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Suitability of Industrial Waste Admixed Expansive Clays for Geotechnical Engineering Applications

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Abstract. Because of rapid industrialization and urbanization in developing countries like India, the disposal of solid wastes on land is becoming increasingly more. Considering the beneficial properties of these wastes, they may be utilized for many civil engineering applications, especially situations in which there is a scarcity of resource materials. Problematic soils are those having low bearing capacity, high compressibility, high swelling/shrinkage nature and as such they are not suitable for any geotechnical application. In order to overcome the disposal problem of solid waste on one side and stabilization of expansive clay on other side, experiments were conducted on expansive clays with different percentage of quarry dust (QD), marble powder waste (MPW), copper slag (CS), blast furnace slag (BFS) and tannery sludge (TS). Results revealed that the plasticity characteristics and percentage swell of clays decreased drastically with percentage of all wastes, except tannery sludge waste. The UCC strength progressively increased with the percentage of all wastes, except tannery sludge. The order of reduction in swell and increment of strength is CS >BFS >QD >MPW. Modifications in soils are attributed to the pozzolanic component present in the waste.

Keywords: *Soil stabilization; expansive soil; waste utilization.*

1. Introduction

Generation of waste from variety of sources, apart from causing environmental degradation, it is also posing the problem of scarcity of land for various civil engineering applications. A proper methodical utilization of waste will greatly solve the burden of waste disposal on to the landfills and also sustainable development is encouraged. Mobasher et al (1996) studied the effect of copper slag on the hydration of blended cementitious mixtures. Copper slag is shown to significantly increase the compressive strength of concrete mixtures. Pozzolonic reactions were verified by means of XRD techniques. They evaluated the use of lime as a hydration activator and shown to improve the rate of strength gain. They obtained the results which indicated the tremendous potential of copper slag as a mineral admixture.

Sobha Cyrus and Roy Thomas (1996) studied the effect of tannery waste on the behaviour of fine grained soil and they observed drastic changes in both index and engineering properties of soil. Asavapisit et al (2001) studied the feasibility of using pozzolanic wastes as mineral additives to improve strength of the compacted soil-lime admixtures. Furnace slag and pulverized fuel ash were added to the clayey soil at 0, 10, and 20% by weight whereas lime was used to induce pozzolanic reactions at the concentration of 0, 5, and 10% by weight. It was observed that the strength of the compacted soils increased with increasing mineral additives and lime concentrations.

In this paper an attempt is made to study the effect of solid wastes namely, quarry dust, marble powder dust, copper slag, blast furnace slag and tannery sludge on the plasticity characteristics, swelling and unconfined compressive strength with increasing percentage of wastes and the results are analyzed and discussed.

2. Materials

In order to evaluate the possibilities of large scale utilization of solid wastes for the stabilization of problematic clays, natural soil was collected from Chennai, Tamil Nadu at a depth of 2.0 m. The natural soil is named as soil NS, whose liquid limit is 62%. Apart from natural soil, commercial soil (Bentonite)collected from local market was also used in the present study for the sake of comparison. The bentonite is pure clay material enriched with montmorillonite (LL = 242%) mineral. The physical proprieties of soils are shown in table 1.

The solid wastes such as Tannery Sludge, Quarry Dust, Marble Powder Dust, Blast Furnace Slag and Copper Slag were selected from nearby industrial areas for the present investigation. Tannery sludge is a residue from chrome tanning process, was collected from common effluent treatment plant, Pallavaram, Chennai, Tamil Nadu and whereas quarry dust and marble powder waste were collected from nearby Chennai quarry site and marble industry respectively. Copper slag which is a byproduct of copper manufacturing unit, and it was collected from Sterlite Industries, Tuticorin, Tamil Nadu and blast furnace slag (a byproduct of Cast –iron products) was collected from Vizag steel plant, Vizag, Andhra Pradesh. Table 2, 3 and 4 show the chemical constituents of tannery sludge, quarry dust, marble powder dust, blast furnace slag and copper slag. Table 5 and 6 show the physical properties of wastes. Among the waste selected, the specific gravity of copper slag is as high as 3.65 and tannery sludge is having the lowest value of 1.8.

Table 1. Physical Properties of Soils Used

Soil Type	NS	Bentonite
Specific gravity	2.75	2.77
LL %	62	242
PL %	37	56
PI %	25	186
SL %	11	13
FSI %	70	250
$\gamma_{d\ max}$ kN / m^3	15.7	12.8
OMC %	28	33
Plasticity Classification	CH	CVH
Swell Classification	High	Very high

Table 2. Chemical Constituents of Tannery Sludge

Description	Values
pH	8-11
Dry Matter Content %	38-42
Total Organic Matter %	28.4
Total N, %	0.5
Total P_2O_5, %	0.1
Total K_2O, %	0.0
Total $CaCO_3$, %	67.4
Total Cr, %	1.95

Table 3. Chemical Constituents of MPW and QD

Description of Constituents %	MPW	QD
Loss on ignition	41.54	0.47
Silica as SiO_2	3.63	63.63
Iron as Fe_2O_3	0.57	13.71
Aluminium as Al_2O_3	2.23	12.91
Titanium as TiO_2	NIL	0.38
Calcium as CaO	35.97	4.68
Magnesium as MgO	16.06	NIL
Sodium as Na_2O	NIL	2.87
Potassium as K_2O	NIL	1.35

Table 4. Chemical Constituents of CS and BFS

Description of Constituents %	CS	BFS
Copper	1.68	-
Iron as Fe_2O_3	53.1	0.56
Silican dioxide	34.29	36

Calcium as CaO	4.196	39
Alumina	3.124	10
Arsenic	0.127	Nil
Magnesium oxide	0.22	12
Cadmium oxide	0.019	Nil
Cobalt	0.0078	Nil
Manganese oxide	Nil	0.44
Sulphur dioxide	1.62	2.0

Table 5. Physical Properties of TS, MPW and QD

Properties	TS	MPW	QD
Specific gravity	1.8	2.75	2.52
Fines (%)	100	95	8
Sand size (%)	Nil	5	92
$\gamma_{d\ max}$, kN / m^3	7.2	15.9	20.4
OMC (%)	32	23	11.31
UCC strength(kN/m^2) at OMC	95	140	170

Table 6. Physical Properties of CS and BFS

Properties	CS	BFS
Specific gravity	3.65	2.36
Gravel size %	1.5	Nil
Sand size %	98.5	85
Silt size %	Nil	15
$\gamma_{d\ max}$, kN / m^3	21.3	18
OMC %	19	23
Angle of internal friction at OMC and $\gamma_{d\ max}$	44.6^0	45^0

3 Methods

Index tests such as liquid limit, plastic limit, shrinkage limit and free swell index tests were conducted on soils for varying % of solid wastes. Similarly, tests such as swell and UCC were conducted for both the soils with increasing percentages of wastes. Odeometer swelling test apparatus was used to study the swelling behaviour of soils with increasing percentage of solid waste using expanding volume method.

4 Results and Discussions

4.1 Influence of Solid Waste on Plasticity Characteristics of Soils

Figure 1 and 2 show the variation of plasticity index on liquid limit for NS and bentonite soils with varying % of waste. It can be seen that the soil of 'CH' type turns to 'CI' upon increasing % waste from 10 to 70 for bentonite soil and from 'CH' to 'CI' or 'CL' nature for NS. This variation in plasticity only indicates that addition of waste gradually reduces the plasticity characteristics and thus the soil becomes more suitable for engineering applications from unsuitability nature except for tannery sludge where addition of waste in soils increases the plasticity characteristics of clays. The down ward arrow marks in figure 1 shows the reduction in the plasticity characteristics upon addition of waste to natural soil and bentonite.

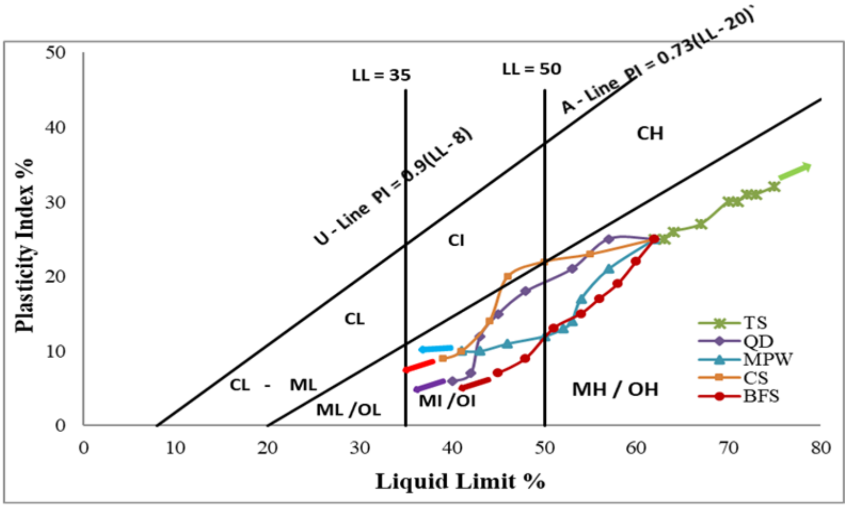

Fig 1. Influence of Solid Waste on PI of Soil – NS

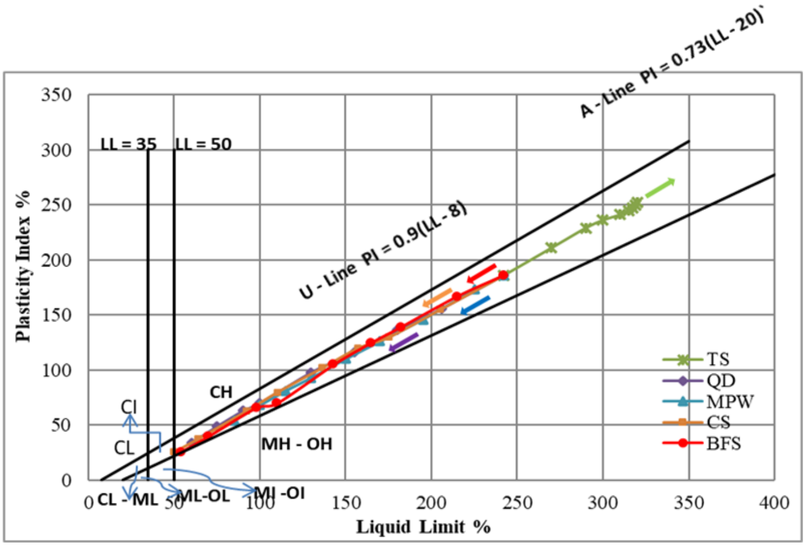

Fig 2. Influence of Solid Waste on PI of Bentonite

4.2 Influence of Solid Wastes on Shrinkage Limit

Except for soil-tannery sludge mix, the shrinkage limit increases with % of waste for both the soils. The variation of shrinkage limit is seen in figure 3 and 4. In general, higher the clay content, higher is the plasticity characteristics and such soils undergoes more shrinkage and thereby low shrinkage limit and vice – versa. However, in the case of soil-tannery sludge mix, there is a reduction in shrinkage limit value. The organic content in tannery sludge is 36 % and being so, water holding capacity of soil-tannery sludge mix increases with % of waste. However, for the other wastes such as QD, MPW, BFS and CS, the shrinkage limit increases considerably with % of waste in soils. The % increase in shrinkage limit ranges from 50 % to 163 % for soil-QD, 42 % to 163% for soil-MPW, 42% to 161% for soil-CS mix, while smaller percentage variation is found for natural soil-waste mix, higher (>100%) variation of shrinkage limit is noticed for bentonite-waste mix.

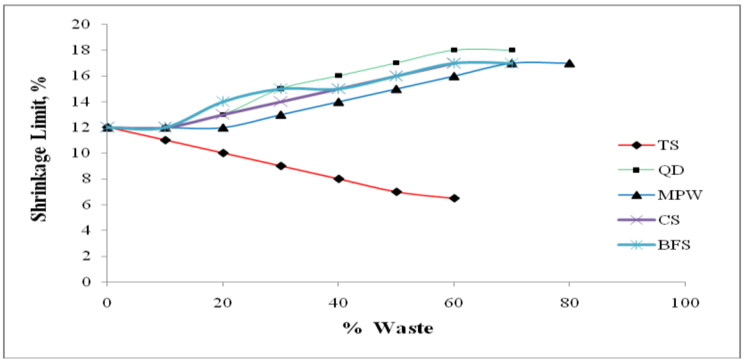

Fig 3. Influence of Solid Waste on Shrinkage Limit of Soil - NS

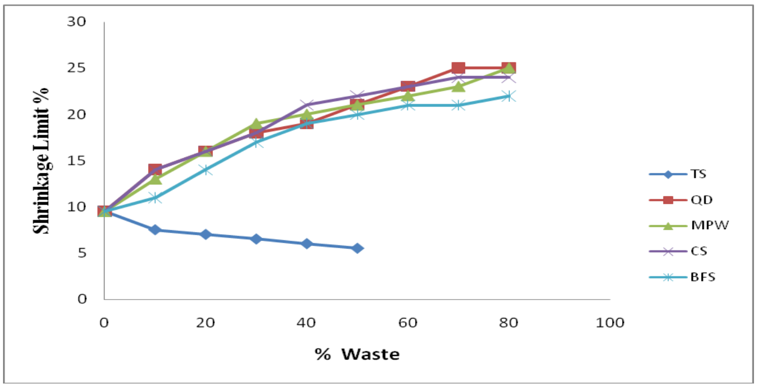

Fig 4. Influence of Solid Waste on Shrinkage Limit of Bentonite Soil

4.3 Influence of Solid Wastes on Swelling Characteristics of Clays

The percent swell values were calculated from time-swell curves for clay-solid waste mixture and presented in figure 5 and 6 with increasing % of solid waste for soils NS and bentonite. The % swell continuously decreased with solid waste for all the soils. The swell test for soil with increasing % of tannery waste was not conducted because, already free swell index was found to increase with % TS. The reduction in % swell is high for bentonite-CS mixture (60% to 70%). For natural soil NS, the % reduction in swell is 55%, 45 %, 60%, and 51% respectively for QD, MPW, CS and BFS corresponding to 70% of wastes. It is known that all the wastes are non-swelling material. Among the waste, the swell reduction is always high for CS > BFS > QD> MPW. Even though all the solid wastes are basically non-swelling nature, still the % reduction is not uniform for all the wastes. This is because, the CS, QD and BFS wastes alone have coarse sand fraction more than 85%, compared to MPW. As the size of coarser fraction increases, the swell reduction also increases proportionately.

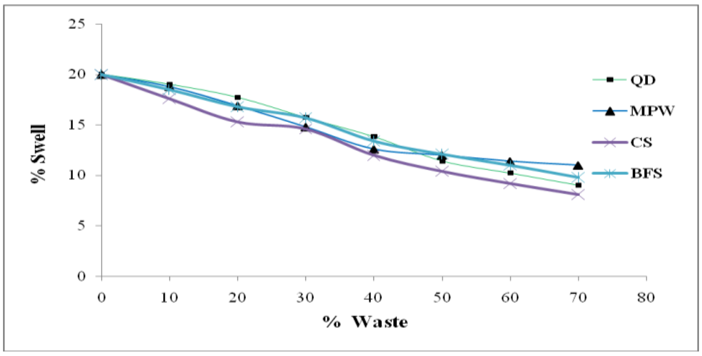

Fig 5. Influence of Solid Waste on % Swell of Clay - NS

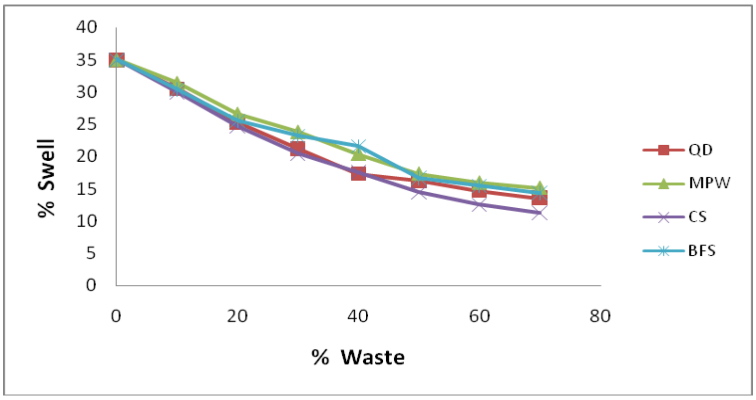

Fig 6. Influence of Solid Waste on % Swell of Bentonite

4.4 Influence of Solid Wastes on UCC Strength Clays

Corresponding to $\gamma_{d\ max}$ and OMC of soil-solid waste mix, the unconfined compressive strength tests of soils NS and bentonite with increasing percentage of TS, MPW, and QD alone were conducted wherever the soil-waste specimens were intact to have stable UCC specimens. Because of the granular nature of CS and BFS, UCC tests were not conducted with them. Figure 7 and 8 show the variation of UCC strength of soils with increasing % of TS, QD and MPW. As seen, there is a continuous decrease in UCC strength for both the soils with % TS. This variation is expected because of the presence of organic matter in the waste. The results thus clear that utilization of TS for improvement of problematic soils may not be beneficial with reference to strength as well as plasticity characteristics. The UCC strength increased continuously for all the types of soils with increasing % of quarry dust and marble powder. At any % of waste in soils, strength enhancement is considerable for quarry dust compared to marble powder waste. The % increase in strength is to a maximum of 49% corresponding to 60% of waste in NS. For bentonite, the maximum strength is with quarry dust for a strength variation from 90 kN /m^2 to 121 kN / m^2. The enhancement of strength upon addition of waste only implies that, addition of QD and MPW as high as 60% are beneficial for the improvement of clays.

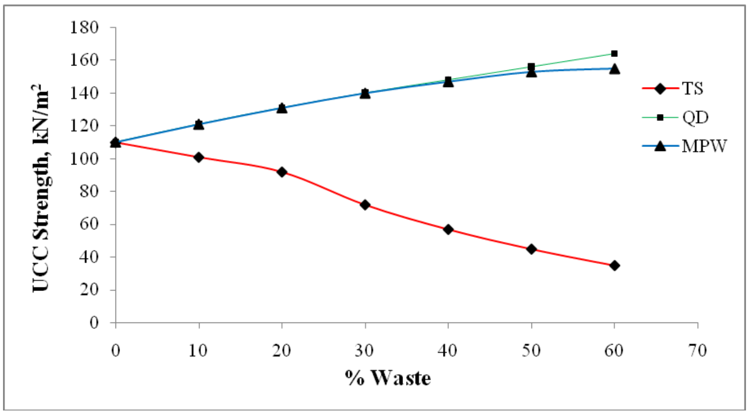

Fig 7. Influence of Solid Wastes on UCC Strength of Clay – NS

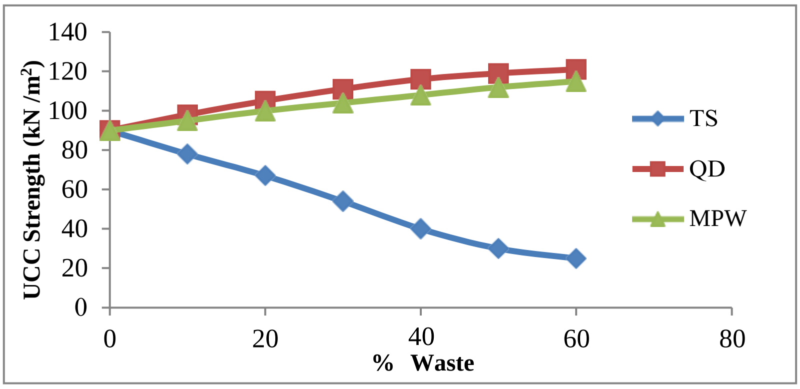

Fig 8. Influence of Solid Wastes on UCC Strength of Clay – Bentonite

5. Conclusion

Based on the analysis of test results of different percentage of quarry dust (QD), marble powder waste (MPW), copper slag (CS), blast furnace slag (BFS) and tannery sludge in natural soil and bentonite, the following conclusions are drawn.

1. The liquid and plastic limit decreases steeply with increasing % of all wastes except for soil-tannery waste wherein the trend is reverse. At any % waste, the order of reduction in plasticity characteristics of soil on the addition of waste is found to be function of decreasing % fines of virgin soil. On the other side, for the NS soil, the % reduction in liquid limit is 56% for soil-CS mix, 60% for soil-BFS mix, while for bentonite, the % reduction in liquid limit is 79% for soil-CS mix, 78% for soil-BFS mix and other soil- waste mix lie in between. The reduction in plasticity characteristics is mainly attributed to reduction in the activity of clay on the addition of coarse sized particles of waste and also the cementitious components such as CaO and MgO present in waste, especially MPW and BFS. On the contrary, the enhancement of plasticity characteristics of the soil with % TS is mainly due to high amount of organic content present in tannery waste.
2. The shrinkage limit increased and free swell index decreased for all the soils with % of solid waste except for soil-tannery waste mix. These changes are correlating very well with the modification in plasticity characteristics.
3. The reduction in % swell is very significant for all the soils with increasing % of wastes and it varied from 48% to maximum of 70 % corresponding to soil +70% waste. The order of reduction in % swell is CS > BFS > QD > MPW.
4. The UCC strength increased for all the soils with % wastes, except soil-tannery sludge waste mix. The increase of strength is as high as 60%, forQD and MPW.

References

1. Asavapisit. S, Nipon Tanpaiboonkul, Phirus Jenwittaya Wetchakum and Wichai Sungwornpatansakul (2001), "Effect of pozzolanic wastes on strength development of compacted clay", Technical note, Geotechnical engineering journal, Vol.32(1), pp.37-41.

2. Asokan Pappu, Mohini Saxena and Shyam R. Asolekar (2007), "Solid wastes generation in India and their recycling potential in building materials", Building and Environment, Vol. 42(6), pp. 2311-2320.

3. Cho and Yeo (2004), "Application of recycled waste aggregate to lean concrete sub base in highway pavement", Canadian journal of civil engineering, Vol.31(6), pp. 1101-1108.

4. Hassan H., Al-Rawas A., Al-Hashmi K., and Al-Alawi Y. (2003), "Improvement of soil geotechnical properties using incinerator ash", proceedings of Indian geotechnical conference, Nottingham, United Kingdom, pp.167-173.

5. IS: 2720 (1985), Part 4, "Indian standard code of practice of grain size analysis of soils", Bureau of Indian Standards.

6. IS: 2720 (1985), Part 5, "Indian standard code of practice of determination of Liquid Limit and Plastic Limits", Bureau of Indian Standards.

7. IS: 2720 (1972), Part 6, "Indian standard code of practice of determination of Shrinkage factors", Bureau of Indian Standards.

8. IS: 2720 (1973), Part 10, "Indian standard code of practice of determination of unconfined compressive strength", Bureau of Indian Standards.

9. Jinxi, Zhang, (2007), "Concrete Sludge Powder for Soil Stabilization", Geomaterials, Journal of Transportation research Board,Jappan, Vol.2026, pp. 54 – 59.

10. Mobasher. M, R. Devaguptapu, A.M. Arino, (1996), "Effect of copper slag on the hydration of blended cementitious mixtures", ASCE, Material Engineering conference, K.Chong. pp 1977-86.

11. Sivapullaiah, P.V. and Sridharan, A. (1985), "Liquid Limit of Soil Mixtures", ASTM, Geotech.Test Journal, Vol. 8(3), pp. 111 – 116.

12. Sivapullaiah, P.V. and Sridharan, A. And Stalin, V.K. (1996), "Swelling behaviour of soil bentonite mixtures", Canadian Geotechnical Journal, Vol 33, pp. 808 – 814.

13. Sobha cyrus and Roy M. Thomas (1996), "Effect of Tannery waste on behaviour of soils", Proceedings of Indian geotechnical conference, Madras, pp. 544–546.