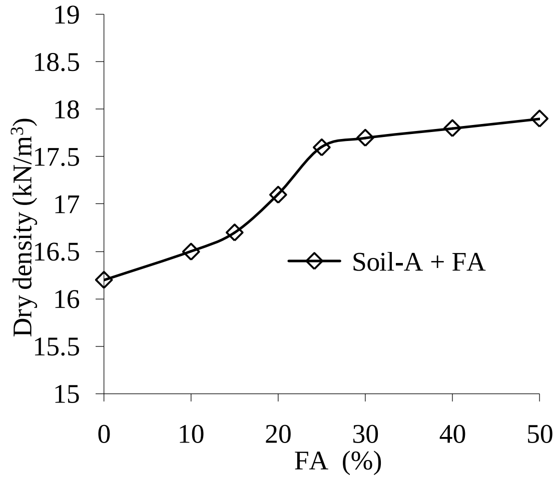

Fig.13 Influence of fly ash (FA) on MDD

Fig.14 presents the MDD variation with the different % of lime. From this figure, it can be seen that as the % of lime increases from 0 to 10%, the MDD of the soil is increasing linearly up to about 4% lime and thereafter further addition of lime causing marginal increase in the MDD. The order of increase in the MDD at 4% lime as compared to the untreated soil is found to be 13%. Similarly the order of increase in MDD at 10% lime as compared to the untreated soil is found to be 14% respectively.

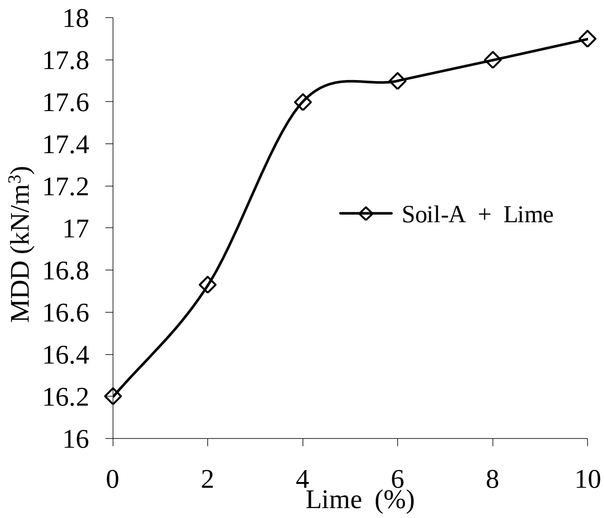

Fig.14 Influence of lime on MDD

Fig.15 presents the MDD variation with the different % of SD. From this figure, it can be seen that as the % SD increases from 0 to 50%, the MDD of the soil is increasing linearly. The linear increase in the MDD can be observed up to a SD proportion of 30% and thereafter almost no increase in the MDD can be seen. The order of increase in the MDD at 30% SD addition to the three soil is found to be 15% as compared to the MDD of the untreated soils. Similarly the order of increase in the MDD at 50% SD addition to the soil is found to be 16% respectively as compared to the MDD of the untreated soils. SD consists of more % of silt content and having more specific gravity compared to the clayey soil, and hence upon addition of SD to the clayey soil caused the marginal increase in the MDD of clayey soil.

ISSN 2348 – 8034
Impact Factor- 5.070

Fig.16 presents the MDD variation with the combination of FA and 4% optimum lime content. The FA+lime proportions used are 0%+0%, 5%+4%, 10%+4%, 15%+4%, 20%+4%, and 25%+4%. From this figure, it can be seen that as the % FA+lime content increases in the above proportions, the MDD of the soil A is increasing linearly. Up to about 15%FA+4%lime, there is almost linear and marginal increase in the MDD for soil and this increase can be quantified as 4%, but for the admixture proportion of 25%FA+4% lime, the increase in the MDD of soil 11% respectively.

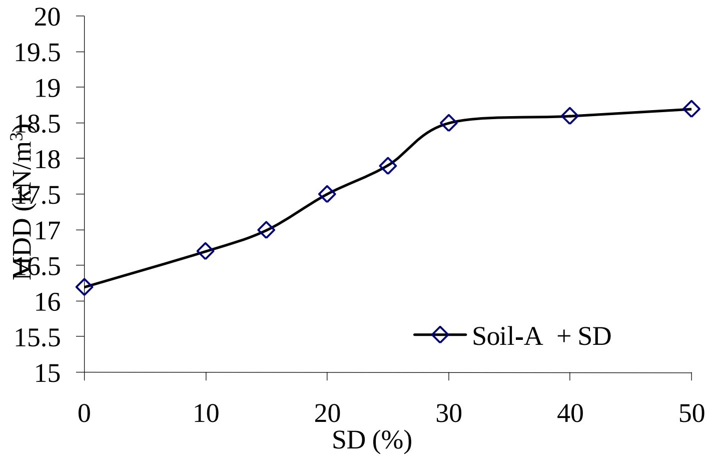

Fig.15 Influence of stone dust on MDD

Overall it is noticed that there is a little increase in the MDD at the admixture proportion of 25%FA+4%lime for soil . The FA and the lime both are light weight materials and hence the MDD values observed are increased

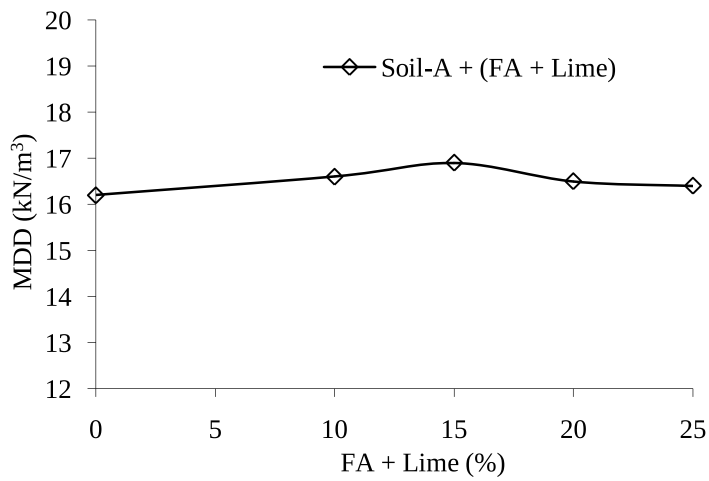

Fig.16 Influence of combination of fly ash (FA) and lime on MDD

Fig.17 presents the MDD variation with the combination of SD and 4% optimum lime content. The SD+lime proportions used are 0%+0%, 5%+4%, 10%+4%, 15%+4%, 20%+4%, and 25%+4%. From this figure, it can be seen that as the % SD+lime content increases in the above proportions, the MDD of the soil is increasing linearly. Up to about 15%SD+4%lime, there is linear increase in the MDD and this increase can be quantified as 6.5% for soil A. At 25%SD+4%lime, the increase in the MDD can be noted as 7% for the soil. Though there is SD content in the soil mixture, due to the presence of lime the changes in MDD levels of soils found to be marginal.

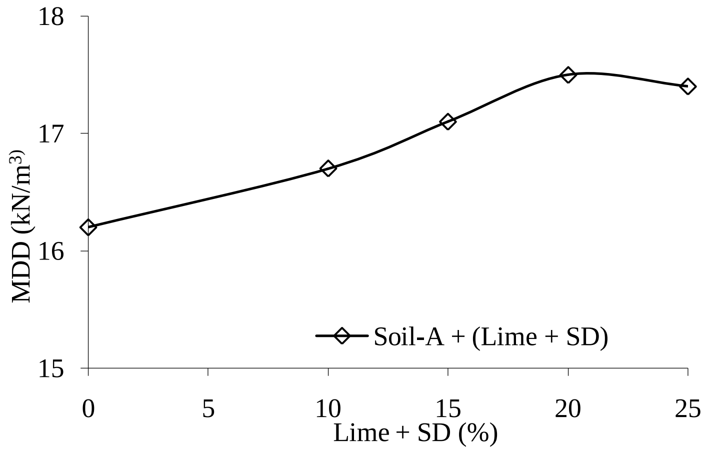

Fig.17 Influence of combination of lime and stone dust (SD) on MDD

Fig.18 presents the MDD variation with the combination of FA+SD. The FA+SD proportions used are 0%+0%, 5%+5%, 10%+10%, 15%+15%, 20%+20%, and 25%+25%. From this figure, it can be seen that as the % FA+%SD content increases in the above proportions, the MDD of the soils is increasing linearly up to 20%FA+20%SD admixture proportion and thereafter the increase in the MDD is negligible. It is noticed that there is a reasonable increase in the MDD at the admixture proportion of 25%FA +25%SD for the soil A and this increase is found to be 16.5% as compared to the untreated soils. Due to the domination of non plastic FA and SD combinations in the soils, the MDD has increased considerably.

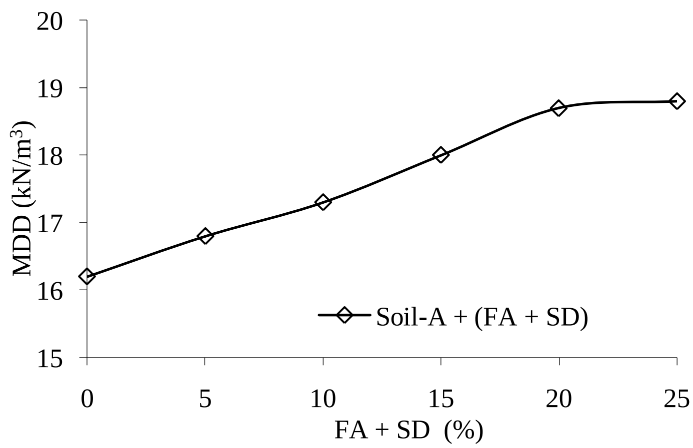

Fig.18 Influence of combination of fly ash (FA) and stone dust (SD) on MDD

IV. CONCLUSIONS

1. The order of reduction in OMC at 50% FA addition to the soil A is found to be 25% as compared to the OMC of the untreated soil. At the 10% lime the reduction in OMC noted as 6% at 50% SD addition to the soil reduction in OMC noted as 44%.
2. At the admixture proportion of 25%SD+4%lime for soil and the increase in OMC is found to be 4%. It is noticed that there is a considerable reduction in the OMC at the admixture proportion of 25%FA +25%SD for the soil and its decrease is found to be 21%.
3. The order of increase in the MDD at 50% FA addition to the soil A is found to be 11.5% as compared to the MDD of the untreated soils. At 4% lime the increase in MDD noted is 13%. Similarly the order of increase in the MDD at 10% lime as compared to the untreated soil is found to be 14%.

ISSN 2348 – 8034
Impact Factor- 5.070

4. At 25%SD+4%lime, the increase in the MDD can be noted as 7%, for the soil. At the admixture proportion of 25%FA +25%SD the increase in the MDD for the soil is noted as 16.5% respectively as compared to the untreated soils.

REFERENCES

1. *Ajith, K., (1993), "Modification of Red Soil by Using Lime and Fly Ash as Admixtures", M.Tech Thesis, University of Kerala, Trivandrum. Construction in India and its Cost Effectiveness", Electronic Journal of Goetech Engineering.*
2. *Frydman (1977). Stabilization of heavy clay with potassium chloride. Journal of Geotechnical Engineering, 8, 95-107.*
3. *Gaulkar, M. P., (1999), "Construction of Roads in Black Cotton Soil", Indian Highways, New Delhi.*
4. *Katti, R.K. (1979). Search for solutions to problems in Black cotton soils, First IGS Annual Lecture, Indian Geotechnical Journal, Vol.9, pp 1-8.*
5. *Little, D.N. (1996), "Hand book for stabilization of pavement, sub-grades and base courses with lime". Hunt publishing company, Iowa, U.S.A*
6. *Petry, TM & Little, DN 2002, „Review of Stabilization of Clays and Expansive Soils in Pavements and Lightly Loaded Structures - History, Practice, and Future', Journal of Materials in Civil Engineering, Nov/Dec, pp. 447-460*
7. *Rogers, C.D. and Glendinning, S., (2000), "Lime Requirement for Stabilization", Transportation Research Record, No. 1721, Transportation Research Board, National Research Council, Washington, D.C., pp. 9-18*
8. *Ramana Murthy, V. (1998). Study on swell pressure and method of controlling swell of expansive soil, Ph.D thesis, NIT, Warangal.*
9. *Ramana Sastry et. al (1993). "Strength characteristics of a plain and fibre reinforced lime treated expansive soils", IRC Highway research bulletin No. 49*
10. *Scott M Mackiewicz and E Glen Ferguson (2005). Stabilisation of soil with self cementing coal ashes. World coasl ash (WOCA) Conference – April 11-15, Lexington, KY, USA, pp.1-17.*
11. *Singh D.V and Murthy (1998), "Flyash in India-Problems and Possibilities". Proceedings of experience sharing meet on use of flyash in roads and embankments, CRRI, New Delhi, pp-5-20.*
12. *Soosan et. al (2005) "Utilization of quarry dust to improve the geotechnical properties of soils in highway construction". Geotechnical testing journal, 391-400.*
13. *Spangler, M.G., and Handy, R.L. (1982). Soil Engineering, 4th Edn., Harper and Row Publishers, New York, U.S.A.*
14. *Venkatabor Rad, G. (1977), Physico-chemical governing the plasticity behavior of soils. Journal of Indian Geotechnical, 7, 261-282.*
15. *Wayne, A.C., Mohamed, A.O., and El-Fatih, M.A., (1984), "Construction on Expansive Soils in Sudan", Journal of Construction Engineering and Management, Vol. 110, pp. 359-374.*